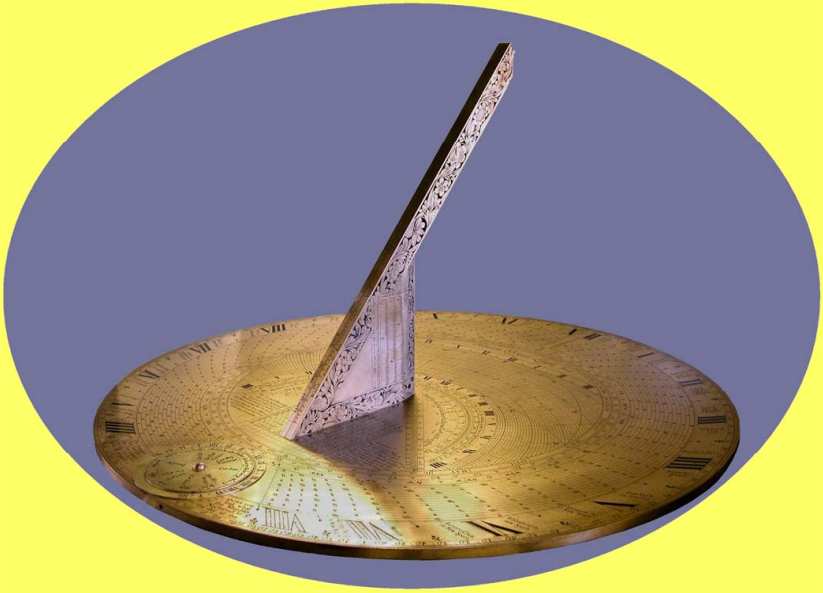
Davis & Lowne

The Double Horizontal Dial

BSS Monograph No. 5

The
DOUBLE HORIZONTAL DIAL

John Davis and Michael Lowne



The British Sundial Society

BSS Monograph No. 5

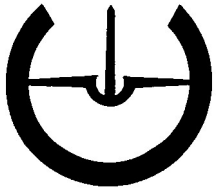
THE BRITISH SUNDIAL SOCIETY

THE DOUBLE HORIZONTAL DIAL

and associated instruments

JOHN DAVIS and MICHAEL LOWNE

BSS Monograph No. 5



First Published 2009 in Great Britain by
The British Sundial Society
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William Oughtred (1574-1660), the inventor of the double horizontal dial

Reverend Clayton Mordaunt Cracherode (1730-1799, FRS 1785) was an MA of Christ Church College, Oxford, and a Trustee of the British Museum. He bequeathed his large library and coin collection to the British Museum. Wenceslaus Hollar (1607-1677), the famous etcher, was originally from Bohemia and came to England in the employment of Thomas, Earl of Arundel. In his household, he also produced the image of Elias Allen on p.138.
The illustration is taken from an engraved copperplate discovered by M. Cowham.

FOREWORD

The introduction of the British Sundial Society's *Monograph* series in 2006, similar in many respects to the highly successful National Maritime Museum series, has enabled various specialist aspects of sundial interest to be tackled in depth and published in single volumes. In some cases, these subjects have previously appeared as a number of separate articles in the *Bulletin*; but bringing them together under one cover has made the material much easier for reference purposes. This study of the double horizontal sundial is one such case.

The double horizontal sundial is so-called since it combines two forms of sundial, the one employing an inclined gnomon, lying in the polar axis of the earth, as with a common horizontal dial, and the other having a vertical gnomon, indicating the position of the sun on a stereographic projection of the celestial sphere. This invention is attributed to the brilliant English mathematician, the Reverend William Oughtred (1574-1660), known for his invention of the sliderule, who also invented the universal equinoctial ring -dial, and who might be described as the 'father' of the English *Art of Dialling* in the 17th century. As with his other mathematical instruments, the earliest of Oughtred's double-horizontal sundials were made for him by Elias Allen (c.1588-1654), the most famous instrument maker of his day and a personal friend.

Whilst various articles have been written about this form of sundial, this is the most exhaustive treatise yet produced, listing every known example extant and covering every aspect of the subject, including horizontal instruments – not to be confused with double horizontal sundials – and horizontal quadrants. The authors of this monograph, John Davis and Michael Lowne, have undertaken meticulous research in this field and have produced a fascinating work of great scholarship that will undoubtedly prove to be the definitive reference on double horizontal sundials, their history and their makers.

Christopher St J. H. Daniel
September 2009

THE STEREOGRAPHIC PROJECTION

according to John Blagrave (c.1561-1611), trying to describe it to a non-mathematician:

"Even as a lofe of dowe or paste, after it is new moulden round and Copped, if you then put it into a presse, will become a flatte-cake: Even such a cake made of the round Sphere of Globe pressed, is the Celestiall of our new Astrolabe, which I would have you now for this purpose imagine to be a lofe or round Globe againe; and that every of his circles had their due convexities in such sort, that a pretty fellow like Tom Thumbe might easily seat himselfe under them as under a Canopy in the very centre of the concavity."

Quoted in RT Gunther: *The Uranical Astrolabe.*

British Sundial Society Monographs in this Series

1. C. Daniel: *The Equation of Time: The Invention of the Analemma. A brief history of the subject*, (2006).
2. J. Wilson: *Biographical Index of British Sundial Makers from the seventh century to 1920,* (2007).
3. A. Cook: *Mass Dials on Yorkshire Churches,* (2008).
4. M. Cowham: *A Study of Altitude Dials,* (2008).
5. J. Davis and C.M. Lowne: *The Double Horizontal Dial,* (2009).
6. Unassigned
7. Ian Butson, Jill Wilson & Tony Wood: *Sundials in Museums of the British Isles,* (2010)
8. D. Scott & M. Cowham: *Time Keeping in the Medieval World – A study of Anglo-Saxon and early-Norman sundials.* (2010).
9. Alan Cook: *Addendum to Mass Dials on Yorkshire Churches*, (2011).
10. Mario Arnaldi: *De Cursu Solis: Medieval Azimuthal Sundials*, (2012).
11. Tony Wood: *Somerset Scratch Dial: the original photographs of Dom Ethelbert Horne*, (2012).
12. Jill Wilson: *Biographical Index of British Sundial Makers from the Seventh Century to 1920, Third edition*, (2019).
13. John Davis (ed.): *BSS Glossary and sourcebook of dialling data, Third edition*, (2020).

ACKNOWLEDGEMENTS AND CREDITS

This monograph would not have been possible without the help of many institutions and individuals as listed below. We are particularly grateful for the permission to reproduce the photographs of instruments and literary sources from many public institutions and from private collections.

Members of the British Sundial Society have also been helpful and supportive. If we have missed anyone from the list, we apologise humbly.

We would specially like to thank Chris Daniel who supplied much information and encouragement. He also kindly supplied many photographs from his early unpublished research into double horizontal dials, as well as allowing republication of his co-authored John Seller paper. Fred Saywer kindly gave permission to republish his NASS Compendium articles and supplied electronic versions of some early books. We also thank Tony Moss for permission to republish his article on the Henry Wynne replica dial.

Adler Planetarium: Marvin Bolt, Devon Pyle-Voles
Beamish Museum: Rosemary Allen
Blenheim Palace: The Duke of Marlborough, Jeri Bapasola & John Forster
Bonhams Ltd: Jon Baddeley
British Library: Many members of staff
British Museum: Silke Ackermann & Liz Gatti
Bedfordshire & Luton Archives & Records Service: James Collett-White
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Stuart Talbot
Viscount Tamworth
Anthony Turner
Fiona Vincent
Fer de Vries
Chris H K Williams
Tony Wood

And all the anonymous private owners who allowed access to their instruments.

INTRODUCTION

The double horizontal sundial was essentially an English development of earlier instruments. Made predominately by London instrument makers who were capable of the high quality and precision required, it nevertheless used the same techniques as other sundials and mathematical instruments. Double horizontal dials were popular from about 1630 until the close of the 17th century, only a few being made after that time, and by about 1730 interest had waned completely. A modern revival of interest has taken place since the late 20th century, with many fine examples having been made. In parallel, there have been studies re-appraising the original literature.

The development of the double horizontal dial in England can be traced from other instruments, principally the horizontal quadrant and the horizontal instrument, both of which are covered in the present work. Earlier instruments using the same horizontal stereographic projection had been developed in Continental Europe, based on even older knowledge from the Islamic world, but these seem not to have been well-known in England.

The double horizontal dial was devised by the English mathematician William Oughtred (1574-1660) and is so-called because it incorporates two distinct types of sundial on the one base plate. It is to be distinguished from other types of double dial, for example the combination of a polar dial and an analemmatic dial popularised by Thomas Tuttell at the end of the 17th century. The true double horizontal (sometimes called an 'Oughtred dial') has a dial of the familiar type with an inclined polar gnomon and another dial with a plan of the sky on a horizontal plane using a stereographic projection. Effectively, this projection is a two-dimensional representation of the hemisphere of the sky on to the horizontal plane of the dial, taken from a point on the whole sphere diametrically opposite to the zenith. It is fully explained in the following articles, as are methods of delineation by calculation and by geometrical construction. The stereographic projection was not originated by Oughtred, it had been in use for many years in astrolabes and for terrestrial and celestial maps. The gnomon for the stereographic projection is vertical and is usually tucked underneath the polar gnomon. The shadow of the style of this gnomon falling on the projection will also indicate the time, but it is necessary to know the declination of the sun which is generally indicated by a scale of dates. Apart from this, the projection can be used to deduce many astronomical quantities, even in the absence of sunlight. These include the times of sunrise, sunset and twilight, the bearing or azimuth of the sun, the duration of night and day and the Right Ascension (RA) of the sun, and indeed it could be used to find many of the quantities which could be determined from a globe. Other instruments also used the stereographic projection, often onto the plane of the equator rather than the local horizon, and derived the time from measures of the sun's altitude in conjunction with its known declination and the latitude.

The horizontal instrument was the subject of an acrimonious dispute between Oughtred and Richard Delamain (1600-1644), who claimed priority for his invention of the similar horizontal quadrant. Delamain was a member of the Joiners' Company and studied mathematics at Gresham College and as a student to Oughtred, later becoming mathematics tutor to Charles I. This dispute has been much discussed in the literature: this monograph, however, concentrates more on actual dials than on the literature. The definitive description of the priority dispute remains the excellent paper by Anthony Turner, published in 1981.

In the early- and mid-20th century there was much confusion in the literature and among museum curators between the horizontal instrument and the double horizontal dial. This was gradually clarified with the revival of interest in the instruments towards the end of the century. Turner's 1981 paper gave an appendix listing all the 17/18th century double horizontal dials, horizontal instruments and horizontal quadrants then known. Only 11 double horizontal dials, 6 horizontal instruments and 4 horizontal quadrants were listed. The formation of the British Sundial Society in 1989 provided a corpus of observers and recorders who rapidly increased these numbers. By the time of Lowne's 2001 paper (reprinted here), the number of double horizontal dials known was 28 (and 3 modern examples). The numbers have continued to grow and this monograph reports 66 historical double horizontal dials plus 28 modern dials, 4 associated instruments, 9 horizontal

instruments and 9 horizontal quadrants. It is virtually certain that not all surviving instruments have been found and further examples are waiting to be discovered. Note that it is the number of double horizontal dials, rather than horizontal instruments or quadrants, which has increased most dramatically: the former are often found in remote garden locations (often, regrettably, in rather poor condition) whereas the others, being portable instruments and kept indoors, tend to be in museums and hence have been known to their curators for many years.

The increase in the number of known dials and instruments requires a reassessment of their relative importance and on their makers and owners. Whereas the horizontal instrument and quadrant remained instruments for use by 'mathematical practitioners', the double horizontal dial passed into the realm of an item of conspicuous consumption, designed to impress and to show the owners' education and knowledge of the latest science. And whilst it remains true that double horizontal dials were generally only made by the top instrument makers of each generation, it no longer seems to be likely that they were made as the 'master-pieces' of succeeding generations of apprentices to prove their abilities, as was once suggested.

The first double horizontal dials were made to Oughtred's design by Elias Allen (who had previously made his horizontal instruments), but they were soon produced by other makers. Of the more than sixty dials now known, nearly half of them are by only three makers: Elias Allen, Henry Wynne and Henry Sutton. Other workers are each represented by just a few dials, sometimes only one.

The aims or purposes of this monograph are to:

- Reproduce some of the early literature on double horizontal dials.
- Bring previous modern articles together in one place.
- Provide background to the development of the instruments, including precursors and development of 17th & 18th century styles.
- Fill in technical details of their design and manufacture, including associated instruments.
- Provide a catalogue of all known double horizontal dials and other instruments using the horizontal stereographic projection.
- Give brief biographies of the dialmakers.
- Comment on the resurrection of double horizontal dials in the 20th century and describe modern developments.

The monograph is organised into sections which follow these aims. Readers who are unfamiliar with the double horizontal dial are advised to start with the modern reprints in Part 2 as the descriptions in the original 17th century publications can be rather obscure. Although the reprints of the authors' earlier articles retain their original text and reference lists, the layout has now been improved and information which has subsequently been obtained has been added as additional notes (with alphabetical superscripts in the text).

Part 1. Historical Reprints, Transcriptions and Commentaries

These include Oughtred's original description of 1636 and other significant contemporary publications.

Part 2. Modern Reprints

Consists mainly of reprints from the *Bulletin of the British Sundial Society*. Details of how to delineate and use the dial are included here.

Part 3. New articles

These are generally articles written especially for the monograph and include descriptions of instruments which may be considered to be the fore-runners of the double horizontal dial. This section also deals with the 17th and 18th century dial-makers and their dials. A 'family tree' shows their master-apprentice relationships. Biographical details are given for each maker and some of their noteworthy dials are described.

Part 4. The Catalogue

Lists all the known instruments which use the horizontal stereographic projection, with full details and photographs where these are available.

Appendices

(1) A concordance showing the relationship between the instruments described in the monograph, those noted by Turner and the serial numbers in the BSS Fixed Dial Register.

(2) A list of early owners of DH dials

(3) A glossary of astronomical terms used in the monograph.

Bibliography and Index

In the examination of the old dials one cannot fail to be impressed with the standards of workmanship and the amount of labour which has been devoted to the (often very detailed) hand engraving. Many dials deserve the accolade of works of art. Modern dials can be equally impressive, but computer-aided design methods and chemical etching techniques have simplified the manufacture considerably.

A Note on Abbreviations

In the text of this monograph, we have made use of abbreviations for the common instrument types:

DH for double horizontal dial
HI for horizontal instrument
HQ for horizontal quadrant.

In addition, in the Catalogue section, we have used the abbreviations

AD for associated dials (those sharing some design features of a DH dial)
MD for modern dials and other instruments which have accompanied the revised interest in all the instruments which employ the horizontal stereographic projection.

John Davis & Michael Lowne *July 2009*

PART ONE

HISTORICAL PUBLICATIONS
Facsimiles, Transcriptions and Notes

THE CIRCLE OF PROPORTION, AND THE HORIZONTALL INSTRVMENT.

Both invented, and the vſes of both written in Latine by that learned Mathematician Mr. W. O. i.e. William Oughtred

BVT

Tranſlated into Engliſh, and ſet forth for the publique benefit by William Forſter, *louer and practizer of the Mathematicall Sciences.*

LONDON

Printed by AVG. MATHEVVES, dwelling in the Parſonage Court, neere St. BRIDES. 1632.

Title page of an early edition of Circle(s)…. Courtesy of the Plume Library, Maldon

THE
CIRCLES OF PROPORTION
AND
THE HORIZONTAL INSTRUMENT

WRITTEN IN LATIN BY

WILLIAM OUGHTRED

AND TRANSLATED INTO ENGLISH BY

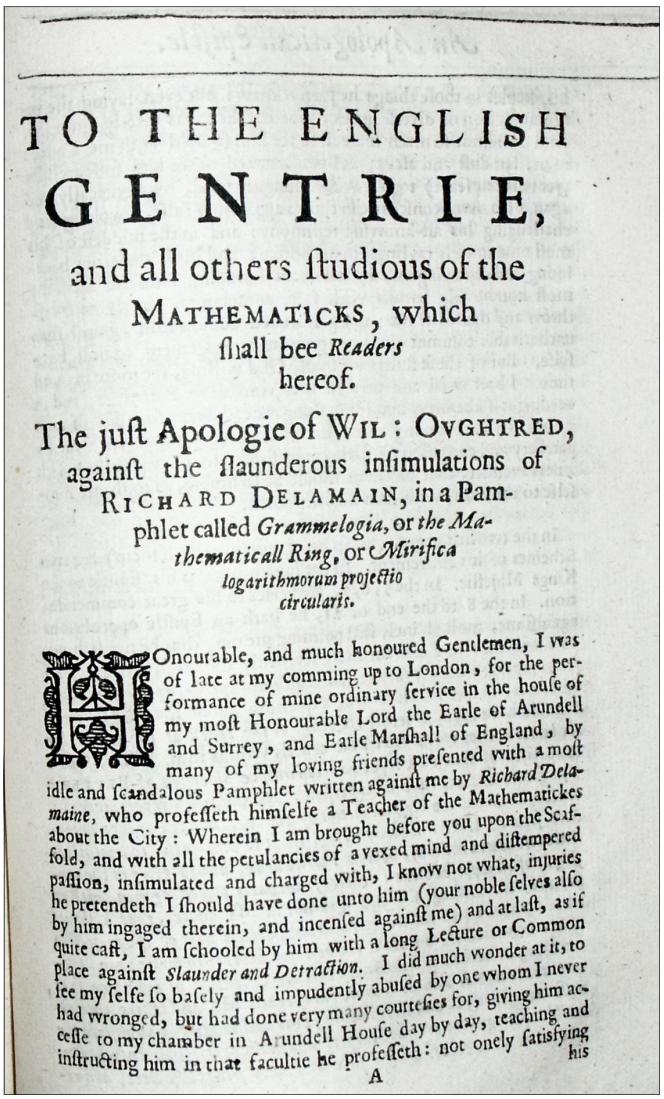
WILLIAM FORSTER

The Circle of Proportion and the Horizontal Instrument (later editions had *Circles...*) is the key text in the story of the double horizontal dial. Written in 1632 by William Forster from a Latin version by William Oughtred, it contains three main sections. The first, *An Apologeticall Epistle*, is Oughtred's long argument against Richard Delamain in the priority dispute over both instruments. This dispute is examined in detail by Anthony Turner (1981). It is of interest to us because in it, Oughtred gives the chronology of the development of the horizontal instrument – and by extension, the double horizontal dial – and he also mentions several versions which he drew. The implications of this chronology to the overall story of the DH dial is considered later in this monograph.

The first part proper of the book deals with the circles of proportion. Although these invariably appear on the back of horizontal instruments made by Elias Allen, this section is not of direct interest for this study.

The "Second Part of This Booke" deals with the horizontal instrument. It gives many examples of how the instrument can be used, both for solar astronomy and for designing dials of many sorts, and it also gives details of how to design and draw the basic instrument. In the text, Oughtred says:

The beginning of Oughtred's 'Apologeticall Epistle' against Richard Delamain, inserted as a long introduction to the 'Circles…'. It provides much of the known early history of the development of the horizontal instrument and also an insight into the characters of the story. It is, of course, a one-sided account but it does have the ring of truth.

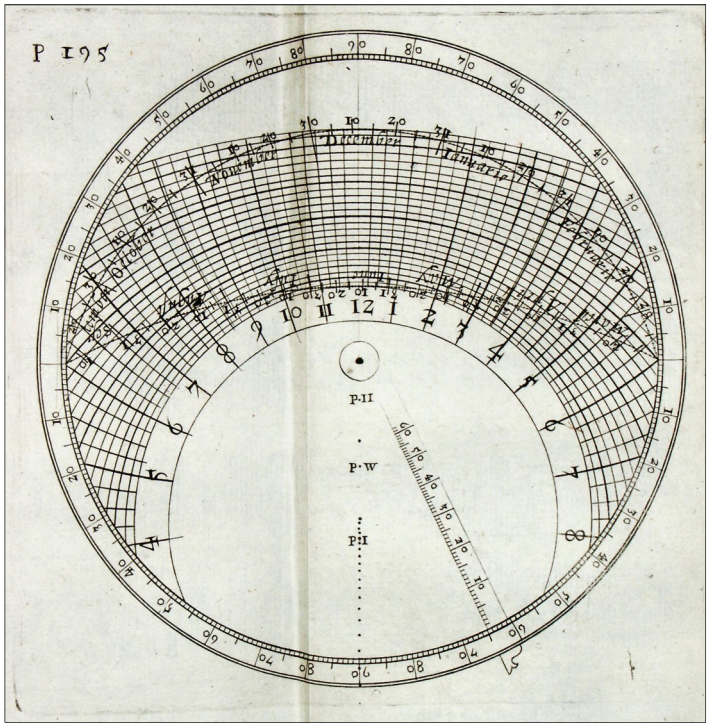


TO THE ENGLISH
GENTRIE,
and all others ſtudious of the
MATHEMATICKS, which
ſhall bee *Readers*
hereof.

The juſt Apologie of WIL: OVGHTRED,
againſt the ſlaunderous inſimulations of
RICHARD DELAMAIN, in a Pamphlet called *Grammelogia*, or *the Mathematicall Ring*, or *Mirifica logarithmorum projectio circularis*.

HOnourable, and much honoured Gentlemen, I was of late at my comming up to London, for the performance of mine ordinary ſervice in the houſe of my moſt Honourable Lord the Earle of Arundell and Surrey, and Earle Marſhall of England, by many of my loving friends preſented with a moſt idle and ſcandalous Pamphlet written againſt me by *Richard Delamaine*, who profeſſeth himſelfe a Teacher of the Mathematickes about the City: Wherein I am brought before you upon the Scaffold, and with all the petulancies of a vexed mind and diſtempered paſſion, inſimulated and charged with, I know not what, injuries he pretendeth I ſhould have done unto him (your noble ſelves alſo by him ingaged therein, and incenſed againſt me) and at laſt, as if quite caſt, I am ſchooled by him with a long Lecture or Common place againſt *Slaunder and Detraction*. I did much wonder at it, to ſee my ſelfe ſo baſely and impudently abuſed by one whom I never had wronged, but had done very many courteſies for, giving him acceſſe to my chamber in Arundell Houſe day by day, teaching and inſtructing him in that facultie he profeſſeth: not onely ſatisfying his

A

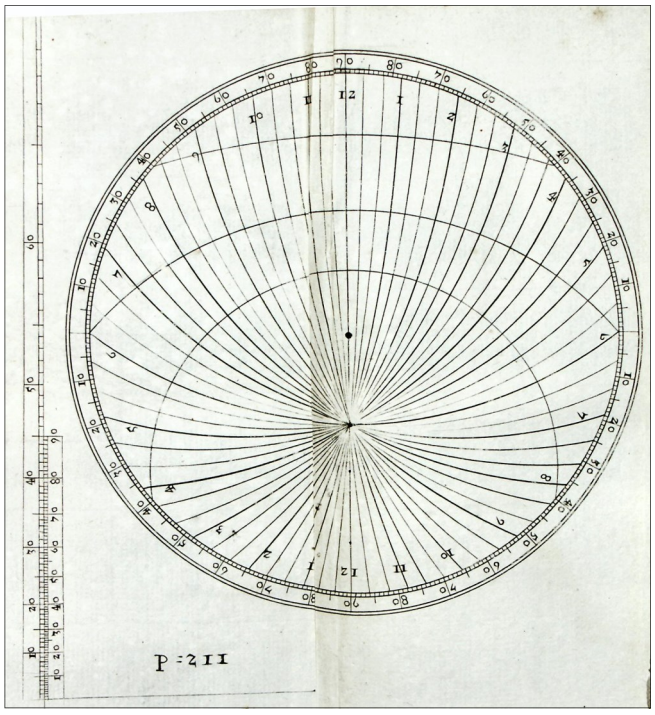


The fold-out illustration of the horizontal instrument from Forster's (Oughtred's) 'Circles…'. It is in Elias Allen's hand and is in exactly the form of several actual instruments by him. It is possible that the print is a counterproof from a real brass instrument but it is more likely to be a copperplate engraving. Note the corrected error for the hour-arc of 8:30 and 3:30.

> "...any that is ingenious, and ready handed may himselfe delineate one sufficient enough to serue his turne, for any eleuation"

Some sections of the *Circles...* have been transcribed in the following pages. It remained in print for a considerable time. For example, an edition was published in Oxford in 1660 which, although largely unchanged, was described on the title page as:

> And now by the AUTHORS consent, Revised, Corrected , and Freed from all mistakes in the former editition ; and also much Amplified and Explained, by A.H. Gent.

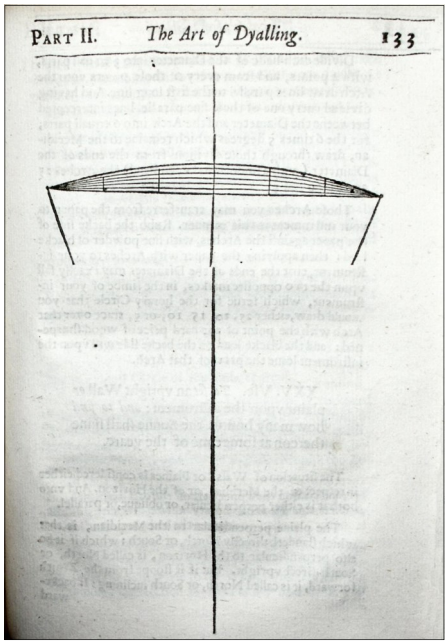


The fold-out engraving from Circles.. Showing the geometrical construction steps for the horizontal instrument. The engraving again appears to be in Allen's hand.

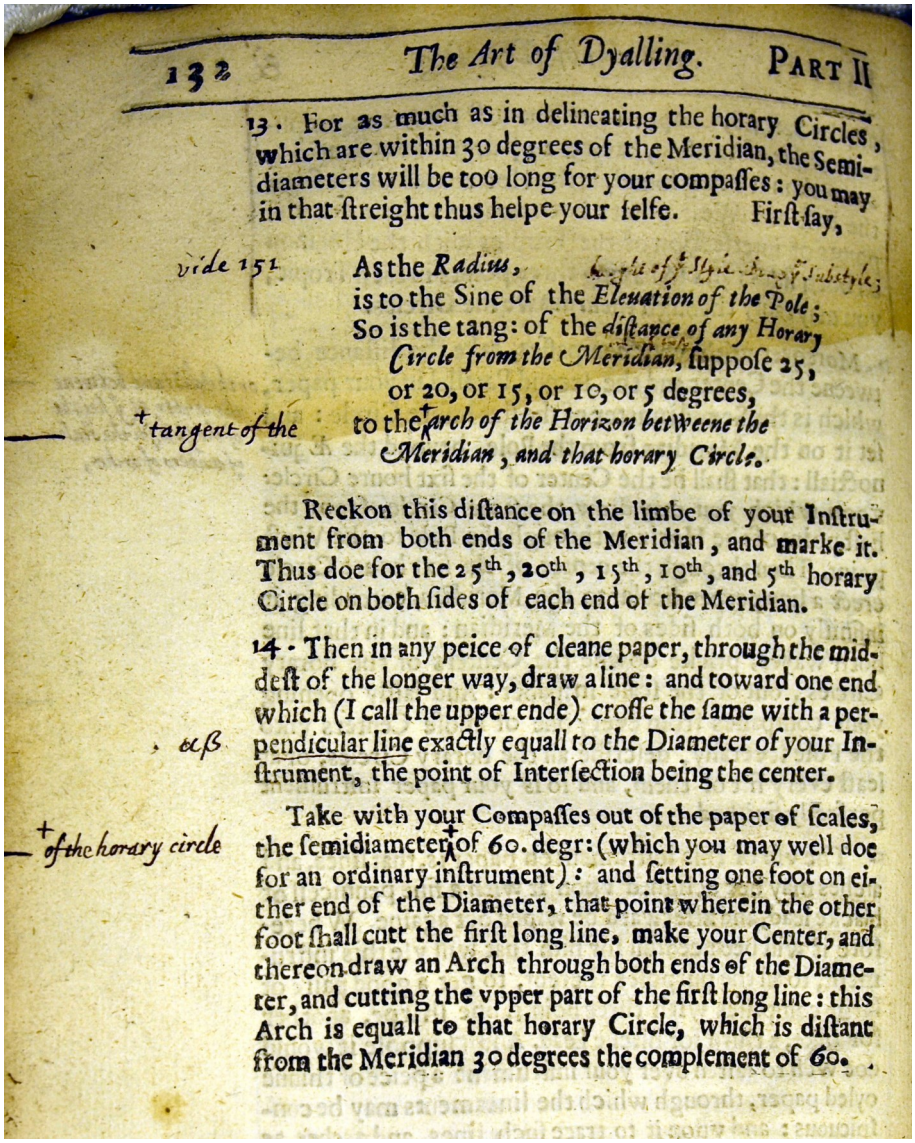
Forster's (i.e., Oughtred's) descriptions of how to draw the horizontal instrument are very detailed and use only compasses as a drawing aid. There are many practical details given, including the use of a piece of thin oiled paper to act as tracing paper to protect the finished instrument when using it for performing dialling and astronomical calculations. The text is accompanied by engravings showing both the layout of the stereographic grid and a completed horizontal instrument. The plates for these engravings were almost certainly produced by Elias Allen as they are the same both in detailed layout and engraving hand as his actual instruments. This includes the use of punches to produce the numerals '0' and '8'.

Another practical tip is that which shows how to draw the hour-arcs for times within 30 minutes of noon. These have very large radii, beyond the capacity of most compasses. Oughtred's solution is to construct several points on the arc and then simply to draw a smooth curve through them.

Oughtred's method of drawing arcs with very large radii, starting with the calculated chord for the arc half and hour before/ after noon.



Circles… is a large book (especially in comparison to the *Descriptions and Use of the Double Horizontal Dial*) and contains considerable material other than the descriptions of the horizontal instrument and the circles of proportion. It covers much ground in basic trigonometry and also has a section giving the right ascensions and declinations of 40 prominent stars, calculated for 1650. These data may have been the basis for the stars shown on Elias Allen's instruments.



132 The Art of Dyalling. PART II

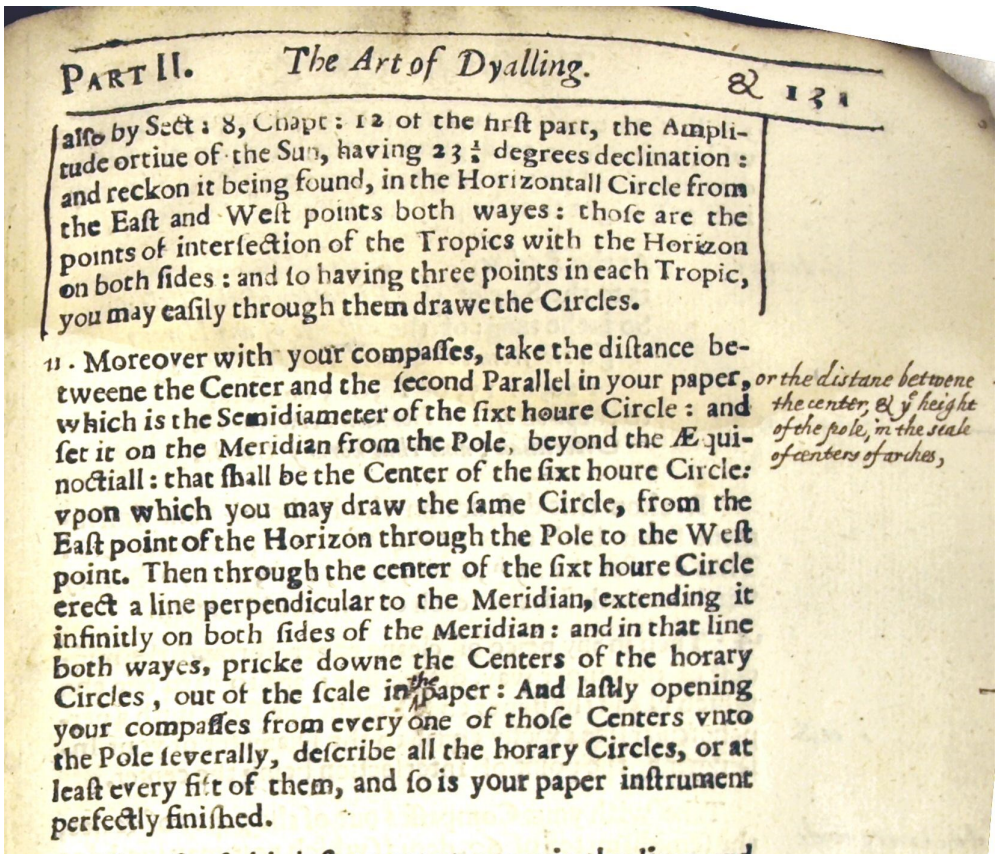
13. For as much as in delineating the horary Circles, which are within 30 degrees of the Meridian, the Semidiameters will be too long for your compasses: you may in that streight thus helpe your selfe. First say,

vide 151 As the *Radius*, is to the Sine of the *Elevation of the Pole*; So is the tang: of the *distance of any Horary Circle from the Meridian*, suppose 25, or 20, or 15, or 10, or 5 degrees, to the †tangent of the *arch of the Horizon betweene the Meridian, and that horary Circle.*

Reckon this distance on the limbe of your Instrument from both ends of the Meridian, and marke it. Thus doe for the 25th, 20th, 15th, 10th, and 5th horary Circle on both sides of each end of the Meridian.

14. Then in any peice of cleane paper, through the middest of the longer way, draw a line: and toward one end which (I call the upper ende) crosse the same with a perpendicular line exactly equall to the Diameter of your Instrument, the point of Intersection being the center.

Take with your Compasses out of the paper of scales, the semidiameter † of 60. degr: (which you may well doe for an ordinary instrument): and setting one foot on either end of the Diameter, that point wherein the other foot shall cutt the first long line, make your Center, and thereon draw an Arch through both ends of the Diameter, and cutting the vpper part of the first long line: this Arch is equall to that horary Circle, which is distant from the Meridian 30 degrees the complement of 60.



PART II. The Art of Dyalling. & 131

also by Sect: 8, Chapt: 12 of the first part, the Amplitude ortiue of the Sun, having 23½ degrees declination: and reckon it being found, in the Horizontall Circle from the East and West points both wayes: those are the points of intersection of the Tropics with the Horizon on both sides: and so having three points in each Tropic, you may easily through them drawe the Circles.

11. Moreover with your compasses, take the distance betweene the Center and the second Parallel in your paper, which is the Semidiameter of the sixt houre Circle: and set it on the Meridian from the Pole, beyond the Æquinoctiall: that shall be the Center of the sixt houre Circle: vpon which you may draw the same Circle, from the East point of the Horizon through the Pole to the West point. Then through the center of the sixt houre Circle erect a line perpendicular to the Meridian, extending it infinitly on both sides of the Meridian: and in that line both wayes, pricke downe the Centers of the horary Circles, out of the scale in the paper: And lastly opening your compasses from every one of those Centers vnto the Pole severally, describe all the horary Circles, or at least every fift of them, and so is your paper instrument perfectly finished.

or the distane betweene the center, & y height of the pole, in the scale of centers of arches,

An extract from William Oughtred's own copy of Circles of Proportion… , *now in the Oxford Museum of the History of Science (Lewis Evans Collection). This 1633 edition, printed by Augustine Mathewes, is annotated in Oughtred's hand with corrections and additions for later editions.*

The page shown provides a method of drawing the hour arcs near noon with very large radii.

The title page of this edition refers to the description of the horizontal instrument in the second part of the book as:

"The Later teaching how to work most Quæstions, which may be performed by the Globe : and to delineat Dialls upon any kind of Plaine."

Another example of Oughtred's very neat annotations.

The Circles of Proportion and the Horizontall Instrument &c.

The Second Part of this Booke.

[A transcription of the part of the book describing how to draw a horizontal instrument, from a late edition of Circles…]

XXIIII. *The Art of Dyalling. And first how to make the Instrument in paper, promised in the beginning of this second part.*

For the Delineation of this instrument in paper, it will be necessary first to shew the manner how the Semidiamiter is to be graduated, or divided into degrees: and how the Centres and Semidiamiters, of the severall kinds of Arches are to be found.

Upon halfe a sheet of strong large Dutch paper, (the larger the better) draw two straight lines, making a right angle neere one of the corners, the one through the length, the other through the breadth of the paper; which two lines I therefore call the longer, and the shorter perpendicular.

Upon the right Angle point, being the center, with a Semidiamiter equall to that by which you intend to delineate your instrument, describe a quadrant of a circle: and on the point where it meeteth with the shorter perpendicular, draw a long tangent line parallel to the longer perpendicular.

Divide the quadrant into 90 degrees, among which from the beginning at the shorter perpendicular, reckon the elevation of the Pole, for which you will make your instrument and applying the Ruler to the end thereof, and to the center, where the Ruler cutteth the tangent line make a prick. And taking with your compasses the distance from the centre to that prick, measure it upon the shorter perpendicular this shall be the *Semidiamiter of the fixt houre Circle*. At the end thereof draw another long line parallel also to the longer perpendicular.

Then out of the Center unto the second parallel through every degree of the quadrant, draw fine streight line, cutting also the first Parallel. The intersection of those lines with the first parallel shall be *The scale of centers of the Arches*. And their intersection with the second Parallel, shall be *The scale of centers of houre circles*. And the segments of those lines, intercepted between the Centre, and the first parallel, shall be the *Semidiamiters of Arches:* and the whole lines between the Center and the second Parallel, shall be *The Semidiamiters of houre circles*. And that you may know for what Circle, every Center, and Semidiamiter serveth you shall note every fifth line from the beginning, with the figure 5, 10,15, 20. &c. Set under the second Parallel, unto 90 which will fall upon the longer perpendicular: that so you may readily find the Center and Semidiamiter of any circle required.

Againe divide the first 45 degrees of the Quadrant in the middest: and applying your Ruler to the Center, and to every one of those halfe divisions, where in each place the Ruler cutteth the first parallel, or tangent line, make a prick. So shall you have upon the Tangent line between the shorter perpendicular and the middlemost line 45. A third scale, which is *The Scale of 90 degrees*, for the graduating of the Semidiamiter of your instrument on the paper: In which you shall also distinguish every fifth degree, with figures set under the tangent line.

Having thus prepared your paper of scales with lines neatly and exactly drawne, keep it by you to have it still in readinesse for the making, and using of the Instrument in paper. The making whereof is thus.

Taking with your compasses the Semidiamiter of the Quadrant in your paper Scales: and therewith upon a piece of strong Dutch paper, Describe the Horizontal circle: which you shall cut into two Semicircles with a Meridian line drawn through the Center: divide them into quadrants in the points of East and West: and each quadrant into 90 degrees to be marked with figures just as is done on the Instrument.

Then with your compasses take the elevation of the Pole upon the scale of degrees in your paper: & set it upon the meridian line from the center which way you please: that shall be the intersection of the Æquinoctiall with the Meridian. Also reckon the complement of the height of the Pole: upon the scale of Centres of Arches, and with your compasses take the distance from the end thereof to the Center: the same shall be the Semidiamiter of the Æquinoctiall, to be drawne from the East point of the Horizon through the point of intersection with the Meridian unto the West point.

Again: take with your Compasses upon the scale of degrees in your paper the complement of the height of the pole: and set it upon the Meridian on the other side of the Center from the Æquinoctiall: there shall be the Pole of the Æquinoctiall, or of the world wherein all the houre lines shall crosse one another.
Next unto the height of the Pole both adde, and subtract 23½ degrees and with your compasses use both these Arches in the scale of degrees: and set them in the Meridian from the center, one falling beyond the Æquinoctiall, and the ther short of it: those shall be the intersections of the two tropicks with the Meridian. Seek also by Sect. 8 Chap. 12 of the first part, the Amplitude ortive of the Sunne, having 23½ degrees declination: and reckon it being found in the Horizontall circle from the East and West points both ways: those are the points of intersection of the Tropicks with the Horizon on both sides: and so having three points in each Tropic you may easily through them draw the Circles.

Moreover with your compasses, take the distance between the Center and the second Parallel in your paper which is the Semidiamiter of the fixt houre circle: or the distance between the center and the height of the pole in the scale of the center of arches, and set it on the Meridian from the pole beyond the Æquinoctiall: that shall be the centre of the fixt houre Circle: upon which you may draw the same Circle, from the East point of the Horizon through the Pole to the West point. Then through the center of the fixt circle erect a line perpendicular to the Meridian line, extending it infinitely on both sides of the Meridian: and in that line both waies, prick downe the centers of the horary Circles, out of the scale in the paper: And lastly opening your compasses from every one of those centers unto the pole severally, describe all the horary Circles, or at least every fifth of them, and so your paper instrument is perfectly finished.

The use of this instrument on paper is that lines, and arches may be designed upon it with a fine pennicell of black lead, and afterward be wiped out againe. Wherefore it will be needfull for him that will use the instrument, to all the purposes thereofs, to get a good pairs of large compasses with three points, one sharp, another for ink, a third for black lead. And I suppose it would doe well to fasten over your instrument with a piece of thin oiled paper, through which the lineaments may be conspicuous: and upon it to trace such lines, and arches as you have occason to use: that so your instrument may be kept cleane, and last longer.

For as much as in delineating the horary Circle, which are within 30 degrees of the Meridian, the Semidiamiters will be too long for your Compasses: you may in that streight thus help yourself. First say,

As the *Radius* is to the *Sine of the Elevation of the Pole*:
So is the *tangent of the distance of any horary Circle from the Meridian*, suppose 25, or 20, or 15, or 10, or 5 degrees,
to *the tangent of the Arch of the Horizon between the Meridian and that horary circle*.

Reckon this distance on the limbe of your instrument from both ends of the Meridian, and marke it. Thus do so for the 25th, 20th, 15th, 10th, and 5th horary circle on both sides of each end of the Meridian.

Then in any piece of cleane paper, through the middest of the longer way, draw a line: and toward on end which (I call the upper end) crosse the same with a perpendicular line exactly equall to the diameter of your Instrument, the point of intersection being the center.
Take with your compasses out of the paper of scales, the semidiamiter of the horary circle 60. deg. (which you may well doe for an ordinary instrument:) and setting one foot on either end of the Diameter, that point wherein the other foot shall cut the first long line, make your center, and thereon draw an arch through both ends of the Diameter, and cutting the upper part of the first long line: this Arch is equal to that horary Circle, which is distant from the Meridian 30 degrees the complement of 60.
Divide each halfe of the Diameter into 3 equall parts with 4 points, and from every of those points unto the Arch draw lines parallel to the first long line. And having divided every one of thos 5 parallel lines intercepted between the Diameter and the Arch into 6 equall parts, for the 6 times 5 degrees which remaine to the Meridian, draw through those divisions from the ends of the Diameter (with a smooth and even hand) the Arches 25,20,15,10 and 5.
Those arches you may transferre from the paper to your instrument in this manner, Rubb the back side of the paper against the Arches with fine powder of black lead: then applying the paper with Arches to your instrument, that the ends of the Diameter may exactly fall upon the two opposite markes in the limbe of your Instrument, which serve for the horary circle that you would draw, either 25, 20, 15, 10, or 5, trace over that Arch with the point of any hard wood sharpened: and the black lead on the back side will upon the instrument leave the print of that arch.

THE DESCRIPTION AND USE OF THE DOVBLE Horizontall Dyall.

WHEREBY NOT ONELY THE Houre of the Day is ſhewn; but alſo the *Meridian Line* is found:

And moſt ASTRONOMICALL Queſtions, which may be done by the GLOBE: are reſolved.

INVENTED AND WRITTEN BY W. O.

Whereunto is added, The Deſcription of the generall HOROLOGICALL RING.

LONDON,
Printed for WILLIAM LEAKE, and are to be ſold at his Shop at the ſigne of the *Crown* in *Fleetſtreet*, between the two *Temple* Gates. 1652.

Title page for the second edition of Oughtred's 'Description and Use".

THE DESCRIPTION AND USE OF THE DOUBLE HORIZONTALL DYALL

WILLIAM OUGHTRED (1636)
TRANSCRIBED BY F. SAWYER 1997

The Description And Use of The double Horizontall Dyall: whereby not onely the hower of the day is showne; but also the meridian line is found: and most astronomical questions, which may be done by the globe, are resolved.

Invented and written by W.O.
London, Printed by Miles Flesher MDCXXXVI

[Editor's Note: This publication was intended for use with the instrument itself; it did not include any graphics. For ease of understanding, reference may be made to the double horizontal dials drawn elsewhere in this volume.]

The description, and use of the double horizontall dyall.

There are upon the plate two severall dyalls. That which is outermost, is an ordinary dyal, divided into howers & quarters, and every quarter into three parts which are five minutes apeece: so that the whole hower is understood to containe 60 minutes. And for this dyall the shadow of the upper oblique, or slanting edge of the stile, or cock, doth serve.

The other dyal, which is within, is the projection of the upper hemisphaere, upon the plain of the horizon: the horizon it selfe is understood to be the innermost circle of the limbe: and is divided on both sides from the points of East & West into degrees, noted with 10.20.30.&c. as far as need requireth: And the center of the instrument is the zenith, or verticall point.

Within the horizon the middle straight line pointing North and South, upon which the stile standeth, is the Meridian or twelve a clock line: and the other short arching lines on both sides of it, are the hower lines, distinguished accordingly by their figures: and are divided into quarters by the smaller lines drawn betweene them: every quarter containing 15. minutes.

The two arches which crosse the hower lines, meeting on both sides in the points of intersection of the sixe a clock lines with the horizon, are the two semi-circles of the ecliptick or annuall circle of the sunne: the upper of which arches serveth for the Summer halfe yeare; and the lower for the Winter halfe yeare: and are therefore divided into 365. daies: which are also distinguished into twelve moneths with longer lines, having their names set downe: and into tenths and fifts with shorter lines: and the rest of the daies with pricks as may plainly be seene in the diall.

And this is for the ready finding out of the place of the sunne every day: and also for the shewing of the sunnes yearely motion, because by this motion the sunne goeth round about the heavens in the compasse of a year, making the foure parts, or seasons thereof, namely the Spring in that quarter of the ecliptick which begins at the intersection on the East side of the dial, & is therefore called the Vernall intersection. Then the Summer in that quarter of the ecliptick which begins at the intersection with the meridian in the highest point next the zenith. After that, Autumne in that quarter of the ecliptick which beginneth at the intersection on the West side of the diall, and is therfore called the Autumnall intersection and lastly the Winter in that quarter of the Ecliptick, which beginneth at the intersection with the meridian in the lowest point next the horizon.

But besides this yearely motion, the sunne hath a diurnall, or dayly motion, whereby it maketh day and night, with all the diversities and inequalities thereof: which is expressed by those other circles drawn crosse the houre lines; the midlemost whereof, being grosser than the rest meeting with the ecliptick in the points of the Vernall, and Autumnal intersections, is the equinoctiall: and the rest on both sides of it are called the parallels, or diurnall arches of the sunne, the two outermost whereof are the Tropicks, because in them the sun hath his furthest digression or declination from the aequinoctiall, which is degrees 23.1/2 : and thence beginneth againe to returne towards the equinoctiall. The upper of the two Tropicks in this our Northern hemisphere is the Tropick of Cancer, and the sunne being in it, is highest into the North, making the longest day of Summer: and the lower next the horizon is the Tropick of Capricorne; and the sun being in it, is lowest into the South, making the shortest day of winter.

Betweene the two Tropicks and the equinoctiall, infinite such parallel circles are understood to be contained: for the sunne, in what point soever of the ecliptick it is carried, describeth by his lation a circle parallel to the equinoctiall: yet those parallels which are in the instrument, though drawne but to every second degree of declination, may be sufficient to direct the eye in imagining and tracing out

through every day of the whole yeare in the ecliptick, a proper circle which may be the diurnall arch of the sunne for that day. For upon the right estimation of that imaginary parallel doth the manifold use of this instrument especially rely: because the true place of the sunne all that day is in some part or point of that circle. Wherefore for the better conceiving and bearing in minde thereof, every fift parallel is herein made a little grosser than the rest.

For this inner dyall serveth the shadow of the upright edge of the stile; which I therefore call the upright shadow.

And thus by the eye and view only to behold and comprehend the course of the sunne, throughout the whole yeare both for his annuall and diurnall motion, may be the first use of this instrument.

II. Use. To find the declination of the sunne every day.

Looke the day of the moneth proposed in the ecliptick, and mark how many degrees the prick shewing that day, is distant from the aequinoctiall, either on the Summer or Winter side viz. North or South.

Example 1. What will the declination of the sunne bee upon the eleventh day of August?

looke the eleventh day of August, & you shall find it in the sixt circle above the aequinoctiall: Now because each parallel standeth (as hath bin said before) for two degrees, the sunne shall that day decline Northwards 12. degrees.

Example 2. What declination hath the sunne upon the 24. day of March?

looke the 24. day of March, and you shall find it betweene the second & third northerne parallels, as it were an halfe and one fift part of that distance from the second: Reckon therefore foure degrees for the two circles, and one degree for the halfe space: So shall the sunnes declination be five degrees, and about one fift part of a degree northward that same day.

Example 3. What declination hath the sunne upon the 13 day of November?

looke the 13. day of Novemb, and you shall finde it below the equinoctiall ten parallels, and about one quarter which is 20. degrees and an halfe southward. So much is the declination. And according to these examples judge of all the rest.

III. Use. To find the diurnall arch, or circle of the sunnes course every day.

The sunne every day by his motion (as hath bin said) describeth a circle parallel to the equinoctiall, which is either one of the circles in the diall, or some where betweene two of them. First therefore seek the day of the moneth; and if it fall upon one of those parallels; that is the circle of the sunnes course that same day: But if it fall betweene any two of the parallels, imagine in your minde and estimate with your eye, another parallel through that point betweene those two parallels keeping still the same distance from each of them.

As in the first of the three former examples, the circle of the sunnes course upon the 11. of August, shall be the very sixt circle above the equinoctial toward the center.

In example 2. The circle of the sunnes course upon the 24. March shall be an imaginary circle between the second and third parallels, still keeping an halfe of that space, and one fift part more of the rest, from the second.

In example 3. The circle of the sunnes course upon the 13. of Novemb: shall bee an imaginary circle between the tenth and eleventh parallels below the equinoctiall, still keeping one quarter of that space from the tenth.

IIII. Use. To find the rising and setting of the sunne every day.

Seeke out (as was last shewed) the imaginary circle or parallel of the sunnes course for that day, and marke the point where it meeteth with the horizon, both on the East and West sides, for that is the very point of the sunnes rising, and setting that same day, and the hower lines which are on both sides of it, by proportioning the distance reasonably, according to 15. minuts for the quarter of the hower, wil shew the hower of the sunnes rising on the East side, & the sunnes setting on the West side.

V. Use. To know the reason and manner of the increasing and decreasing of the daies & nights throughout the whole yeare.

When the sunne is in the equinoctiall, it riseth and setteth at 6. a clock, for in the instrument the intersection of the equinoctiall, and the ecliptick with the horizon is in the sixe a clock circle on both sides. But if the sunne be out of the equinoctiall, declining toward the North, the intersections of the parallel of the sunne with the horizon is before six in the morning, and after 6. in the evening: and the diurnall arch greater than 12. howers; and so much more great, the greater the northerne declination is. Againe, if the sunne be declining toward the South, the intersections of the parallel of the sunne, with the horizon is after sixe in the morning and before sixe in the evening: and the diurnall arch lesser then 12. howers; and by so much lesser, the greater the southerne declination is.

And in those places of the ecliptick in which the sun most speedily changeth his declination, the length also of the day is most altered; & where the ecliptick goeth most parallel to the equinoctiall changing the declination, but little altered. As for example, when the sunne is neere unto the equinoctiall on both sides, the dayes increase and also decrease suddenly and apace; because in those places the ecliptick inclineth to the equinoctiall in a manner like a straight line, making sensible declination. Againe when the sunne is neare his greatest declination, as in the height of Summer; and the depth of winter, the dayes keep for a

good time, as it were, at one stay, because in these places the ecliptick is in a manner parallel to the equinoctiall, the length of the day also is but little, scarce altering the declination: And because in those two times of the yeare, the sun standeth as it were still at one declination, they are called the Summer solstice, and Winter solstice. And in the meane space the nearer every place is to the equinoctiall, the greater is the diversity of dayes.

Wherefore we may hereby plainly see that the common received opinion, that in every moneth the dayes doe aequally increase, is erroneous.

Also we may see that in parallels aequally distant from the equinoctiall, the day on the one side is aequall to the night on the other side.

VI. Use. To find how farre the sunne riseth, and setteth from the true East and West points, which is called the suns amplitude ortive, and occasive.

Seeke out (as was shewed in III. Use) the imaginary circle, or parallel of the sunnes course, and the points of that circle in the horizon, on the East and West sides cutteth the degree of the amplitude ortive, and occasive.

VII. Use. To finde the length of every day and night.

Double the hower of the sunnes setting, and you shall have the length of the day; and double the hower of the sunnes rising, and you shall have the length of the night.

VIII. Use. To find the true place of the sun upon the dyall, that is, the point of the instrument which answereth to the place of the sun in the heavens at any time, which is the very ground of all the questions following.

If the dyall bee fixed upon a post: Looke what a clock it is by the outward dyall, that is, looke what hower and part of hower the shadow of the slanting edge of the stile sheweth in the outward limbe. Then behold the shadow of the upright edge, and marke what point thereof is upon that very hower, and part in the inner dyall among the parallels, that point is the true place of the sun at the same instant.

If the dyall bee not fixed, and you have a meridian line noted in any window where the sun shineth: place the meridian of your dyall upon the meridian line given, so that the top of the stile may point into the North: and so the dial is as it were fixed, wherefore by the former rule you may finde the place of the sunne upon it.

If the dyall bee not fixed, neither you have a meridian line, but you know the true hower of the day exactly: hold the diall even and parallel to the horizon, moving it till the slanting edge of the stile cast his shadow justly upon the time or hower given: for then the diall is truly placed, as upon a post. Seek therfore what point of the upright shadow falleth upon that very hower, and there is the place of the sunne.

But if your diall be loose, and you know neither the meridian nor the time of the day. First, by the day of the month in the ecliptick, find the sunnes parallel, or diurnall arch for that day, then holding the diall levell to the horizon, move it every way untill the slanting shadow of the stile in the outward limbe, and the upright shadow in the sunnes diurnal arch, both shew the very same hower and minute, for that very point of the sunnes parallel, which the upright shadow cutteth, is the true place of the sun on the diall at that present.

But note that by reason of the thickness of the stile, and the bluntnesse of the angle of the upright edge, the sunne cannot come unto that edge for some space before and after noone. And so during the time that the sunne shineth not on that upright edge, the place of the sunne in the diall cannot bee found.

Wherefore they that make this kind of double diall, are to be carefull to file the upright edge of the stile as thinne and sharpe as possible may be.

That which hath here bin taught concerning the finding out the sunnes true place in the dyal, ought perfectly to be understood, that it may be readily, and dexterously practised, for upon the true performance thereof dependeth all that followeth.

IX. Use. To finde the houre of the day.

If the diall be fastned upon a post: the hower by the outward diall, or limbe, is knowne of every one: & the upright shadow in the suns parallel, or diurnal arch will also show the very same hower.

But if the dyall be loose, either hold it or set it parallel to the horizon, with the stile pointing into the North and move it gently every way untill the hower shewed in both dials exactly agreeth, or which is all one, find out the true place of the sunne upon the dyall, as was taught in the former question, for that point among the hower lines sheweth the hower of the day.

X. Use. To find out the meridian, and other points of the compasse.

First you must seeke the true hower of the day (by the last question) for in that situation the meridian of the dyall standeth directly North and South: and the West into the West, and the rest of the points may bee given by allowing degr: 11.1/2 unto every point of the compasse.

XI. Use. To find out the azimuth of the sun, that is, the distance of the verticall circle, in which the sun is at that present, from the meridian.

Set your dyal upon any plain or flat which is parallel to the horizon, with the meridian pointing directly North and South, as was last shewed: then follow with your eye the upright shadow in a straight line, till it cutteth the horizon: for the degree in which the point of intersection is, shall show how farre the suns azimuth is distant from the East

and west points, and the complement thereof unto 90. shall give the distance thereof from the meridian.

XII. Use. To find out the declination of any wall upon which the sun shineth, that is, how farre that wall swerveth from the North or South, either Eastward or Westward.

Take a board having one streight edg, & a line stricken perpendicular upon it; apply the streight edg unto the wal at what time the sun shineth upon it, holding the board parallel to the horizon: Set the dyal thereon, & move it gently every way, untill the same hower and minute be shewed in both dyals: and so let it stand: then if the dyall have one of the sides parallel to the meridian, strike a line along that side upon the board, crossing the perpendicular, or else with a bodkin make a point upon the board, at each end of the meridian, and taking away the instrument from the board, and the board from the wall, lay a ruler to those two points, & draw a line crossing the perpendicular, is the angle of the declination of the wall. And if it bee a right angle, the wall is exactly East or west: but if that line bee parallel to the perpendicular, the wall is direct North or South without any declination at all.

You may also finde out the declination of a wall, if the dyall be fixed on a post not very far from that wal, in this manner. Your board being applyed to the wal, as was shewed, hang up a thred with a plummet, so that the shadow of the thred may upon the board crosse the perpendicular line: make two pricks in the shadow and run instantly to the dyall and looke the horizontall distance of the sunnes azimuth or upright shadow from the meridian. Then through the two pricks draw a line crossing the perpendicular: and upon the point of the intersection, make a circle aequall to the horizon of your instrument, in which circle you shall from the line through the two pricks measure the horizontall distance of the upright shadow, or azimuth from the meridian, that way toward which the meridian is: draw a line out of the center, to the end of that arch measured: and the angle which this last line maketh with the perpendicular shall be aequall to the declination of the wall.

XIII. Use. How to place the dyall upon a post without any other direction but it selfe.

Set the dyall upon the post, with the stile into the North, as neare as you can guesse: then move it this way and that way, till the same hower and minute be shewed, both in the outward and inward dyals by the severall shadowes, as hath bin already taught, for then the dyal standeth in its truest situation; wherefore let it be nailed downe in that very place.

XIIII. Use. To find the height of the sun at hight noone every day.

Seeke out the diurnall arch or parallel of the sunnes course for that day, (by Use III.) and with a paire of compasses, setting one foot in the center, and the other in the point of intersection of that parallel with the meridian, apply that same distance unto the semidiameter divided: for that measure shall therein shew the degree of the sunnes altitude above the horizon that day at high noone.

XV. Use. To finde the height of the sunne at any houre or time of the day.

Seeke out the diurnall arch, or parallel of the sunnes course for that day: and marke what point of it is in the very houre and minute proposed. And with a paire of compasses, setting one foot in the center, and the other in that point of the parallel, apply the same distance upon the semidiameter divided: for that measure shall shew the degree of the sunnes altitude above the horizon at that time.

And by this meanes you may finde the height of the sun above the horizon at every hower throughout the whole yeare, for the making of rings and cylinders and other instruments which are used to shew the hower of the day.

XVI. Use. The height of the sunne being given, to find out the hower, or what it is aclocke.

This is the converse of the former: Seeke therefore in the semidiameter divided, the height of the sunne given. And with a paire of compasses, setting one foot in the center, & the other at that height, apply the same distance unto the diurnall arch, or parallel of the sunne for that day: for that point of the diurnall arch, upon which that same distance shall light, is the true place of the sunne upon the diall; and sheweth among the hower lines, the true time of the day.

XVII. Use. Considerations for the use of the instrument in the night.

In such questions as concerne the night, or the time before sunne rising, and after sunne setting, the instrument representeth the lower hemisphaere, wherein the southerne pole is elevated. And therefore the parallels which are above the aequinoctiall toward the center, shal be for the southerne, or winter parallels: and those beneath the aequinoctiall, for the Northerne or Summer parallels; and the East shall be accounted for West, and the west for East; altogether contrary to that which was before, when the instrument represented the upper hemisphaere.

XVIII. Use. To find how many degrees the sunne is under the horizon at any time of the night.

Seeke the declination of the sunne for the day proposed (by Use II.) And at the same declination on the contrary side imagine a parallel for the sun that night: and marke what point of it is in the very hower and minute proposed: And with a paire of compasses, setting one foot in the center, and the other in that point of the parallel, apply that same distance unto the semidiameter divided: for that measure shall shew the degree of the sunnes depression below the horizon at that time.

XIX. Use. To find out the length of the crepusculum, or twylight, every day.

Seeke the declination of the sunne for the day proposed (by Use II.) And at the same declination on the contrery side imagine a parallel for the sun that night. And with a paire of compasses setting one foote in the center, and the other at 72 degrees upon the semidiameter divided, apply that same distance, unto the sunnes nocturnall parallel: for that point of the parallel, upon which that same distance shal light, sheweth among the hower lines, the beginning of the twilight in the morning, or the end of the twilight in the evening.

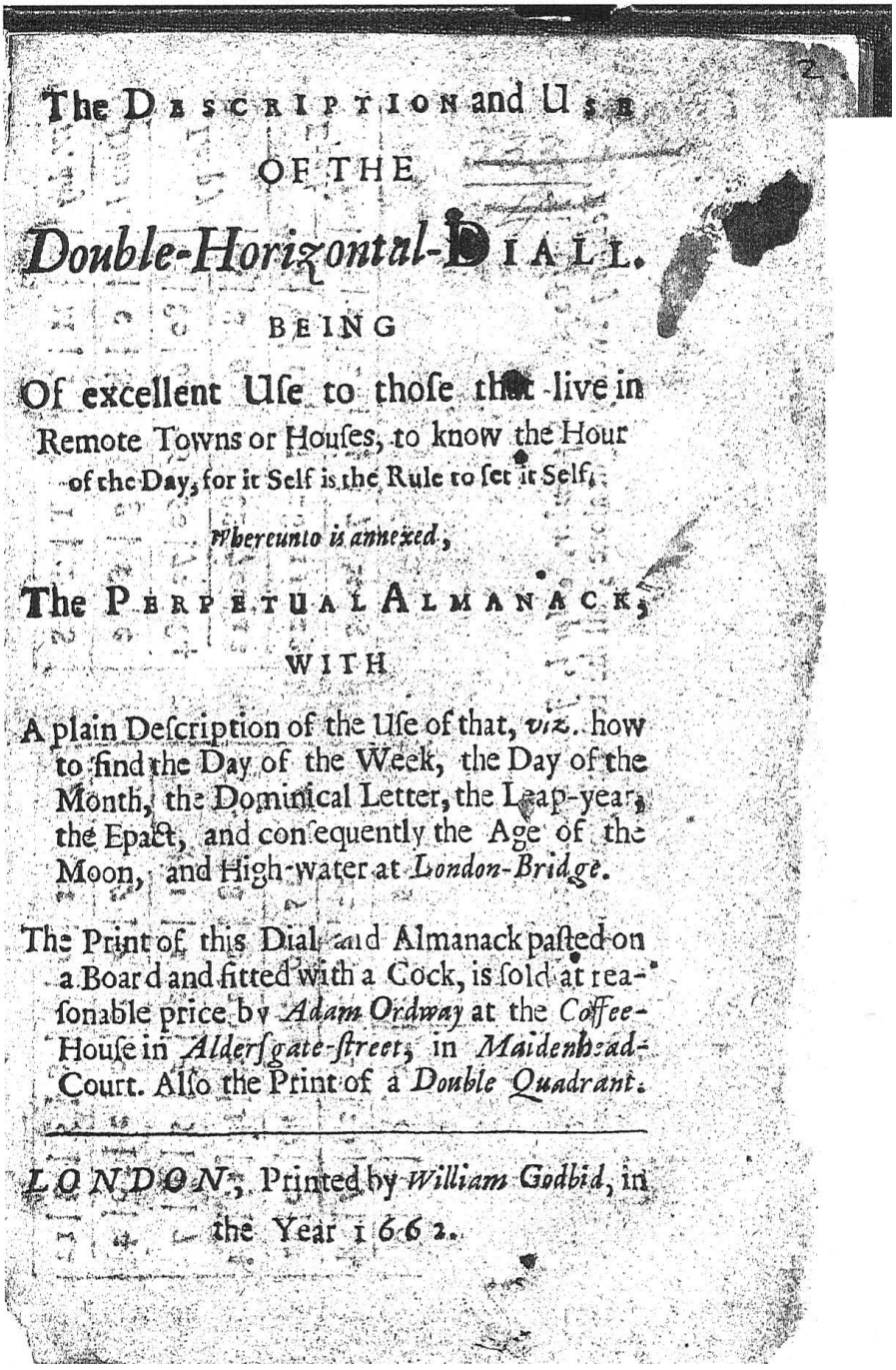
XX. Use. If the day of the month be not knowne, to find it out by the dyall.

For the working of this question, eyther the dyall must be fixed rightly on a post, or else you must have a true meridian line drawne in some window where the sun shineth, wherefore supposing the dyall to bee justly set eyther upon the post, or upon the meridian, Looke what a clock it is by the outward dyall, and observe what point of the upright shadow falleth upon the very same minute in the inner dyall, and through that same point imagine a parallel circle for the sunnes course; that imaginary circle in the ecliptick shall cut the day of the month.

These instrumentall dyalls are made in brasse by Elias Allen dwelling over against St. Clements Church without Temple barre.

Finis.

ADAM ORDWAY'S DESCRIPTION AND USE OF THE DOUBLE-HORIZONTAL-DIALL. (1662)



The DESCRIPTION and USE
OF THE
*Double-Horizontal-*DIALL.
BEING
Of excellent Uſe to thoſe that live in Remote Towns or Houſes, to know the Hour of the Day, for it Self is the Rule to ſet it Self,
Whereunto is annexed,
The PERPETUAL ALMANACK,
WITH
A plain Deſcription of the Uſe of that, *viz.* how to find the Day of the Week, the Day of the Month, the Dominical Letter, the Leap-year, the Epact, and conſequently the Age of the Moon, and High-water at *London-Bridge*.
The Print of this Dial and Almanack paſted on a Board and fitted with a Cock, is ſold at reaſonable price by *Adam Ordway* at the *Coffee*-Houſe in *Alderſgate-ſtreet*, in *Maidenhead*-Court. Alſo the Print of a *Double Quadrant*.
LONDON, Printed by *William Godbid*, in the Year 1662.

The title page of Adam Ordway's booklet of instructions for a double horizontal dial.
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THE DESCRIPTION AND USE

OF THE

Double-Horizontal-DIALL.

BEING

Of excellent Use to those that live in Remote Towns or Houses, to know the Hour of the Day, for it Self is the Rule to Set it Self

Whereunto is annexed,

THE PERPETUAL ALMANACK

WITH

A plain Description of the Use of that, viz. how to find the Day of the Week, the Day of the Month, the Dominical Letter, the Leap-year, the Epact, and consequently the Age of the Moon, and High-water at *London-Bridge*.

The Print of this Dial and Almanack pasted on a Board and fitted with a Cock, is sold at reasonable price by *Adam Ordway* at the Coffee-House in Aldersgate Street, in Maidenhead-Court. Also the Print of a Double Quadrant.

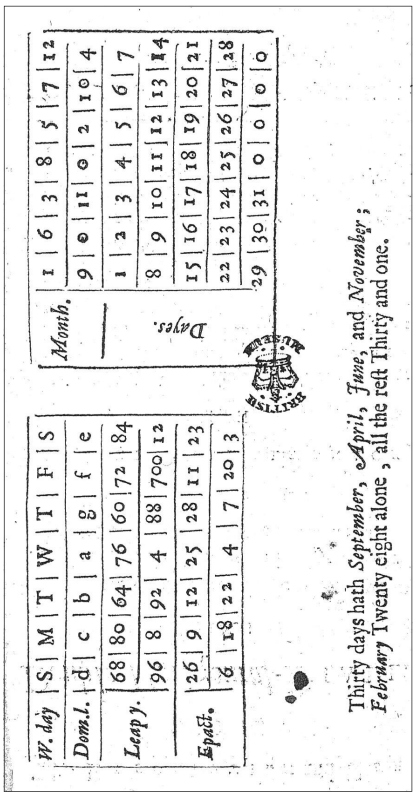
LONDON, Printed by *William Godbid*, in the Year 1662.

This small (15 × 9 cm) 16-page instruction booklet is obviously designed to accompany a paper version of a double horizontal dial. Unfortunately, there are no known examples of the actual dial surviving. It seems likely, given the year of printing, that the dial was based on engraved plates from Henry Sutton. Although some of Sutton's dials have almanacs in a different form to those shown here by Ordway, other dials have none. Ordway specifically says that his almanack is "by the Tables on each side of the Cock or Gnomen" and so these were clearly pasted on.

The booklet gives a long (4-page) and rambling description of how to use the perpetual almanack and then drifts into a description of the double horizontal dial. It gives some general uses of the dial in the absence of sunshine before going on to set it up:

"Let the Dial be set in the Window or some other level place where the Sun shineth, there will be two shadows, the one from the upermost part of the Cock, the other from the inward upright part of the Cock:"

continuing on to align the dial by obtaining the same time on the two parts of the dial. The booklet then reverts to a description of Epact and the tides at London Bridge.



The almanac printed on page 4 of Ordway's booklet.

BENJAMIN SCOTT DH DIAL INSTRUCTIONS

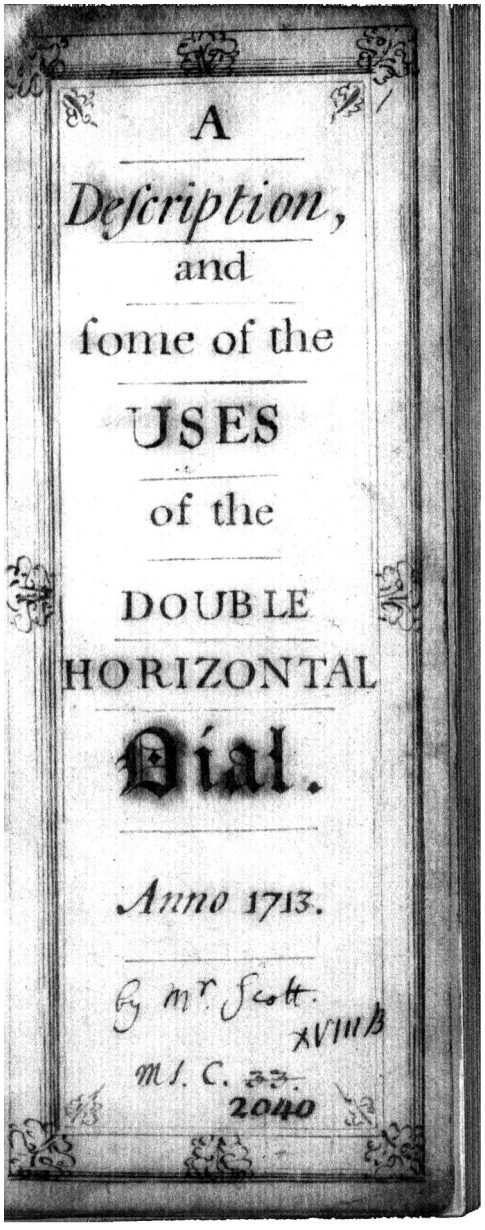
There is a slim booklet in the British Library (Sloane MS 2040) which is a set of instructions for using a double horizontal dial. The title page (below) is printed but the main contents of the booklet, comprising just seven pages, is hand-written in a neat but small script. We can say with near certainty that the booklet was produced to accompany Scott's 'French' dial (DH-26) currently in the Musée des Artes et Metiers, Paris. Superficial evidence is that this is the only known DH dial by Scott. But more telling evidence is the section of the booklet dealing with the place names in the main chapter rings and their meridians. The relevant text states:

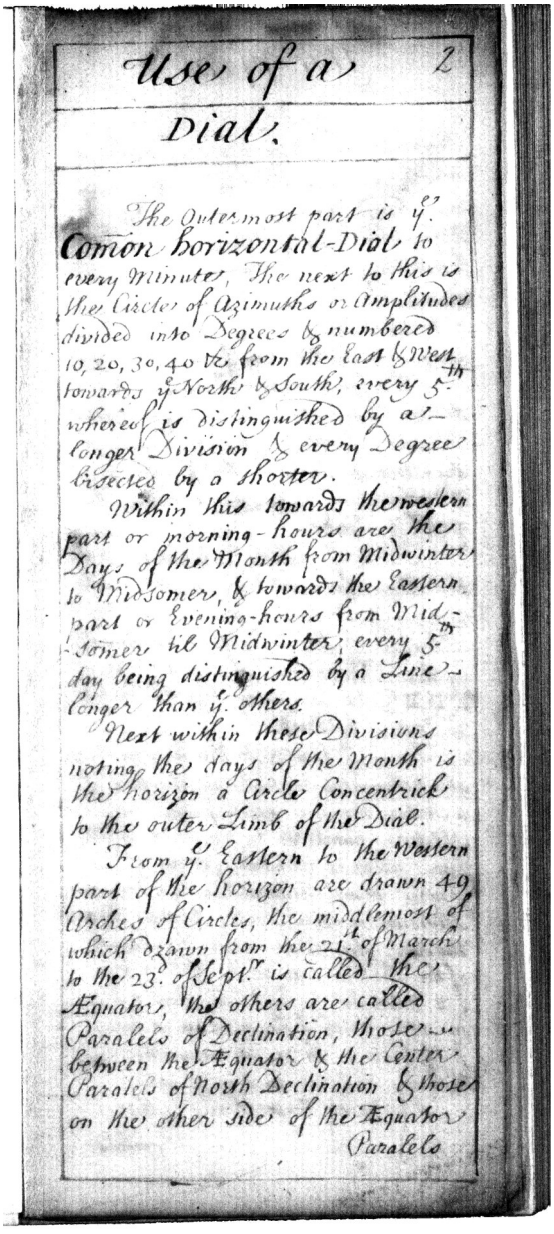
> "In the outer part is engraved several Names of Cities shewing y^{e} Difference of Meridians, e.g. Madrid stands ag^{t} 22 parts which shews that it's 22 past 12 at Paris when it is Noon at Madrid."

Thus it is clear that the dial is expected to be located in Paris. Furthemore, DH-26 does indeed include Madrid in the chapter ring with its noon marked at 12:22. Actually, the true longitude difference between Paris (2° 20' E) and Madrid (3° 45' W) is equivalent to a time difference of 24m 20s rather than 22m 0s.

It is not known how the instructions became separated from the dial within 40 years of its production and to come into the possession of Sir Hans Sloane (1660-1753) and thence via the British Museum to the British Library.

The transcription which follows retains the original spelling wherever possible.


A
Description,
and
some of the
USES
of the
DOUBLE
HORIZONTAL
Dial.
Anno 1713.
By mr. Scott.
XVIIIth
MS. C. 22.
2040


Use of a 2
Dial.

The Outermost part is y^{e} Comon horizontal-Dial to every Minute, The next to this is the Circle of Azimuths or Amplitudes divided into Degrees & numbered 10, 20, 30, 40 &c from the East & West towards y^{e} North & South, every 5th whereof is distinguished by a longer Division & every Degree bisected by a shorter.

Within this towards the western part or morning-hours are the Days of the Month from Midwinter to Midsomer, & towards the Eastern part or Evening-hours from Midsomer till Midwinter, every 5th day being distinguished by a Line longer than y^{e} others.

Next within these Divisions noting the days of the Month is the horizon a Circle Concentrick to the outer Limb of the Dial.

From y^{e} Eastern to the Western part of the horizon are drawn 49 Arches of Circles, the middlemost of which drawn from the 21th of March to the 23^{d} of Sept^{r} is called the Æquator, the others are called Paralels of Declination, those between the Æquator & the Center Paralels of North Declination & those on the other side of the Æquator Paralels

Title page and first page of handwritten text from Benjamin Scott's DH dial instructions.
The actual size of the booklet is approx. 150 mm × 50 mm.

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A Description, and some of the USES of the DOUBLE HORIZONTAL DIAL.

Anno 1713.

[by M^r^ Scott M.I.C.]

Use of a Dial.

The Outermost part is y^e.^ Com□on horizontal-Dial to every minute, The next to this is the Circle of Azimuths or Amplitudes divided into Degrees & numbered 10, 20, 30, 40 &c from the East & West towards y^e.^ North & South, every 5^th^ whereof is distinguished by a longer Division & every Degree bisected by a shorter.

Within this towards the western part or morning-hours are the Days of the Month from Midwinter to Midsomer, & towards the Eastern part or Evening-hours from Midsomer til Midwinter, every 5^th^ day being distinguished by a Line longer than y^e.^ others.

Next within these Divisions noting the days of the Month is the horizon a Circle Concentrick to the outer Limb of the Dial.

From y^e^ Eastern to the Western part of the horizon are drawn 49 Arches of Circles, the middlemost of which drawn from the 21^st^ of March to the 23^rd^ of Sept^r^ is called the Æquator, the others are called Paralels of Declination, those between the Æquator & the Center Paralels of North Declination & those on the other side of theÆquator Paralels of South Declination, Both which are counted from y^e^ Æquator numbered 10, 20 to 23½. On the Æquator from y^e^ Western to the Eastern part of the horizon is numbered y^e^ Sun's Right Ascension from 1 to 12 & back again from the Eastern to the Western from 12 to 24.

Crossing those Paralels are drawn hour-Circles to every fifth Minute, y^e^ whole hours distinguished by Stronger Lines & the figure at y^e^ end the halfe and Quarters by prick'd Lines.

From y^e^ Com□on Intersections of the Æquator and horizon are drawn 2 prick'd Arches representing the 2 halfs of the Ecliptick, distinguish'd by the Characters of the 12 signs ♈ ♉ ♊ ♋ &c and every Sign divided into 30 Degrees by Pricks.

From y^e^ Center to the horizon there are delineated 2 Scales in the form of a Sector, the one called y^e^ Sun's Altitude numbered 10, 20, 30 &c to the Sun's greatest Altitude, every 5^th^ Degree being distinguished by a longer Division & every Degree bisected by a shorter, the other called the Length of the Shadow number'd 5, 6, 7, 8, 9, 1, 2, 3 &c to 30, & divided from 3 to 4 in every tenth, from 4 to 10 in every half, from 10 to 20 in every whole one & from 20 to 30 in the 25 only.

Between those Scales & the Paralels of Declination is another Calendar of the Months & Days & right against them the Æquation of time.

In the outer part is engraved several Names of Cities shewing y^e^ Difference of Meridians, e.g. Madrid stands ag^t^ 22 parts which shews that it's 22 past 12 at Paris when it is Noon at Madrid.

The Stile is twofold, one part thereof is sharp & perpendicular to the Plane of the Dial at the center, the other oblique & broad.

The oblique Stile is used as in Com□on horizontal Dials to shew the hour of the Day by the Extremity of the Shadow on the Outer Divisions.

The Perpendicular Stile is to shew the hour of the Day by the hour-Circles.

Of the Problems to be performed by this Projection some are only when the Sun Shines, others whether it shines or not.

And first of those which are to be performed when y^e^ Sun doth not shine. Any one of these following being given all the rest may be found Viz^t^ The Month & Day, the Sun's Declination, the Sun's Place, the Sun's right Ascension, the Sun's oblique Ascension, the Sun's Amplitude, the time of Sunrising or setting, the length of Day & Night, the beginning & end of Twilight, the Æquation of time, which amount to 90 Different Problems; Nine of w^ch^ follow by giving the Month & Day w^ch^ suppose to be y^e^ 12^th^ of August.

Prob. 1.

To find y^e^ Sun's Declination.

Seek y^e^ division which Answers to y^e^ 2^d^ of Sept^r^ & where that meets the horizon observe what Paralel of Declination meets it; & you will find it to be Paralel of 15:5 North w^ch^ is the Sun's Declination for the 2^d^ of Sept^r^.

Prob. 2.

To find the time of Sun Rising.

See what Morning-hour-Circle meets y^e^ horizon where the Paralel of Declination meets it, In this Example you will find it to be that of 48 past 4, which is the time of Sun rising for that day; And in the same manner if you look among y^e^ Evening-hours you may find the time of Sun setting.

Prob. 3.

To find the Sun's Amplitude.

Lay the Edge of a Streight Ruler (or conceive a Line drawn) from y^e^ foot of the Perpendicular Stile to y^e^ com□on Intersection of the horizon with the Day of the Month, or with the Circle of Declination; & it will cut in the Circle of Amplitudes (w^ch^ in this Example is 23.15) the Sun's Amplitude that day.

Prob. 4.

To find y^e^ Length of Day & Night.

Double the time of Sunrising it is the Length of the Night, Double the time of Sunsetting it is the length of the Day.

Prob. 5.

To find y^e^ beginning of Twilight.

Put the foot of a Pair of Compasses in the Center of the Dial and extend y^e^ other to 15 Degrees on the Scale of the Sun's Altitude, with this Distance one foot in the Center turn the other about til it fall on the Paralel of 15 South when the Sun's Declination is North (& North when South) among the Evening-hours, and the hour Line that the Point of the Compasses rests on is the time in the Morning that Twilight begins, which in this Example will 30 past 2, And in like manner may the end of Twilight be found if the Morning-hours be used instead of the Evening.

Prob. 6.

To find the Sun's place.

See where y^e^ Paralel of Declination meets y^e^ Ecliptick between the day of the Month & the Meridian, & that is the Sun's place, which in this Example is ♌ 19°.25.

Prob. 7.

To find y^e^ Sun's Right Ascension.

Carry yo^r^ Eye along the hour-Circle that passeth from Sun's place to the Æquator & the Com□on Intersection of that hour-Circle with the Æquator is the Sun's Right Ascension, which in this Example is 9^h^. 27.

Prob. 8.

To find y^e^ oblique Ascension.

Find how much the Sun riseth before or after 6, & this added to Right Ascension for South Declination (& subtracted from it for North) gives the oblique Ascension, w^ch^ in this Example, is 18^h^.15.

Prob. 9.

To find y^e^ Equation of time.

Seek the Day of the Month in y^e^ Æquation-Circle & right ag^t^ it you have the Æquation faster or slower which in this Example is 4½ too fast:

Besides these already mentioned ye Sun's Altitude & the length of the Shadow (either) being given, the other may be found.

Moreover, any two of these being given, Viz^t^ the Sun's Altitude, y^e^ Sun's Azimuth, the Sun's Declination, the hour of the day, the others may be found, which Produces 6 different Problems, 2 of w^ch^ follow.

Prob. 10.

Given y^e^ Altitude and Declination, to find y^e^ Hour.

Put one foot of the Compasses in the Center, extend y^e^ other on y^e^ Scale of Altitudes to the Altitude given, with that Distance turn y^e^ other about til it meet the Paralel of Declination (amongst y^e^ Morning hours if in the Morning or amongst the Afternoon hours if in the Afternoon) & where it meets y^e^ Paralel count the hours among the hour Circles.

Prob. 11.

Given y^e^ Altitude and Declination, to find y^e^ Azimuth.

Lay a Ruler (or conceive a Line drawn) from y^e^ Center to the point of the Paralel of Declination on w^ch^ the point of the Compasses rested in foregoing Problem; & that Ruler (or line) produced to the Circle of Azimuths shews the Sun's Azimuth counted from the East in the Morning & the West in the Afternoon.

Note that instead of the Declination, any of those things mentioned in the 9 first Problems, (or instead of the Altitude were given the Length of Shadow, hour & Azimuth) may be found, which vastly multiplies the Problems to be performed hereby.

Problems to be performed when y^e^ Sun shineth.

Prob. 12.

The Dial being truly seated how to know the hour of the Day by the hour-Circles.

See where the Shadow of the upright Stile meets the Paralel of the Declination for that Day, & that intersection gives the time by hour-Circles.

Prob. 13.

To seat y^e^ Dial.

First see that the upper face of the Pedestal be horizontal, then turn the Dial about upon it til the hour of the Day by the Shadow of the oblique Stile on y^e^ outer part be the same as the hour of the day shewn by the upright Stile on the hour-Circles.

The Dial being truly seated & the Sun Shining may be found y^e^ Sun's Declination, Place, Right Ascension, Oblique Ascension, Month & Day, Time of Rising & Setting, Beginning & End of Twilight, Amplitude, Altitude, Azimuth, Length of Shadow, Equation of time.

Thus

First see y^e^ hour of y^e^ Day on y^e^ outer part, & then the comon Intersection of the Shadow of y^e^ Upright Stile with the like hour-Circle shews the Sun's Declination, From whence as in y^e^ 9 first Problems may be found his Place, Right Ascension, Oblique Ascension, Month & Day, Time of Rising & Setting, Beginning & Ending of Twilight, Amplitude, Equation of Time, & then by the 12^th^ & 13^th^ may be found for that Moment the Azimuth, Altitude & Length of Shadow.

PART TWO

MODERN REPRINTS

Articles published in the *BSS Bulletin*, the *NASS Compendium* and the *SIS Bulletin*

WILLIAM OUGHTRED'S DOUBLE HORIZONTAL DIAL

FRED SAWYER (GLASTONBURY CT)

[This paper is reprinted from the *NASS Compendium*, 4(1), pp.1-6 (March 1997). Readers should note that there are some differences in terminology to BSS papers and that the direction of the y axis is reversed.]

Some three hundred and thirty-four years ago, the English diarist Samuel Pepys spent a pleasant June morning enjoying his double horizontal sundial. When his friend Dean Michael Honeywood visited, he was so taken with the dial that Pepys felt compelled to present it to him.

> Up betimes and studying my Double Horizontall diall against Deane Honiwood comes to me, who dotes mightily upon it and I think I must give it him.
>
> - Samuel Pepys, June 3, 1663

The double horizontal sundial is not well known today, but it was an instrument to be prized in the seventeenth century.

The instrument itself was a combination of two dials: the traditional horizontal dial with its gnomon parallel to the celestial axis; and an azimuthal dial with vertical stile and a network of hour and date lines based on a stereographic projection of the sky onto the horizontal plane. Although the stereographic projection had been used in dialing since at least the early 16th century, its introduction into England came with William Oughtred's design early in the 17th century of a portable instrument to read the time and azimuth from the sun's altitude.

Oughtred shared his design with a number of people in the early decades of the century - people who included Edmund Gunter, who published a description in 1624, and Elias Allen, who was interested in making the dials. Allen was provided with written instructions, and Oughtred claimed that Richard Delamain saw his writing and had a dial made as if it were his own design. An irate Oughtred confronted Delamain, who denied seeing any such instructions. But he did acknowledge reading of the dial in a publication by Gunter, who had learned of it from Oughtred. The disagreement seems to have dissipated, since Oughtred agreed to review page proofs for Delamain's publication describing the horizontal instrument.

However, the debate returned, becoming very bitter and public, after one of Oughtred's students suggested in print that someone (Delamain) had rushed into print with descriptions of the horizontal instrument and the circular slide rule only to claim priority for himself when in fact they had been invented by William Oughtred. Several accusations and denials appeared in print during the early 1630s, and the dial evidently sold rather well. (For a discussion of this battle, see A.J. Turner's "William Oughtred, Richard Delamain and the horizontal instrument in seventeenth century England", *Annali dell'Instituto e museo di storia della scienza di Firenze* 6(2):99-125. Florence, 1981.)

Oughtred's dial, in both its early single and later double horizontal forms, was made by Elias Allen, the premier English instrument-maker of his day. As A.J. Turner [1981] has suggested, this type of dial may perhaps be viewed as an identifier for Allen and generations of his students; it seems to have been an instrument produced only by the best craftsmen.

Given the notoriety of the priority battle, the superior craftsmanship of those instrument-makers who offered this instrument, the ease with which many of the astronomical problems of interest to the layperson were solved without calculation, and the fact that the double horizontal combination results in a self-orienting dial which determines its own meridian line - this was a dial well worth doting upon.

xxXxx

DRAWING THE DIAL

To draw the dial, begin with coordinate axes x,y increasing to the east and north, respectively. Draw a circle with center on the origin and with unit radius.

If we identify a point on the celestial sphere by the coordinates a, z corresponding to the point's altitude and azimuth, respectively, then the stereographic projection maps the point a,z to x,y on the horizontal plane, where

$$x = \sin z \cos a / (1+ \sin a)$$

$$y = \cos z \cos a / (1 + \sin a)$$

Lines of equal azimuth are straight lines through the center of the circle; the angle the azimuth line makes with the meridian NS is z. So this projection preserves azimuth.

Lines of equal altitude are concentric circles about the origin. The circle corresponding to altitude a has radius $\cos a / (1 + \sin a)$. This expression defines a scale of distance from the origin; the scale is often reproduced on an alidade attached to the center of the dial and allowed to rotate. In this way, it is possible to find a point corre-

sponding to a given altitude without having the clutter of many additional circles actually being drawn in.

Note that, if the denominator in these equations were sin *a* instead of (1 + sin *a*), then the layout would simply be the usual gnomonic projection, with the tip of the vertical stile (with unit height) casting its shadow at exactly the projection point for the current altitude and azimuth. By introducing the new denominator, we lose this feature, but gain the advantage that the entire range of altitudes is included within the horizon circle - the point corresponding to the sun at rising or setting is no longer infinitely far away from the projection's center.

It is now a relatively easy matter to pinpoint at any time the exact point on the projection that corresponds to the sun's current position - assuming we know its altitude. If we place a vertical stile at the origin, its shadow will fall along the line $x/y = \tan z$ and will therefore pass through the desired point. To pick out the exact point on this shadow line, we can use the alidade, which rotates in the plane about the origin. The alidade has an altitude scale allowing the user to find the correct distance from the origin. Move the alidade so that the stile's shadow falls along its measuring edge and note the point on the scale corresponding to the sun's altitude. This point is the projection of the sun's current position.

Drawing The Declination Arcs

Identify the points a and c on the circumference of the circle, as in Figure 1, such that the arcs are as follows, with

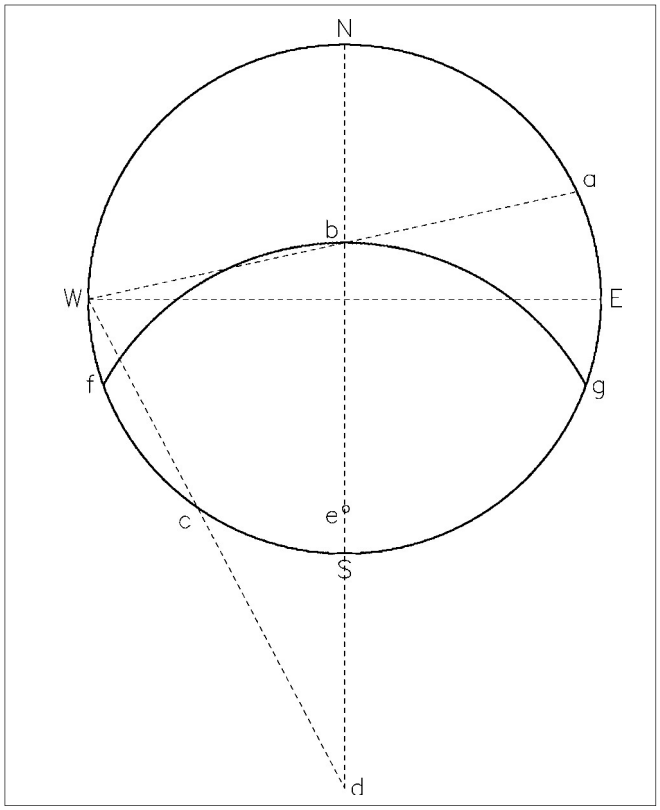


Fig. 1.

angles measured from the center of the circle and clockwise from N:

$Na = 90^o + \text{Dec} - Lat$ $\quad Nc = 270^o - Dec - Lat$

Draw lines connecting the point W with each of a and c; these lines meet the (extended) meridian line in points b and d, respectively.

The two points b and d determine a diameter of the circle representing the declination *Dec*. The center e of the circle is on the meridian line, midway between b and d. A drawing compass can now produce the circle - with center at e and with radius equal to the length from b or d to e.

The circle determined in this manner will either lie wholly outside the horizon circle NESW, wholly inside, or there will be an overlap. If the declination circle lies outside NESW, then the sun is never above the horizon on a day with declination Dec. If the circle is totally contained within NESW, then the sun is above the horizon for 24 hours on the given day. Of course, these two circumstances will occur only at latitudes within the arctic circles.

For all other latitudes, each declination circle will overlap with NESW; the intersections f and g of the circles represent the locations of the sun on the horizon at times of rising and setting.

Note that only those arcs of the declination circles contained within NESW need to be drawn; arcs that fall outside, therefore corresponding to a sun that is below the horizon, are extraneous to the instrument's use as a sundial.

Calculating The Declination Arcs

For the dialist interested in reproducing the placement of the declination arc by calculations suited to a computer drawing, the following equations will be useful:

$Ang1 = (Lat - Dec) / 2 \qquad Ang2 = (Lat + Dec) / 2$

Center: $x = 0 \quad y = (\tan Ang1 - \cot Ang2) / 2$

Radius: $\text{abs}(\tan Ang1 + \cot Ang2) / 2$

Consider the value $M = -\tan Lat \tan Dec$. If $M>1$ or $M<-1$ then the sun is never on the horizon for the given day. In either of these cases, if *Lat* and *Dec* have the same sign, then the sun is above the horizon all day; otherwise, the sun is hidden in a long arctic night.

For those declinations which yield a sunrise and set, and therefore two points of intersection with the circle NESW, the coordinates of those points can be identified as follows:

$R = \cos (Lat + Dec) \cos (Lat - Dec)$

$x = \pm (R^{**} 0.5) / \cos Lat$

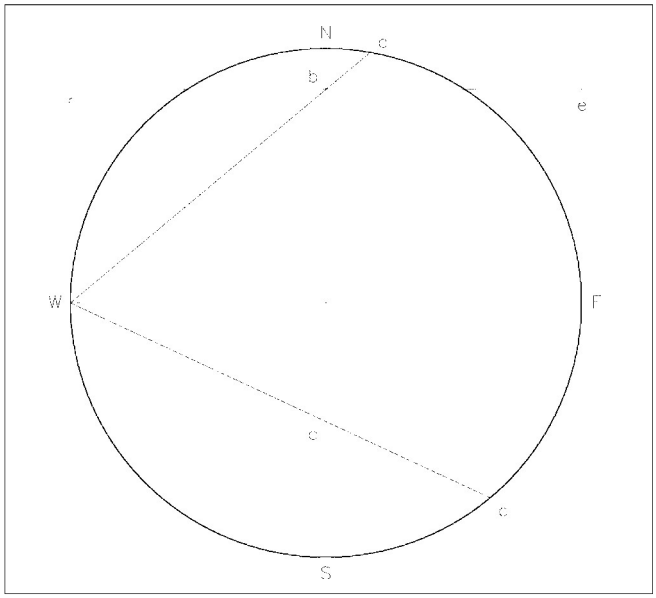


Fig. 2.

y = - sin *Dec* / cos *Lat*

Drawing The Ecliptic Arcs

The ecliptic is represented on this projection by two arcs, one for positive declinations and the other for negative. Each of these arcs is drawn using the same graphical procedure as above for the declination arcs, except for the placement of the points a and c. The defining arcs for the placement of these points are:

For positive *Dec*.	For negative *Dec*.
Na = 113.45º - *Lat*	*Na* = 66.55º - *Lat*
Nc = 293.45º - *Lat*	*Nc* = 246.55º - *Lat*

Note that the intersections of both arcs with the horizon circle are the points W and E.

Calculating The Ecliptic Arcs

To place these arcs using calculations, the following equations suffice.

For the first arc:

Center: $x = 0$ y = -1 / tan (*Lat* - 23.45º)
Radius: abs(1 / sin (*Lat* - 23.45º))

For the second arc:

Center: $x = 0$ y = -1 / tan (*Lat* + 23.45º)
Radius: abs(1 / sin (*Lat* + 23.45º))

Both arcs intersect the horizon circle at the points W (-1, 0) and E (1, 0).

Drawing The Hour Arcs

Identify the points a and c on the circumference of the circle, as in Figure 2, such that the arcs are as follows, with angles measured from the center of the circle and clockwise from N:

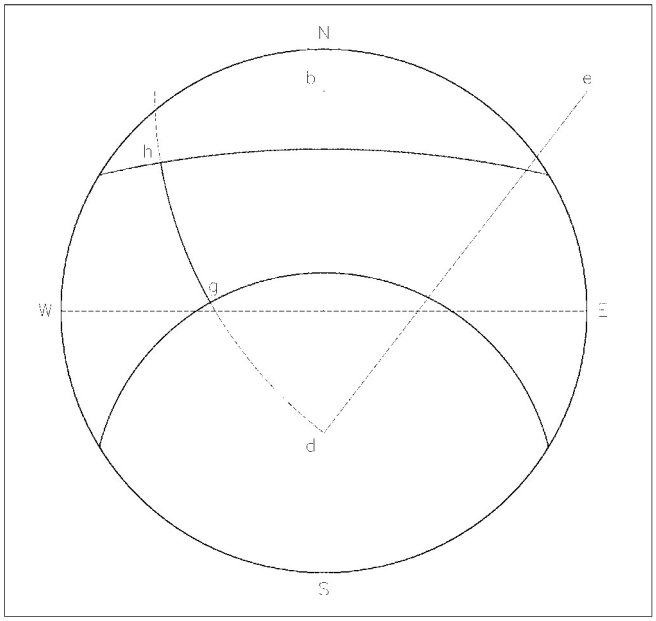


Fig. 3.

Na = 90º - 2 × *Lat* Nc = 180º - *Lat*

Draw lines connecting the point W with each of a and c; these lines meet the meridian line in points b and d, respectively.

Draw the line fbe perpendicular to the meridian and passing through the point b. The hour arcs are portions of circles whose centers lie on this line. The point d represents the pole, and each hour arc passes through d.

Our task now is to determine exactly where on the line fbe the center of the circle is to be found. Draw a line de, as in Figure 3, so that the angle bde that the line makes with the meridian is equal to T+90º for morning hours (i.e. T<0º), and T-90º for afternoon hours (i.e. T>0º). In determining T, each hour before or after noon corresponds to 15º. In laying out bde, a positive angle is measured clockwise from N or S, and a negative is measured counterclockwise. The hour arc for noon is the straight line bd, bound by its intersection with the solstice arcs.The line de intersects the line fbe in point e, the center of the hour circle. The radius of the circle is simply the length *de*.

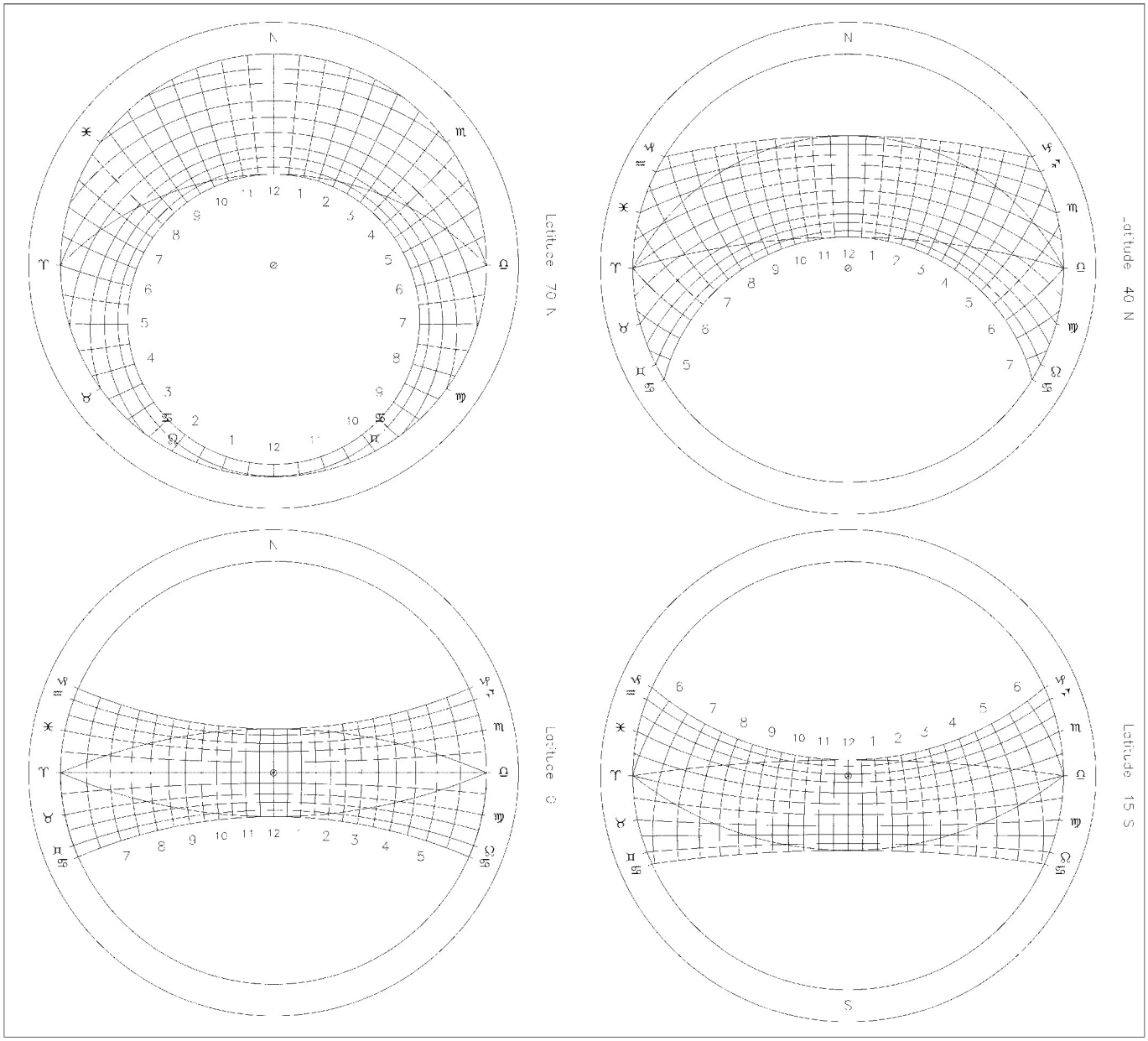
A drawing compass can now produce the hour arc - with center at e and with a radius equal to *de*. The portion of the circle to be drawn is only that arc between g and h, the intersections with the horizon circle or the declination arcs for the solstices.

Calculating The Hour Arcs

These arcs may be reproduced by calculation, using the following equations:

Center: x = -1 / (cos *Lat* tan T) y = tan *Lat*

Radius: abs(1 / (cos *Lat* sin T))



Let D = 23.45º for North (positive) latitudes and -23.45º for South (negative) latitudes; let M be the hour angle such that cos M = - tan Lat tan D; and let N be the angle such that tan N = -cos T / tan Lat.

Then, the values of T for which arcs actually appear within the bounds of the horizon circle are those such that -M <= T <= M.

The declination/hour-angle coordinates of one of the end points of the hour arc are (D,T). The second end point of the arc has coordinates (N,T) if -23.45º < N < 23.45º; otherwise, the second end point is (-D, T).

Finally, given the coordinates of these points expressed in terms of declination and hour-angle, we can convert to the (x,y) coordinate system using the following conversions, first to altitude a and azimuth z, and then to x and y:

sin a = sin Lat sin Dec + cos Lat cos Dec cos T
tan z = sin T / (cos T sin Lat - cos Lat tan Dec)

sin z = cos Dec sin T / cos a

x = sin z cos a / (1+ sin a); y = cos z cos a / (1 + sin a)

Or, more directly:

$$x = \frac{\cos Dec \sin T}{1 + \sin Lat \sin Dec + \cos Lat \cos Dec \cos T}$$

$$y = \frac{\cos Dec \sin Lat \cos T - \cos Lat \sin Dec}{1 + \sin Lat \sin Dec + \cos Lat \cos Dec \cos T}$$

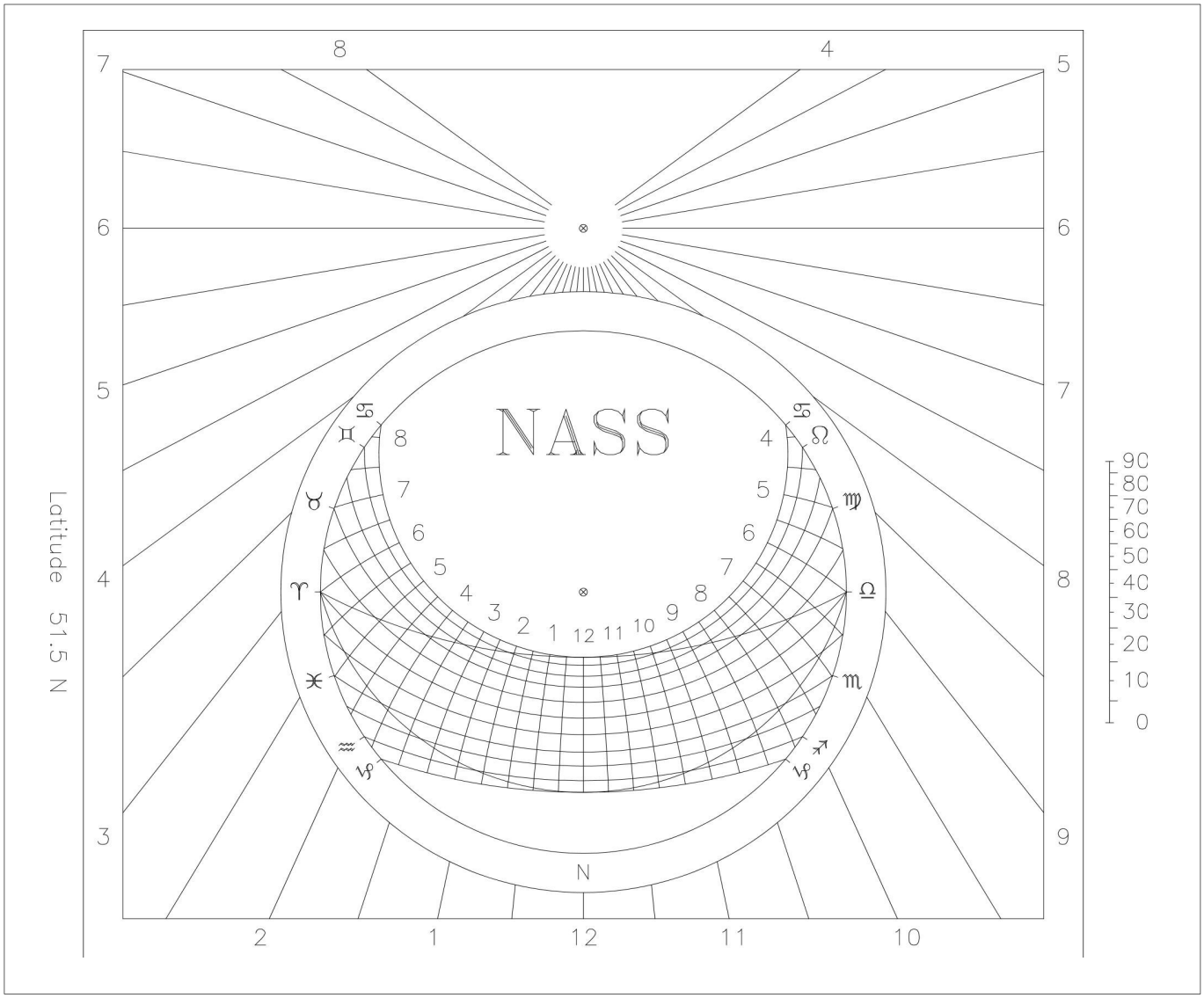
Using The Dial

In its original form, the single version of this dial (consisting only of the stereographic projection, omitting the traditional horizontal dial) is held suspended in the vertical plane with its perpendicular stile projecting horizontally. By pointing this arrangement towards the sun, the user can read the sun's altitude by noting where the

stile's shadow falls on a simple scale marking degrees around the circumference of the instrument. (We have not reproduced these markings here because they play no essential role in the double horizontal.) Now turn the altitude alidade attached to the center of the dial until the appropriate altitude mark falls on the current day line, being sure to select morning or afternoon as appropriate. If the altitude scale is given separately and does not appear on an alidade, a drawing compass can be used: set the compass open to a distance equal to that between the current altitude mark and 90 degrees; then place one leg on the center of the dial and draw an arc with the other until it intersects the current day line. The resulting point of intersection gives a reading of the time. If the dial is placed horizontally and turned until the stile's shadow passes through this point, then the noon line of the dial determines the meridian of the location.

In the double horizontal form that is our primary interest here, the dial does not need to be held up for a reading of the solar altitude. Instead, the user can simply place it on a horizontal surface and turn it until the time reading, given by the intersection of the stile's shadow and the current day curve, agrees with the reading given on the traditional dial (with gnomon parallel to the celestial axis) incorporated into the instrument. When the two times agree and they are in the appropriate half of the day (i.e. morning or afternoon), then the instrument is properly aligned, is reading the correct solar time, and has its noon line on the meridian.

The stereographic portion of the instrument also allows us to solve a number of other interesting problems. For example, to determine the time of sunrise today, simply follow the current day curve until it intersects with the horizon circle on the morning half of the dial. The time listed at this point is the time of sunrise. A number of other problems relating to time, altitude, azimuth and declination are solvable; for inspiration, the reader is referred to the instruction manual William Oughtred himself wrote for using the instrument. This manual is reproduced in this issue of The Compendium [see page 9 of this monograph].



THE DESIGN AND CHARACTERISTICS OF THE DOUBLE-HORIZONTAL SUNDIAL

MICHAEL LOWNE

[This paper appeared twice in the *BSS Bulletin* due to a number of printing problems on the first occasion. The corrected version which should be used for all future references, was *BSS Bulletin* 13(iv), pp.138-146, (December 2001).]

INTRODUCTION

The seventeenth century was a time of rapid development in many branches of science, particularly those of astronomy and mathematics. Pre-eminent in this latter field was the English mathematician William Oughtred (1575-1660).[1] Born at Eton, he was educated at Eton College and at King's College, Cambridge. After ordination as a priest in about 1603 he held the livings at Shalford and at Albury, both in Surrey, only occasionally visiting London. He took mathematical pupils and maintained correspondence with other leading mathematicians of his day which together with publications in Latin and English established his reputation at home and abroad. An engraved printing plate of a portrait of Oughtred has recently come to light.[2] His contributions to the art of gnomonics included the design of the 'horizontal instrument' and the 'double-horizontal sundial'.

COMPARISON OF THE TWO INSTRUMENTS

It is necessary to distinguish between the two related but separate instruments. The first version (the horizontal instrument) was devised early in the seventeenth century. It is portable and consists of a plan of the sky on a horizontal plane, delineated with hour circles, parallels of declination and ecliptic arcs with date scales enabling the sun's declination to be found for any day. There is a scale of altitudes around the rim and a centrally-pivoted alidade also carrying an altitude scale. In use the instrument is suspended vertically by a ring at the top and held edge-on to the sun so that the shadow of a central pin falls on the outer altitude scale. The reading from this is then transferred to the alidade which is rotated until the altitude coincides with the declination of the sun for that day. The time can then be read at this coincidence point and the times of sunrise and sunset can also be determined. Instrument makers such as Elias Allen became aware of the instrument and made fine examples, although no printed information was available until 1632[3] when a pupil of Oughtred, William Forster, translated and published Oughtred's Latin manuscript which also included a description of his 'Circles of Proportion', a circular slide-rule.

The double-horizontal sundial is a fixed-dial development of the portable horizontal instrument. There are two sets of graduations on the baseplate, the more usual variety with time-marks corresponding to an inclined polar gnomon, and another set with a central vertical gnomon and graduations which are a plan of the sky in the same format as the earlier instrument. Having a vertical gnomon this part of the dial operates from the azimuth of the sun, that is to say the bearing of the point where a vertical line through the sun meets the horizon. The essential difference between the two instruments is therefore that the one operates from the altitude and the other from the azimuth of the sun. Both are made for a specific latitude and require knowledge of the sun's declination as the third parameter. Descriptions of the double-horizontal dial and its uses were given by Oughtred in pamphlets issued in London in 1636[4] and later editions.

Studies of the dial by A J Turner[5] and F W Sawyer[6] have been of assistance in the preparation of this article. Turner gives details of an acrimonious dispute between Oughtred and Richard Delamain, also a mathematician, who claimed priority in the invention of the circles of proportion and the horizontal instrument. A reprint of Oughtred's 1636 description and uses is provided by Sawyer.

It appears that the first double-horizontal dials were made by Elias Allen but they were soon produced by other instrument makers. Few of the dials are dated but from the known dates of the makers it seems that the dials were not in vogue for very long, the last known example being made by Benjamin Scott in about 1713.

DESCRIPTION OF A DIAL

The surviving double-horizontal dials are now three hundred or more years old and where they have been left *in situ* are quite possibly patinated or eroded and difficult to decipher.[7] One well-preserved example is a very fine dial by John Seller which is now in a private collection. Seller was not only an instrument maker: he was a cartographer and held the appointment of 'Hydrographer to the King' over three or four reigns. Figure 1 is a view of his dial (which is made for latitude 51½°N) showing the inclined polar gnomon and tucked underneath it the shorter vertical gnomon. The long polar gnomon is necessary to ensure that the shadow reaches the outer graduations when the

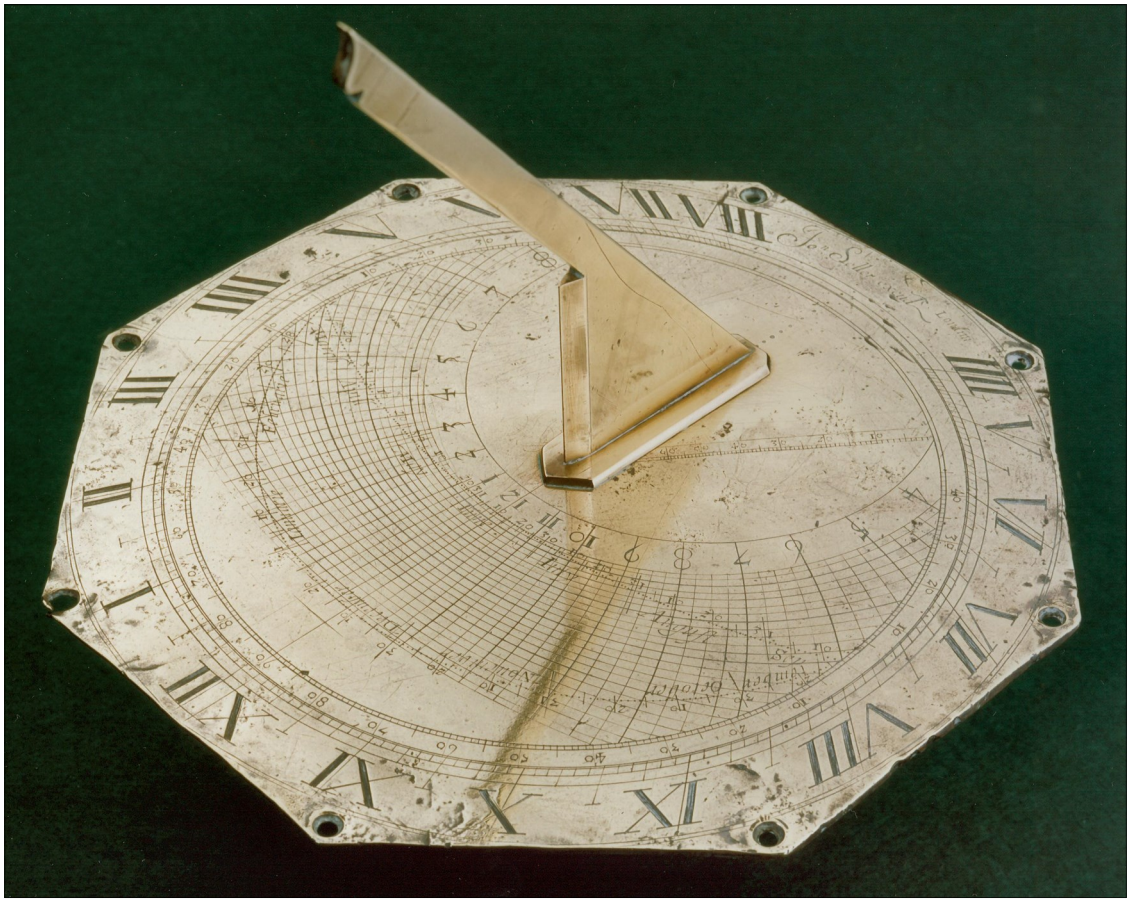


Fig. 1. Double horizontal dial by John Seller.

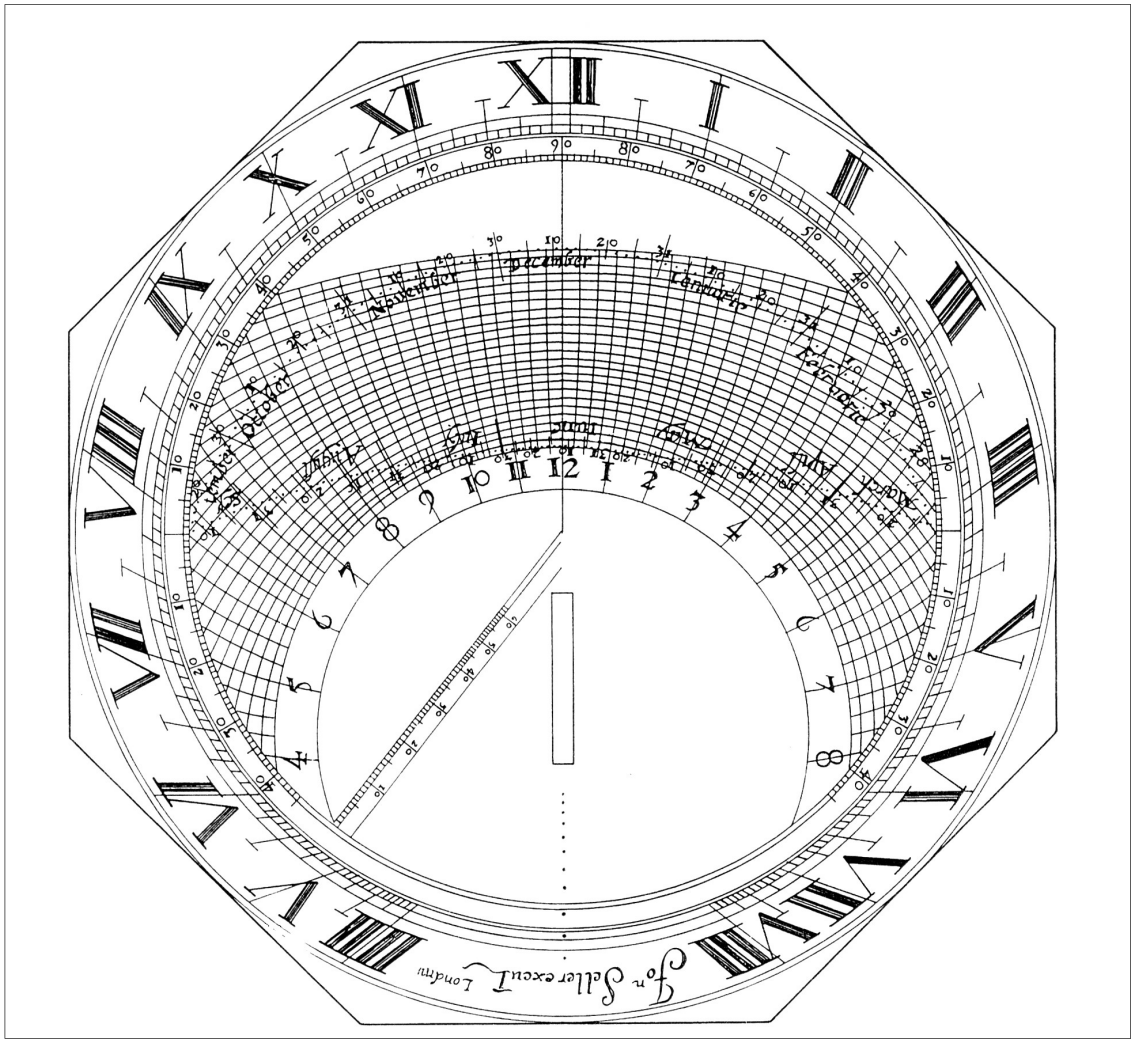


Fig. 2. Dial-plate of the Seller dial.

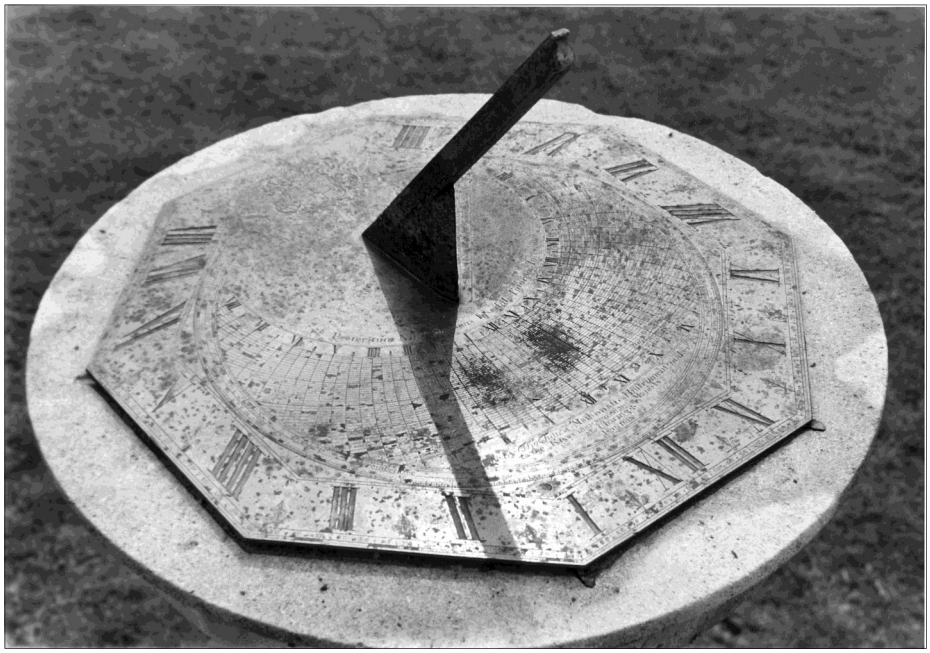


Fig. 3. A dial by Thomas Tuttell.

sun is high in the sky. The fillet around the gnomon base would interfere with the operation of both dials at low solar altitudes and suggests a later repair or replacement. A face-on drawing of the dialplate is shown in Figure 2: here the Roman numerals and time graduations (divided to five-minute intervals) relating to the polar gnomon are seen around the periphery. Inside these are the graduations of the azimuth dial which enable a number of astronomical quantities to be derived from the shadow of the vertical gnomon. The shadow-casting part of this gnomon is chamfered to a sharp vertex: there is then no need for a discontinuity in the graduations at noon to allow for the gnomon thickness as with the polar dial. However, the azimuth dial reading is limited by the vertex angle of the gnomon. In the Seller dial (and others) this is about 30°, so that if the sun is within 15° of the meridian the shadow will be cast, not by the vertex, but by one or other of the edges of the V, giving incorrect readings. This will occur between about 11am-1pm in midwinter and 11.30am-12.30pm in midsummer, in the latitude of the British Isles.

THE AZIMUTH DIAL

The shadow of the vertical gnomon on the dial face is diametrically opposed to the azimuth of the sun: the dial plan is therefore turned through 180° with respect to the sky. Immediately inside the polar dial time graduations is a circle centred on the foot of the vertical gnomon. This represents the horizon and is divided to degree intervals of azimuth and labelled every 10°. The zero points are to east and west and the numbers increase until they meet at 90° at the south point. North of east and west they again increase but only to 40° on each side. These are the northerly limits of sunrise and sunset at the summer solstice and further graduation is unnecessary.

Running across the dial from east to west is an array of curved arcs with some thicker than others. These represent the path of the sun across the sky depending on its declination, the angular distance north or south of the celestial equator. They are not labelled but it is easy to see that the central thick line is the equator and others are spaced at two-degree intervals (only 1½° for the outer interval from 22° to 23½°) with thicker lines at 10° and 20° north and south. The thick lines are not shown on Figure 2.

Crossing the declination lines are others labelled with Arabic numerals from 4 in the east through 12 in the north-south line to 8 in the west. These are hourly time-lines and each hour is divided into quarters. Some dials have declination arcs for every degree: the dial by Thomas Tuttell shown in Figure 3 is one example. The time scale on the Tompion dial at Hampton Court[8] is divided to five minute intervals.

Two arcs meet the azimuth circle at the east and west points and curve round to touch the declination lines at the extremes of ±23½° on the north-south line. These show the annual path of the sun through the sky (the ecliptic) inclined at 23½° to the equator, the tilt of the Earth's axis of rotation relative to the orbit (the obliquity). They carry a scale of dates, divided to individual days and labelled for the 10th, 20th and last day of the month. The declination of the sun for every day of the year is thus indicated, but individual days between the 5-day markers are shown only schematically on Figure 2. The solstices (sun at 23½°) are shown as June 11 and December 11, and the equinoxes (sun at 0°) as March 11 and September 13, ten days earlier than our present reckoning. When this dial was made in the late seventeenth century Britain was still using the Julian calendar, at that time ten days behind the reformed Gregorian calendar we now use.

A diagonal scale running from the gnomon point to the NE horizon is an almucantar for determining the altitude of the sun. It is divided to degrees and labelled every 10°.

THE USE OF THE DIAL

Much astronomical information can be found from this construction and the shadow of the vertical gnomon. By reading the azimuth scale where it is met by the shadow (or its extension if it doesn't reach that far) the sun's azimuth can be determined. If the date is known the time can be found by locating the date on the ecliptic scale, noting

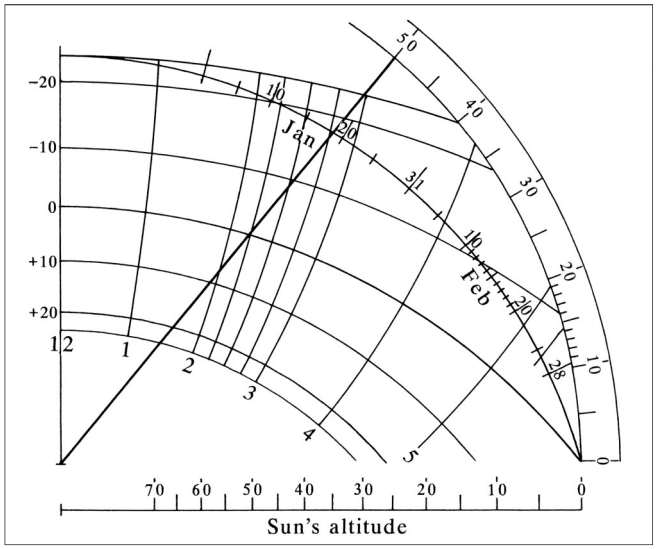


Fig. 4. To illustrate the use of the azimuth dial.

Quantity	Derived from dial	Calculated
Declination	-10°	-9.9°
Time	2:32pm	2:31pm
Sunset time	5:09pm	5:10pm
Sunset azimuth	16° S of W	16.0° S of W
Sun's altitude	20°	20.5°

Table 1

the corresponding declination (probably between two lines) and following that declination round until it intersects the gnomon shadow. The position on the hour scale of this intersection shows the time. In a reverse procedure, the declination and approximate date can be found be taking the time from the outer dial, transferring this to the corresponding inner dial time-line and noting the declination where this crosses the gnomon shadow. Following this back to the ecliptic gives the date. This method of finding the date is not very sensitive: the maximum rate of change of the sun's declination (at the equinoxes) is only 0.4°/day. At the solstices the declination changes very slowly and remains effectively at the same value for several days at a time. Some dials, notably the late example by Benjamin Scott, have the scale of dates at the ends of the declination arcs. A few dials do not carry a date scale: for these it is necessary to use the time derived from the outer dial as explained above to find the declination.

Having found the declination of the sun, the line can be followed to the horizon circle at east or west side. This will give the times of sunrise and sunset by reading the time graduations at those points. The azimuth at rising and setting can also be found from the horizon circle. The times of sunrise and set can of course be found for any day of the year, not just the current date, by following the appropriate declination line to the horizon.

The altitude of the sun is found by setting one point of dividers upon the derived position of the sun at the declination-gnomon shadow intersection and the other on the foot of the vertical gnomon. Transferring this distance to the almucantar scale enables the sun's altitude to be read off. These properties are demonstrated by the simplified drawing of the south-west quadrant of the azimuth dial in Figure 4, with just sufficient detail to show the principle. A diagonal line represents a gnomon shadow which indicates a solar azimuth of 50° south of west. Suppose the date is February 13: this day-mark on the ecliptic curve gives the declination as -10°. Following this line to its intersection with the shadow shows the time to be just after 2.30pm, say 2.32. In Table 1 these and other quantities derived from the dial by the above methods are compared with values calculated for that azimuth and date.

As is traditional in gnomonics, the effects of atmospheric refraction are ignored in the time and azimuth of sunset. The agreements between the calculated values and those derived from the dial are most satisfactory!

In the 1636 description Oughtred gives no less than twenty possible uses of the dial, although some of these are rather repetitious. In addition to those already mentioned, it is possible by use of the azimuth scale to determine the declining angle of a wall, either with the dial unmounted or permanently fixed. In the latter case a horizontal board is used with a line drawn perpendicular to the wall. The shadow of a plumb-line as it crosses this line is marked off. Then, says Oughtred, "run instantly to the dial" and take the reading of the sun's azimuth. This angle, if drawn relative to the marked position of the plumb-line shadow, shows the north-south line. The angle between this and the perpendicular to the wall gives the declining angle.

By imagining the dial to represent the hemisphere of the sky which is below the horizon, the duration of twilight and the depression of the sun can be found. Another quantity (apparently not envisaged by Oughtred) which can be deduced is the right ascension (RA) of the sun, the angular distance along the celestial equator (measured in time) from the March equinox to the hour circle through the sun. This can be obtained by ignoring the time figures and counting the hours and minutes forward along the equator from the equinoctial points to the hour line containing the required date, starting the count at 0 hours at the March equinox and 12 hours at that of September. As the sidereal time is defined by the RA which is due south on the meridian, the sidereal time at apparent noon is equal to the sun's RA. Adding 12 hours to this (strictly 12 hours 2 minutes) will give the sidereal time at midnight. A dial by Elias Allen now in the Science Museum and illustrated by Turner[5] has subsidiary small figures along the 0° declina-

tion arc to facilitate determining the RA of the sun in this way. It also gives the RA of twelve bright stars to the nearest quarter-hour. These include 'Great Dog', 'Lion's heart', 'Bull's eye' and 'The Goate', respectively Sirius, Regulus, Aldebaran and Capella. There is 'A Moone Dial' consisting of small Arabic numerals just inside the Roman numerals of the polar dial and a table of ages of the moon and corresponding hours to correct the dial reading. The presence of the moon dial implies that the star table is also intended as a means of telling the time at night. I am not suggesting that the wakeful owner should venture out in his nightshirt to consult his dial by candle-light; it would be simple to memorise the midnight sidereal time and the RA of a few stars which transit in the hours of darkness at that season. By observing the position relative to the meridian of a star of known RA an estimate of the sidereal time can be made. The difference between this and the midnight sidereal time will give an approximate figure for the solar time.

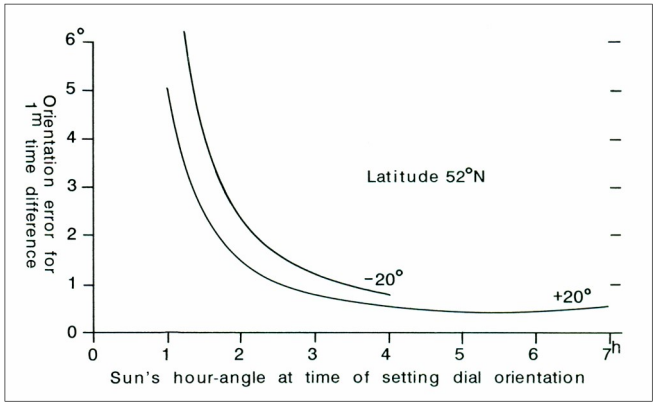


Fig. 5. The orientation error for a one minute time difference.

Other dials, notably some of the large instruments made by Henry Wynne, also carry moon-dials and the RA of some stars.

THE SELF-SETTING PROPERTY

The combination of polar and azimuth dials implies that the instrument is self-setting: by rotating it in a horizontal plane until both dials show the same time it will in principle be correctly oriented in the meridian. Although Oughtred makes much use of this property he does not mention the limitations of determining the orientation in this way. The crucial factor is the error in the orientation which will be caused by a small difference between the times shown by the two dials. From practical tests I find that the mutual agreement of the time readings cannot be judged to better than a minute. Even such a small difference will introduce an orientation error whose extent is strongly dependent on the hour-angle of the sun at the time of the operation and is also affected by the sun's declination and the latitude. Figure 5 shows the relation between the hour-angle of the sun and the orientation error, the angle through which the dial can be rotated to either side of the true position before a difference of one minute between the dial readings can be detected. It is drawn for latitude 52°N and two declinations, +20° and -20°. Looking at the +20° (summer) line, the orientation error for one minute difference between the dial readings cannot be less than about ½° and then only if the sun is at least four hours off the meridian. At smaller hour angles the error builds up very rapidly and it would be useless to try to obtain an accurate setting if the sun is within about 2½ hours of meridian passage. In winter (-20°) it is hardly possible to obtain a satisfactory orientation at all. The latitude dependence is such that at 58° the error is about 50% greater than shown in Figure 5 but is only about half as much at 40°.

Any error in the orientation will of course have an effect upon the time-keeping of the dial. Broadly, an error of one degree in the orientation will cause an error of four minutes in the indicated time. Even at the most favourable time of setting the orientation the time error caused by one minute difference between the dials will be about 2 minutes. The error rises rapidly under unfavourable conditions and the dials could be as much as twenty minutes wrong if orientation is attempted with the sun near the meridian. Matters can be improved by rotating the dial first in one direction and then the other to find and mark the two positions where a time difference can be detected. The midpoint of the two marks will provide a fair indication of the true orientation if the sun is not too close to meridian passage.

THE MAP OF THE SKY

In common with all map-makers Oughtred was faced with the problem of depicting part of a sphere (in this case the complete visible hemisphere of the sky) on a plane surface. The resulting flat map is termed the projection of the sphere and many types of projection have been devised. All involve some distortion in representing a sphere on a plane, and it is a question of selecting the best projection for the particular purpose. The one used by Oughtred is known as the stereographic projection (Greek *stereos*, solid; *graphein*, to write). In the 17th century this was much used for terrestrial and celestial maps, such as those by Cellarius[9] sometimes reproduced as calendar illustrations. It suffers from distortion and large variation of scale, but for the present purposes these defects are not significant and the projection has other properties which make it ideal for this application. One of the useful properties is that circles on the sky project as circles on the plane, except for great circles passing through the origin, which project as straight lines. This contrasts with the gnomonic projection

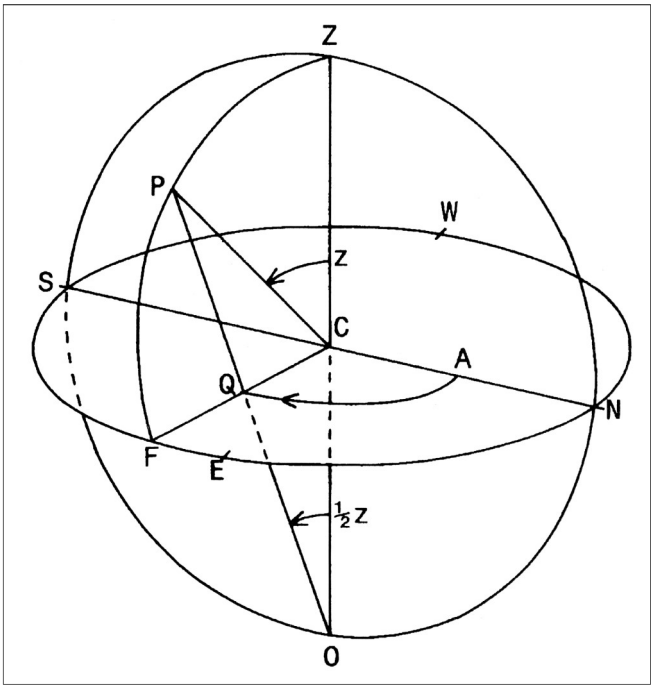


Fig. 6. The principle of the stereographic projection.

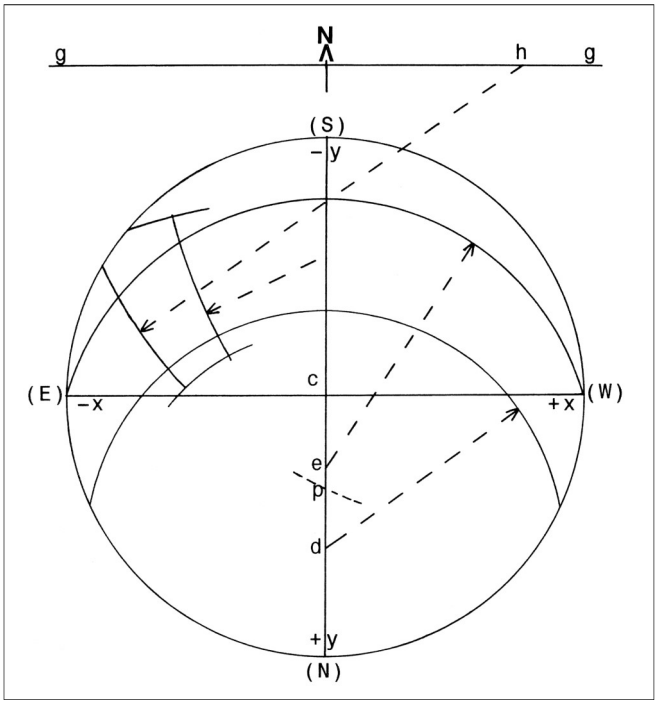


Fig. 7. Delineating the azimuth dial.

used in polar-gnomon plane dials, in which great circles project as straight lines and small circles appear as conic sections. (Great circles are those whose plane passes through the centre of the sphere: all other circles are small circles. For example, on the Earth meridians of longitude and the equator are great circles and parallels of latitude are small circles.) Another useful property of the stereographic projection is that angles on the sky are reproduced on the map, in the sense that the tangents to the arcs of projected lines at their intersection meet at the same angle as the corresponding arcs on the sky: this is of use in a geometrical delineation of the dial. Except in the case of the horizon the centres of the circles on the map do not coincide with the corresponding centres on the sky and the necessary centres and radii to draw them must be found by calculation or geometric construction. In Figures 1 and 2 the row of small pits on the line of the gnomon are some of the centres from which the declination arcs were struck.

The principle of the stereographic projection applied to the case of a horizontal dial-plate is shown in Figure 6. The circle NZSO represents the meridian with Z the zenith and O the opposite point, the nadir. NESW is the dial plate in the plane of the horizon and ZCO is the vertical through its centre. A position on the sky is shown at P and ZPF is the vertical arc through P meeting the dial plane at F. The angle NCF is the azimuth (A) of P from north. The nadir O is the origin of the projection and a line joining PO cuts the plane NESW at Q which is called the stereographic projection of P. As Q lies in the line CF, the azimuth of P from the north point is exactly reproduced on the dial by angle NCQ. By joining CP, the angle ZCP is the angular distance of P from Z, called the zenith distance (z) of P. The triangle PCO is isosceles (PC=OC, both radii of the circle) so the angle COQ is $z/2$. Triangle OCQ is right-angled at C, therefore the distance CQ is proportional to $\tan(z/2)$. At the horizon z=90° and $z/2$=45° whose tangent is 1, so if R is the chosen radius CF of the horizon circle on the dial the distance CQ is $R\tan(z/2)$.

In the following formulae and those of the next section, the symbols used are:

ϕ	Latitude
h	Sun's hour-angle
δ	Sun's declination
ε	Obliquity of the ecliptic (23.44° at the current era)
R	Radius of the horizon circle on the dial
r	Radius required to draw a projected circle

The rectangular coordinates x and y on the projection are referred to the meridian and the prime vertical, the great circle which passes through the zenith from the east-west points of the horizon. Both circles project on to the dial as straight lines as shown in Figure 7. In astronomical usage, x increases to the west and y increases to the north so, remembering that the dial plan is rotated by 180° and taking the centre of the dial as the zero-point, the signs of x and y appear on the dial as in Figure 7. (Sawyer[6] uses the opposite sign convention for y.) Any point on the sky (defined by its hour-angle and declination and the latitude), can be plotted from the general formulae:

$$x = \frac{R\left(\cos\delta\sin h\right)}{\left(1+\sin\phi\sin\delta+\cos\phi\cos\delta\cos h\right)} \qquad ...1$$

$$y = \frac{R\left(\cos\phi\sin\delta-\sin\phi\cos\delta\cos h\right)}{\left(1+\sin\phi\sin\delta+\cos\phi\cos\delta\cos h\right)} \qquad ...2$$

DELINEATION OF THE STEREOGRAPHIC PROJECTION

An interesting challenge to a present-day dial-maker would be to build a modern version of the double-horizontal dial. My own effort (somewhat simplified and made only in chipboard and plywood) is shown in Figure 8. The early dial-makers most probably used geometrical methods for the delineation but in these days of computers (or even pocket calculators) it is a simple matter to calculate the necessary details. The arcs of the projected declinations and the two ecliptic curves are symmetrical on either side of noon, so that their centres lie on the meridian (x=0) line. In Figure 7 a declination arc is shown centred at d and one of the ecliptic arcs centred at e. The centre of a declination arc is given by:

$$y = \frac{R\cos\phi}{(\sin\phi + \sin\delta)} \qquad ...3$$

The radius required to draw the arc is:

$$r = \frac{R\cos\delta}{(\sin\phi + \sin\delta)} \qquad ...4$$

The two ecliptic arcs require different centres and radii. For the March-June-September arc:

$$y = \frac{R}{\tan(\phi - \varepsilon)} \qquad ...5$$

$$r = \frac{R}{\sin(\phi - \varepsilon)} \qquad ...6$$

and for the September-December-March arc:

$$y = \frac{R}{\tan(\phi + \varepsilon)} \qquad ...7$$

$$r = \frac{R}{\sin(\phi + \varepsilon)} \qquad ...8$$

The centres of the hour lines (as at h) lie on a straight line g-g which is parallel to the x-axis. For this:

$$y = -R\tan(\phi) \qquad ...9$$

The centres and radii of the arcs are given by:

$$x = -\frac{R}{\cos\phi\tan h} \qquad ..10$$

$$r = \frac{R}{\cos\phi\sin h} \qquad ..11$$

Lines which are separated by 12 hours have the same centres and radii. The hour lines need only be drawn over the range covered by the declination arcs between +23.5° and -23.5°, or down to the horizon if -23.5° is below the horizon at that point, as can be seen on Figures 1 and 2 and indicated on Figure 7. It will be found that lines close to the meridian are nearly straight, with centres at considerable distances from the dial centre-line. If the radius required is more than can conveniently be handled by compasses or trammels, it is possible to calculate the x,y positions at intervals by the general formulae (1,2), plot the resulting points and join them with a suitable curve.

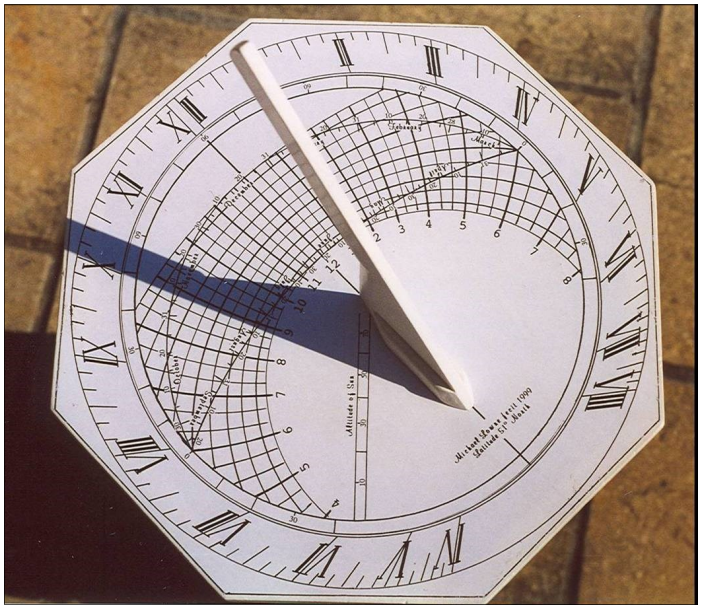


Fig. 8. A modern double-horizontal dial by the author.

Some of the formulae for the radius r may give a negative value: this may be ignored and the absolute value taken. In delineating the dial, various checks can be made. The arc for the equator (δ=0°) should pass through the east and west points of the horizon, as will the two ecliptic arcs, which should also touch the limits of declination (±23.44°) on the meridian. Although it is not necessary to extend the hour lines beyond the range of the declination arcs, they should pass through the projected pole of the sky which is on the meridian and at y=tan{(90- ϕ)/2}, p in Figure 7. The arc for 6 hours hour-angle (h=90°) is centred at x=0 and should pass through the east and west points of the horizon.

It remains now to put the scale of dates on the ecliptic arcs. The distance along the ecliptic traversed by the sun during 24 hours varies, due to the elliptical nature of the Earth's orbit around the sun and the resulting variations of orbital velocity. The average daily motion of the Sun is 59 arcminutes, but when the Earth is closest to the Sun (at perihelion) in early January it is 61'/day and at its furthest (aphelion) in early July it is 57'/day. If the mean and true sun are taken as together at perihelion, three months later the sun is 1.92° (or nearly two days' motion) ahead of the position it would occupy if the Earth's orbit were circular. The sun then drops back until at aphelion mean and true positions again coincide. After three months the sun is 1.92° behind the circular motion position.

The x,y coordinates of the sun on the dial for each day can be derived from the true longitude of the sun, its angular distance along the ecliptic from the 'first point of Aries' at longitude 0° where the ecliptic intersects the equator at the March equinox. Throughout the leap-year cycle there are small variations in the daily longitudes, but for the present purpose these are disregarded and average values taken. It is convenient to use the midday values of the longitude which is calculated by applying a correction for the elliptic motion to the longitudes found from the average daily motion of the sun of 0.9856°/day (=360°/365.25 days). The longitude (averaged over the leap-year cycle and adjusted to allow for the leap-year differences) on December 31 at midday is 280.1° and at the present time the Earth is at perihelion on January 3. The sun's longitude L is given by

$$L = 280.1 + 0.9856d + 1.92\sin\{0.9856(d-3)\} \quad ..12$$

where d is the day of the year: January 1 = day 1, February 1 = day 32 and so on. February 29 is ignored.

The x,y coordinates of the daily points are given by:

$$x = \frac{R\cos L}{1+\cos(\phi-\varepsilon)\sin L} \quad ..13$$

$$y = \frac{-R\sin(\phi-\varepsilon)\sin L}{1+\cos(\phi-\varepsilon)\sin L} \quad ..14$$

from March 21 to September 22 (L 0° to 180°)

and from September 23 to March 20 (L 180° to 360°)

$$x = \frac{R\cos L}{1-\cos(\phi+\varepsilon)\sin L} \quad ..15$$

$$y = \frac{R\sin(\phi+\varepsilon)\sin L}{1-\cos(\phi+\varepsilon)\sin L} \quad ..16$$

The daily points for the sun's position should of course lie along the pre-drawn curves for the ecliptic.

The almucantar operates from the zenith distance (z) of the sun but is graduated for the altitude (a): z = (90-a). Radial distances from the foot of the gnomon are given by:

$$r = R\tan\{(90-a)/2\} \quad ..17$$

The height of the vertical gnomon should be not less than half the radius of the horizon circle. This constrains the placing of the root of the polar gnomon and at low latitudes may result in an excessive distance from the dial centre.

DELINEATION BY GEOMETRICAL METHODS

As mentioned earlier, it is possible to delineate the dial by geometrical construction and it seems most probable that the seventeenth century dials were made that way. Sawyer[6] has given full details and it is not proposed to repeat the explanation here. Briefly, the principle is that the projected arcs, if drawn as complete circles, would intersect the meridian line in two points, generally one above and one below the horizon. The centre of the arcs must lie midway between the projections of these two points and the radius is half their separation. The line of the centres of the hour arcs is at the mid-point of the projections of the north and south poles and the centres are found by drawing lines from the pole at the appropriate hour-angles to meet the line of centres. From these points the arc radius is the distance to the pole. A major difficulty with the geometric method is that some of the projected points lie at considerable distances from the centre of the dial, necessitating the use of a large setting-out table. Such an item would have been common in an early instrument-maker's workshop.

How the scale of dates was inserted on the ecliptic is not known: one method would have been to plot the tabulated right ascension of the sun for each day along the ecliptic arc using the hour-lines, the reverse of the procedure mentioned earlier.

THE EXISTING DIALS

[The original paper listed in 'Table 2' the DH dials known at the time of publication. Since that time many more dials have become known so the reader is instead referred to the Catalogue section of this monograph.]

ACKNOWLEDGEMENTS

The photograph and drawing of the Seller dial in Figures 1 and 2 were kindly provided by the owner of the dial. The major part of the list of surviving dials was supplied by Mr Christopher St J H Daniel: other information was provided by Mr J Moir, Mr M Kenn and Dr J Davis. I am indebted also to Mr Daniel for the photograph of Figure 3 and for much technical help and encouragement. Miss R J Wilson provided biographical details of some dial makers.

REFERENCES

1. Dict. Nat. Biog., XIV, pp1250-1252, London 1909.
2. M Cowham, *Bull.BSS.* **11** (iii), 111-113, Fig 10 (1999).
3. *The Circles of Proportion and the Horizontal Instrument. Both invented and the Uses of both Written in Latine by Mr W.O.* Translated by William Forster, London 1632.
4. W. Oughtred: *Description and use of the double horizontal dial*, London, 1636.

5. A. J. Turner, 'William Oughtred, Richard Delamain and the horizontal instrument in seventeenth century England', in *Of Time and Measurement*, Aldershot, 1993.
6. Frederick W. Sawyer, III, 'William Oughtred's Double Horizontal Dial', *Compendium, Journ NASS* **4**, 1-6, (1997).
7. *Bull.BSS.***11**(i) 26, Fig 1 (1999).
8. C.St.J.H Daniel, *Bull. BSS*.**98.2** 26-31 (1998).
9. Andreas Cellarius, *Atlas Coelestis seu Harmonica Macrocosmica*, Amsterdam, (1661).
10. M Cowham, *Bull. BSS*.**12** (i), 23 (2000).
11 *Bull. BSS.***12**(iii) 130, 2000.
12 BSS: *The Sundial Register, Third Edition,* (2000).

THE 'BACON' DOUBLE HORIZONTAL SUNDIALS

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INTRODUCTION

The double horizontal dial, originally developed by William Oughtred in the early 17th century, is rightly regarded by gnomonicists as one of the most interesting and useful of all the dial types. Its layout and construction have been described in modern articles.[1,2] Only a relatively small number of double horizontal dials are known, having mostly been made by the most skilled British scientific instrument makers in the 17th and 18th centuries. The makers of most of the extant dials listed[1] are reasonably well known. However, the original 'Bacon' dial which is the subject of this article first became known to the authors when it appeared for sale in America[10] in 2000 and its maker, date and original location all remain unknown. It is an intriguing dial for many reasons, and has prompted the construction of a near-replica for a member of the present-day Bacon family.

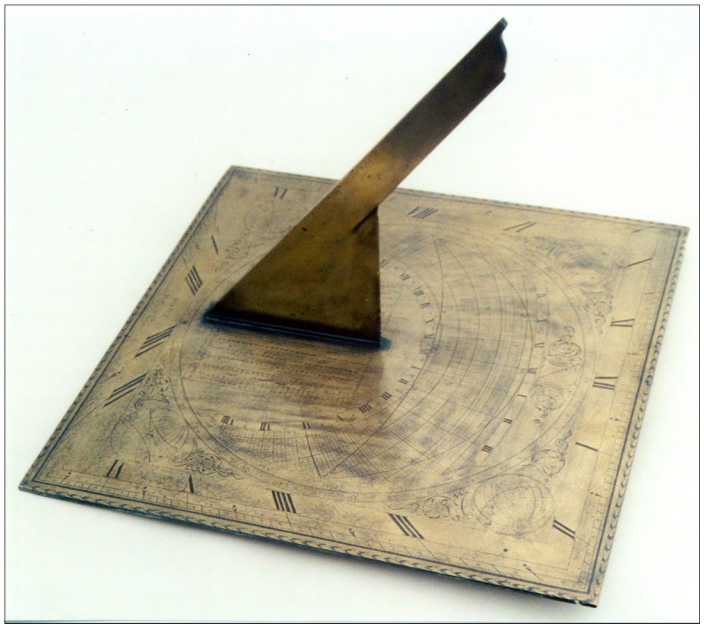


Fig. 1. The original 'Bacon' double horizontal dial (photo: D. Coffeen).

THE ORIGINAL BACON DIAL

The original dial is shown in Figs. 1 & 2. The brass dial plate is approximately 13 inches (330 mm) square and the characteristic double horizontal gnomon is mounted so that its toe is quite close to the southern edge of the plate. This permits the maximum height for the vertical style although it does rather cramp the main hour scale near sunset and sunrise. The only direct clues to the origin and manufacture of the dial are the name 'BACON', the latitude 51º 56' engraved to the south of the gnomon and a coat of arms. There are no dial makers called Bacon in the Directory of Scientific Instrument Makers,[3] which lists all of the craftsman makers known to have made this type of dial - many of them descending in a master-apprentice relationship from Elias Allen, who made the first dials for Oughtred himself.[4] Of the three Bacons who are listed, the earliest worked around 1805, which is too late for our dial.[A]

The format of the name, with just a surname and no place or 'fecit' descriptors, suggested that perhaps Bacon was the name of the first owner, rather than the maker. However, the set of arms to the north of the stereographic grid is not one which has ever been associated with a known Bacon family. They may be 'blasoned' (i.e. described in heraldic language) as *On a Bend ermined, three Leopards' Heads*. This description matches the arms of Sir William Stephenson, who was Lord Mayor of London in 1764, but his will gives no hint that he owned property at the appropriate latitude. It also matches the arms used by the Victorian actor Charles Kemble, having originally been granted to George Kemble of Wydell, Wiltshire, in 1602. The Venerable John Kemble (1599-1672) was executed for saying mass at the family property of Pembridge Castle near Welsh Newton, Herefordshire. The latitude of the castle is 51º 52.1', well within the measurement tolerance of the time to the dial latitude. Research into the possible connection is ongoing.

The dial has a square main chapter ring, with the Roman numerals orientated to read from the centre of the dial ('inward' in Table 1). This is the form used by many early English makers (for example, Elias Allen) and contrasts to that used by Benjamin Scott in his famous c.1715 dial[5] where the numerals are arranged to be read from its periphery ('outward'). In general, the numerals are aligned along their hour lines but this is not so for those along the southern edge, which are very elongated by the close proximity of the origin. The dial is delineated in minutes, with three-dot markers for the five-minutes and other markers for the quarters and half-hours. On such a relatively small dial, this leads to the need for some very fine engraving. Surprisingly, there is no noon gap to allow for the thickness of the gnomon, causing time errors and a discontinuity of about six minutes in the time readings at noon. This oversight has been corrected on the replica. The azimuth

Maker	Dial location	Azimuth scale origin or style	Main numerals orientation	Declination date scale	
				Horizon circle	Ecliptic
'Bacon'	USA	E/W	Inward	Clockwise	Zodiac, clockwise
Elias Allen	Science Museum	E/W	Inward	None	Months, clockwise
John Seller	Private collection	E/W	Inward	None	Months, clockwise
Henry Wynne	Confidential	N/S, and compass	Inward	Clockwise	Zodiac, clockwise
Henry Wynne	Drumlanrig Castle	32 pt compass	Inward	Clockwise	-
Henry Wynne	Sotheby's catalogue	N/S	Inward	Clockwise	Zodiac
Benjamin Scott	Paris Museum	E/W	Outward	Anticlockwise	Zodiac, anticlockwise
Henry Sutton	?		Inward		
Daniel Delander	Stanford Hall	32 pt compass	Outward		
?	Boughton Monchelsea	32 pt compass	Inward		on alidade
W Croft, Ilminster	Corton Denham House	E/W	Inward	Clockwise	Zodiac, clockwise

Table 1. Showing the style and scale orientations of some known double horizontal dials.

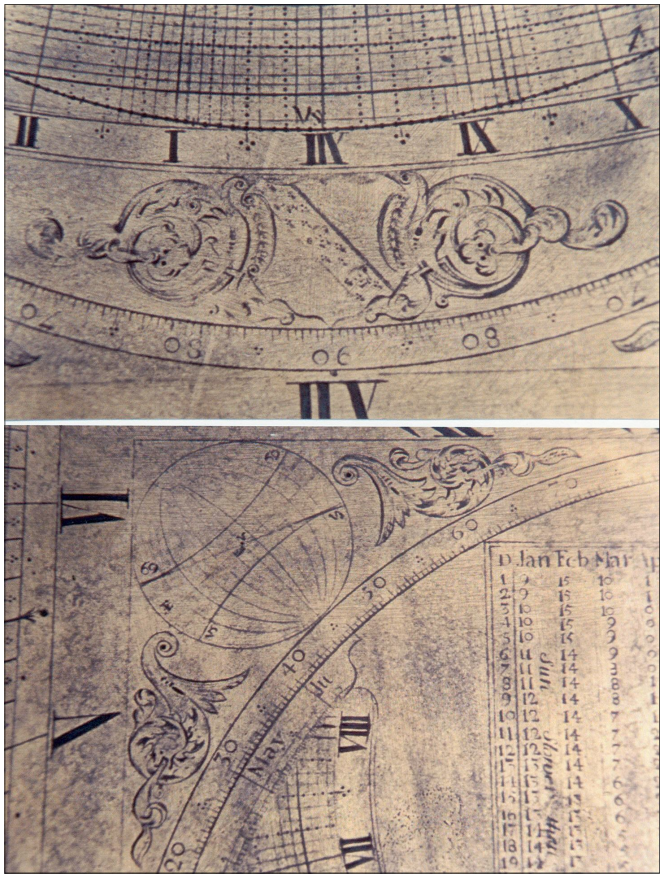


Fig. 2. Details of the original 'Bacon' dial, showing (top) the coat of arms and part of the stereographic grid and (bottom) the South-East spandrel and part of the Equation of Time table (photos: D. Coffeen).

scale is centred on the base of the perpendicular style, in the physical centre of the dial plate, and is of the four times 0-90º type, with the origins at the East and West points. It shows half-degree increments. Although East/West appears to be the most common choice of the origins for the azimuth scale on a double horizontal dial, at least two examples are known, by the famous maker Henry Wynne,[7] with North/South origins.

The stereographic grid is a demonstration of the engraver's prowess, featuring lines for every degree of declination and 5-minutes of time. The quarter-hours, and the 10º's of declination, are marked by dots which neatly fall in the gaps between the lines running in the other direction. The two arcs for the ecliptic feature dots for each degree of solar longitude with the signs of the zodiac engraved over the grid, running clockwise round the arcs. The corresponding dates are identified by a non-linear calendar scale running around the outside of the horizon circle, with each day shown and every fifth day with a three-dot marker. This calendar scale was not used by Elias Allen and John Seller on their dials. Henry Wynne did place the dates around the horizon circle on some of his dials but when Benjamin Scott did so, the months ran anticlockwise round the circle. The styles of the markings of the various double horizontal dials are summarized in Table 1. This table is by no means complete, but it is clear that there is a wide variety of styles and conventions so that it is difficult to use these features to identify a maker.

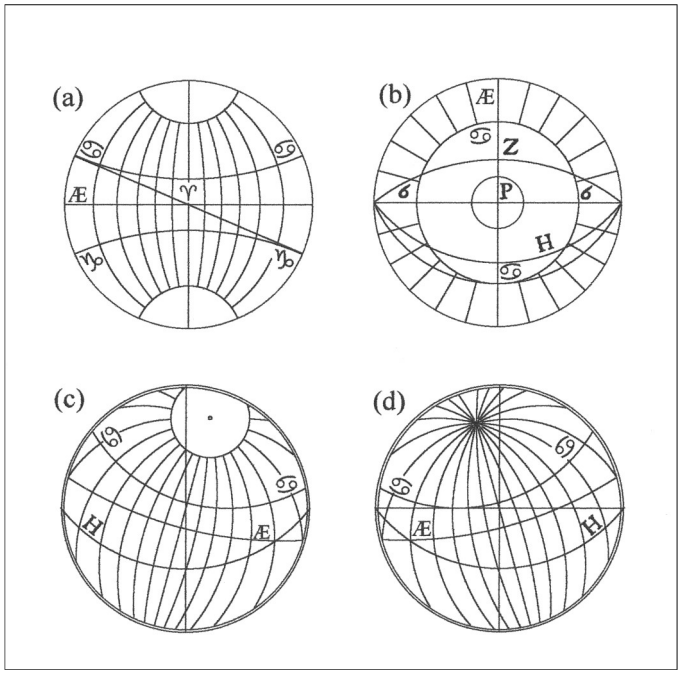


Fig. 3. Diagrams of spandrels (a) south east, (b) south west, (c) north east, (d) north west. The individual plans are rotated a multiple of 45° so that the centre of the dial is at the bottom of each drawing. The drawings show the 'corrected' projections for the replica dial.

The Spandrels

The designs in the four spandrels initially appear to be interesting engraving flourishes but on closer inspection turn out to be one of the most intriguing features of the dial. All the designs are based on stereographic projections: in spite of their small scale the accuracy is sufficient for their features to be determined. They are intended to be read from the centre of the dial and are inclined at 45º to the cardinal directions. They are shown in a reconstructed form in Figure 3.

In the south-east corner of the dial plate is a projection of the sky centred on the 'First Point of Aries' (♈ in Figure 3a and also labelled with ♎, the 'First Point of Libra', 180º opposite). The straight line 'Æ' is the celestial equator. The tropics of Cancer (♋) and Capricorn (♑) are shown and a line tangential to these is the ecliptic passing through ♈. Hour circles at 15º intervals are drawn between two arcs at about 10º distance from the poles: these arcs have been altered on the replica dial to represent the Arctic and Antarctic circles.

In the south-west corner, the projection is centred on the north pole of the sky (P in Fig. 3b) with the arctic circle around it. The periphery is the equator, labelled Æ. The stronger line running from the east and west points (labelled 6 for 6am and 6pm) is the ecliptic meeting the central line at the summer solstice, ♋. The tropic of Cancer at declination 23.5º is shown and is also labelled ♋ on the opposite side. Hour lines radiating from the pole appear from this declination circle to the equator. The mark resembling a backwards (on the original dial only) 'Z' is taken to indicate the zenith at latitude 50º, not very different from the dial latitude of 51º 56'. A curve running from east to west through Z is the 'prime vertical'. Another east-west curve on the opposite side is labelled 'H' and is probably intended as the northern horizon of Z, but it is not in the correct place, being only 80º from Z instead of 90º. This position has been corrected in the replica.

The other two projections in the north-east and north-west corners (Figs. 3c and 3d) are more difficult to interpret. They are contained within double circles and are projections centred on 18º north declination (or latitude: they could be intended as terrestrial plans), and are inclined to the 45º line to the dial centre by about 15º. They show the equator Æ, and the tropic of Cancer ♋. Hour lines at 15º intervals meet at the pole on the north-west plan but stop short at a radius of about 13º from the pole on the north east plan. Some aspects are not very accurately drawn: the tropic is misplaced and the hour line spacings are rather irregular. Each has a curve labelled H, apparently the horizon for a more northerly latitude, 52º on the north-west plan and 56º on the north-east. The horizons are inclined to the central meridian by 15º (or one hour of time). It seems that the plans are drawn for 18º latitude (approximately that of Jamaica, for example) and horizons relevant to locations in Britain have been superposed, but the time or longitude difference is not understood. The double circles around the edge might possibly indicate that two latitudes are depicted. It seems most probable that these two plans had significance to the original owner of the dial, but this cannot now be determined. They have been copied on the replica dial with the drawing errors 'corrected'.

The Equation of Time Table

The area around the base of the gnomon is dominated by the large Equation of Time table, with one column for each month and an entry, in minutes only, for every day. The presence of the table strongly suggests that the date of the dial is after 1672, when the first proper EoT table in England was published by John Flamsteed.[6] The dates of the maxima and minima show that the table is calculated for the Julian calendar, as indeed are the equinoxes on the stereographic grid. This implies that the dial was made before 1752, when England legally adopted the Gregorian calendar. The presentation of the EoT in the form of a table is inefficient in terms of space on the dial plate and engraving effort. This might suggest that the dial dates from towards the beginning of the 1672 to 1752 period, as the neater circular arc format was introduced (in London) by Thomas Tompion and Henry Wynne by the 1690s.

Comparison of the dial table has been made with two contemporary tables, that of Flamsteed (1672)[6] and one prepared by (or for) Thomas Tompion[9] in 1683. [See Note B.] Direct comparison between these two tables shows that they can differ by more than 20 seconds, the Flamsteed values being larger numerically than those of Tompion. The greatest discrepancies occur around the times of the solstices and equinoxes and can be ascribed to the use of different values for the eccentricity of the Earth's orbit around the Sun. Flamsteed has used a value of 0.0173 and Tompion 0.0166: the true value was part-way between these two at 0.01685 and perhaps was not accurately known at the time. Although the one-minute resolution of the Bacon table makes the comparison difficult (and it is not helped by the Flamsteed tabulation being in degrees of solar longitude rather than calendar dates) the discrepancy makes it easier to determine which one is most likely to apply to the Bacon dial. A very simple test is to inspect the range of dates which are covered by the maximum and minimum values. From January 24 to February 5 (Julian) the dial shows the EoT as +15 minutes and in the Tompion table those values which exceed 14^m30^s (and so round up to 15^m) run from January 25 to February 6, 13 days in each case. However, Flamsteed's values exceeding $+14^m30^s$ cover 18º of solar longitude, effectively just over 18 days. Similarly, at the October minimum, the dial figures and the rounded Tompion value of -16^m each cover 18 days, whereas the rounded Flamsteed values cover 22º or over 22 days. The greater extent of the Flamsteed ranges is explained by the excess of Flamsteed values over Tompion. Mathematical analysis shows that overall the Tompion table is a much better fit to the dial values than that of Flamsteed. The evidence leads to the firm conclusion that the Bacon dial table, if not directly derived from the Tompion one, is based on much the same parameters. Perhaps this choice was based on the difficulties that instrument makers had in interpreting Flamsteed's longitude-based table.

The location of the EoT table on the dial plate precludes the inclusion of an altitude scale, usually found running diagonally from the foot of the vertical style. This suggests that the dial was intended for timekeeping purposes, rather than astronomical ones.

In principle, the accuracy with which the dial was originally delineated could be assessed by measuring the radii and centres of the stereographic arcs. This would only be possible with direct access to the dial. Working from photographs, the best that can be done is to measure where the declination arcs meet the horizon circle, using the in-built azimuth scale. These points correspond to the azimuths of the astronomical (true) sunrises/sunsets, which may be calculated exactly and compared to the dial values. This has been attempted for the dates where the photographs allow reasonable measurements. A standard deviation of 0.13º for the sunset azimuth errors for declinations from +13º to +23.5º was obtained, but it is unclear how much of the apparent errors is due to the photographic measurement technique.

THE BACON CONNECTION

'Bacon' is quite a common English surname so it is not possible to be certain which particular family originally owned or made the dial. [See Note A.] However, it would have been an extremely expensive item when it was new, and its scales would only have been decipherable by an educated person so it is likely to have been a family of high standing. The most famous of the Bacon families is that which descended from Sir Nicholas Bacon, born in Kent in 1510 but who later moved to Norfolk and became a member of Queen Elizabeth's Privy Council. Sir Nicholas' second son of his first marriage (Sir Nathaniel) married Anne, the daughter of Sir Thomas Gresham, founder of the famous Gresham College. His second son by his second marriage was Sir Francis Bacon. The Bacon family included several MPs for Norfolk constituencies and for Ipswich, and had many ancestral homes, mainly in East Anglia.

The 51º 56' line of latitude for which the dial was made just clips the south of Suffolk before passing though Essex, Herts, Beds, Bucks, Oxon, Gloucs and Herefordshire, and on into Wales. So far, no ancestral Bacon home has been found to correspond to this line. This reinforces the conclusion from the coat of arms that 'Bacon' does not refer to the owner. Thus at the moment, the history of the dial remains mysterious.

THE REPLICA DIAL

With the current revival of interest in double horizontal dials, making a replica of the Bacon dial was an interesting challenge, especially as the original is no longer in its home country. Good photographs of the original were available, so it was possible to produce a computer-aided design (CAD) drawing (Fig. 4) starting from careful measurements and scaling of the photographs. Although care was taken to preserve the feel of the original design, there are several important areas where the design was purposely changed. The main change is the latitude of the dial; whereas the original was made for 51º 56' North, the replica was accurately delineated for 52º 31' North, to suit its new home in Norfolk. Another major change was to the EoT table, where the original values were substituted by modern ones (averages for the period 2000-2049) in the Gregorian calendar. Next, the heraldic arms on the original

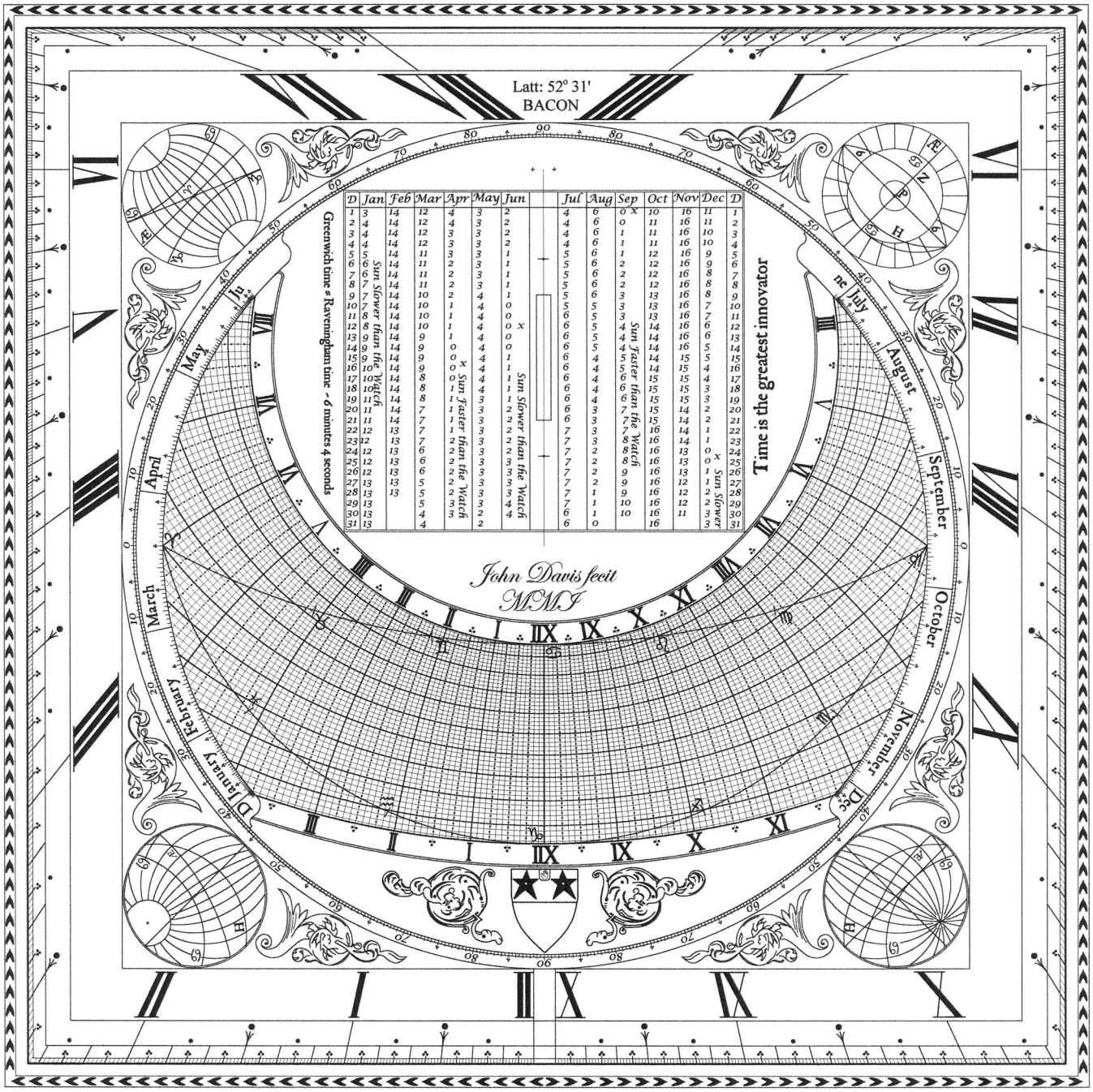


Fig. 4. A computer aided design (CAD) drawing of the replica dial.

were replaced by those of the modern Bacon family. Although double horizontal dials, as scientific instruments, did not usually carry mottoes, one was included on the replica with the wording:

Time is the greatest innovator

This is a quotation[8] from the great Tudor statesman and philosopher of science, Sir Francis Bacon, and so is particularly apt. The change from local to Greenwich time for everyday time-keeping has occurred since the original dial was made and this has been reflected by the addition of a simple equation giving the time correction for the longitude of the dial's intended location. Finally, the replica is signed and dated by the maker, as is customary - a practice which would have saved much confusion had the original maker followed it! The lettering on the replica dial is in computer generated fonts which give it a period feel although they are not strict reproductions of the original.

The replica dial (Fig. 5) was manufactured by photolithography and wet chemical etching of the brass plate, whereas the original was of course made by skilled hand engraving. This produces some differences in the style of the lines produced. The photomask was home-produced using an inkjet printer and, combined with a dry-film, negative pho-

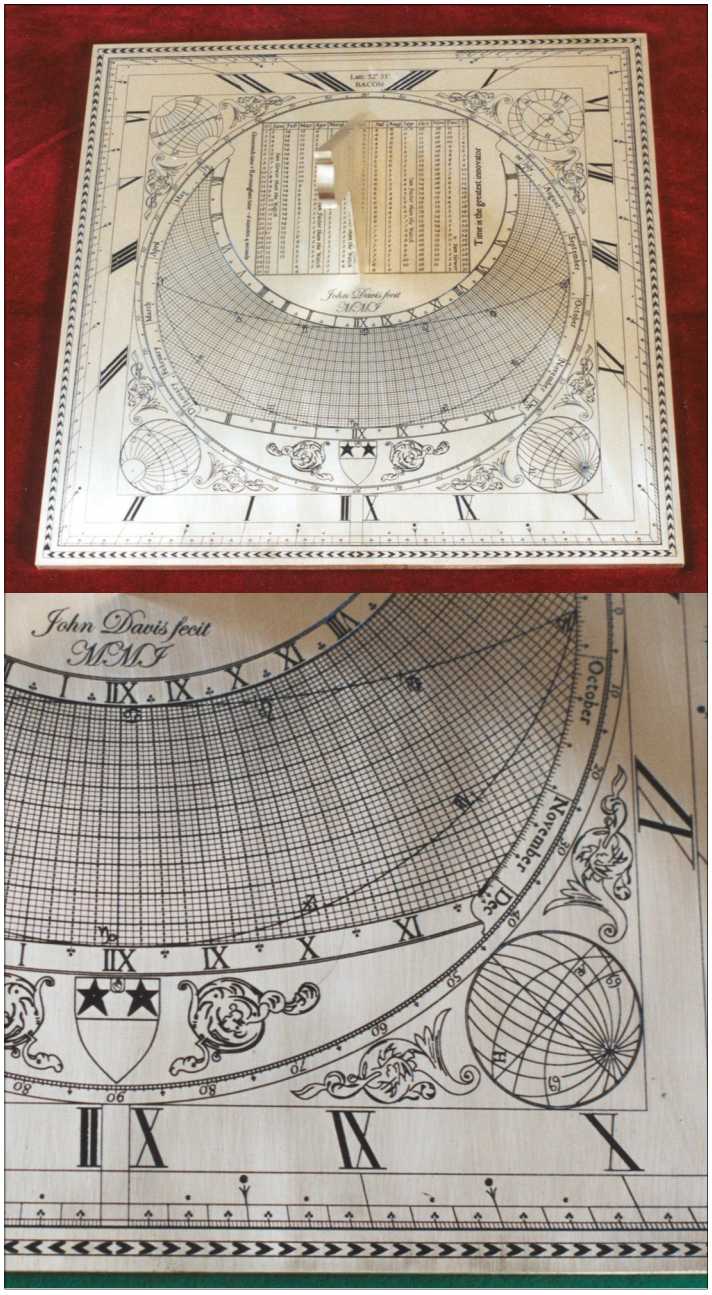


Fig. 5. The replica 'Bacon' dial, showing (top) an overall view and (bottom) details of the North-West spandrel design and the Bacon coat of arms.

toresist, gave a minimum printed linewidth of 50 microns (approximately two thousandths of an inch). Wet chemical etching is an isotropic process so, as the etching progresses, the etch gradually undercuts the photoresist and widens the lines as they increase in depth. This limits the fineness of the lines that can be achieved for a given depth and in practice a minimum linewidth of 150 microns was achieved on the finished dial. The etching was performed in the standard ferric chloride solution, in a bubble-agitated vertical tank at 40ºC. Because the flow of etchant is naturally reduced in the narrow lines, where the undercut resist reduces turbulance, etching is slower in the fine features than it is in the larger open areas. This fortuitous effect gives the differential line depth that a hand engraver would achieve by using a larger graving tool and more force in these areas. However, whereas the engraved line would have a 'V' profile, the etched one is more like a 'U'. The major difference between the two techniques is in the larger areas which are flat-bottomed when etched but made up of a number of parallel Vs when engraved. The engraving on the original dial would almost certainly once have been wax-filled but this is not now apparent. On the replica, the lines were filled with black enamel paint and the brass surface given a fine satin finish with a rubberised texturing block. It has been left in an unsealed state so that it can weather naturally.

The presence of the EoT table means that the gnomon cannot be buttressed without obscuring the table and hence its fixing is not as mechanically solid as it might otherwise be. On the original dial, it is presumably held in place by a hand-cut tenon passing through the dial plate and pulled tight by tapered pins through it. Modern machining methods, such as the availability of brass screws and steel taps, not to mention milling machines, allow a better-engineered solution of a milled slot and counterbored brass screws. The back of the replica, which is 6 mm thick, has been left flat so that the dial may be simply mounted on its pedestal with silicone or epoxy and without disfiguring screws.

ACKNOWLEDGEMENTS

We are greatly indebted to Dr David Coffeen (Tesseract) for providing the photographs of the original dial, and for permission to publish them here. The commission from Sir Nicholas Bacon gave the project a great impetus. Thanks are due to Anthony Turner, Patrick Powers, Mike Cowham and Andrew James for photographs of dials and EoT data. Tony Wood together with Clive Cheesman (*Rouge Dragon Pursuivant)* and Thomas Woodcock at the College of Arms provided much of the heraldic research.

REFERENCES

1. C.M. Lowne 'The Design and Characteristics of the Double-Horizontal Sundial', *BSS Bulletin* 13(iv), pp. 138-146, (December 2001).
2. F.W. Sawyer: 'William Oughtred's Double Horizontal Dial' NASS Compendium, 4, pp1-6 (1997).
3. G. Clifton: *Directory of British Scientific Instrument Makers 1550-1851*. Zwemmer. London (1995).
4. A. Turner: 'William Oughtred, Richard Delamain and the Horizontal Instrument in Seventeenth Century England', Annali dell Instituto e Museo di Storia della Scienza di Firenze. Anno VI, Fasc 2 (1981).
5. A. Turner: 'Le cadran solaire de Benjamin Scott', La Revue, Musée des arts et Métiers, Paris. pp55-57, September 1998.
6. J. Flamsteed: *De Aequatione Dierum* (1672). See www.burnley.gov.uk/townley/tryall/jftable.htm.

7. Andrew James, private communication.
8. F. Bacon: 'Of Innovations' in *The Essayes* (1625). The full quotation reads "He that will not apply new remedies must expect new evils: for time is the greatest innovator". See www.phnet.fi/public/mamaa1.bacon/htm.
9. R.W. Symonds: *Thomas Tompion - his life and work.* Spring Books, London (1969).
10. Tesseract Catalogue 66, Item 22 (Spring, 2000: Hastings-on-Hudson, NY).

NOTES ADDED FOR THIS MONOGRAPH

A. We have now become aware of the clockmaker William Bacon of Colchester (working c. 1648 – c. 1680). Two clocks by him are signed "Guilielmus Bacon, Colcestria fecit' and 'William Bacon, Colchester'. The latitude of Colchester is 51° 53' N, i.e. very similar to that on the dial. Ref: B. Loomes: *The Early Clockmakers of Great Britain.* NAG Press, London (1981).

B. Further work on early EoT tables has shown that Tompion's table was derived from a slightly later calculation by Flamsteed and became a major source for EoT data on late 17th and very early 18th century dials. Ref: J. Davis: 'The Equation of Time as represented on Sundials' *BSS Bulletin*, 15(iv), pp 135-144, (2003) and J. Davis: 'More on the Equation of Time on Sundials', *BSS Bulletin*, 17(ii), pp. 66-75, (June 2005).

HENRY WYNNE'S DOUBLE HORIZONTAL DIAL AT STAUNTON HAROLD

JOHN DAVIS and MICHAEL LOWNE

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INTRODUCTION

About a third of all the known 17th century double horizontal dials are by the great mathematical instrument maker Henry Wynne[1]. Many of his dials were very large (around 30" in diameter), including the one described in this paper and which is perhaps the most sophisticated of all 17th century dials. As well as being a double horizontal, the dial is a moondial, a star dial and a 'geographical' dial, and it includes a nocturnal, calendar tables, age of the moon tables and possibly the earliest Equation of Time (EoT) table ever placed on a dial.

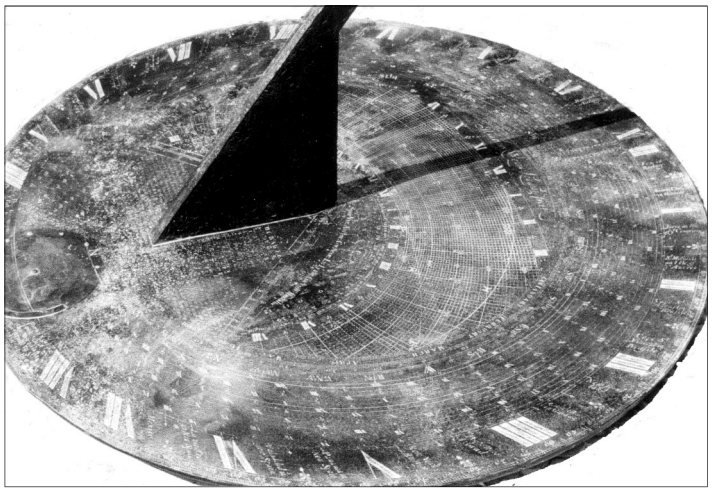


Fig. 1. The original Wynne double horizontal dialplate. It has been dusted with talcum powder to make the engravings visible.

The dial, shown in Fig. 1, was made for Staunton Harold in Leicestershire (Fig. 2). Although it does not carry a date it is believed (see below) to have been made in 1685 and was probably commissioned by the Baronet Sir Robert Shirley (1650-1717), later to become the 1st Earl Ferrers. The Earl had been busy rebuilding and refurnishing Staunton Harold (Fig. 2i) after his father had been imprisoned in the Tower of London during the Civil War and he spent lavishly[2] remodelling the garden and buying pictures and books for the house, so a fine sundial would have been a natural acquisition. The dial fits neatly in a sequence between two other Wynne double horizontals of similar size: the 1682 Wrest Park, Bedfordshire, dial (a replica is on display in the English Heritage garden) and the 1692 Drumlanrig Castle, Dumfrieshire, dial.[3]

The 1st Earl's eldest son, also Robert (1673-99), was for a short time before his early death a Fellow of the Royal Society where he would have been exposed to the latest research results from Isaac Newton, Robert Hooke, John Flamsteed and the other prominent members. Later, the 5th Earl was a passionate amateur astronomer and in 1761 was also elected an FRS for a paper he presented on the transit of Venus. He made major changes to the gardens and buildings at Staunton Harold and is believed to have moved the dial to the position on the lawn on the Lion Front (Fig. 2ii) that it occupied until 1954. He owned a magnificent orrery and was the origi-

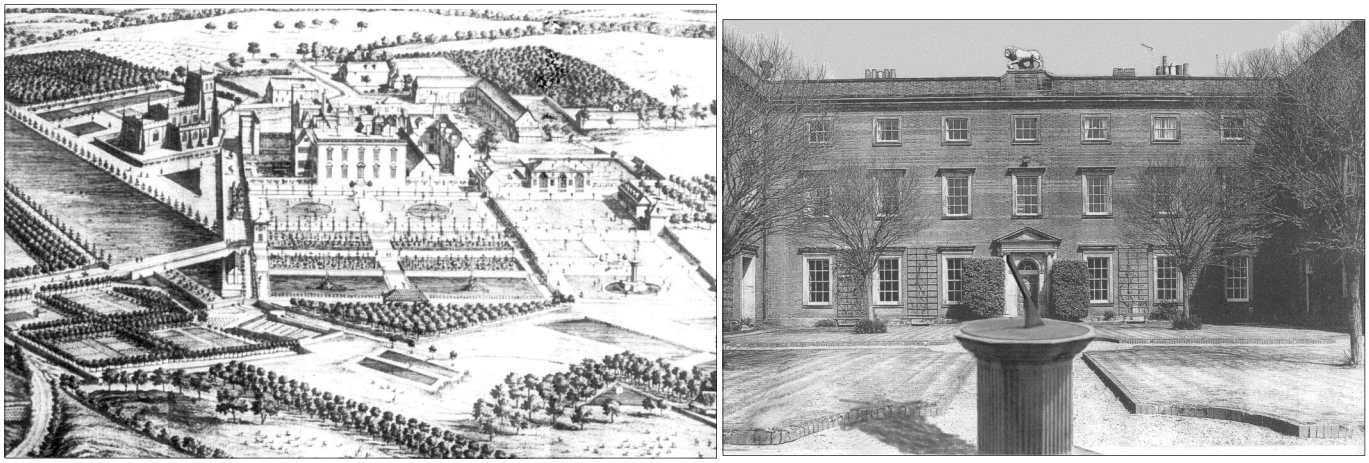


Fig. 2. Staunton Harold in Leicestershire. (i) 1702 engraving by Kip of the buildings in the time of the 1st Earl Ferrers. It is believed that the dial can just be seen in the original engraving, just beyond the house. (ii) Composite photograph (2002) of the Lion Front at Staunton Harold as rebuilt by the 5th Earl and the replica dial on the pedestal, showing the appearance for the majority of the dial's life.

nal purchaser (for £10 0s 0d) of the famous oil painting by Joseph Wright of Derby entitled "The Lecture on the Orrery".[4]

The 12th Earl Ferrers arranged the sale of Staunton Harold in 1954 but, sadly, died the night before. At the sale, the house was sold to demolition contractors but, some three months later, it was purchased by Group Captain Cheshire so that it could be used as one of his Cheshire Homes for the incurably sick. The property, now a Grade 1 listed building, was put up for sale again in November 2002. The Wynne dial and its stone pedestal were moved by the present (13th) Earl to Hedenham Hall in Norfolk and then subsequently to Ditchingham Hall, Norfolk, where it remains.

Staunton Harold was surrounded by coal mines and the sulphurous coal was universally burnt in that part of the country. As a result of 250 years of rainfall in the form of a weak sulphuric acid, the dial had become badly corroded by the time it was moved from Leicestershire. In the 1970s, the Victoria and Albert Museum advised that it should be immersed in a number of weak alkaline solutions. This arrested the corrosion but, unfortunately, the engravings became far less precise and very difficult to read. The already fragile nocturnal was lost in the process. In 1985, after a period on loan to the National Maritime Museum, a respected firm of antique restorers improved the legibility slightly by mechanical treatment of the surface and an application of coloured wax. They also made a resin replica so that the original could finally be moved indoors in order to protect it from further deterioration and from the weather. It had been planned to re-engrave the replica so that the engravings could be read but without a full drawing of the dial this had not proved possible. When the present authors came across the replica dial in July 2002 it was already deteriorating badly, possibly because the resin may be on a ferrous core which is rusting and expanding. They were delighted when Earl Ferrers allowed full access to the original for a detailed study and were even happier to have the resulting drawings used as the basis for a new replica to be made, this time in solid bronze, by BSS member Tony Moss.

HENRY WYNNE

Henry Wynne served his apprenticeship under Ralph Greatorex, beginning in 1654 and gaining his freedom in the Clockmakers' Company in 1662. Greatorex was himself a maker of at least one double horizontal dial[1] and, in turn, had served his apprenticeship under the illustrious Elias Allen, the maker of the first of these dials for their inventor, William Oughtred. Wynne is credited[5] with nine apprentices, including the well-known dial-makers Richard Whitehead, Richard Glynne and Thomas Tuttell. Although Tuttell is primarily known as a clockmaker,[A] one double horizontal dial by him is known, preserving a long line of makers in this Guild.

Wynne's premises were in Chancery Lane, London, and given as "At the Pope's Head", "Next the Sugar Loaf", "over against the Rolls" and "near Sergeant's Inn" at various stages of his career. He made all sorts of mathematical instruments but was particularly well known for his compasses and dipping needles: amongst the customers for these were John Flamsteed at Greenwich and James Gregory at the St. Andrew's Observatory. Robert Hooke is known[6] to have visited Wynne's shop on several occasions and on 26 May 1678 (some years before the manufacture of the Staunton Harold dial) he was accompanied by Samuel Pepys. Wynne is known to have made at least nine double horizontal dials, far more than any other maker. Although the one made for Windsor Castle[7] is missing (its partner there, a standard garden dial, is still in position), several of the others are listed in the BSS Register, including one at Powys Castle.[8] In addition, a further nine garden horizontal dials are known, some in private collections and one in America. He wrote a leaflet in 1682 describing the use of Oughtred's universal equinoctial ring dial which he was producing: one of these is in a private collection. All his instruments are of the highest quality. They are usually signed either "Henricus Wynne Londini fecit" (Fig. 3) or just "Henry Wynne fecit" when space was more limited. When he died in 1709 his stock was sold off .



Fig. 3. "Henricus Wynne Londini fecit" - the signature favoured by Wynne on his large dials - this one from the Wrest Park (replica) dial.

OVERALL DESCRIPTION AND CONSTRUCTION

The original Staunton Harold dial (Figs. 1 and 4) is in bronze,[B] 770 mm (30") in diameter and 10 mm (about 3/8") thick. The massive gnomon is a full 19 mm (3/4") thick and stands a proud 592 mm (about 23") along the polar style. The whole dial needs two people to lift it. The horizontal distance between the toe of the polar gnomon and the vertical style in the centre of the dialplate is 200 mm. This is a larger offset than the 177 mm on the slightly larger Wrest Park dial. It is likely that this design change was made to allow the vertical style to be slightly taller as, on the Wrest Park dial, its shadow does not reach the edge of the stereographic projection near the summer solstice. The gnomon is located by two large tenons of unequal size, passing though the dialplate. The tenons are currently



Fig. 6. Part of the gnomon of the original dial (dusted with talcum powder).

rather crudely brazed to the underside of the plate but this is thought to be a recent repair as it would have required an oxyacetylene torch which was not available to Wynne. On the Wrest Park dial, the tenons have large rectangular holes for wedges.

The back of the dialplate has the fairly undulating surface typical of a hand-hammered casting which has not received the careful scraping to produce the smooth, flat surface of the dial face. It does have a minimal amount of engraving in the form of two circles representing the main chapter ring. There are two small holes which show the origins of the two polar styles but, unlike dials in thinner material, these do not penetrate through to the top surface to act as locators for the gnomon. Surprisingly, there are no holes in the dialplate for it to be fixed to its pedestal, so it rests freely in a depression in the stonework.

Even though the dial is badly corroded, it is clear that Wynne was a superlative engraver (Figs. 5, 6). The numbering and lettering is generally oriented to be read from the inside of the dial (or the south) showing its ancestry from the earlier Elias Allen dials. Later dials of this size

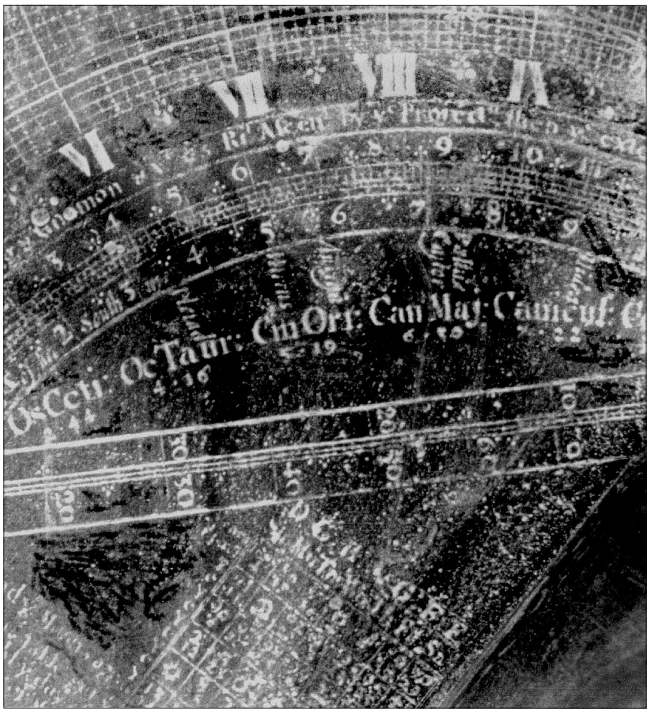


Fig. 5. Photograph of part of the dial face, including parts of the stereographic grid, the moon's age scale and the Epact table.

tend to have an outward orientation of the lettering.[9] There is a wide range of lettering sizes, varying from 31 mm for the main hour numerals down to 2.2 mm for some of the tables. Wynne adopts two different fonts to cover this range, a formal Roman font for the larger letters and an italic one for the smaller one. The complexity of the letters, sigils, fleur-de-lys and other flourishes is not as high as in the early Tudor period (e.g. the dials by Humphrey Cole) but still more ornate than the later Georgian dials.

THE STEREOGRAPHIC PROJECTION

The central area of the dial is dominated by the stereographic projection of the celestial sphere. This is 222 mm in diameter and of a fairly standard format. It has lines for every five minutes of time (or right ascension) with the quarter- and half-hours dotted, and for every individual degree of declination with the 5-degree lines dotted. The 10s of the declination lines are numbered (Arabic) in several places. The two arcs of the ecliptic are shown, labelled with the zodiac sigils and dotted for each degree of solar longitude. Wynne has inadvertently interchanged the symbols for Leo (♌) and Capricorn(♑). Additional Arabic numerals along the celestial equator show the right ascension, running (0)-12 from the vernal to the autumn equinox and from 13-(24) back to the vernal equinox. The right ascension of the sun is the angular distance along the celestial equator from the March equinox to the hour circle through the sun, measured in time. Two sets of Roman numerals just outside the summer and winter solstice arcs show the time. Around the outside of the horizon circle, the names of the months are given in English (e.g. IANUARY, FEBRUARY), running clockwise. This scale is divided into individual days.

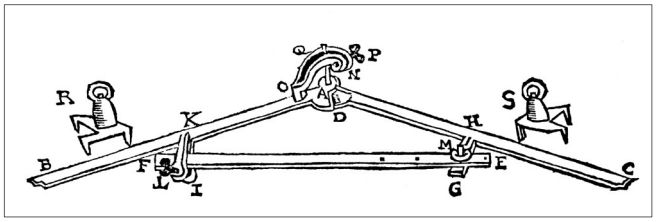
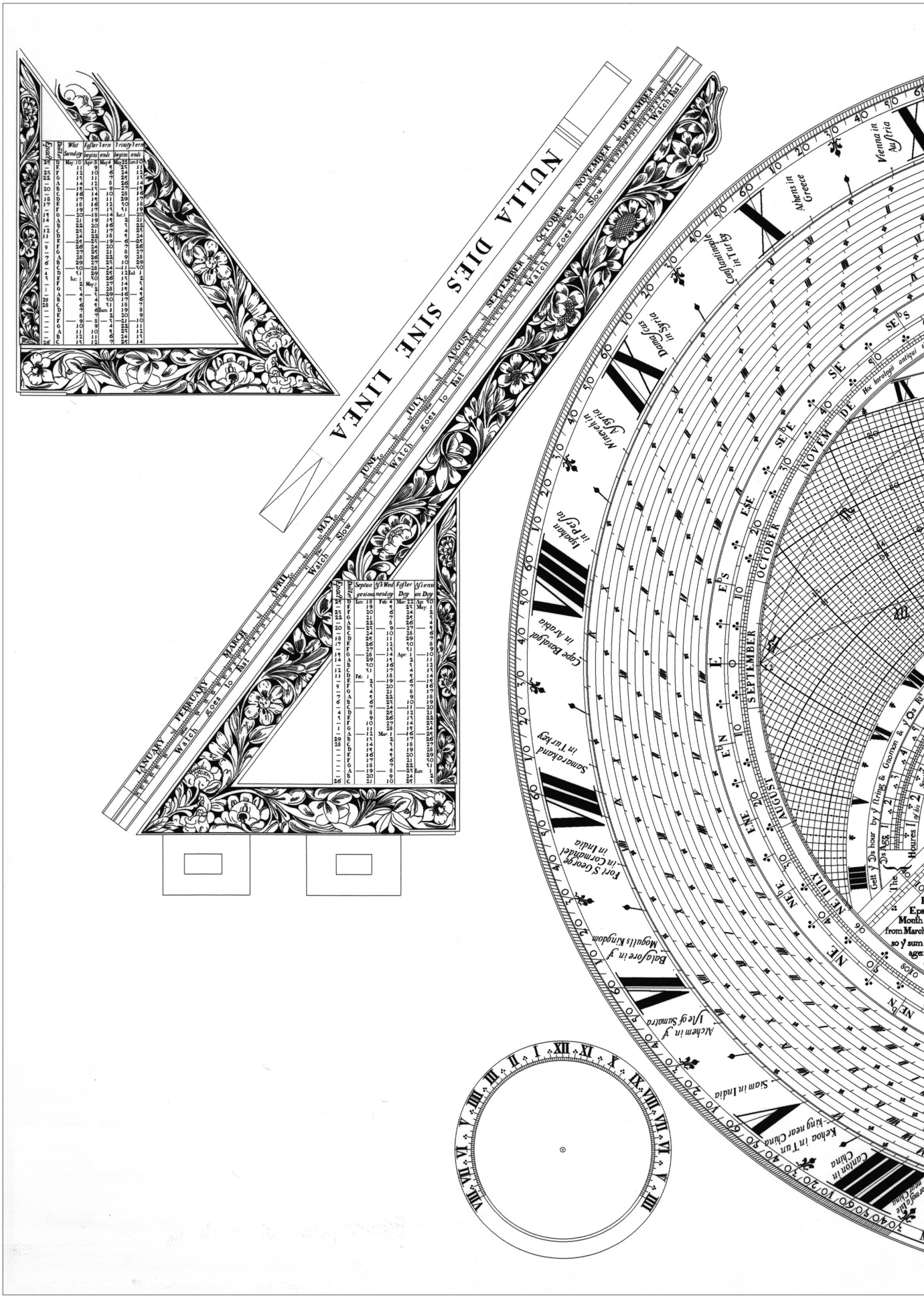
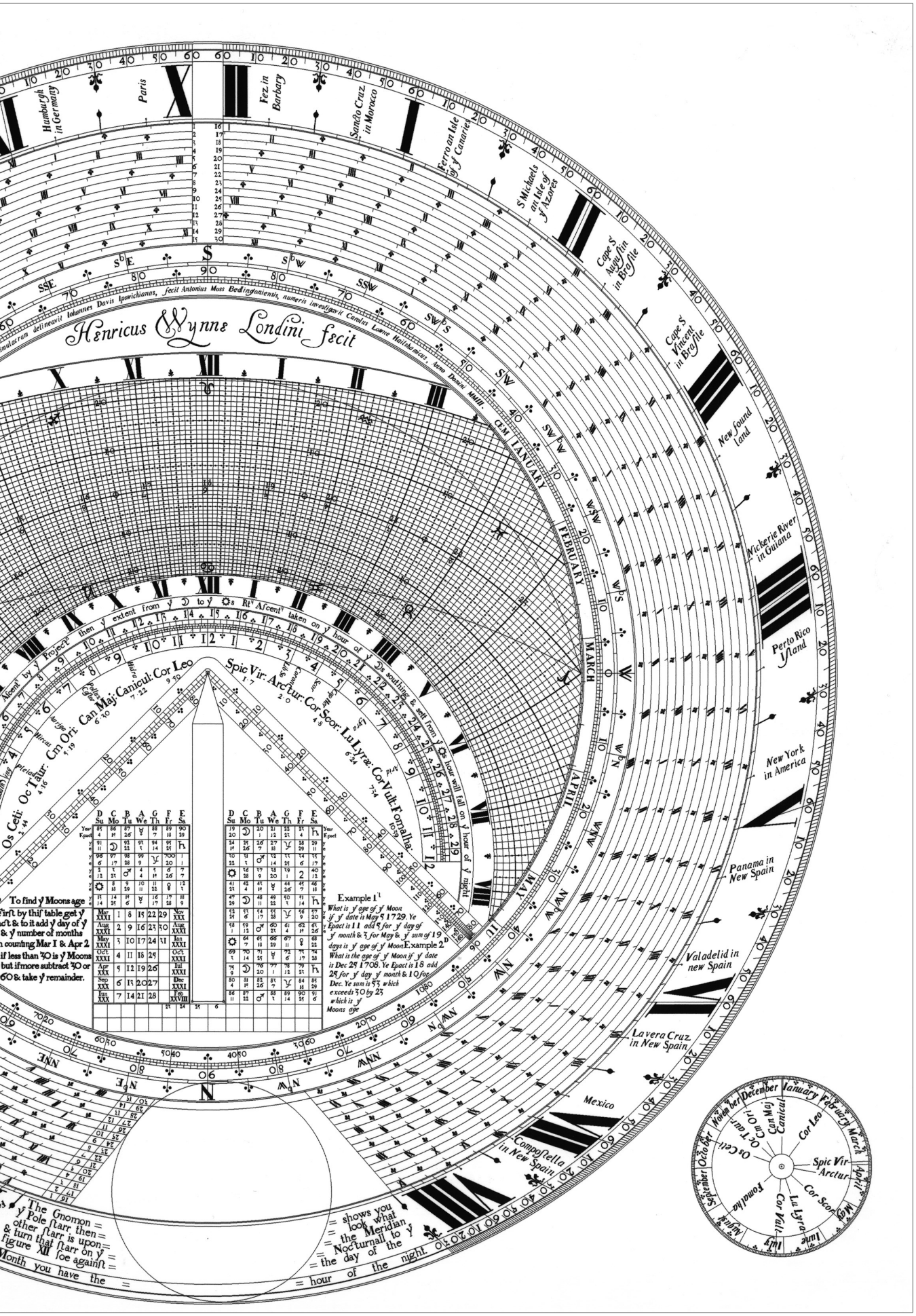


Fig.7. Blagrave's "instrument of three straight rules, better than any Compass to describe any Arch with be his center never so farre off".


NULLA DIES SINE LINEA
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
Watch goes to fast
Watch goes to Slow
Vienna in Austria
Athens in Greece
Damascus in Syria
Mecca in Arabia
Cape Bascalgat in Arabia
Samarchand in Turkey
Fort S George in Coromandel in India
Bengala in y Mogulls Kingdom
Achem in y Isle of Sumatra
Siam in India
Canton in China
Keshoa in Tunquin China
Cochin China in Turky
Ethiopia
Nubia
Abyssinia
Guinea
Congo
Angola
Monomotapa
Cafraria
Monomotapa
Cafraria
Monomotapa
Cafraria


Henricus Wynne Londini fecit
Humburgh in Germany
Paris
Fez in Barbary
Santo Cruz in Morocco
Ferro an Isle of y Canaries
S Michaels an Isle of y Azores
Cape S Augustin in Brasile
Cape S Vincent in Brasile
New found land
Nickerie River in Guiana
Perto Rico Island
New York in America
Panama in New Spain
Valadelid in new Spain
Lavera Cruz in New Spain
Mexico
Compostella in New Spain
JANUARY
FEBRUARY
MARCH
APRIL
MAY
Spic Vir: Arctur: Cor Scor: Lu Lyra: Cor Vult: Fomalha:
Os Ceti: Oc Taur: Cm Ori: Can Maj: Canicul: Cor Leo
To find y Moons age
Example 1
Example 2
The Gnomon =
= shows you
= what
= the Meridian
= Nocturnall to y
= the day of the
= hour of the night

Drawing the stereographic grid would have been a major feat. The arcs for 11:55 and 12:05 have radii in excess of 17m and their centres are a similar distance off the edge of the dial. It is extremely unlikely that Wynne had a setting-out table and trammel compasses large enough to have achieved this. Instead, it is suggested that he used a device such as that described by John Blagrave in 1585[10] and illustrated in Fig. 7.[C] In use, the graver is fitted through the hollow hinge at A and the two outside rules are slid along the fixed dogs R and S. Positioning the dogs and finding the appropriate setting on the centre rule cannot have been easy. On many double horizontal dials, a row of dots running from the toe of the gnomon towards the south can be seen, having been used as the centres to strike the declination arcs. These are not visible on either the Staunton Harold or Wrest Park dials although the radii of the arcs would have made the use of ordinary compasses feasible.

The four linear scales running from the base of the vertical style to the horizon circle (at 45º) are associated with the stereographic projection. The scale nearest to the gnomon on the west side (left side in Fig. 4) runs (90)-(0) from the centre outwards, delineated to single degrees and numbered in 10s. It is the standard scale found on most double horizontals and represents the altitude of the sun. The equation of the scale is

$$r = r_0.\cos a/(1 + \sin a)$$

where a is the altitude and r_0 is the radius of the horizon circle. The scale which is paired with this runs (0)-(45) and is numbered in 10s with the 5s marked (as elsewhere on the dial) by a three-dot symbol. It matches the altitude scale at all degree points and its equation is

$$r = r_0.\tan z$$

where z is the zenith angle. It is left to the reader to show that these trigonometrical expressions produce exact matches at all points!

The two linear scales on the east (right in Fig. 4) of the gnomon do not appear to be directly related to the projection. The outer one, running (0)-(90) gives the sin of the angle and the inner one, running (0)-(180) and matching it at all degree points, is sin of half the angle. The base of the vertical style is raised slightly off the dialplate allowing access to the origins of these four scales with the leg of a pair of dividers, so it is presumed that Wynne's intention was that the scales could be used in the same manner as those on a sector.

THE COMPASS

The compass runs around the outside of the stereographic projection. The first thing which is noticed is that the labels are reversed, with S in the noon gap, N by the toe of the gnomon and E and W mirrored from their geographical directions. This, of course, is done because it is intended to show the direction of the sun (or moon) from its shadow as projected from the vertical style. The innermost rings of the compass show the azimuth to half-degrees, numbered by 10s 0-90 by four, with the zeroes placed at the east and west points. This is the most common orientation of the azimuth scale (see the 'Bacon' dial[18] for another example) but in contrast to the Wrest Park dial which places the zeroes on the north and south points. Outside the azimuth angle, the 32 compass points are labelled (e.g. ENE, NW^{b}N etc) and these are further divided into half-points (5.625º) and quarter points (2.8125º). There is an additional numbering of the azimuth scale in the quadrant between the SW and SE. It runs (0)-90 in both directions but with the 45º point aligned to the S (bottom of Fig. 4). The purpose of this scale, also present on the Wrest Park dial, is unknown to the authors.

THE ASTRONOMICAL AND CALENDRICAL INFORMATION

In addition to the usual properties of a double horizontal dial mentioned above, the Wynne instrument has many other features. Prominence is given to methods of telling the time at night by the use of the moon or certain stars. Various tables to find the age of the moon and use it for time-telling are included, but some explanation is perhaps needed to understand the use of the tables[11] before actually describing them.

The *Dominical Letter* of a year identifies the calendar dates of Sundays in that year; the letters A-G are placed in succession against the dates, starting with A on January 1. The letter which stands against Sundays is the dominical letter. No letter is placed against February 29 in a leap year, which therefore has two letters, one for January and February and another for the rest of the year. Perpetual calendars can be prepared giving the dates for days of the week if the dominical letter is known.

The *Golden Number* is a device for determining the age of the moon based on the *Metonic Cycle*. In about 432 BC the Greek astronomer Meton noticed that the phases of the moon recurred on the same day of the year after an interval of 19 years, in which there are 235 lunations. The golden number of a year represents its place in the 19-year cycle and is obtained by adding one to the remainder when the year is divided by 19. As twelve lunations take 354 days (on average) the phases of the moon occur earlier by eleven days in the course of a year. Tables are prepared which give the dates of new moon for every year number in the cycle. The day of new moon is called day one and the full moon occurs on day 14. Knowledge of the day of full moon is required to determine in advance the date of East-

er Day. Different Christian communities celebrated Easter on varying days until 325 AD when the Council of Nicea fixed Easter Day as the Sunday following the full moon which falls on or next after the day of the vernal equinox, which was defined as March 21. This full moon (the Passover or Paschal moon) was to be determined by the Metonic cycle. However, the cycle is not exact, the period of 19 Julian years of 365.25 days is longer than 235 lunations by about 1½ hours and the predicted day of full moon gradually falls later than the true moon. By the time of the Gregorian reform of the calendar in 1582 the tabular day of full moon using the golden number was three or four days late. This, together with the inaccuracy in the length of the year in the Julian calendar, was having a direct effect on the date of Easter which was tending more and more towards the summer.

The *Epact* is an improved method for finding the age of the moon, adopted for the Gregorian calendar on the change from the Julian calendar. The epact for any year is the age of the moon on the day before January 1 and runs on a 19-year cycle similar to that of the golden number. The system is more flexible in that the sequence of epacts can be adjusted to keep the predictions in line with the true moon; such adjustments are usually made in centennial years. The dates of new moon depending on the epact can be tabulated and are then used in the same way as those for the golden number. However, any tabular method of finding the age of the moon can be in error by a day or so, the complicated motion of the moon cannot be well represented by simple means. In acknowledgement of this, the moon's age from the tables is generally known as the 'ecclesiastical moon'.

THE EPACT TABLES

Tables on the dialplate alongside the gnomon give, for every year from 1685 to (at least) 1791, the epact of the year and the dominical letter. Wynne has not included the first letter of leap years but instead gives the planetary symbol for the weekday on which February 29 falls. When the dial was made, Britain was still using the Julian calendar but in order to improve the accuracy of the moon's age predictions Wynne has adapted the epact method to the Julian calendar by adding the difference between the two calendars, i.e. ten days up to 1699 and eleven thereafter. He put a very similar set of tables on the Wrest Park dial, with the main table running from 1685 to 1836. However, on that 1682 dial, extra cells for 1683 and 1684 were added at the top. This leads to the view that, because the extra cells were not needed for the Staunton Harold dial, it was made in 1684/5. The actual values of epact on the Wrest Park dial (correctly) start off the same as the Staunton Harold ones but then increment by an extra day every time it reaches 29 so that it has accumulated a 7 day error by 1806. Clearly, Wynne discovered this mistake before he made the Staunton Harold dial.

Instructions are given for finding the age of the moon on any particular day. Engraved to the west (left in Fig 4) of the epact table:

To find @ Moons age
Fir! by thi$ table get @
Epa# & to it add @ day of @
Month and @ number of months
from March counting Mar 1 & Apr 2
so @ sum if less than 30 is @ Moons
age but if more subtract 30 or
60 & take \@ remainder/

Two examples of the method were put on the dialplate to the east side of the gnomon but due to corrosion are now illegible; alternative versions have been substituted. In addition to the time-keeping possibilities, the age of the moon would be a useful guide for night-time travellers to the presence or absence of moon-light.

THE MOON DIALS

Having found the moon's age, the dial has two methods of using it to determine the time of night. Just inside the main chapter ring of the polar gnomon is a series of 15 concentric circles labelled with the moon's age from one to fifteen and from sixteen to thirty. Each circle has a time calibration (hour numerals and indicators for the half- and quarter-hours) which enable the time to be read directly from the shadow of the polar gnomon cast by the moon. In an apparent attempt to compensate for the fact that the moon continually loses time against solar time (approximately 48 minutes per 24 hour day or two minutes per hour) Wynne has spaced the hour markings in each circle at intervals equivalent to 62 minutes of solar time. Unfortunately this is incorrect: in the course of an hour the moon moves 15º westward by the earth's rotation and ½º eastward by its own orbital motion so the correct spacing is 14½º per hour equivalent to 58 minutes of solar time, not 62.[D]

The second method of telling time by the moon is by use of a scale which gives the time when the moon is due south (the 'southing' or meridian transit) depending on the age as found from the epact. The scale gives "The]s Age" running (0)-29½ days and divided down to one eighth days, against "The Houres of his Southing" running (0)-12 hours (twice) and divided to half- and quarter-hours and then to 5 minutes.

The dial instructions are written in a single arc between the hour numerals of the projection and the moon time scale:

Stars with quoted RA					
Dial name	**Identity**	**Popular name**	**Dial RA**	**1650 RA**	**Notes**
Os Ceti	α Cet	-	2^h44^m	2^h44^m	Whale's mouth
Oc Taur	α Tau	Aldebaran	4 16	4 16	Bull's eye
Cm Ori	ε Ori	Alnilam	5 19	5 18	Orion's belt (cingulum)
Can Maj	α CMa	Sirius	6 30	6 29	Great dog
Canicul	α CMi	Procyon	7 22	7 21	Little dog
Cor Leo	α Leo	Regulus	9 50*	9 50	Lion's heart
Spic Vir	α Vir	Spica	1 7*	13 7	
Arctur	α Boo	Arcturus	2 0*	13 59	
Cor Scor	α Sco	Antares	4 8	16 8	Scorpion's heart
Lu Lyra	α Lyr	Vega	6 24	18 25	Lucida (brightest)
Cor Vult	α Aql	Altair	7 34*	19 34	Vulture's heart
Fomalha	α PsA	Fomalhaut	10 39*	22 38	
Stars by time scale					
Dial name	**Identity**	**Popular name**	**Scale RA**	**1650 RA**	**Notes**
Pleiad	η Tau	Alcyone	3^h30^m	3^h27^m	
Hircus	α Aur#	Capella	4 50	4 51	Goat star
Auriga	β Aur	-	5 35	5 34	
Castor	α Gem	Castor	7 10	7 12	
Pollux	β Gem	Pollux	7 25	7 23	
Hidra	α Hyd	Alphard	9 10	9 10	
Lib So	β Lib	-	2 55	14 58	
Coron	α CrB	Alphecca	3 20	15 20	
Scor	α Sco	Antares	4 10	16 8	
Cap Her	α Her	-	5 0	16 59	Hercules' head
Lyra	α Lyr	Vega	6 25	18 25	
Arid	α Cyg	Deneb	8 30	20 29	Arided (old name for Deneb)

The dial RAs are given in 2×12^h format to agree with the time scale on the nocturnal.
* RAs so indicated are illegible and have been replaced with values from a contemporary Wynne dial.
\# This was misprinted as α Tau in the original paper.

Table 1. Star names and right ascensions.

> Gett @]s hour by @ !ring & Gnomon & @ Os Rt(A$cent (by @ Proje#n then @ extent from @] to @ Os Rt (A$cent(taken on @ hour of @]s southing & sett from @ Os hour will fall on @ hour of @ night.

This wording is very obscure, at least to modern eyes, in marked contrast with other lucidly-written instructions. It seems quite unnecessary to involve the right ascension of the sun in the calculation; all that is required is to add the time shown by the gnomon shadow on the outer polar dial to the time of southing, subtracting 12 hours if necessary to put the result into the twelve-hour system of time reckoning. So far as Wynne's method can be interpreted it seems that the derived time would have been the same.

The two methods are unlikely to give the same result! Apart from the error in calibrating the hourly intervals mentioned above, the two scales are based on different values for the amount by which the moon transits later from night to night (the 'daily retardation of transit'). The values from the scale of southing use an interval of 48.8 minutes (24 hours divided by 29½ days, the average length of a lunation). The circular scales are based on 30 days for the lunation, giving daily intervals of 48 minutes; in fact both are wrong. In the course of an average lunation the earth rotates 29½ times but the moon goes round the earth once in the same direction, so losing one revolution and returning to the meridian only 28½ times: 24 hours divided by 28½ gives the correct average value of 50½ minutes for the retardation. Due to the variable speed of the moon in its orbit the actual retardation can be as little as 40 or as much as 60 minutes. From these and other causes, times found by the moon could be wrong by up to an hour or more.

The small size of the script used for the numerals on the moon-dials would make them rather difficult to read by moon-light. The full moon has an intensity half a million times fainter than sunlight and the first and last quarter-moons are nine or ten times fainter still. The human eye is not adapted to resolve fine detail at such low levels of illumination. However, when the dial was new the face could probably give an almost specular reflection if viewed at the correct angle, effectively increasing the illumination over limited areas.

THE PERPETUAL CALENDAR

Just below the table of epacts on the west side is a perpetual calendar. Much of the table is unreadable and the details have been taken from the similar one on the Wrest Park dial. It appears to show the dates of Sundays when the dominical letter is D: presumably instructions were given to derive dates for other letters and how to allow for leap years. The writing in the logical place for such instructions below the table is now unreadable and no attempt has been made to reproduce it.

THE STAR NAMES AND POSITIONS

The names of twelve stars and their right ascensions (RA) are given between the gnomon and the stereographic projection. Their details are shown in Table 1. The same twelve stars are also shown on the earlier Wrest Park dial but the later Drumlanrig Castle dial seems to use a slightly different set.[12] The RAs appear to match calculated values for epoch 1650, some of which have been substituted for unreadable values on the dial. A further twelve names in much smaller script appear alongside the arc of the moon's transit times which thereby serves the additional purpose of giving their RAs. Corrosion is bad on the east side and names here were difficult to decipher.

THE NOCTURNAL

The decision to include a nocturnal on the dial seems to have been made late in the design process. Firstly, it covers some engraving already on the dial-face; if this had not already been in position, it would have been possible to engrave the features of the lower, fixed, disk directly on the face. Secondly, the nocturnal is not on the exact centre -line of the dial but displaced approximately 10mm to the east. This meant that the moon rings could not be completely symmetrical and the labels for the age of the moon had to be omitted on the east side (although this now can only be deduced rather than actually seen).

It is unfortunate that the original nocturnal has not survived. Nocturnals were often included on other instruments: for example, see Ref 13 for one on the back of a Gunter's quadrant by Wynne's contemporary John Prujean. For the replica dial, one has been designed which, although conjectural, will reproduce the features and method of use of the original. It consists of an outer fixed ring carrying times from IIII pm to VIII am (increasing anti-clockwise) and an inner rotating disc with calendar dates running clockwise. Twelve stars are indicated on this, placed so that their names are against the dates when each star is due south at midnight. To avoid overcrowding, only those twelve stars whose right ascensions are given on the dial have been included. The instructions for use are written on either side of the nocturnal:

> The Gnomon shows you
> @ Pole !arr then look what
> other !arr is upon the Meridian
> & turn that !arr on @ Nocturnal to @
> figure XII $oe again! the day of the
> Month you have the hour of the night.

If the star is on or very near the meridian the derived time should be correct to within a few minutes and moreover would be in local mean time, not apparent solar time. However, if Wynne had used the same stars which appear on the dial, the selection is rather poor with gaps of two and three hours in right ascension which severely limits the chance of finding a star near the meridian at a particular time. To use the nocturnal some artificial means of illumination would be necessary, but it does not seem likely that the dial owner would venture outside with a lantern or candle to read the instrument when he could with much less effort visit the household clock!

THE DATES OF EASTER AND ASSOCIATED FESTIVALS

An abbreviated table can be drawn up for each epact giving the date when the Paschal full moon falls on a Sunday, depending on the dominical letter. From this the date of Easter Day can be derived, not only for those conditions but for any year with the same epact and a different dominical letter. On the east and west triangular sides of the gnomon Wynne has placed such a table of epacts, dominical letters and the dates of the Sunday Paschal moons. He has however mistakenly called those dates Easter Day; it is implicit in the Easter rules (and is often stated explicitly) that, if the Paschal moon occurs on a Sunday, not that day but the next Sunday is Easter. Additionally, Wynne gives the dates of associated festivals (Septuagesima, Ash Wednesday, Ascension Day and the start and finish of Easter and Trinity terms) but all are seven days too early. As Britain was still using the Julian calendar the dates of Easter given by the golden number method were relevant and Wynne would have had to relate the epact to the golden number to derive his table. It is possible that his mistake arose either here or by a simple mis-interpretation of the rules. [see Note E.] Even with this wrong identification it

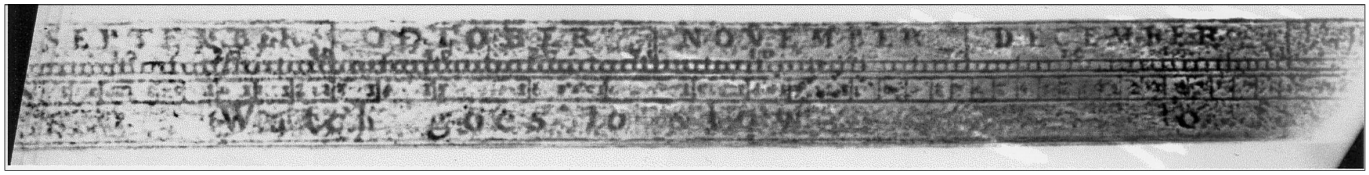


Fig. 8. A digitally-enhanced, negative photograph of the least-corroded part of the EoT scale on the gnomon.

would have been possible to derive the correct dates of Easter Day for those years in which the Paschal moon did not fall on a Sunday but the dial appears to carry no instructions for the use of the tables.

GEOGRAPHICAL DIAL

The main chapter ring of the dials has a standard set of large Roman hour numerals running IIII-XII-VIII. In most instances, the hour line is allowed to run between the numerals, rather than being incorporated against one side of a broad stroke, as became standard for later makers. A narrow scale inside the main ring is divided down into half, quarter and eighth hours, with a 'spade' symbol on the half -hours. The individual minutes are shown around the outside of the chapter ring; thus they are on the periphery of the dial making them as large as is possible. They are numbered in 10s, with the figure 60 appearing on both sides of the noon gap. The half hours are indicated by an elaborate and ornate fleur-de-lys which is similar, though not identical, to that found on other dials by Wynne and also by his apprentices.

Between the hour numerals, on the quarter and three-quarter hours, are the names of (probably) 34 world-wide locations (Table 2), making this a 'geographical' dial. Several of the names, especially in the evening hours, are difficult or impossible to read. The dial may thus be regarded as the prototype for the 'Grocers pattern' dials[9] which became so widespread over the next three-quarters of a century. Wynne made other geographical dials (such as those at Euston Hall and Wrest Park) having complete chapter rings for each location, in the position occupied by the moon rings on the Staunton Harold dial. On the Drumlanrig Castle dial, he used two dedicated rings to show the times of noon for 50 locations,[12] in the style later adopted by Thomas Wright. The names of the places used on the various dials are not in general the same. Clearly, on the Staunton Harold dial, some were chosen simply because they had (or were believed to have) the right longitude for the time on the dial. Thus although places such as "Athens in Greece" are a natural choice, "Bala$ore in @ Mogulls Kingdom" or "Nickerie River in Guiana" took much effort to read and to locate on a modern map. Table 2 shows that Wynne's longitudes were generally within a degree or two of the correct values and also confirms that he made the proper allowance for the longitude of Staunton Harold.

GNOMON AND EoT SCALES

The gnomon is literally covered by engraving on all surfaces (Fig 6). The rectangular calendar scales on both sides of the main triangular area have already been described. Surrounding these tables are superb floral borders (perhaps sunflowers or daisies?) engraved in deep relief. Similar, though not identical, borders can be seen on the Wrest Park double horizontal and also the Windsor Castle garden dial though in these cases they surround coats of arms and a pierced monogram, respectively.

On the underneath edge of the tail of the polar gnomon is a motto running top to bottom:

NULLA DIES SINE LINEA

which may be translated as 'no day without lines' or, more freely, as 'another day, another line'. This motto has been found on other dials, for example the stained glass dial originally at Wendon Lofts, Essex. It is likely that very few casual viewers of the dial ever notice this motto.

The most exciting part of the gnomon is the fact that it has an Equation of Time scale running the full length of the top edge (Fig. 8) and reading from bottom to top. Assuming that the dial was made in 1685, this could well be the earliest extant EoT scale on a dial (the 1675 Wynne dial at Kinnaird Castle is sometimes claimed[19] to be the earliest but the table was added about a century later[14]). The position, believed unique, means that the scale is just 17mm high but around 550mm wide. It is now badly corroded, especially near the bottom, so that only some of the values can be read. The scale gives the months, named in full and divided to individual days with the 10s numbered. Then there are numbered tick marks for each minute of EoT and finally the legends "Watch goes to Fast (Slow)" (sic). Just visible at the maxima/minima of EoT, amongst the minute numerals, is faint evidence that the excess number of seconds has been recorded, although the values cannot be read with certainty. Thus, at an early stage of development, all the features of the EoT scale on high quality dials for the next century are found.

Careful study[14] of the EoT values which can be read leads to a strong indication that the source of the data that Wynne used was the same as that printed by Thomas Tompion in 1683 as a table for pasting inside his longcase clocks, and also engraved on one of his sundials.[15] Certain-

Name on dial	Time on dial	Modern name	Implied Long.	Actual Long.
Formosa Isle near China	3:45	Taiwan	122º E	121º E
Canton in China	4:15	Canton, China	115º E	113º E
Kehoa in Tunking near China	4:45	?Kontum, Vietnam	108º E	108º E
Siam in India	5:15	Thailand	100º E	101º E
Atchem in y^{e} Isle of Sumatra	5:45	?Sigli, Sumatra	92º E	96º E
Balasore in y^{e} Mogulls Kingdom	6:15	Balasore, India	85º E	87º E
Fort S^{t} George in Cormandel in India	6:45	Madras, India	77º E	80º E
Samarakand in Turkey	7:15	Samarkand, Uzbekistan	70º E	67º E
Cape Basalgat in Arabia	7:45	Ras al Hadd, Oman	62º E	60º E
Ispahan in Persia	8:15	Isfahan, Iran	55º E	52º E
Ninevah in Asyria	8:45	Nineveh, Iraq	47º E	43º E
Damascus in Syria	9:15	Damascus, Syria	40º E	36º E
Constantinople in Turkey	9:45	Istanbul, Turkey	32º E	29º E
Athens in Greece	10:15	Athens, Greece	25º E	24º E
Vienna in Austria	10:45	Vienna, Austria	17º E	16º E
Humburgh in Germany	11:15	Hamburg, Germany	10º E	10º E
Paris	11:45	Paris, France	2º E	2º E
Fez in Barbary	12:15	Fès, Morocco	5º W	5º W
Sancto Cruz in Morocco	12:45	?	13º W	
Ferro an Isle of y^{e} Canaries	1:15	Hierro, Canaries	20º W	18º W
S^{t} Michaels an Isle of y^{e} Azores	1:45	San Miguel, Azores	28º W	28º W
Cape S^{t} Augustin in Brasile	2:15	Recife, Brazil	35º W	35º W
Cape S^{t} Vincent in Brasile	2:45	Sao Paulo, Brazil	43º W	47º W
New found Land	3:15	(S^{t} Johns), Newfoundland	50º W	52º W
Nickerie River in Guiana	3:45	Nickerie R, Surinam	58º W	57º W
Perto Rico Island	4:15	Puerto Rico, W.Indies	65º W	67º W
New York in America	4:45	New York, USA	73º W	76º W
Panama in New Spain	5:15	Panama City, Panama	80º W	79º W
Valadelid in new Spain	5:45	Valladolid, Mexico	89º W	88º W
La vera Cruz in New Spain	6:15	Veracruz, Mexico	95º W	96º W
Mexico	6:45	(Mexico City), Mexico	103º W	99º W
? Compostella in New Spain	7:15	Compostela, Mexico	110º W	105º W
??	7:45	?	118º W	

The implied longitudes have been calculated using a longitude of 1º 27' W for Staunton Harold. All longitudes are rounded to the nearest degree.

Table 2. Place names in the chapter ring.

ly, the values do not match the very earliest tables of Flamsteed or Huygens. Robert Hooke was working closely with Tompion on a spring driven watch and meeting him almost daily[16], and is known[17] to have given him an equation table on 13 December 1674 (although the original source of the table is unknown). Since Wynne was also in contact with Hooke, it seems likely that he also had access to the same data.

CONCLUDING REMARKS

It may be of interest to examine how many of the features of the dial can still be used, more than three hundred years after the original was made. Obviously the polar dial is still operational and so is the azimuth dial if ten days are added to the date scale to compensate for the change to the Gregorian calendar in Britain. The tables of epact and dominical letters are of course out of date but if the epact of the current year is known the age of the moon can be found by Wynne's method and the moon dials will work as accurately (or rather inaccurately) as before. The star right ascensions have been altered by precession and are now about 15 minutes later than the 1650 positions leading to a corresponding error in times found by the nocturnal.

There is no doubt that the Staunton Harold dial represents a peak in the dial-makers art, combining well established astronomy with the latest research results and much artistic

flair. Despite the occasional mistakes in its design, it formed a prototype for succeeding generations of dial-makers.

ACKNOWLEDGEMENTS

The authors are pleased to thank the following people for their help in preparing this article: The Earl and Countess Ferrers, Christopher Daniel, John Fox, Leicester Record Office, English Heritage, Michael Cowham, George Huxley.

REFERENCES

1. C.M. Lowne: 'The Design and Characteristics of the Double-Horizontal Sundial', *BSS Bulletin*, 13(iv), 138-146 (2001).
2. J. Fox: *Staunton Harold,* Kairos Press, Leicester (2001).
3. F. Evans: 'The British Sundial Society in Scotland, 3-11 June 2000', *BSS Bulletin*, 12(iii), p.130 (2000).
4. J. Uglow: *The Lunar Men,* Faber & Faber, London, p.123, (2002).
5. G. Clifton: *Directory of British Scientific Instrument Makers 1550-1851,* Zwemmer, London (1995).
6. E.G.R. Taylor: *The Mathematical Practitioners of Tudor & Stuart England*, Cambidge University Press (1954).
7. J. Walker: 'A Sundial at Windsor Castle', *BSS Bulletin*, 98.2, 9-11 (1998).
8. D. Petrie: 'Wales 2001', *BSS Bulletin*, 13(iv), p151, (2001).
9. J. Davis: 'Some 18th Century Dialmakers in the Grocers' Company' *BSS Bulletin*, 15(i), pp 6-14, (2003).
10. J. Blagrave: *The Mathematical Jewel*, Imprinted in London by Walter Venge, 1585. Also reprinted in R.T. Gunther: 'The Uranical Astrolabe and other Inventions of John Blagrave of Reading', *Archaeologia*, Vol. LXXIX (1929).
11. Explanatory Supplement to the Astronomical Ephemeris, Section 14E: HMSO, London (1961).
12. C. St.J.H. Daniel: private communication.
13. R. & M. Webster: *Western Astrolabes*, Adler Planetarium, Chicago (1998).
14. J. Davis: 'The Equation of Time as represented on Sundials', *BSS Bulletin*, 15(iv), pp 135-144, (2003).
15. Sotheby's: *Instruments of Science and Technology*, 30 October 2002.
16. S. Inwood: *The Man Who Knew Too Much - The strange and inventive life of Robert Hooke 1635-1703,* Macmillan, Basingstoke & Oxford (2002).
17. A. Kitto: 'Richard Townley and the Equation of Natural Days', *BSS Bulletin*, 13(ii), 60-65 (2001).
18. J.R. Davis & C.M. Lowne: 'The 'Bacon' Double Horizontal Sundials', *BSS Bulletin*, 13(iv), 160-165 (2002).
19. A.J. Turner: 'Essential Complementarity: the sundial and the clock' in *Sundials at Greenwich* by H. Higton, OUP, Oxford, 15-23 (2002).

NOTES ADDED TO ORIGINAL

A. Although Tuttell was a freeman of the Clockmakers' Company, he did not actually make clocks but was a mathematical instrument maker, hydrographer and writer.

B. The dial is now known to be of a brass. See page 100 in this monograph for a more detailed analysis.

C. But see also the method suggested by Oughtred on p.3.

D. For a fuller description of the inaccuracies of moondials, see C.M. Lowne: 'Moondials and the moon', *BSS Bull* 17(i), pp.3-12, (March 2005).

E. Alternatively, Wynne has taken the dates of Easter in the Gregorian calendar (as found by the epacts) and subtracted ten or eleven days to convert them to the Julian calendar. If this gives a date before the earliest permissible date of March 22, four weeks are added. However, Easter dates in Britain before the adoption of the Gregorian calendar were not derived in this way, the old golden number method was used up to the change of calendar in September 1752, (J.R. Stockton, private communication).

HENRY WYNNE'S DOUBLE HORIZONTAL DIALS – UPDATE

JOHN DAVIS and MICHAEL LOWNE

[This paper was originally printed in BSS Bulletin 18(i), pp.33-34 (March 2006).]

In our 2003 paper[1] describing Henry Wynne's 1685 double horizontal dial originally made for Staunton Harold in Leicestershire, we 'faked' a picture of the dial in front of the Lion Front there, in the position that it occupied in 1951, just before it was moved to Norfolk. Since then, research has continued and we are highly indebted to local historian Dr Irene Brightmer for further information about the dial in the 19th and 20th centuries.

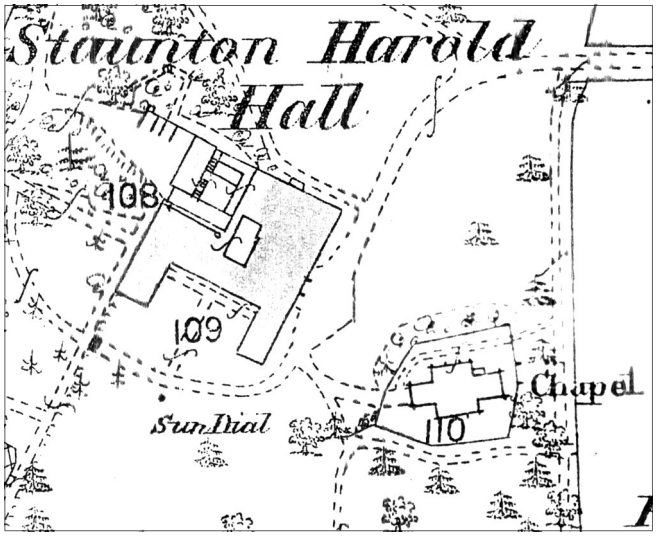


Fig. 1. Part of the 1881 First Edition OS Survey map (25 inches to 1 mile) showing the position of the sundial.

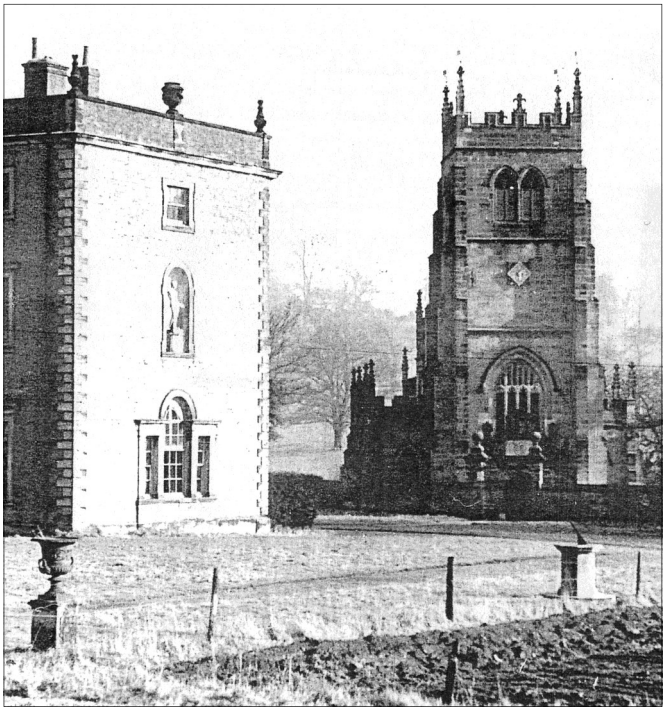
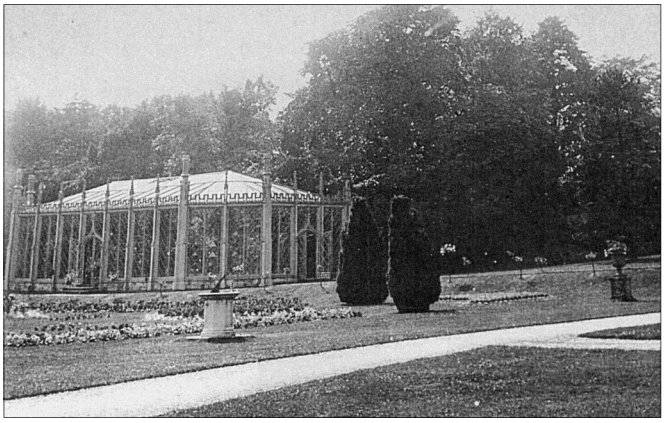


Fig. 2. The dial in position to the west of Staunton Harold church. © Leicester Records Office.

Amazingly, the dial is actually shown on the 25 inches to the mile First Edition Ordnance Survey map of 1881 (Fig. 1). The position of the dial to the south of the Lion Front is remarkably similar to our faked picture, if a little further from the house. An undated photograph (Fig. 2) in the Leicester Records Office confirms this position, to the west of Staunton Harold church. Another photograph, c. 1900, (Fig. 3) shows the dial viewed from nearer to the house, looking outwards towards a now-demolished Orangery. Other photographs also exist, such as a postcard by E Martin of Melbourne, Derbyshire, and in an article in *Country Life* for 5 April 1913.



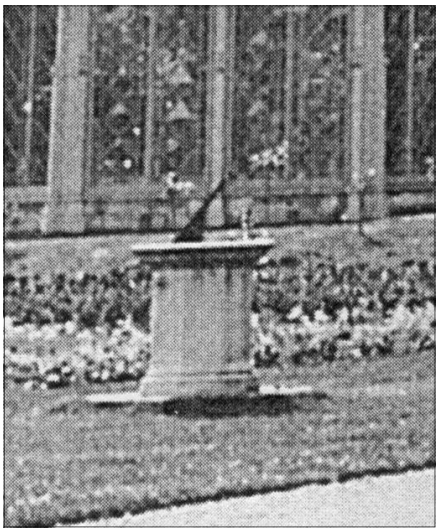


Fig. 3a (above). The Staunton Harold dial viewed from the Lion Front and looking towards the Orangery, now demolished. (c. 1900, from the archives of the late Dorothy Watson).

Fig. 3b (left). Magnified view of the dial.

The Staunton Harold dial was almost certainly commissioned by the first Earl Ferrers, Robert Shirley (1650-1717). A painting of the Earl, who is an ancestor of the present owner of the dial, is in the Long Gallery at Sudbury Hall, Derbyshire. It is by John Michael Wright (1617-1694) and is shown in Fig. 4. Another painting of the Earl is in a private collection.



Fig. 4. The 1st Earl Ferrers, painted by John Michael Wright (1617-94). Photo: © M.I. Brightmer 2004.



Fig. 5. The Wynne DH dial at Powis Castle, October 2005. The gnomon remains bent….

The slightly earlier (1682) Wynne double horizontal dial at Wrest Park, Bedfordshire, was also described in the earlier papers[1,2] and has also featured in the recent book *Sundials of the British Isles*.[3] The dial on display in the English Heritage garden is actually a resin replica but on the original marble pedestal. The original dial is in store.[4] A second replica, and the mould, is believed to be on display at Fort Cumberland, Portsmouth. In 2004, another dial originally from Wrest Park was sold by Sotheby's.[5,6] This was the magnificent Tompion dual-latitude Equation dial and which is dated to the first decade of the 18th century. A sundial seems to be visible in front of the house in Johannes Kip's c.1715 engraving from Leonard Knyff's original painting[6] but it is not known if it represents the Wynne or the Tompion dial. The purchase of a second very high quality dial when the Wynne dial was only about 20 years old can perhaps be put down to the requirement to have the equation of time engraved on the dialplate. The Wrest Park Wynne does not have an EoT scale whereas the Staunton Harold one has the unique linear scale along the style face.

A further Wynne DH dial mentioned in our earlier paper, the one at Powis Castle (NT), Welshpool, has also appeared in *Sundials of the British Isles*.[7] This dial has long had a serious kink to its gnomon. At the time that the book was in preparation, the dial was away for restoration so the writers confidently wrote that "It is shown here with a bent gnomon but this has recently been restored." See Fig. 5. Unfortunately, this is not the case as the National Trust's curators and 'professional' restoration advisors thought that it was supposed to be like that and even advanced the view that the angle of the upper section was "appropriate for Constantinople"! Whilst it has to be admitted that close inspection of the metal at the bend does not reveal obvious or recent damage, it is a sad reflection of the Trust's knowledge and care for the nation's dialling heritage. They now take the view that the bend is "part of the dial's history" and so it should be conserved as it is, rather than being restored. Would they take that view if it were a vandalised painting?

REFERENCES AND NOTES

1. J. Davis and C.M. Lowne: 'Henry Wynne's Double Horizontal Dial at Staunton Harold', *BSS Bulletin*, 15 (ii) pp 46-58 (2003).
2. J. Davis and C.M. Lowne: *Henry Wynne's Double Horizontal Dials*, presented at the BSS Annual Conference, Oxford (2004).
3. M. Cowham (Ed.): *Sundials of the British Isles*, pp. 83-84, Cowham, Cambridge (2005).
4. ID No. 794486. We are grateful to Tony Wood's Museums Survey for this information.
5. M. Cowham: 'Dial Dealings', *BSS Bull.* 17(i), p. 30, (March 2005).
6. See colour illustration in Sotheby's: *Scientific instruments, clocks, barometers & mechanical music*, London, (15 June 2004). The original is in a private collection.
7. Ref 3, p. 100.

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the assistance provided by a number of people in gathering the information for this update: Irene Brightmer, Ben Dale & Margaret Gray (NT), Tony Wood, Mike Cowham, Harriet James.

DOUBLE TROUBLE
The realization in bronze of the Henry Wynne Replica dial

TONY MOSS

[This paper was originally published in BSS Bulletin 18(i), pp.35-39, (March 2006).]

The background to the re-creation of this beautiful and complex sundial has been extensively covered by John Davis who, in consultation with Michael Lowne, created the TurboCAD® files from which the film artwork was generated.[1] The latter was a very long story in itself but not for coverage here. (Fig. 1.) It was in mid 2002 that John contacted me to enquire if I would be interested in recreating a 30" diameter bronze dial. As I had recently completed a 48" diameter stainless steel item for Melton Mowbray Rotary Club,[2] the idea of 30" of the more-familiar bronze seemed easy by comparison and I readily agreed.



Fig. 1. The Wynneing Team! L to R: Tony Moss, Michael Lowne and John Davis.

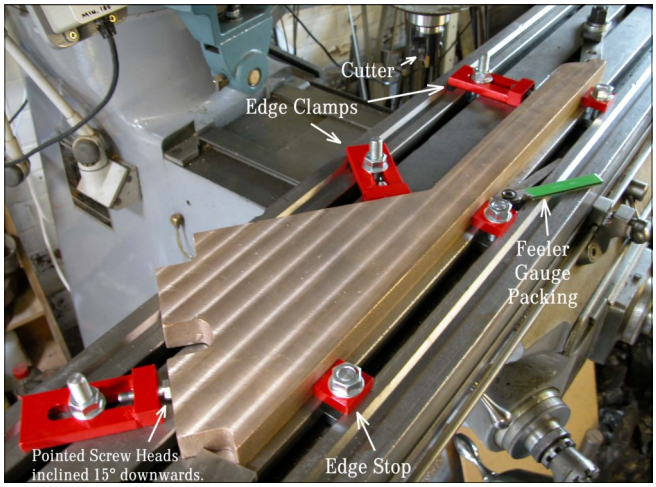
Creating the bronze disc and the gnomon casting were all assessed as being straightforward pattern making in wood before casting at a local foundry (Fig. 2). After some discussion, the chosen metal was to be LG2 which is a leaded gunmetal with a pleasant golden hue and good weather resistance comprising 5% tin, 5% zinc, 5% lead and the remainder copper. Patterns were made from MDF and painted in standard foundry colours which tell the foundryman how they are to be treated. Brick red = body casting, yellow = to be machined. Special router cutters had to be made in my workshop to create the slight 'draw' angle which would allow the patterns to be withdrawn from the moulding sand.

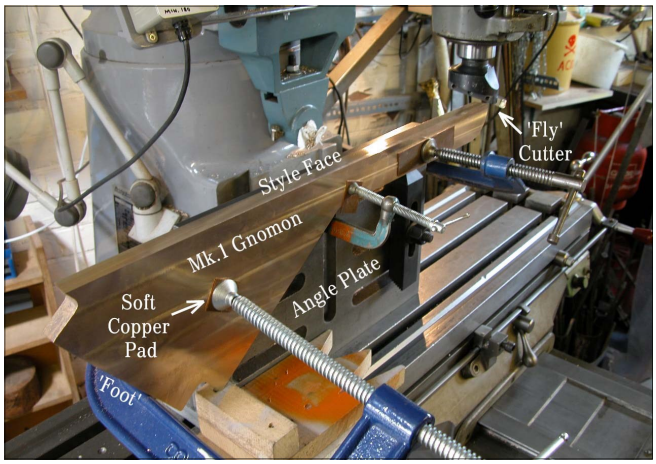
The foundry in South Shields is attached to an engineering company and their offer to rough-machine the disc on their vertical spindle lathe, a 'merry-go-round', was readily accepted. This operation would have been *possible* in my workshop but would have stretched even the Bridgeport milling machine to its limits. Finishing to a suitable surface for etching and shadow casting was done by hand in my workshop.

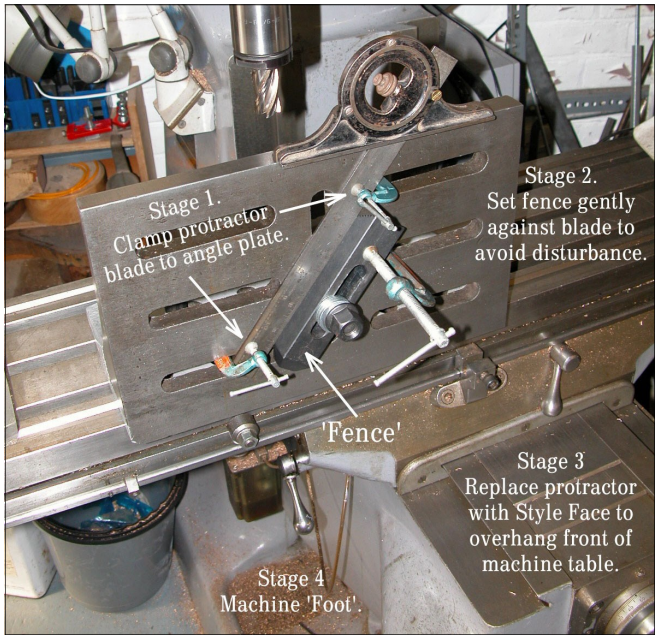


Fig. 2. Wynne & a vertical dial frame patterns for casting.

The smaller gnomon casting initially just presented the usual challenges associated with machining castings. They have no truly flat faces so any attempt to bolt them to a machine table ends in distortion. As a result, after the top surface is machined flat, it will spring back to a curve when the clamps are released. In industry such problems can be overcome by e.g. setting the casting in a shallow tray of 'Woods metal', a high-bismuth alloy (expensive) which melts off again in hot water. As no clamping is needed a truly flat surface can be achieved in one operation which in turn can be firmly clamped down to allow the whole thing to be machined parallel and to thickness…..in theory! In practice, however, machining the second side may release surface tension in the cast metal skin causing more distortion. Several reversals and a series of fine cuts later the casting *may* be true to thickness







Above, top to bottom:
Fig. 3. Second face machined.
Fig. 4. Setup for milling the style face.
Fig. 5. Setup for milling the latitude angle.

and ready for profiling. Alternatively, the workpiece could be ground to thickness using a special grinding wheel on a surface grinding machine.

None of the above technology was available to me. No costly Woods metal was to hand and my surface grinder

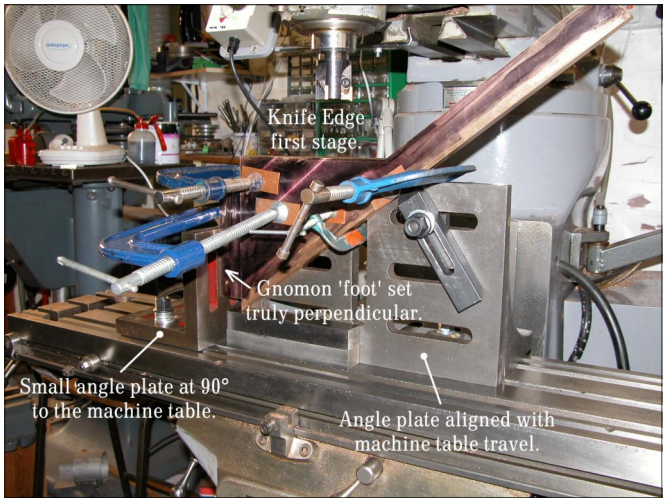


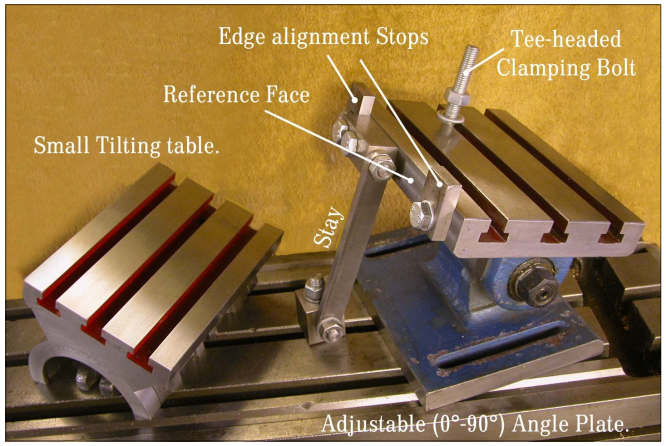
Fig. 6. Milling tenons to thickness.

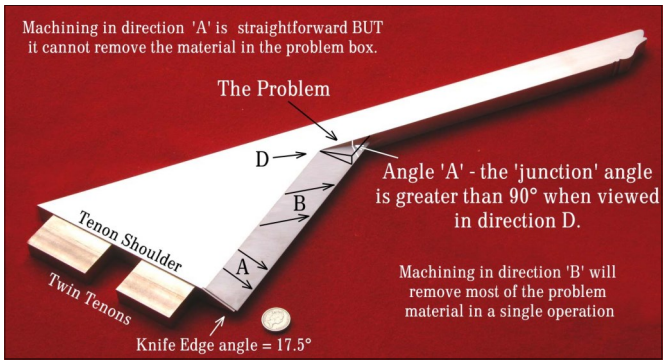
was too small for such a large area. To achieve the first flat surface the casting was to be 'edge clamped' requiring a full day manufacturing a set of clamps and 'stops' (Fig. 3). Doing most machining jobs is usually quick and easy: it is making the things to hold the workpiece securely that takes time. Being held only by the edges necessitated light initial cuts as the Bridgeport's powerful motor was quite capable of flinging the whole casting across the workshop. A 'safety clamp' barely touching the work was a reassurance but had to be moved around as the work progressed. Cutting forces cause the metal to bend downwards unless supported from below so any gaps and hollows had to be filled to prevent this**.** Several sets of old feeler gauges are kept for just this purpose. It took seven reversals and fine cuts to produce a flat and parallel casting.

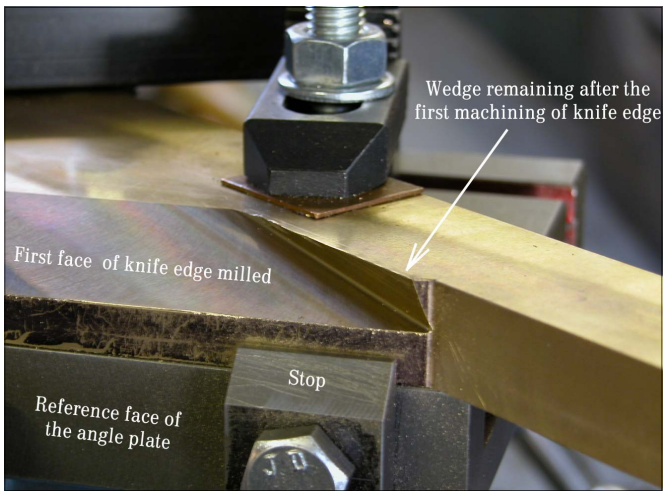
Machining the profile began with the style edge which required my longest angle plate to hold the faces perpendicular to the machine table (Fig. 4). To get the style height angle a steel 'fence' was set on the angle plate using a bevel protractor (Fig. 5). This was much easier and more accurate than attempting to align the heavy gnomon casting directly while manipulating a finely-set instrument with the other hand. After machining the latitude angle it was double checked for accuracy with a vernier protractor as mistakes thereafter could not be rectified. With an accurate 'foot' now machined, it was now possible to machine the cheeks of the twin tenons which would pass through mortise slots in the plate. A precision parallel set in line with the machine table travel served as an alignment fence so that the shoulders of the tenons would form the correct latitude angle with the style edge and also be co -planar with each other to contact the dial plate closely all round (Fig 6).

The vertical knife-edge was begun by first milling a flat at the correct distance from the style origins. To ensure its









Top to bottom:
Fig. 7. Milling a face for the vertical knife-edge.
Fig. 8. Tilting table and angle plate.
Fig. 9. The Problem!
Fig. 10. The wedge overhang.

eventual perpendicularity to the dial face, quite an elaborate setup of two angle plates was required. The larger one held the body in the vertical plane and the smaller one at right angles held the milled foot truly upright (Fig. 7). Having carefully milled the required flat to the point where the vertical knife edge would encounter the underside of the style, it should now have been possible to mill the style to width. It was only at this point that I began to wonder how much excess style length was available to serve as a hold-down point during machining. On measuring the film artwork and comparing it with the machined body the awful truth began to sink in.

It was 14 millimetres TOO SHORT!

When and how this discrepancy arose is still a mystery but no matter how many times I checked, re-checked and wished otherwise there just wasn't enough metal to complete the gnomon after several weeks of careful work. All sorts of 'fixes' suggested themselves but any type of join would inevitably show. To cut the artwork to fit was an unworthy 'bodge' for such a prestigious reproduction and so the inevitable had to be accepted:

I would have to begin all over again.

The old pattern was extended and re-cast and about a month later the machined gnomon was again ready for the most crucial operation, the machining of the vertical knife edge. This piece of complex solid geometry had occupied my waking thoughts for weeks prior to the event. Fortuitously, I had recently faced the same problem on a smaller scale for another BSS member which allowed me to devise a sequence of operations to complete the task….or so I thought.

Machining a bevelled edge on a Bridgeport milling machine is elementary stuff. The milling head and cutter can be set at almost any angle and the work passed beneath it. Alternatively, the machine head can remain upright with the workpiece held at the required angle on an adjustable angle plate or tilting table (Fig. 8). For a variety of reasons, the adjustable angle plate was chosen for the job and set to half of the included angle of the knife edge. Additional stops were added to the raised edge (hereinafter referred to as the reference face) of the angle plate to allow what would become the knife edge to be set flush and clamped in place. This whole assembly was then rotated on the miller table so that one of the style edges lay in a vertical plane aligned with the travel of the machine table. The bevelled face was then machined away in a series of careful cuts. Adjustable angle plates are not beyond readjusting themselves if too much cutter force is applied so light cuts and a home-made stay ensured that there was less chance of having to begin yet again for a *THIRD* time.

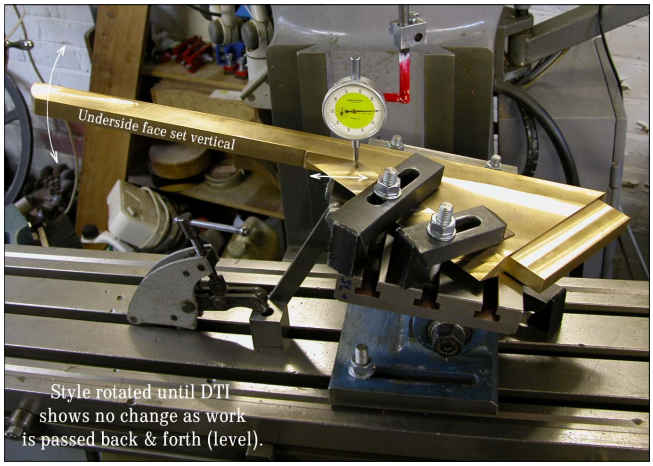


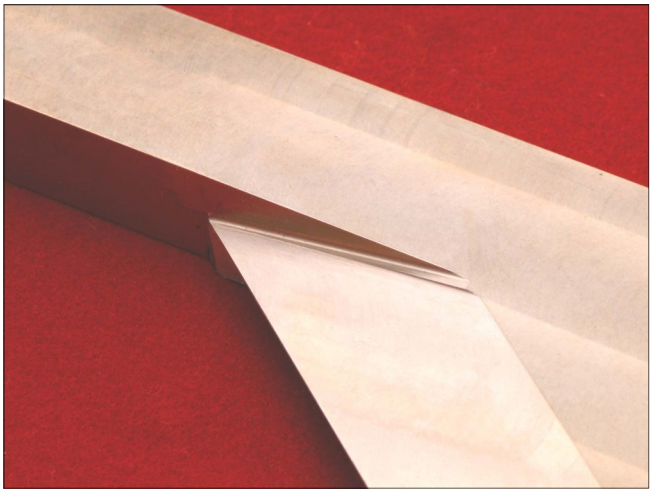
Fig. 11. 'Clocking' the knife edge.

The problems that made this aspect of the job so tricky are summed up in Figure 9. The angle *A* between the underside of the style and the bevelled face of the knife-edge (the junction) is greater than 90° so cannot be machined in a single pass with standard cutters. Because the gnomon was on the tilted angle plate, the style face was also tilted back from the vertical plane as was the underside face of the gnomon. Because the cutter produces either horizontal or vertical planes, a wedge shaped 'overhang' was left when the cutter tip was almost in contact with the junction at the underside (Fig. 10).

The gnomon was then re-set so that the style face was perpendicular to the reference edge and the plate angle re-set so that the junction was horizontal by using a dial test indicator (DTI) as the assembly was wound back and forth (Fig. 11). This then allowed careful machining of the overhanging wedge. I had hoped that this would be the final stage but, because of the complex solid geometry, a tiny secondary wedge remained (Fig. 12). More head scratching and angle plate juggling was needed until at last the junction was perfect with every scrap of remaining metal removed by careful machining with no hand finishing needed. The final workshop operation was to profile the tip to the exact shape of the Wynne original (Fig. 13).

My etching facilities are generally limited to 24" x 24" so the etching of plate and gnomon were done by a specialist local company where the job proved to be much more difficult than anticipated. The gnomon in particular is etched on six separate faces with the side cheeks overlapping onto the knife edges. At each etching stage all the previous work had to be 'stopped out' to prevent attack by the etching fluid. This was an anxious process as any exposed parts would be ruined.

Final assembly was achieved when the two mortise slots were milled back in my workshop and numerous taper pins were inserted to ensure a solid and rigid attachment leaving only delivery to John Davis for installation in a special cradle made to carry the dial plate securely to its destination. Certainly 'Wynnifred' (Figs. 14, 15, 16), as this remarkable dial has become known to those of us involved, is among the most challenging pieces of work I have ever undertaken and, but for the painful memories associated with repetition of the stumpy gnomon, very rewarding. That 'spare' is certainly the most valuable piece of scrap metal I have ever made.



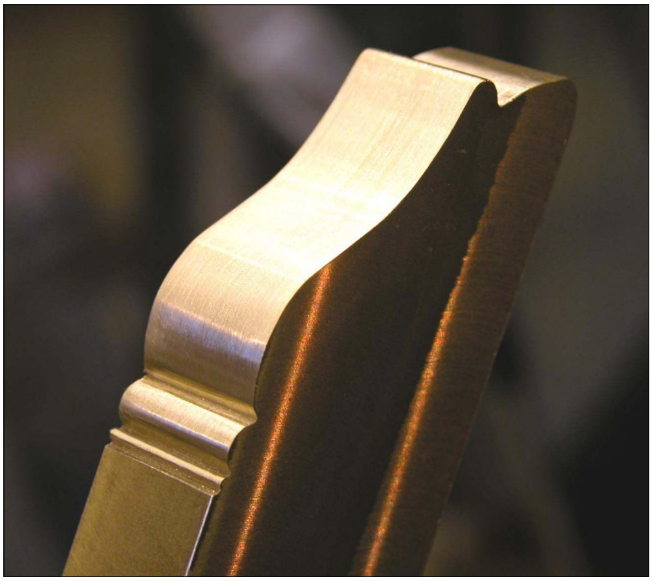


Fig. 12 (top). Oh no! A secondary wedge!

Fig. 13(above). Tip profiling.

REFERENCES

1. J. Davis and C.M. Lowne: 'Henry Wynne's Double Horizontal Dial at Staunton Harold', *BSS Bulletin*, 15(ii) pp 46-58 (2003).
2. D.A. Bateman: 'A large horizontal dial in stainless steel for Melton Mowbray', *BSS Bull*, 15(iii) pp. 124-8, (2003).

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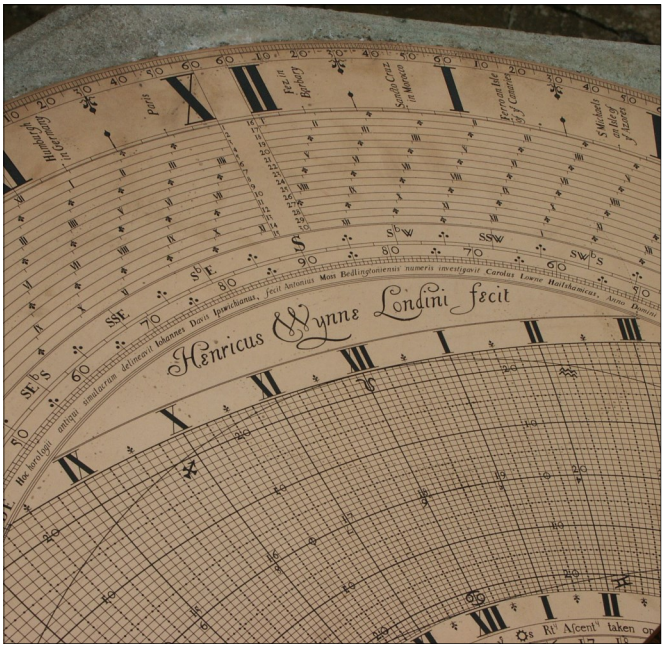


Fig. 16. Close-up of the replica dial showing the facsimile of Wynne's signature and, just above, the Latin inscription of the makers.

Fig. 15 (left). The finished dial installed on the original pedestal, in its home in Norfolk.

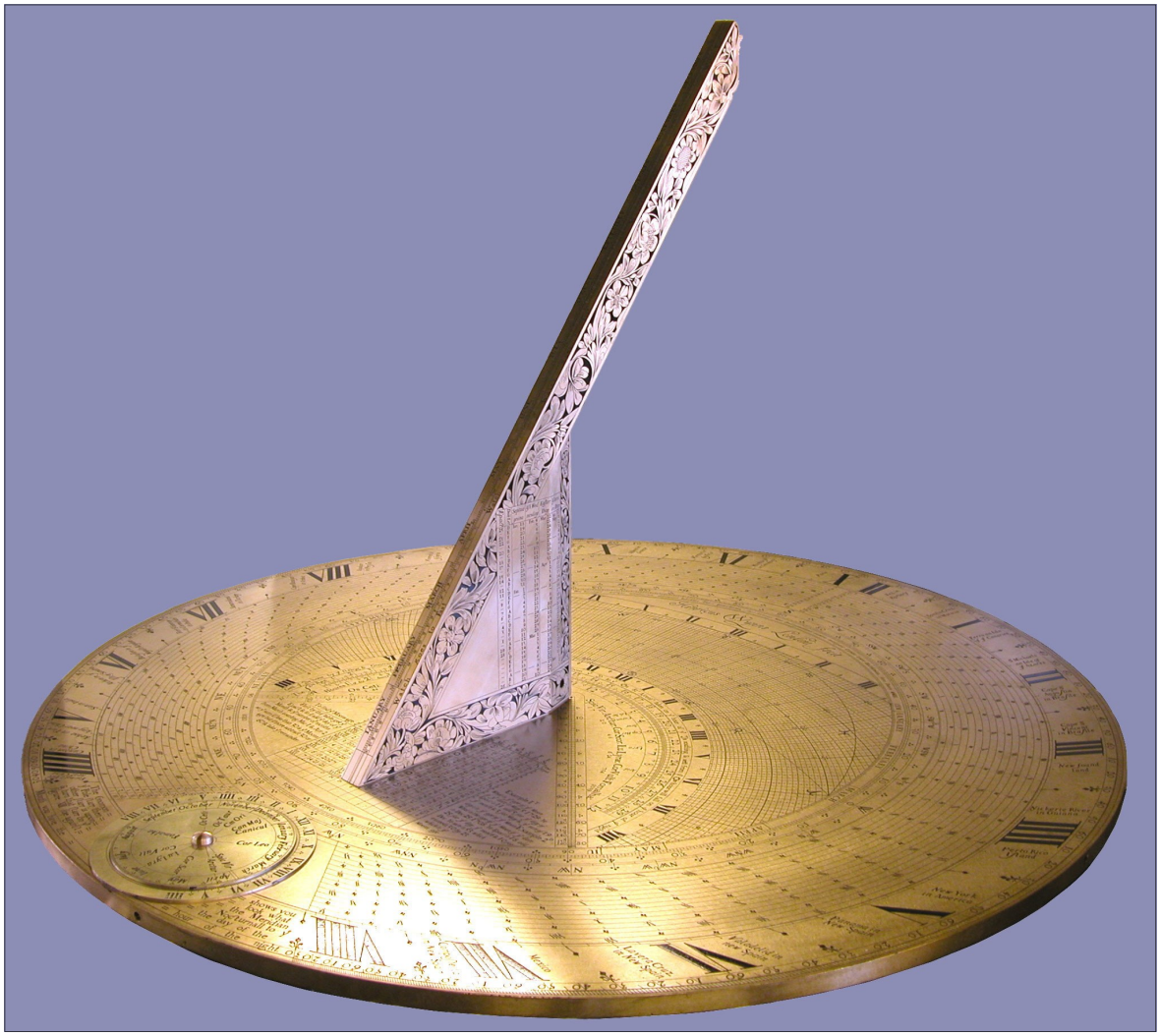


Fig. 14. The finished dial.

A TRIPLE HORIZONTAL DIAL FOR CALIFORNIA

JOHN DAVIS

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Introduction

There are not many clients for a horizontal sundial who have consulted an original copy of William Leybourn's 1682 book[1] on dialling before arriving to discuss their dial design. But Dr Rudy Light, of Redwood Valley, California, had done so and also brought a copy of Leybourn's diagram of "An Horizontall Dial with its Furniture" (reproduced in Waugh[2] and shown in Fig. 1) with him when he visited me in the summer of 2003. When he explained that he wanted a large scientific dial to position outside his house and that he "wasn't afraid of complications", I knew it would be an interesting project.

We started with a list of features which the dial should show. The essentials were:

* a time ring for Pacific Standard Time (or the solar version thereof)
* the equation of time
* declination lines for solstices, equinoxes and several family anniversaries
* the sun's azimuth
* the sun's declination
* the sun's altitude
* sunrise/sunset times
* right ascension of the sun.

An additional list of possible features included:

* local apparent time
* times of noon at various places
* a compass rose
* a moondial
* a nocturnal
* owner's and maker's names
* motto(es)
* subsidiary direct east and direct west dials on the sides of the gnomon.

It took numerous iterations of the design before we came up with the instrument shown in Fig. 2 which meets most of the requirements. I do my designs using TurboCad™ software and, such was Rudy's dedication to the project, he also installed a copy of the program so that we could correspond about the fine details of the design. The story of how the design developed and was eventually turned into bronze follows.

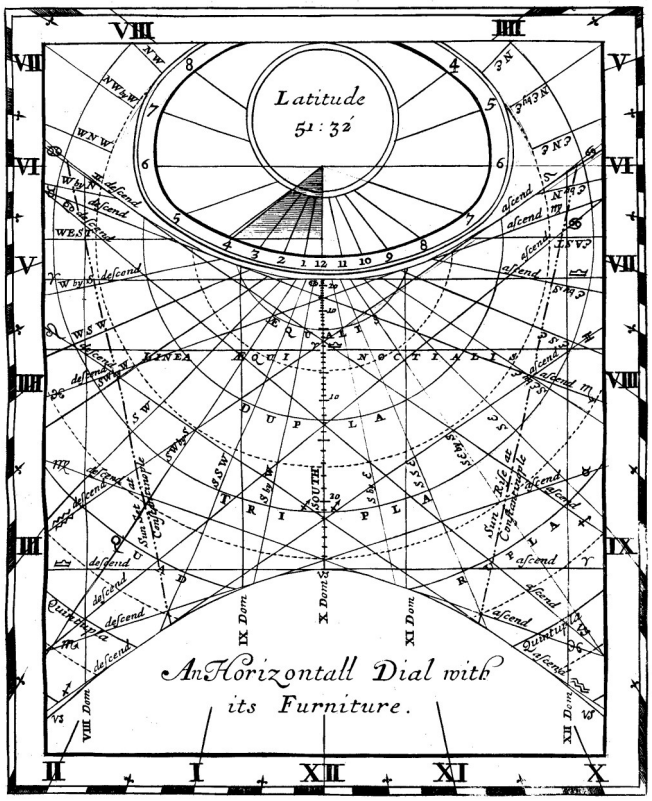


Fig. 1. A 'conventional' horizontal dial with a full set of furniture from Leybourn (ref. 1).

A Double Horizontal Dial?

The starting point was a standard horizontal dial with a polar-pointing gnomon and a nodus, designed to fit on a rectangular dial plate like the Leybourn example. The multitude of lines produced a rather messy-looking design, though. As an alternative, the double horizontal dial[3,4] seemed an attractive proposition as its stereographic projection maps the whole visible half of the celestial sphere, allowing many of the measures of the sun's position to be shown directly. At the time, I was busy researching the large double horizontal dial made in 1685 by Henry Wynne, probably for the 1st Earl Ferrers of Staunton Harold.[5] I had made several double horizontal dials before but never one for America. I showed a drawing of the Wynne dial to Rudy and he was much taken with it, so we decided that his dial should be based on, or include, a double horizontal dial. It is worth mentioning that a replica of the Staunton Harold dial has subsequently been finely crafted by Tony Moss.[6]

I quickly found a snag when laying out the dial. The stereographic projection is read from the shadow of a vertical knife-edge gnomon positioned in the centre of the

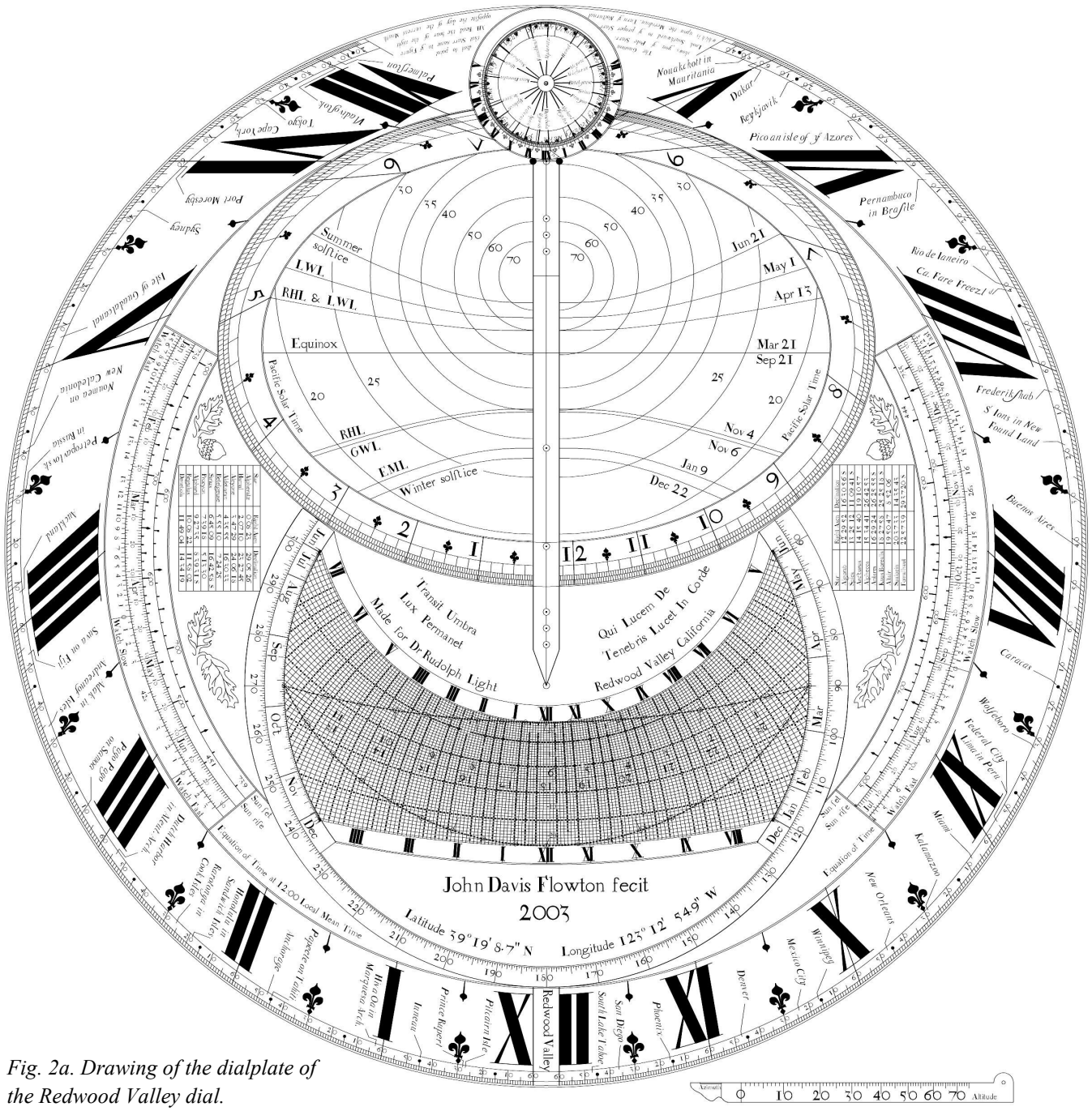


Fig. 2a. Drawing of the dialplate of the Redwood Valley dial.

grid. In a double horizontal dial, this vertical gnomon fits underneath the polar-pointing gnomon needed for the standard horizontal dial which is placed around the outside of the dial plate. The difficulty is to get the vertical gnomon tall enough to cast a shadow across the grid in the summer sun. In a conventional English double horizontal dial, this is achieved by putting the vertical gnomon in the centre of the dial plate and offsetting the origin of the polar gnomon as far as possible towards the southern edge of the dial plate (an extreme example of this can be seen in the 'Bacon' dial[7]). This tends to result in a rather narrow 'tail' for the upper part of the gnomon and a high percentage of old double horizontal dials have bent or broken gnomons. In designing a dial for California, at a much more southerly latitude (approximately 39° as opposed to 51.5° for London), the problem is significantly worse than in England both because the polar gnomon is at a shallower angle and because the sun can be much higher in the sky, leading to shorter shadows.

The solution which I adopted was to move the whole of the stereographic grid towards the northern edge of the dial plate, allowing a taller knife-edge to be fitted underneath the polar gnomon. This resulted in the grid no longer completely dominating the design. The features of the grid largely follow those of a Henry Wynne design. It has declination lines at 1° intervals and hour arcs for every five minutes of time. The 5° and 15° declination lines and the quarter- and half-hour lines have dots on them to make it easier for the eye to follow them – a feature which is easy to describe but time-consuming to do! The two arcs for the

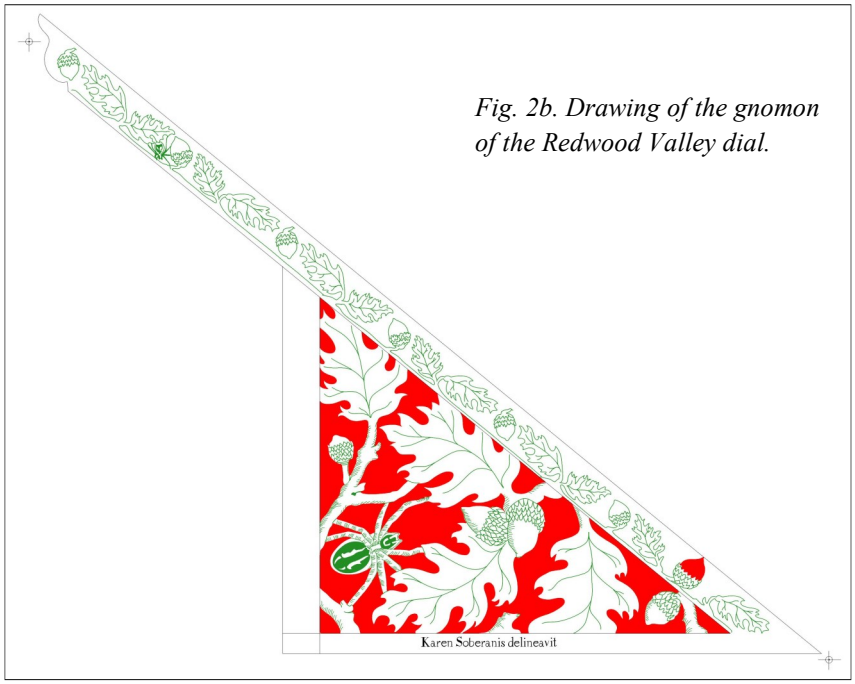


Fig. 2b. Drawing of the gnomon of the Redwood Valley dial.

ecliptic also have dots on them; a total of 360 spaced for each degree of solar longitude. Every 10th dot is emphasized and the zodiac sigils are placed at 30° intervals. The form of the sigils is that seen on Wynne's hand-engraved dials: I had produced a font of his lettering styles (there are two major ones) so it seemed a nice touch to make this new dial with old-style lettering.

The declination line for the equinoxes, running across the centre of the stereographic grid, is numbered [0] to [12] and then upside down back to [24], showing the right ascension of the sun.

The date scale running around the horizon circle of the grid uses the modern Gregorian calendar, of course, rather than the Julian one on a Wynne dial. We also chose to make it run anti-clockwise, so that the outward-facing names of the months read conventionally from left to right. This is an arrangement that was not adopted on English dials until around 1710, right at the end of Wynne's career. It does make for a more practical dial than Wynne's inward-facing engraving.

An azimuth scale is placed around the outside of the date scale. It runs from 60° in the southwest to 300° in the southeast, with 180° at the north. It might seem that this clockwise arrangement is the wrong way round but it is designed to show the bearing of the sun directly from the shadow of the knife-edge. Old English dials normally used a 4× 0-90° scale, often with the zeroes at the East and West points, but this is not very convenient today.

With a stereographic projection, the sun's altitude is measured from the origin of the grid to the point where the knife-edge shadow crosses the declination line for today's date. The scale is non-linear, ranging from 0° on the horizon circle (sunrise and sunset) to 90° (zenith) at the centre. It would be possible to show the altitude by a set of unequally-spaced concentric circles engraved over the grid but they would look confusing. Although one or two early 17th century drawings show these circles, I am not aware of any real dial with them. Instead, a straight ruler-like scale was usually engraved elswhere on the dial so that the sun's height could be measured with the aid of a pair of dividers. On some dials, provision is made for this by cutting away the foot of the knife-edge, allowing easy access to the origin of the grid. An alternative would be to provide a separate rule or alidade, pivoted about the origin and capable of being rotated to the shadow position. It is thought that some old dials had such a device although none is now extant. We decided to have a pair of alidades, mirror images of each other. The reason for having a second alidade is that the thickness of the brass casts a shadow and this can lie exactly where the measurement is being taken. With a pair of alidades, one of them can be chosen so that its fiducial edge is facing the sun. A slight extension to the length of the alidades also allows them to provide a reading on the azimuth scale.

A Third Dial

Moving the stereographic grid towards the north of the dialplate left an empty space to the south of the centre. No self-respecting 17th century English mathematical instrument maker would leave valuable brass un-engraved so we too sought a good use for the space. Our choice was for another dial face and thus we arrived at the triple horizontal dial of the title. This third face was given an elliptical chapter ring, both because it filled the space rather efficiently and because the different shape seemed to add something to the aesthetics. It also nicely matches the elliptical inner ring of the Leybourn design. The third dial uses the same polar-pointing gnomon as the main dial on the periphery of the plate. So that is does not simply duplicate that dial, it is delineated with the longitude offset of Redwood Valley from the standard parallel 120° W, amounting to 12.8 minutes. Labelled "Pacific Solar Time" (rather than Pacific Standard Time), it is divided to single minutes. To avoid the spacing getting too small, this is arranged in two rings, the inner one showing the even numbers of minutes and the outer, the odd ones. This feature was used on the Thomas Heath dial at Erddig, in Wales and then adopted by George Adams Jnr in the 18th century.

The elliptical dial also has a set of declination lines, necessitating a nodus on the gnomon. This is not a standard feature of a traditional double horizontal line. The declination lines are for the solstices and equinoxes and also for five family anniversaries, discreetly labelled with initials. The nodus (actually a pair of noduses, separated by the thickness of the gnomon – see below) also allowed

a set of lines for the altitude of the sun to be added. These are pairs of semi-circles, separated by the gnomon thickness. In Leybourn's design, the altitude lines are for *Equalis, Dupla, Tripla* etc., depending on the length of the shadow of a vertical gnomon of unit height. But we opted for the more modern approach of altitude in 5° and 10° steps.

I normally draw the outline of the gnomon on the dial plate in very narrow lines, together with the centres of any bolt or dowel holes. These etch to provide a good centre-mark for later drilling, ensuring proper alignment. At the 'toe' of the gnomon, the two origins of the horizontal dial delineation are marked by 2 mm diameter black circles. When finally assembled, the tip of the gnomon should cover exactly a quarter of each circle. On old English dials, these spots are often actual holes drilled right through the dial plate though they have usually become filled with corrosion products over the centuries. It is believed that these holes were used to locate some form of rotating ruler while the dial was being delineated but the process does not seem to have been documented.

The Outer Dial

The main horizontal dial around the periphery of the plate is very traditional. The large Roman numerals face outwards and are skewed along the hour-lines. The division to individual minutes (numbered in 10s) is on the very perimeter of the dial so that they can have maximum spacing. The half-hours are marked by fleur-de-lys though the style chosen was not the intricate design of Wynne but that of Thomas Wright who worked a generation after him. The dial naturally reads Local Apparent Time (solar time) and this point is stressed by having the location, Redwood Valley, engraved in the noon gap. Showing the times of noon at various places around the globe is another feature which Wynne frequently used (and may have actually introduced). He had a number of formats for doing this including a series of separate chapter rings but the one which we adopted is copied from the Staunton Harold dial. The names of the places are engraved in small letters in the main chapter ring with one, or sometimes two, place(s) in each half-hour space. A short line to the minute ring gives the exact time of noon, by Redwood Valley LAT, of the place. The choice of place names (Table 1) mixed traditional locations such as S^{t} Iohns in New Found Land and Pico an Isle of y^{e} Azores as used by Wynne, and others such as Kalamazoo (surely not seen on a dial before?) and Wolfeboro to which Rudy had a personal connection. The font used was again Wynne's, including his use of the long-s as in Frederik£hab.

The Nocturnal

Yet another feature copied from Wynne was the inclusion of a nocturnal. This is in the form of two concentric discs placed immediately to the south of the gnomon. The outer disc, designed to be fixed, is calibrated anticlockwise VII-XII-V hours, sub-divided to 5-minutes, on a 15° per hour basis. There is a small secondary mark at 12:13 labelled PST for Pacific Standard Time (the main nocturnal scale indicates local mean time). The inner disc carries a calendar scale and, superimposed on it, the names of 19 stars prominent in the Californian sky (Table 2). These are positioned so that their right ascensions correspond to the dates with 12:00 at the first point of Aries. Instructions for using the nocturnal are engraved, in a slightly paraphrased version of Wynne's original script, on the dial:

The Gnomon shows you @ Pole Starr.
Look southward to @ proper Starr which is upon the Meridian.
Turn@No#urnal dial to point that Starr name to@ figure XII.
Read the hour of the night oppo£ite the day of the current month.

The full list of right ascensions and declinations of the chosen stars, epoch 2000.0, are shown in two rectangular tables to the east and west of the elliptical dial.

Other Scales and Furniture

The other features which complete the scientific part of the dial are the arc segments containing the equation of time and sunrise/sunset data. I normally use equation of time data averaged over the next 50 years for engraving on dials, aiming at a continued accuracy over the life of the dial (or its owner!). For this dial, though, Rudy wanted to keep all of the design features for a particular year, in this case the millennium of 2000. Tabulated data is easy to obtain but most almanacs show the EoT for 0 hours UT each day. This is ideal for an astronomer but less convenient for a Californian sundial, likely to be observed around noon local time. So the data were interpolated to give appropriate values for 12:00 local mean time each day. The common English EoT display, showing a continuous date scale and the number of minutes "Watch Slow" or "Watch Fast" against it, requires a further calculation to work out the decimal day number when the EoT is an integer number of minutes. The decimal dates for half-minute EoT values (and 15-second intervals in some places) were also calculated. One further figure occurs at the maxima and minima, where the two adjacent numbers on the minutes scale are the same. Here, the extra number of seconds at the absolute max/min were calculated and inserted with a small 's' to indicate seconds. Thus, for example, on November 2.8, the EoT is shown as 16m 26s (Watch slow). All this was second nature to an 18th century mathematical instrument maker in London – no wonder they served a seven-year apprenticeship.

The same date scale also serves for the sunrise and sunset scales. The solar times of local sunrise/sunset were first calculated on a daily basis, assuming no refraction, using the standard equations. These were then converted to local mean time. These were finally used to calculate theoretical dates when the sunrise/sunset would fall at a desired time, in five-minute steps, for the scale. The result is a highly

Place name	Lat °	'	Lon °	'	Noon wrt Redwood
			east		
Palmerston	-12	26	130	50	7:04
Vladivostok	43	08	131	55	6:59
Tokyo	35	42	139	48	6:28
Cape York	-14	00	142	30	6:17
Port Moresby	-9	28	147	11	5:58
Sydney	-33	52	151	12	5:42
Isle of Guadalcanal	-9	26	159	57	5:07
Noumea on New Caledonia	-22	17	166	26	4:41
Petropavlovsk in Russia	54	52	169	08	4:31
Aukland	-36	51	174	44	4:08
Suva on Fiji	-18	07	178	26	3:53
DATE LINE			180	00	3:47
			west		
Adak in Andreanof Isles	51	42	176	42	3:34
Pago Pago on Samoa	-14	43	170	45	3:10
Dutch Harbour in Aleutian Arch.	53	54	166	50	2:54
Rarotonga in Cook Isles	-21	12	159	50	2:26
Honolulu in Sandw. Isles	21	18	157	51	2:19
Anchorage	61	13	149	52	1:47
Papeete on Tahiti	-17	32	149	34	1:45
Hiva Oa in Marquesa Arch.	-9	45	139	00	1:03
Iuneau	58	19	134	25	12:45
Prince Rupert	54	18	130	16	12:28
Pitcairn Isle	-25	04	130	06	12:27
REDWOOD VALLEY	39	19	123	13	12:00
South Lake Tahoe	38	19	120	00	11:47
San Diego	32	43	117	08	11:36
Phoenix	33	27	112	07	11:16
Denver	39	44	104	58	10:47
Mexico City	19	27	99	08	10:24
Winnipeg	49	53	97	09	10:16
New Orleans	29	27	90	05	9:47
Kalamazoo	42	17	85	34	9:29
Miami	25	47	80	13	9:08
Lima in Peru	-12	03	77	03	8:55
Federal City	38	54	77	01	8:55
Wolfeboro	43	35	71	13	8:32
Caracas	10	30	66	54	8:15
Buenos Aires	-34	36	58	23	7:41
S$^{t.}$ Iohns in New Found Land	47	33	52	43	7:18
Frederikshab	62	00	49	41	7:06
Ca. Fare Freezl^{d}	59	46	43	24	6:41
Rio de Ianeiro	-22	54	43	11	6:40
Pernambuco in Brasil	8	03	34	54	6:07
Pico an Isle of y^{e} Azores	38	28	28	20	5:41
Reykjavik	64	08	21	56	5:15
Dakar	14	40	17	26	4:57
Nouakchott in Mauritania	18	06	15	58	4:51

Table 1. The place names used on the dial.

non-linear scale, completed at each end with the extreme sunrise/set times for the solstices.

The final dial furniture comprises the names of the maker and owner, the latitude and longitude, and some decorative oak leaves and acorns. We also decided to have two mottoes. Mottoes on double horizontal dials are rare but not unknown – one used by Henry Wynne was *Nulla Dies Sine Linea* or 'No day without a line' – an injunction not to be idle, particularly appropriate for the many-lined double horizontal design.[8] With a surname like 'Light', the temptation was to use something along the lines of 'Lumen in umbra, Lumen ab intus' (*light in shadows, light from within*) but this was resisted as too immodest. Rudy finally chose "Transit Umbra, Lux Permanet" (*the shadows pass, light remains*)[9] and "Qui Lucem de Tenebris Lucet in Corde" (*he who [sends] light from darkness shines in his heart*).[10]



Fig. 3. The pierced and engraved gnomon of the dial (actually a modern replica) by Thomas Tompion in Kew Gardens, the inspiration for the gnomon on the Redwood Valley dial.

The Gnomon

The general shape of a double horizontal gnomon is largely fixed by the geometry of the dial plate. When shown the first design, with plain slab sides in the form of a solid triangle, Rudy's wife commented, quite correctly, that it looked rather 'clunky'. On his double horizontal dials, Wynne generally covered the triangular sides with engraved coats of arms or calendrical tables but this would not have broken up the much larger triangle for our dial. On his visit to England, Rudy had visited Kew Gardens where he had seen the (replica) dial by Thomas Tompion with its elegantly pierced gnomon (Fig. 3) and so we decided that we needed some decorative piercing, enhanced by engraved lines. Rudy has a long-standing passion for oak woodland conservation and has planted thousands of oak trees on his ranch so, instead of the traditional vine or acanthus leaves, details from the the local Californian black oak tree (*Querus kelloggii*) were to be included. Additionally, a local species of garden spider (*Argiope trifasciata*) was added, seen from in dorsal view on the east side of the gnomon and in ventral view on the west. A smaller spider is engraved near the tip of the gnomon. As I have no artistic abilities, Rudy had a local artist draw the required design and this fact is recorded by an engraving on the west side of the base of the gnomon reading "Karen Soberanis delineavit".

The choice of a nodus type for a horizontal dial is always full of compromises between visibility for all positions of the sun, non-ambiguous readings and aesthetics. This is especially the case when the gnomon is quite thick. In the past, I have used V-cuts, 'W' forms and short cylindrical cross-pieces (Fig. 4). In general, the cut-out forms have the disadvantage of disappearing at noon and consuming a significant length of the style edge when the sun is low, whereas any form of addition to the style edge leads to difficulty in deciding which part of the shadow is the intended position. After some experiments, I found that putting a hole through the gnomon, just behind the style edge so that it broke through and produced a narrow slit, worked well at all times other than noon and it was also very neat. If a reading is needed at noon, a short rod can be temporarily laid across the slit. I did the experiments using a circular hole but there is no need for it to be this shape. On the actual dial, we made the hole in the shape of an acorn and had its cup engraved as part of a decorative leaf-and-acorn border running up the side of the gnomon (see Fig 4(e)).

Making the Dial

By the time the dial design was finalised, it had grown from its initial diameter of 24" to be 27" (686 mm). The dial plate was to be 5/16" (8.3 mm) thick and the gnomon was a substantial 5/8" (16 mm). Although originally specified as brass, this had now been changed to phosphor-bronze (PB102). The old adage of "you will appreciate the quality long after you've forgotten the cost" was used to justify this Rolls-Royce material. Certainly, although 17th and 18th century English dials were made of alloys which were essentially brasses, many of them contain a low percentage of tin which is thought to have accounted for their surviving several centuries of weathering, at least at locations which avoided the worst of the acid rain during the Industrial Revolution.[11] As well as cost, the other implication of the change from brass to bronze was one of availability. Brass is readily available in high-

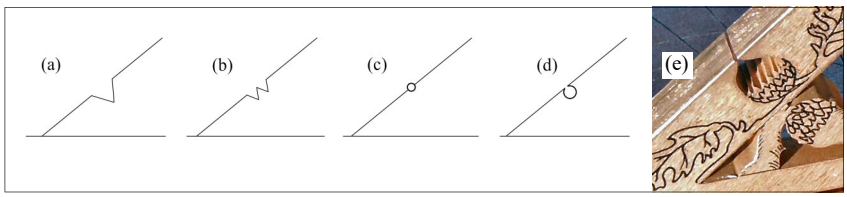


Fig. 4. Diagram of various nodus types for a horizontal dial. (a) V-cut, (b) 'W' form, (c) cross-cylinder, (d) through-hole. Photograph (e) shows the form actually implemented.

Scientific star name	Common star name	Right ascn			Declination		
		h	m	s	°	'	"
a Andromedae	Alpheratz	0	08	23	+29	05	26
a Arietis	Hamal	2	07	10	+23	27	45
hTauri	Alcyone	3	47	29	+24	06	18
a Tauri	Aldebaran	4	35	55	+16	30	33
a Orionis	Betelgeuse	5	55	10	+7	24	25
a Canis Majoris	Sirius	6	45	09	-16	42	58
a Canis Minoris	Procyon	7	39	18	+5	13	30
a Hydrae	Alphard	9	27	35	-8	39	31
a Leonis	Regulus	10	08	22	+11	58	02
b Leonis	Denebola	11	49	04	+14	34	19
d Corvi	Algorab	12	29	52	-16	30	56
a Virginis	Spica	13	25	12	-11	09	41
a Bootis	Arcturus	14	15	40	+19	10	57
a Coronae Borealis	Alphecca	15	34	41	+26	42	53
a Scorpii	Antares	16	29	24	-26	25	55
l Sagittarii	Kaus Borealis	18	27	58	-25	25	18
a Aquilae	Altair	19	50	47	+8	52	06
a Delphini	Sualocin	20	37	33	+14	35	43
a Piscis Austrini	Fomalhaut	22	57	39	-29	37	20

Table 2. The stars on the nocturnal. (Star locations for epoch 2000.0.)

quality cold-rolled sheets but for bronze the larger sizes are produced by hot-rolling, resulting in an inferior surface finish. This was to lead to added difficulties during manufacture.

Normally, I do all my own photo-etching but the size of this dial put it beyond the capacity of my facilities. With the kind assistance of Tony Moss, this work was contracted out to the same company in the Newcastle area (several hundred miles from my home) that had produced the Henry Wynne replica. This meant that the photomasks, which for in-house (literally!) use I can produce as black-on-clear plots using an inkjet printer, had to be commercially produced as large clear-on-black plots. It took some time to find a company who could do this to the required quality, working from my TurboCad files of the design. The files sizes, after converting to the appropriate printer-driver, ran to several Gbytes and each print took several hours.

The next difficulty to overcome was that the slab of bronze for the gnomon was discovered to be bowed, being several millimetres out over its length. In-house attempts to flatten it using a 3-ton hydraulic jack only succeeded in lifting the roof of my garage – phosphor bronze has a lot of spring! Luckily, Tony's engineering connections had much larger presses and were able to reduce the bow to a fraction of a mm, though it still took much work with a belt sander (thanks, Tony!) to achieve an acceptable surface finish.

The gnomon required both etching (on two sides) for the oakleaf-and-spider pattern and also waterjet cutting of the piercing and outline shape. There was much discussion over the best order for these procedures. If the etching and filling of the lines was done first, the waterjet cutting would have to be aligned to these patterns and there was a chance of surface damage to them from side-spray. But if the cutting was done first, the intricate cut edges would have been almost impossible to protect from the etching so this method was not feasible. In the event, the company of Aquajet did a fine job of aligning the heavy slab of engraved bronze in their machine and very little remedial work to the fill of the etched lines was required. Once again, conversion of the CAD design into suitable form to drive the waterjet machine produced very large file sizes (spiders are not a normal engineering requirement) and an overnight run. The machine had to be run very slowly to keep the sharp angles intact and the cuts perpendicular through the thickness of the bronze.

The two large pieces of bronze were then shipped back to my workshop for cutting and finishing. The quality of the waterjet cutting for the gnomon was such that the interior piercing required very little cleaning up with files and other hand-tools. However, the approximate 1° draw on the cut meant that the outside profile did need machining to square-up the edges and this had been allowed for in sizing the outline. In principle, this was a straightforward milling machine operation but the length of the style edge meant that I had to make two passes on my rather small milling machine (Fig. 5). Tony Moss has described[6] the process of machining the knife-edge of a double horizontal







Fig. 5 (left). Milling the style edge on the waterjet-cut gnomon.

Fig. 6 (centre). Milling the top of the knife edge where it intersects the polar gnomon. Note the stay supporting the gnomon tail.

Fig. 7 (right). Machining the edge of the dial plate, mounted on a motor-driven rotary table.

gnomon and this was more-or-less the procedure which I followed, though it stretched my milling machine to the limit (see Fig. 6).

The circular dial plate was roughly cut from the square sheet by bandsaw and then mounted on a rotary table on the milling maching (Fig. 7). A low-voltage motor rotated it slowly like a merry-go-round while the edges were gradually machined to the finished profile.

With the nocturnal and alidades having been completed in-house months earlier, all that now remained was to mate the gnomon to the dial plate. This was achieved with a combination of dowel pins for alignment and stability and M6 stainless steel allen bolts for the fixings. As this was a private dial destined for relatively benign conditions, extreme precautions against vandalism were not deemed necessary. Flush-fitting brass fixings were supplied to attach the dial to the pedestal so that, as on many old dials, the only visible signs after weathering will be three pairs of tiny holes.

After some rapid photographs of the completed dial in the rather weak February sunshine (not quite Californian) shown in Figs 8 and 9, it was packed up into two purpose-made wooden crates for shipping across the Atlantic. A square package with the dial plate weighed 30.5 kg (77 lbs) which made the delivery driver groan rather but the other package with the gnomon and the accessories was 'only' 9.5 kg (21 lbs) – the piercing had left a good fraction of the original bronze slab in my scrap bin. There was a mild panic three days later when the carrier's truck delivered a single package to Redwood Valley but, to much relief, the other one turned up the following day. The dial is currently on a temporary pedestal awaiting its final purpose-designed one.

I think we met our original design brief fairly well with all the 'essential' requirements met and many of the possible extras included. The only significant omission was the moondial and these are never terribly practical anyway. I hope Henry Wynne would approve of our updating of his design.



Fig. 8. The completed dial before shipping. Note the nocturnal to the south of the gnomon.

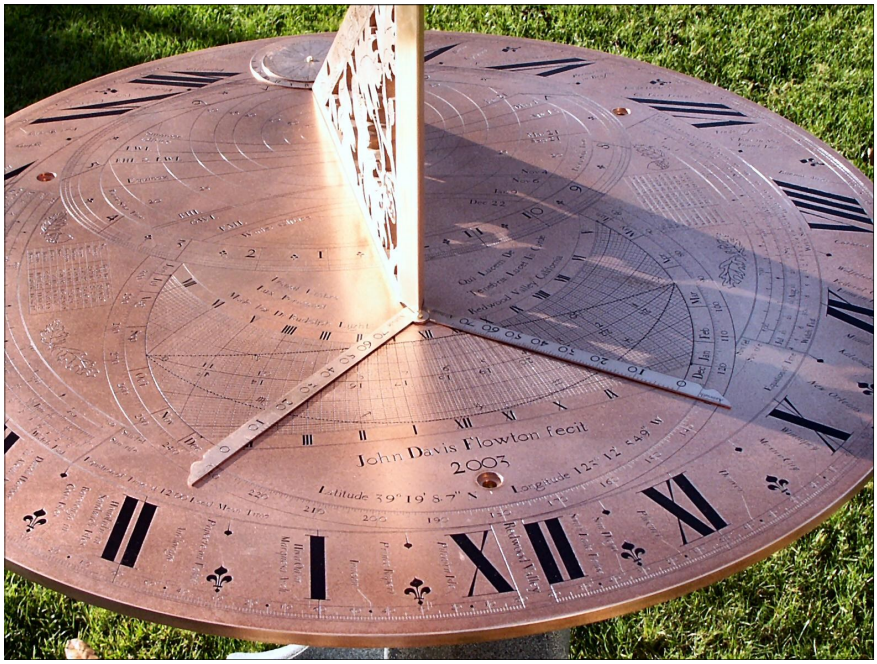


Fig. 9. The dial from the north, with the two alidades pivoted underneath the knife-edge.

Acknowledgements

It is a pleasure to thank Dr Rudy Light both for commissioning the dial and his substantial input to the design; Tony Moss for much advice and practical help with the machining (not to mention divulging commercial secrets); Michael Lowne for astronomical input, and Karen Soberanis for her artistic drawings.

REFERENCES

1. William Leybourn: *Dialling,* London, (1682).
2. A.E. Waugh: *Sundials – their theory and construction*, Dover Publications, New York, (1973).
3. F.W. Sawyer: 'William Oughtred's Double Horizontal Dial', *NASS Compendium*, 4(1), pp.1-6 (March 1997).
4. C.M. Lowne: 'The Design and Characteristics of the Double-Horizontal Sundial', *BSS Bull* 13(iv), pp 138-146, (2001).
5. J. Davis & C.M. Lowne: 'Henry Wynne's Double Horizontal Dial at Staunton Harold', *BSS Bulletin*, 15(ii) pp 46-58 (2003).
6. T. Moss: 'Double Trouble – the realization in bronze of the Henry Wynne replica dial', *BSS Bulletin,* 18(i), pp.35-39, (March 2006).
7. J. Davis & C.M. Lowne: 'The "Bacon" Double Horizontal Sundials', *BSS Bulletin*, 13(iv), pp 160-165 (2001).
8. The phrase *Nulla dies sine linea* is attributed to Pliny, describing the hard-working Greek artist Appelles.
9. Mrs Gatty's *Book of Sundials* has 'Transit hora, lux permanet' (*The hour passes, light remains*).
10. Corinthians 2, iv, 6.
11. J. Davis, T.M. Brown & I. Brightmer: 'Brass or Bronze?', *BSS Bulletin,* 19(i), pp.50-55, (June 2007).

JOHN SELLER – INSTRUMENT MAKER AND PLAGIARIST

JOHN DAVIS and CHRISTOPHER DANIEL

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Plagiarism, i.e. taking the work, design or idea of someone else and passing it off as one's own, is a human failing that is as prevalent today as it was in the 17th century. That the title of this article should be '*John Seller – Instrument Maker and Plagiarist*' suggests that Seller was notorious as a plagiarist, whereas, in comparison with others of his time, he was not. Well known clockmakers, instrument-makers and those who employed apprentices and others to produce their works of scientific art, would commonly have their signature on the finished article: this was not regarded as plagiarism. However, Seller indulged in various practices which far exceeded the term 'plagiarism', as we will show beyond all reasonable doubt later in this paper.

John Seller (1632-1697) was a leading mathematical practitioner of his day, an instrument maker, describing himself as a 'compass-maker' and map-seller, who maintained a flourishing and unrivalled nautical business near the Hermitage Stairs in Wapping, London, for some forty years.[1] The son of Henry Seller, a cordwainer of Wapping, he was apprenticed in the Merchant Taylors' Company, becoming a Freeman of the Company in 1654. In 1667, he was also accepted into the Clockmakers' Company, becoming a Free Brother of the Company in 1671, which more closely fulfilled his needs as an instrument maker. Indeed, he served as a warden of the company from 1692 to 1696, when he was excused the Mastership due to his infirmity. He died a year later in 1697 from oedema, known more commonly as 'dropsy,' and was buried at St John's, Wapping, in May of that year.[2]



Fig. 1. Title page of John Seller's Praxis Nautica: Practical Navigation*...published in 1669.*

John Seller lived in the turbulent times of the English Civil War, three of the Anglo-Dutch Wars, the Great Plague and the Great Fire of London. He lived and worked mainly in Wapping, at the sign of "The Mariner's Compass", (sometimes using the address 'under the sign' of "The Compass and Hour-Glass" (1658), but later 'under the sign' of "The Mariners Compass and Globe"), on the north bank of the River Thames, east of the Tower of London, which area was the centre of much of the maritime trade in the seventeenth century. John Seller was evidently an industrious and enterprising individual, since, after he became a Freeman in 1654 and in the years before the Restoration in 1660, he had already established his thriving enterprise. As a compass-maker, he made magnetic compasses for the use of mariners, and, as a map-seller, he necessarily stocked quantities of different maps and charts. He also advertised that he made or stocked a great variety of other instruments, such as azimuth compasses, back-staffs or Captain John Davis's quadrants, cross-staffs, globes for both terrestrial and celestial use, hour-glasses and running-glasses, telescopes, universal equinoctial ring-dials, pocket sundials and horizontal sundials, constructed for any latitude.[3]

However, Seller was also interested in the use of the instruments that he sold and in the mathematical arts for which they were required, to the extent that he wrote a book on navigation, namely *Praxis Nautica: Practical Navigation: or, an Introduction to the Whole Art*, which he dedicated to Sir Nicholas Millet, his patron. (Fig. 1.) He published this work in 1669, which established a creditable reputation for Seller in the maritime community. The book was frequently reprinted over the years and, indeed, some thirty years later it was described as "the most useful book for Seamen yet extant". [4]

This success encouraged John Seller to venture further into publishing, for which he was certainly not qualified, and to

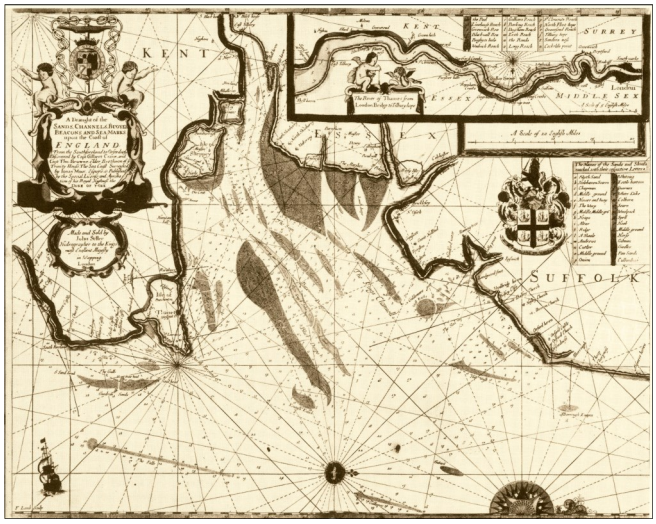


Fig. 2. Chart of the Thames Estuary by John Seller (1671) from Jonas Moore's survey.

expand his business. In the following years, perhaps when he considered himself to be more prosperous, he advertised other addresses for his shop(s) in the city itself, as in 1671-1675 "And in Exchange Alley near the Royal Exchange"[5] and from 1675-1681 "And in Pope's Head Alley in Cornhill". From 1682-1686, he is advertised as "And the West Side of the Royal Exchange". However, in 1690 he gives his address as "And at his Shop in Westminster Hall" which also might have represented a financial improvement in his circumstances.[6]

About the year 1663, Seller appears to have travelled to Holland, where he acquired a collection of old, worn copperplates, which had been made originally in 1620, copied from obsolete plates of 1608, for a counterfeit edition of a Blaeu sea-atlas. Seller immediately recognised the possibility of producing his own charts with the use of these plates, at comparatively little expense. He was not a printer, neither was he a publisher; but this did not deter him from moving into what he saw as a new and profitable field in nautical commerce. He had the copperplates 'refreshed' and planned to publish his own equivalent of the famous Dutch sea-atlases, called 'Waggoners', of the early seventeenth century. To refurbish and convert his Dutch copperplates, Seller employed two engravers, one being James Clarke and the other Francis Lamb.[7] Clarke appears to have made most of the folio plates for the atlases that were to be included in the 'Sea Waggoner' since Lamb, having a rather better reputation at this time, was probably somewhat more expensive to employ.

In the late 1660s, despite the forthcoming publication of his *Praxis Nautica*, Seller must have been impatient to embark on what he saw as his great publishing enterprise, *his* 'Sea Waggoner', which he intended to publish under the title of *The English Pilot*, in six volumes. Perhaps the need to recoup losses, which he may have incurred during the time of the Great Plague and the Great Fire, caused him to act hastily, since he published the first volume of 'his' *English Pilot* in 1668, three years ahead of the advertised publication date. Despite it being 'refreshed', this sea-atlas was in all other respects exactly the same as the counterfeit edition of the Blaeu atlas, made in 1620.[8]

How many copies of this 'pre-publication' edition were issued is not known; but it is evident that a copy came into the hands of a certain Colonel Thomas Phillips, a military engineer, who travelled out to Tangier with Samuel Pepys in 1683, when they apparently discussed the accuracy of marine charts.[9] Furthermore, during the course of the voyage, Phillips seemingly shocked Pepys, such that he reported that "Mr Phillips at sea examined and showed me how Seller's book [*The English Pilot*] in 1668 was the very same platts with the Dutch without a Dutch word so much as turned into English…and has used them in his pretended new book." [10]

At around the same time that he published this 'new' work, Seller somehow acquired a copy of an incomplete manuscript chart of the Thames Estuary by Jonas Moore. Without seeking permission, he had this engraved by James Clarke, printed and incorporated into this volume. (Fig. 2.) Thomas Phillips came to know of this and presumably told Pepys, who later recorded that Phillips "says that Sir Jonas Moore himself told him that Seller did print a platt of his survey as if it had been his, before he himself had ever finished his draught of it….".[11] Criticised for this act of plagiarism, Seller reacted quickly and, no doubt due to the urgency of the situation, had a new plate engraved by Francis Lamb, which acknowledged Jonas Moore as the proper author of the chart.

This chart was incorporated in the first official edition of *The English Pilot*, issued early in 1671, together with an accompanying volume, that gave Seller the approbation that he hardly deserved. However, the fact that Seller dedicated this work to James, Duke of York, may have had some bearing on the matter, since a Royal Warrant, dated 22 March 1671, granted John Seller a Royal Privilege, which enjoined "any person to print any work, under other titles, reprinting, or counterfeiting, for thirty years…". A second Royal Warrant, issued only two days later, gave Seller the title of 'Hydrographer to the King". After receiving the privilege and the title, Seller was quick to incorporate them into his publications. He reissued *The English Pilot* in the early summer of 1671 and went on to publish various other volumes of *The English Pilot* in 1672.[12]

Whilst it has been acknowledged that Seller was industrious and enterprising, he appears to have been over confident, if not too ambitious. In 1675 he began to experience financial difficulties and, in 1676-1677, he was obliged to seek partners for his great 'Sea Waggoner' enterprise. These were principally made up of John Seller's rivals in the trade and, perhaps not surprisingly, the partnership was dissolved in 1679, by which time Seller had lost nearly everything that he had so keenly

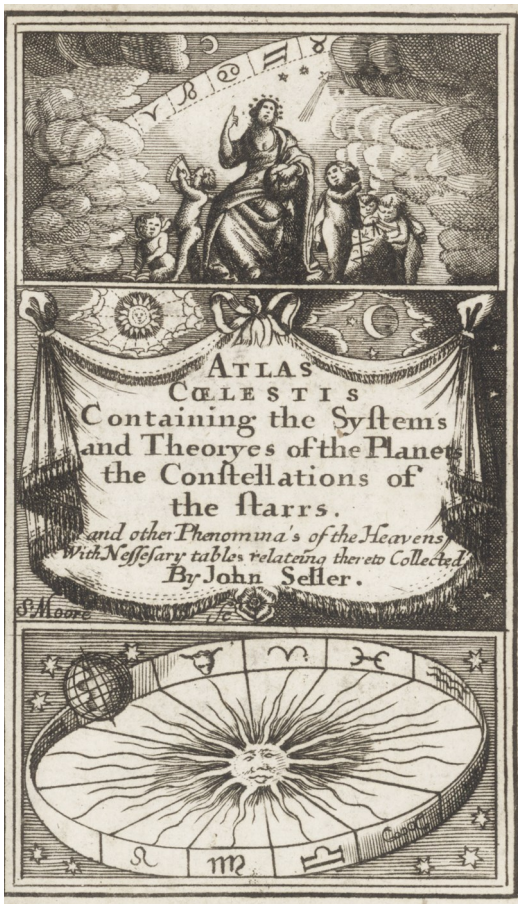


Fig. 3. Title page of Seller's Atlas Coelestis*, published in 1680.*

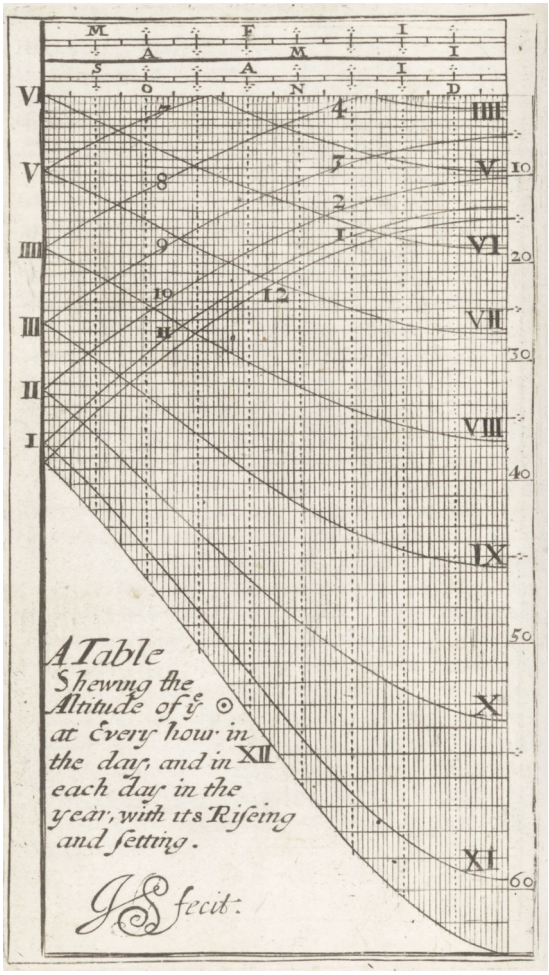


Fig. 4. A table of the altitude of the sun 'by Seller' from his Atlas Coelestis*, inscribed '*J.S. fecit*'. Seller has attempted to expunge what appears to be the letter 'G' on the printer's plate, prior to replacing this with his own signature. The table could well have been the work of the noted astrologer John Gadbury or the well known mathematical instrument-maker Ralph Greatorex.*

acquired since he first embarked on his publishing venture. Yet it may be said that it was John Seller who founded the chart trade in London, seeking to break the Dutch monopoly, although it was left to others to build up the reputation of the English in this field, eventually to become the finest in the world.[13]

Following the dissolution of the partnership, Seller tried to re-establish himself[14] and proceeded to produce a new series of publications, notably small 'pocket' works, such as *A Pocket Book containing…Surveying and Dialling* in 1677 and an *Atlas Coelestis*, (Fig. 3) published in 1680. The latter was one of the first 'pocket' astronomical atlases to be printed and contained numerous astronomical maps, diagrams and tables. A number of these, bearing his name or signature, imply that they were the work of Seller himself[15] but evidence (Fig. 4) suggests otherwise.

Whilst Seller's cartographic publishing enterprise was of great importance to him, it should not be forgotten that he had a successful business as a mathematical instrument-maker, especially as a compass-maker. In 1672, he had obtained a contract to supply compasses and glasses – "half-hour and half-minute glasses" – to the Royal Navy in the store at Chatham, continuing to supply such instruments for many years.[16] At the same time, he was making surveying instruments, drawing instruments, and instruments for use in gunnery. According to his advertisements, he also made sundials.[17]

Only one sundial bearing John Seller's name is known so it is surprising that this is a double horizontal dial. The double horizontal sundial is widely regarded as one of the most useful and important sundial types.[18-20] It developed from the horizontal instrument[21] which was designed by William Oughtred in the late 16th century and was the focus of an acrimonious priority dispute with Richard Delamain.[22] Most of the early examples were made by Oughtred's "loving friend"[23] Elias Allen. Later, in the mid-17th century, Henry Sutton developed a more sophisticated format but it remained an instrument produced by only the very best makers. Only around 60 examples are known[18], most made by the line of descendants by apprenticeship from Allen: examples exist by John Allen, Ralph Greatorex, Henry Wynne, Thomas Tuttell and Richard Glynne, as well as by some of the other great makers, notably John Rowley and his apprentices.

Seller's double horizontal dial is shown in Fig. 5. It has been described previously[24] and is also pictured and drawn in the paper by Lowne.[20] Examination of the dial shows that its simple form matches that used by Elias Allen exactly, despite the fact that, by the time Seller was working in the last quarter of the 17th century, the more sophisticated Henry Sutton format had been widely adopted by Seller's contemporaries such as Henry Wynne and John Marke. For example, Allen marked the ecliptic arcs with calendar dates but Sutton moved these to around the horizon circle and put the zodiac signs along the ecliptic.

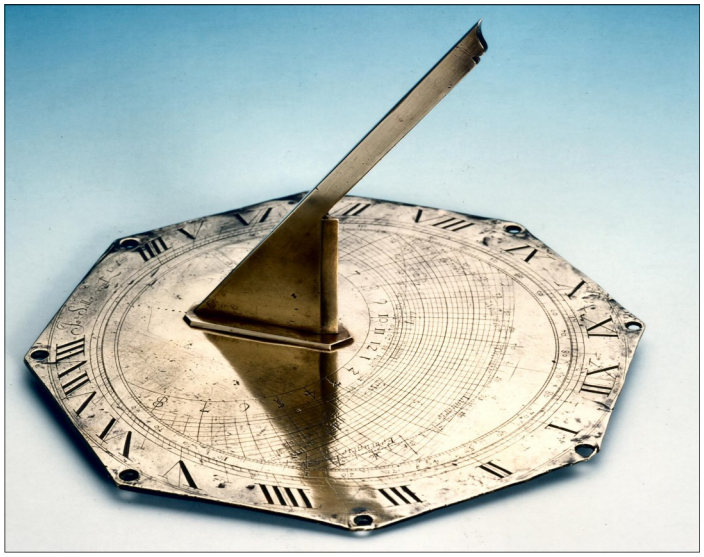


Fig. 5. An overall view of the double horizontal dial signed by John Seller.



Fig. 6. Close-ups of 'Sep' engraving on (top) the Seller and (below) Allen dials.

Recently, it has been possible to compare the Seller double horizontal dial side-by-side with the Elias Allen one sold in 2007 by Bonhams,[25] as well as photographically with several other Elias Allen double horizontals (a total of 11 such dials are currently known[18]). It was clear that, as well as the general layout and size, the details of the lettering were also very similar indeed. Elias Allen had quite a distinctive engraving hand, partly shared with his apprentices (particularly John Allen and Robert Davenport; less so with Ralph Greatorex). One particularly characteristic feature is his lowercase 'p' in which no attempt is made to close the top, making it look like a 'y' with the descender on the left side. A comparison of Allen's 'p' and that on the Seller dial is shown in Fig. 6. Other characteristic Allen features, all to be found on the Seller dial, are

* lower case 'c' with almost non-existent lower curve,
* numeral '2' which is very angular, almost a 'Z',
* upper case 'M' with characteristic leading serif,
* lower case 'b' with forward facing ascender

and so on. The authors concluded that the Seller dial had been made in the Allen workshop, probably by Elias Allen himself. The signature, "Jo^{n} Seller excud□ $^{\text{Londini}}$" shown in Fig. 7, was next examined. It was clear that the 'Jo^{n} Seller excud□' part was by a different hand to the dial delineation. Key characters which are different in style are both capitals, the double 'll', the centre bar of the 'e' etc. However, the flourish after the final 'd' is very much in the Allen style (see Fig. 8 for a typical Allen signature), as is the 'Londini'.

Thus it seems that the dial was in fact an old one to which Seller put his name. The question was, did he (or his engraver) just put his signature on a blank space or did he actively erase Allen's name to insert his own? Allen, of course, ought not to have produced an unsigned dial but there are many anonymous dials showing it sometimes happened. A magnified view of the signature taken with diffuse side-lighting (Fig. 9) shows that Allen's name has been obliterated in a most deceitful manner. Traces of the capitals 'E' and 'A' are clearly visible and there is also evidence of the lowercase letters. The forger has cleverly left the flourish of the 't' of 'fecit' and incorporated it into the 'd' of 'excud□'. Other signs are visible too. One of the row of dots, running southwards from the gnomon and



Fig. 7. (Top) Signature of the Seller dial.

Fig. 8. Signature of an Elias Allen double horizontal dial.



Fig. 9. Close-ups of three regions of the John Seller signature. Note the traces of the imperfectly erased signature of Elias Allen.

acting as the centres for striking the declination arcs of the stereographic projection, is missing, The thickness of the dialplate in the region of the original signature has been reduced by between 0.10 and 0.15mm (difficult to measure accurately as the dial plate is not uniform in thickness). The back of the plate has been hammered to bring the front surface level, leaving a slight depression on the back in the region of the signature.

Who made the change to the dial? The most obvious candidate is John Seller himself. But perhaps a more likely suggestion is James Clark(e), one of Seller's engravers and who later emigrated to Scotland.[26] Three sundials signed by Clark are known.[27] Two of them are double horizontals, both made for Scottish locations. One of them, currently in Liverpool Museum, is in exactly the format developed by Henry Sutton and also used by his apprentice John Marke.[28] In the light of the discovery of the changed signature of the Seller dial, the original maker of the Liverpool dial must be regarded with some suspicion though its rather poor condition makes it difficult to make a definite statement.

The 'Seller' double horizontal dial has had a hard life. The gnomon currently fitted is an old replacement. This is not unusual: the gnomons of all double horizontals are very vulnerable and this is particularly the case for those made by Elias Allen where over a third of the extant dials have replacement or broken gnomons. Undoubtedly the use of a rather coarse-grained cast brass with little cold-working contributed to their vulnerability.[29] The replacement gnomon on the Seller dial is of a reasonably appropriate design and it is fitted into a patch of brass expertly inset into the dial plate around the gnomon slot. This insert is covered by the 'foot' of the gnomon when the dial is assembled and was thought to be a repair to damage caused when the original gnomon was ripped out. On closer inspection, however, it was found that the patch has a keyhole shape (Fig. 10). Whilst it is possible that this was just a convenient shape to remove the damaged area of the dialplate (a 'dutchman', in woodworking terms) an alternative theory is that the dial has at some time been used as the escutcheon plate of a lock and the centre of the dial was opened up to accept the key! Although this may seem an unlikely (and sacriligious) use of a scientific instrument, there is at least one precedent known, on the door of the church in Sydenham, Oxfordshire.[30]

The component parts of the Seller dial have been metallurgically examined by energy dispersive analysis of x-rays.[31] They show that the original dial plate is a simple

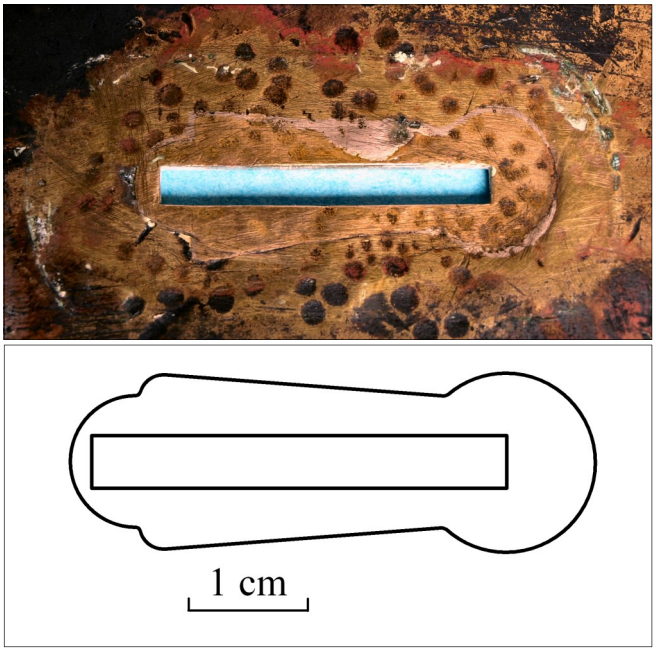


Fig. 10. Rear view of the Seller dial showing the inset patch around the gnomon slot. The outline of the patch is also drawn.

brass with a composition of approximately 64% Cu and 36% Zn. This is a rather high percentage of zinc for the cementation process which would have been used to produce the brass but in line with that found in double horizontal dials by Elias Allen. In contrast, dials by Seller's contemporaries such as John Rowley and Henry Wynne have much lower zinc concentrations (15-25%) and also, in the latter case, the addition of 5% of tin.

Analyses of the replacement gnomon of the Seller dial, and of the patch in the dial plate, show them to be made of a more modern 'common brass' with a 60% Cu, 40% Zn alloy. This composition is not possible by the cementation process and, although William Campion patented a method of distilling metallic zinc from calamine in 1738, it was not until the work of George Muntz in the 1830s and '40s that brass with high zinc concentrations became common in Britain.[32]

It is not possible to say when the dial suffered such wretched treatment or who recognised its true worth and rescued it. The period of around four decades between the original manufacture and it falling into Seller's hands seems too short for such a valuable instrument to become obsolete, be used as recycled brass and then recovered for refurbishment. Double horizontal dials were still much prized thoughout this period[33] and still made until around 1730. This suggests that its use as a lock occurred in the late 18th or early 19th century, leaving its expert repair perhaps to have been in the Victorian era (as supported by the metallurgical composition). This is pure speculation. The manner of the repair, complete with a steel retaining plate for the replacement gnomon made from part of a clockspring, gives the impression that the work was done by an expert clockmaker of that period. If this is the case, Seller can be absolved of this part of the story, though the stain on his character for claiming another man's work as his own remains.

Acknowledgements

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References and Notes

1. H. Wallis: 'Navigators and Mathematical Practitioners in Samuel Pepys's Day', (The Eva G. R. Taylor Lecture), *The Journal of Navigation*, Vol. 47, No.1, p.7 (January 1994).
2. C. Verner: 'John Seller and the Chart Trade in Seventeenth-CenturyEngland', *The Compleat Plattmaker*, (Ed. N. J. W. Thrower), University of California Press, pp.132 & 139, (1978).
3. *Ibid*., p. 132.
4. E. G. R. Taylor: *The Mathematical Practitioners of Tudor & Stuart England*, Cambridge University Press for the Institute of Navigation, p. 92, (1954).
5. G. Clifton: *Directory of British Scientific Instrument Makers 1550-1851*, (Ed. G. L'E. Turner), Zwemmer – in association with the National Maritime Museum, p.247, (1995).
6. C. Verner: 'John Seller and the Chart Trade in Seventeenth-CenturyEngland', *The Compleat Plattmaker*, (Ed. N. J. W. Thrower), University of California Press, p.136, (1978).
7. *Ibid*., p.140.
8. *Ibid*., p.140.
9. E. G. R. Taylor: *The Mathematical Practitioners of Tudor & Stuart England*, Cambridge University Press for the Institute of Navigation, p.271, (1954).
10. C. Verner: 'John Seller and the Chart Trade in Seventeenth-Century England', *The Compleat Plattmaker*, (Ed. N. J. W. Thrower), University of California Press, pp.140, (1978).
11. *Ibid*., pp.142-143.
12. *Ibid*., p.143 & 146.
13. *Ibid*., pp.156 & 157.
14. *Ibid*., p. 138.
15. N. Kanas: *Star Maps – History, Artistry and Cartography*, Praxis Publishing, Chichester, pp.202-205, (2007).
16. C. Verner: 'John Seller and the Chart Trade in Seventeenth-Century England', *The Compleat Plattmaker*, (Ed. N. J. W. Thrower), University of California Press, p.136, (1978).
17. *Ibid*., p.135.
18. J. Davis & C.M. Lowne: *The Double Horizontal Dial*. BSS Monograph No. 5, (t.b.p. 2009).
19. F.W. Sawyer: 'William Oughtred's Double Horizontal Dial', *NASS Compendium*, 4(1), pp.1-6 (March 1997).
20. C.M. Lowne: 'The Design and Characteristics of the Double-Horizontal Sundial', *BSS Bull* 13(iv), pp 138-146, (2001).
21. For a recent description of a horizontal instrument, see A.D. Morrison-Low: 'Recent acquisition by the National Museums of Scotland: William Oughtred's horizontal instrument and 'Circles of Proportion' by Elias Allen, London, 1648', *SIS Bulletin*, 85, pp.20-22, (June 2005).
22. A. Turner: 'William Oughtred, Richard Delamain and the Horizontal Instrument in Seventeenth Century England', *Annali dell Instituto e Museo di Storia della Scienza di Firenze*, Anno VI, Fasc 2 (1981).
23. See letter from William Oughtred to Elias Allen (20 August 1638) addressed to "Good Mr Allen" and signed "Your very loving friend and servant William Oughtred". Cambridge University Library MS Add 9597/13/5/215.
24. C. Daniel: 'Best Seller', *Clocks*, The Sundial Page, p.38 (February 1993).
25. Bonhams sale 15617 lot 127, London, 28 Nov 2007. The dial was shown in M. Cowham: 'Dial Dealings', *BSS Bull* 20(i), p. 40, (March 2008).
26. D.J. Bryden: ' "Mr Clerk the graver"; a Biographical Study in the Cultural Infra-Structure of Early Modern Scotland', *Review of Scottish Culture, 11,* pp.13-31 (1998-9).
27. A. Morrison-Low: BSS Andrew Somerville Memorial Lecture 2008 (unpublished).
28. For details of John Marke double horizontal sundials, see papers by I Brightmer, J Davis and F Coe in *BSS Bulletin* 20 (iii), (September 2008).
29. For an initial study of the metallurgy of double horizontal sundials, see J. Davis, T.M. Brown & I. Brightmer: 'Brass or Bronze?', *BSS Bulletin,* 19(i), pp.50-55, (June 2007). Further details will be in Ref. 18.
30. C. Daniel: *Sundials*, Shire Books, Princes Risborough (2004). The Sydenham dial is illustrated on p.4.
31. Analysis at Derby University in a Leo 1450VP SEM.
32. W.O. Alexander: 'A Brief Review of the Development of the Copper, Zinc and Brass Industries in Great Britain from AD 1500 to 1900', *Murex Review* Vol. 1 No 15, pp 389-427 (1955).
33. Pepys wrote about his double horizontal sundial in his diary entries for Wed 3 June and Thurs 4 June, 1663.

PART THREE

NEW ARTICLES

THE DEVELOPMENT OF THE DOUBLE HORIZONTAL DIAL AND ASSOCIATED INSTRUMENTS

PRECURSORS

The stereographic projection has a very long history. As a means of representing points and lines on the 3D celestial sphere by projection onto a 2D plane, it was almost certainly known by the ancient Greeks and has been attributed by Neugebauer[1] to Hipparchus of Nicaea (c. 180-125 BC). Vitruvius, the Roman writer on architecture of the first century BC, wrote about an anaphoric water clock that evidently made use of the projection. The oldest surviving mathematical treatise on stereographic projections is Claudius Ptolemy's (fl. 127-151 AD) *Planisphaerium* (The Planisphere). Although the Greek text is lost, we have an Arabic translation made around 1100 AD and a Latin translation of that about half a century later.

The Musātira

The most commonly used form of the stereographic projection is that onto the plane of the equator, as used by the majority of astrolabes. But the *horizontal projection*, that is a stereographic projection onto the plane of the local horizon, was also known by Arab astronomers, certainly at the beginning of the second millennium AD, if not before. According to Turner[2] the earliest Arab account is by Hāmid b. al-Khidr al-Khujandi in the 10th century and then, after a gap of three centuries, in a treatise by al-Marrākushi which has been translated by Sédillot.[3]

One use of the horizontal projection was for the Arabic instrument known as the *musātira* ('the instrument which conceals'). A manuscript by Najm al-Dīn al-Mīsṛī, writing in Egypt around 1350, shows this already well-established instrument and its construction. The manuscript, translated and described in detail by François Charette,[4] provides much information on many astronomical instruments and various types of sundial.

The musātira is shown in Fig. 1 where it can be seen to be very similar in form to the horizontal instrument. It is drawn, not particularly accurately, for a latitude of 36° N using a method which uses geometry and look-up tables (Fig. 2). Having drawn the horizon circle and placed an angular scale around it, the points where the declination arcs cut it are found by measuring the azimuths of sunrise and sunset, obtained from a table, from the E and W points. The point where the declination arc crosses the meridian line is obtained by measuring the noon altitude angle around the horizon circle from the S point and con-

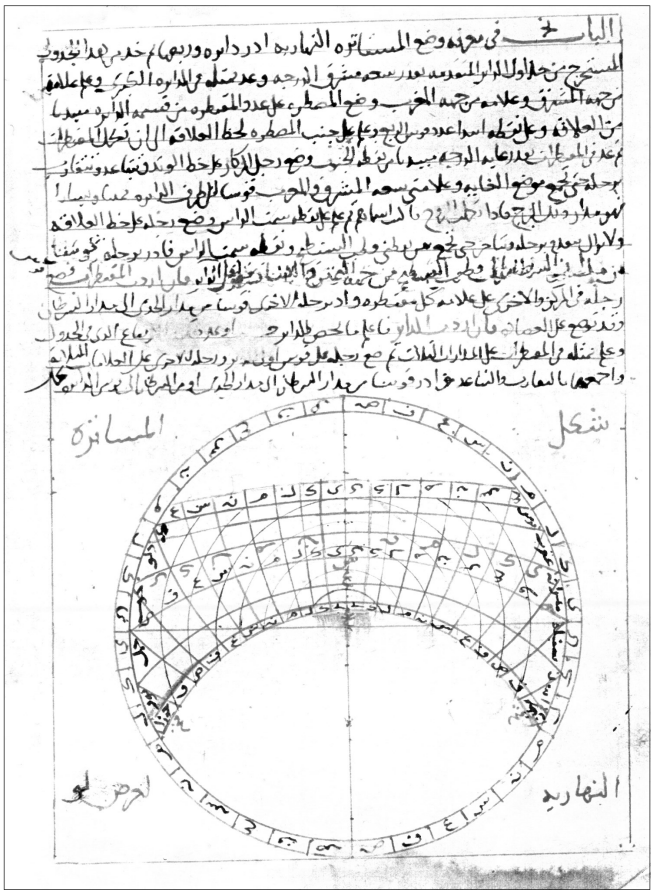


Fig. 1. The musātira, from a manuscript c.1350.[4]

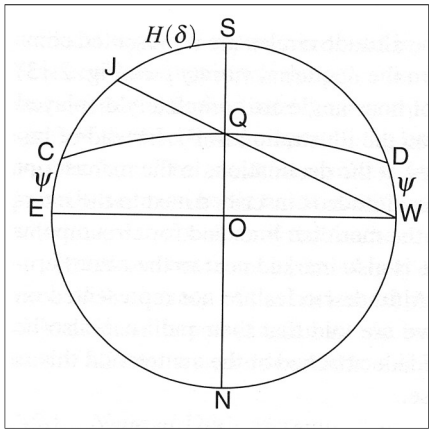


Fig. 2. The construction of the declination lines of the musātira, after Charette.[4]

necting this to the W (or E point): the intersection of the line with the meridian gives the desired point. With three points on the circumference of the declination arc and knowing that its centre must lie on the meridian line, it can then be drawn with compasses, using trial-and-error to locate the centre. The declination lines in the example of Fig. 1 are drawn for the zodiac signs but are confusing because their labels are written above the lines and there is another arc above the Capricorn (winter) one which is actually superfluous.

The next step is to draw the altitude arcs. (It is worth noting that these arcs are rarely seen on 17th century horizontal instruments and double horizontal dials but were often found on earlier instruments.) Their crossing positions on the meridian line are found by the same method as above, i.e. by measuring the altitude angle from the S point. They are all concentric with the projection of the zenith, i.e. the centre of the plate. The (equal) hour arcs are found by using tables of the sun's altitude on the solstices and equinoxes for each hour. This provides three points on each circular arc. The 6 hour circle is first positioned as its centre lies on the meridian line. The centres for the other hour circles then lie on a line running E-W through that point.

Unfortunately, there is no known physical example of a musātira extant.

EUROPEAN DEVELOPMENTS

The earliest example currently known of the use of a horizontal stereographic projection to produce a European instrument design is a drawing in manuscript workbook now in the Bayerisches Staatsbibliothek (Munich).[5] It is anonymous, called simply 'Astronomische Zeichnungen' (*astronomical drawings*) and has been dated to the period 1508 to 1520. The workbook consists almost entirely of drawings of instruments of many types of sundial and astrolabe, together with a number of tables but with very little descriptive text. The introduction does include some biographical notes on Johannes Campanus of Novara (1220-96), an astronomer/mathematician who wrote the *Theorica Planetarum* describing a planetarium and who was possibly the conduit for data from the Arab world to Europe.

Amongst the beautiful drawings is the one reproduced in Fig. 3. It shows what is essentially a horizontal instrument

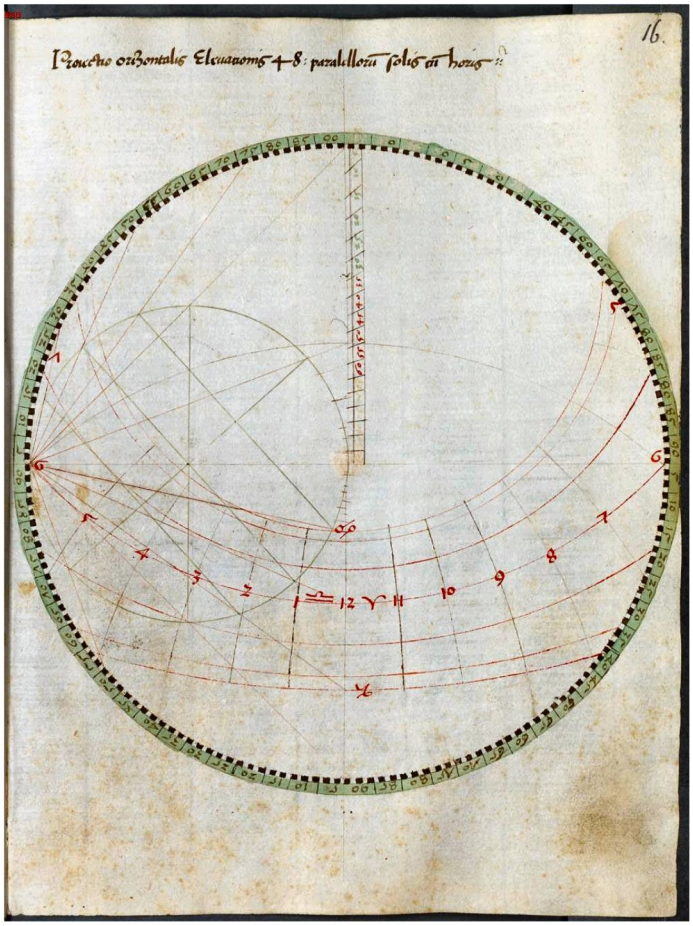


Fig. 3. An early European manuscript drawing of a horizontal stereographic projection. Courtesy Bavarian State Library.

but without the ecliptic arcs. It is drawn for a latitude of 48° N which is appropriate for Vienna, the likely location of the author. Of particular interest is the inset small circle which indicates the geometrical method by which the drawing was constructed. Although no physical version of the instrument is known, it is possible that knowledge of it passed to the astrolabe maker Georg Hartmann.

Hartmann's Practika

The great German astrolabe and instrument maker Georg Hartmann wrote an unpublished manuscript work-book[6] in 1527/8, now published as the *Practika*, describing the mathematical methods (really geometry) used to design a large number of instruments. This manuscript has been translated from the original Low German by John Lamprey[7] and the diagrams redrawn in modern form. Hartmann described in his Book 6 a device called a *compast* which is again essentially a horizontal instrument, i.e. a stereographic projection onto a horizontal plane. (The use of the term 'compast' – compass – is confusing as it was also used to describe a much simpler dial, a form of ivory diptych with a magnetic compass.)

Hartmann's *compast* is actually a form of magnetic azimuth dial. The hour numbers run, unusually for a northern hemisphere dial, counter-clockwise around the stereographic grid. The dial is aligned so that the shadow of a vertical pin gnomon falls along the central diameter. The

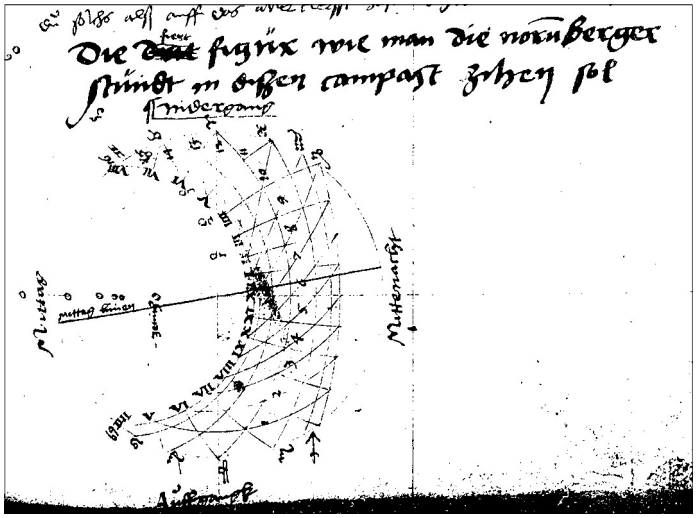


Fig. 4. A typical page of Hartmann's 'Practika' showing the construction of his 'compast'.[6]

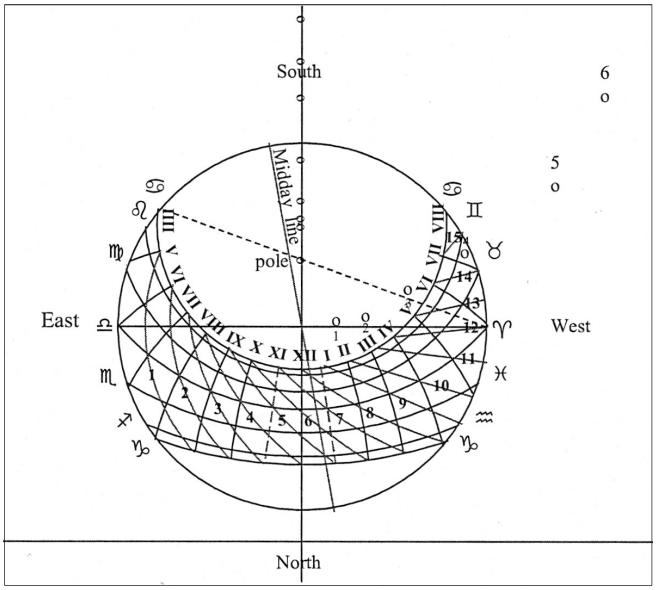


Fig. 5. A modern interpretation of Hartmann's 'compast' drawing by John Lamprey.[7]



Fig. 6. Hartmann's compast AD-4.

time is then read by the position of the magnetic needle over the grid. A full description of the device was published (without attribution) by the court mathematician Andreas Schöner (1528-1590) in his 1562 book *Gnomonice…* The details of the construction method used by Schöner to draw the stereographic grid have recently been described by Sawyer, Schilke & Severino.[7a]

Fig. 4 shows one of Hartmann's four drawings and Fig. 5 is a modern version. Hartmann's procedure first found the centre of the equinoctial circle appropriate for the desired latitude (49° 27' for Nuremburg in his case) on the meridian line using a simple geometric construction. This circle crosses the horizon circle at the E and W points and the meridian line using the same construction as described for the musātira, giving three points on the equinoctial arc. (In Book 1 Proposition 5, Hartmann describes how to find the centre of a circle passing through any three points, using just a compass and ruler.) The declination lines for the other zodiac signs are then constructed geometrically using their declination values to find their meridian crossing and a table of sunrise/sunset azimuth values ("*amplitudo ortua*") to give another two points. Thus the method closely follows that used for the musātira.

The construction of the equal hour arcs begins with drawing the single circle for 6am and 6pm, much in the manner of the musātira. The circumference of this circle is then divided equally into 12 parts and lines drawn from each position to the pole. Where these lines cross the line running E-W through the 6 hour circle is the centre of each of the other hour lines. Knowing their centres and the fact that they must pass through the pole, they are easily drawn.

Hartmann included extra lines for Nuremburg hours on his compast. (These comprise Babylonian hours in the day and Italian hours in the night. They were numbered 1-16, starting at sunrise, and hence can be confused with ordinary Babylonian hours.) For his location in Nuremburg, Hartmann made the approximation that the maximum day length in mid-summer was 16 hours, rather than the actual 16 hours 6 minutes, as this simplified the drawing and was not thought to give a significant error. With this approximation, the 1st Nuremburg hour was at the 5th equal hour ('small hours' in Hartmann's terminology) when the sun was at Cancer; the 7th equal hour at Aries and 9th at Capricorn. Given these three points, the circle through them can be simply drawn. For the other Nuremburg hours, the numbers of the equal hours at each season just increment in step.

Hartmann allows for the magnetic variation of approximately 8½° W at that date and location by rotating the grid relative to the centreline of the instrument which he labels, rather confusingly, the 'midday line'.

An actual example of Hartmann's device (AD-4) exists and is shown in Fig. 6. It is briefly described and illustrat-

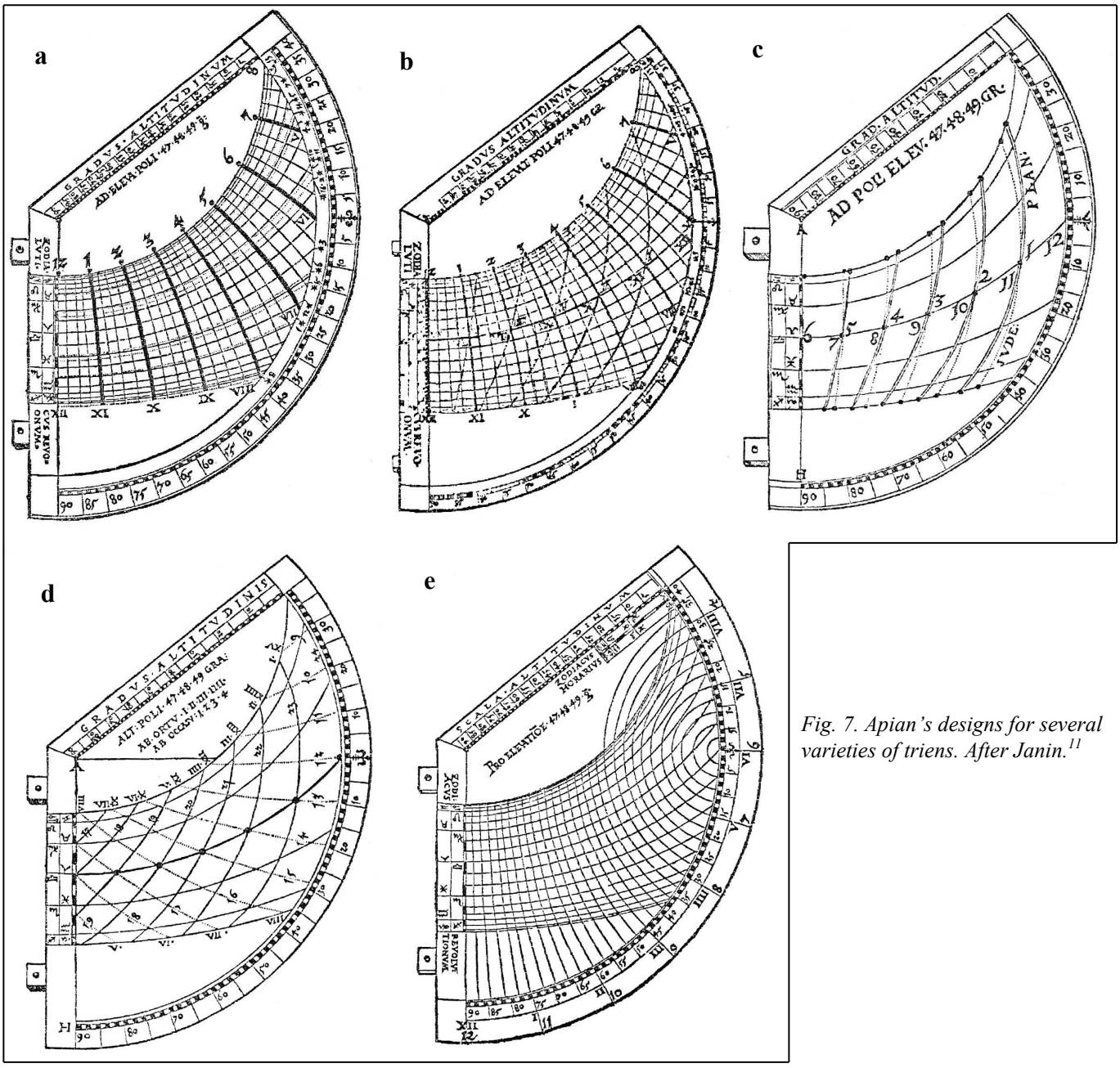


Fig. 7. Apian's designs for several varieties of triens. After Janin.[11]

ed in Zinner.[8] It follows the drawings in the *Practika* quite closely, incuding the midday line, although the magnetic needle is now missing and it is unclear what form of gnomon was used to cast the shadow.

Horizontal Quadrants – Triens

By folding the horizontal stereographic projection in half along the meridian (noon) line, a smaller instrument is obtained but still containing all the information of the full hemisphere. Philip Apian, son of Peter Apian (1495-1552), described a device in 1586 based on this principle which he attributed to his father and called a *triens* (i.e. a third of a circle).[9] There were five different variants of the design, shown in Fig. 7. The basic instrument (e.g. Fig. 7a) has a pair of sights along one edge and provision for a plumb-bob suspended from the centre of the projection. It would have been used to measure the sun's altitude against a degree scale on the limb. A bead on the string would then have been slid along the string to a position appropriate for the altitude using the scale on the right-hand edge. Finally, the string was moved so that the bead lay on the correct declination line for the date, allowing the time to be read. The fact that the instrument is labelled for use at latitudes of 47, 48 & 49° indicates that it was not expected to provide great precision. It can be seen that the instrument is in the same form as Richard Delamain's horizontal quadrant and predates it by several decades.

Other variants of Apian's triens were delineated to show temporary (seasonal) hours (Fig. 7b); planetary and Jewish hours (Fig. 7c); and Babylonian and Italian hours (Fig. 7d). An unexpected variant (Fig. 7e) is designed to show the sun's position on the hectemoros arc, from the east or west points of the horizon, and provides a most unusual grid of lines.

Of all these, it is the sun's position type for which we have an actual example, made by the Augsberg maker Christoph Schissler the Elder in 1566. His instrument, HQ-8, de-

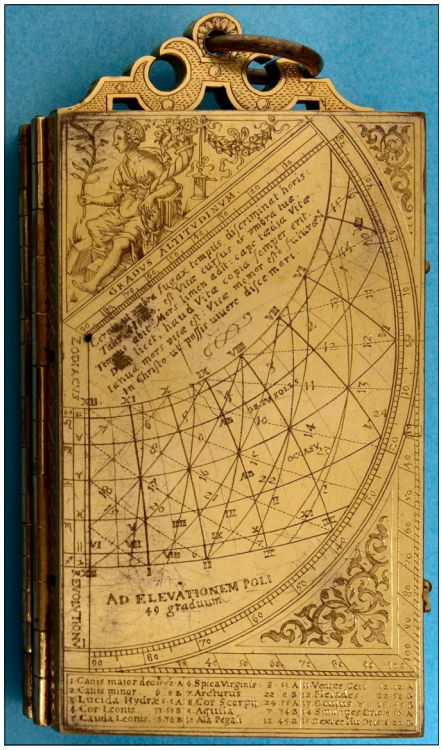
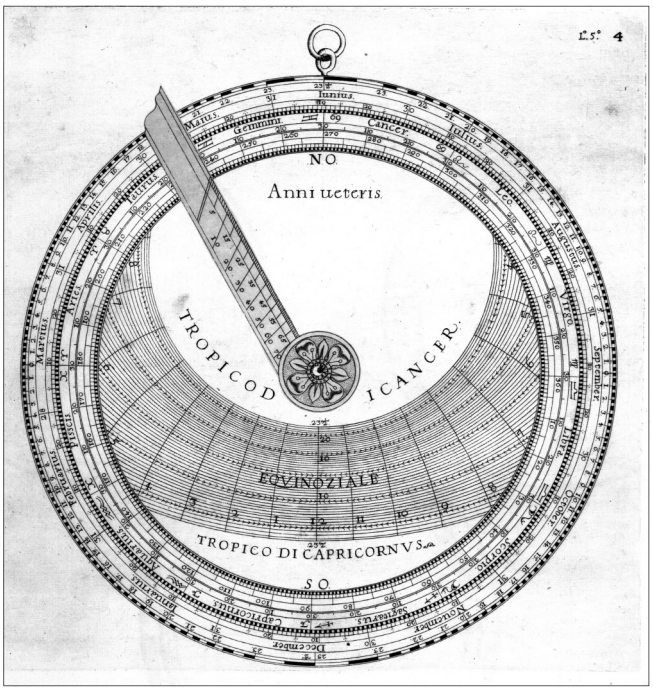


Fig. 8. The folded horizontal stereographic projection on the Linden com-pendium HQ-9.



Fig. 9. Dudley's azimuth dial AD-3.

Figs. 8 & 9, courtesy of the Trustees of the British Museum.



Below right: Fig. 10. The drawing of Dudley's azimuth dial in his 'Dell'Arcano del'Mare'. Courtesy Bodleian Library, Oxford.

scribed by Zinner[10] and Janin[11], is discussed on p.126 of this monograph. Using the instrument to find the time in equal hours is possible but by no means straightforward. It seems possible that it was made as part of a set of all the Apian triens types but is the only one to have come down to us.

Linden (HQ-9)

This instrument, described by Ward,[12] is a superlative compendium dated 1596 by Johann Anton Linden of Heilbronn. It comprises a large number of astronomical instruments including a full astrolabe and several sundials and solar/lunar volvelles. Of importance to this monograph is the triens on the outside of the case (Fig. 8). Ward describes it as a calculator diagram rather than an instrument. Certainly, it lacks any sights which would allow it to measure the sun's altitude but that function could easily be supplied by several of the other instruments of the compendium, and it did once have a plumb-bob and bead (now missing) suspended from the centre of the projection. The engraving shows most of the hour scales of the original Apian drawings all on the single instrument including equal hours and temporary hours. It seems likely that the compendium was an 'exhibition' piece for conspicuous consumption rather than a working device. This is shown by its sumptuous construction in silver and gilt, the absence of any wear and the impacticality of actually using any of the instruments due to their small size and their weight.

Dudley's Azimuth Dial

Sir Robert Dudley (1573-1649) was an English nobleman who emigrated to Italy in 1605/6.[13] He was a writer on navigation and other topics and designer of mathematical instruments, many of which were made for him in England and which he took to Florence. One instrument (AD-3) which is now to be found in the British Museum has been attributed to Charles Whitwell. It is engraved in a later hand "An Azimoth dyall for the latitude of 52 · deg · inuented by S^{r} Ro: Duddeley Ano 1598 * " and clearly shows a horizontal stereographic projection with standard declination lines and hour arcs. (Fig. 9) The versa side of the instrument is a universal stereographic planisphere or *Saphea*. The instrument has a shackle from which it can be hung but this is only centred for the engraving of the planisphere: the engraving of the recto side is rotated by around 4°. A replacement alidade is fitted. Dudley's much later (1647) book *Dell'Arcano del Mare*[14] shows a diagram of the instrument fitted with the intended device (Fig. 10). It has an altitude scale running from [0] at the horizon circle to 90° at the centre although for some reason the scale is engraved slanted rather than perpendicular to the edge. (Only DH-52 has a similar, though fixed, scale.) It is not

clear how the dial was to operate as there is no provision for a compass or any other means of finding the sun's azimuth.

Dudley was a contemporary of Oughtred but there is no evidence that they ever met and they may not have been aware of each others' instruments.

THE DEVELOPMENT OF THE HORIZONTAL CIRCLE & DOUBLE HORIZONTAL DIAL

A full, though possibly one-sided, account of the development of the horizontal instrument is given by William Oughtred himself in the introductory *Apologeticall Epistle* at the beginning of the 1632 book *Circle of Proportion and the Horizontal Instrvment…*[15] (see page 3). The book was actually translated into English by William Forster, one of Oughtred's students, from his original Latin notes. Oughtred describes how, while still a student of mathematics (i.e. around 1600), he set out to make himself a pocket instrument to "finde the houre, and try other conclusions by". He found that quadrants, rings and cylinders (pillar dials) did not meet his requirements. Although he was very well aware of the stereographic projection and would have known of its use in astrolabes, it is not clear if he had any knowledge of earlier horizontal instruments such as the *musātira* or the *triens*. Having decided that the globe itself, projected onto the horizontal plane, would provide what he needed, he states that he did not have the necessary compasses to lay out the projection and so proceeded to invent and produce paper templates to allow him to do so. At the time of writing (c. 1632) Oughtred says that he still had these templates.

Oughtred goes on to say that he drew a version of the horizontal instrument for "Prelate Doctour Bylson" about 30 years ago, viz. c.1602. Thomas Bilson (1546/7-1616) was Bishop of Winchester and had ordained Oughtred.[16] Searches in Bilson's papers at the Morley Library of Winchester Cathedral, Winchester College and at New College Oxford have so far failed to find this paper instrument.

Next, Oughtred says that in c.1607 he gave another version to "a noble Ladie, the wife of a worthy and learned Knight, then abiding neere the place where I live, but since dwelling in Worcestershire". This instrument is described as "tricke[d] out in colours and mettall, the coate armes of both those families joyned in pale". At this time, Oughtred was the vicar of Albury in Surrey. Surprisingly, investigations with the Record Offices of Surrey (Guildford) and Worchestershire have failed to identify the Lady concerned. This is a great shame as the possibility of a gilded and coloured horizontal instrument in Oughtred's own hand would be a tremendous find.

In 1618, Oughtred was introduced by his friend Henry Briggs to Edmund Gunter who had recently been appointed as the professor of astronomy at Gresham College. Oughtred says they met in the chambers of "Doctor Brooks" (this may be Christopher Brookes, later his son-in-law). Gunter, who was working on various quadrants at the time, was shown a horizontal instrument and took notes on it. Soon after, Briggs gave Oughtred a printed version of a horizontal instrument taken (probably as a counterproof) from a brass instrument which Gunther had had made. It was Oughtred's understanding that the original brass instrument had been presented to the Earl of Bridgewater. (This title was created in 1617 for John Egerton, 2nd Viscout Brackley.) This instrument is not known to be extant and neither is it known who would have engraved it. It is unlikely to have been Elias Allen as Oughtred would surely have remarked upon that.

In Gunter's 1624 book on *The Sector…*[17], he shows, amongst a number of other projections and instruments, a horizontal instrument (see Fig. 13). Gunter makes no claim to having invented the device though neither does he give Oughtred credit. However, Oughtred says in his *Apologeticall Epistle* that he has a letter from Briggs dated 2 June 1618 in which he says he is enclosing the print of Gunter's drawing of "your [Oughtred's] Horizontall Diall".

One clear difference between the horizontal instrument and earlier instruments is the provision of a pair of arcs representing the ecliptic circle and labelled either with the

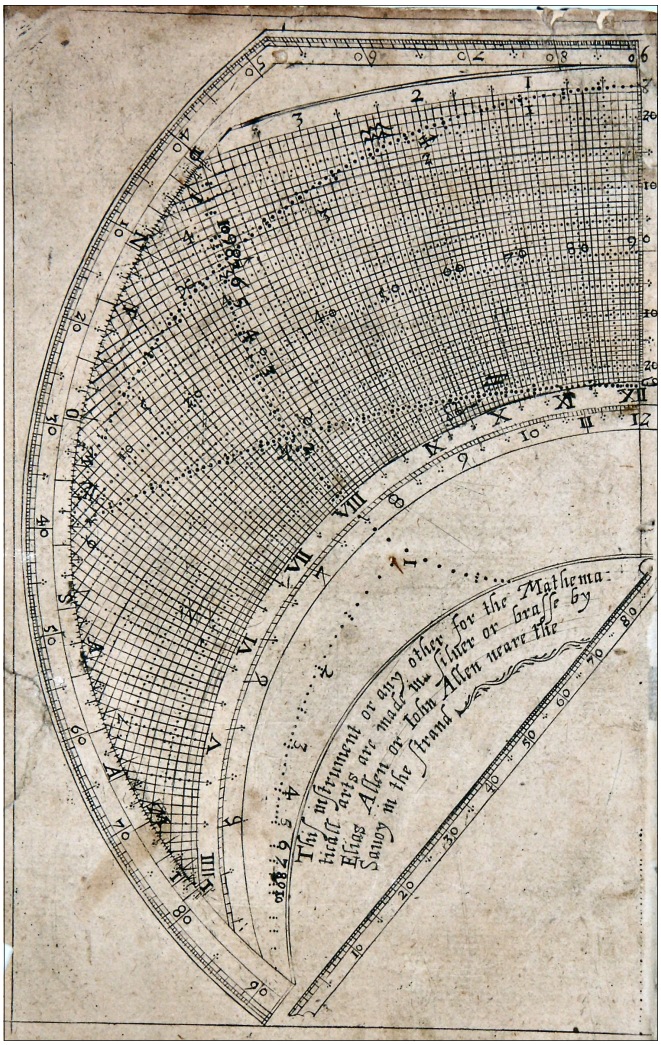


Fig. 11. The frontispiece drawing of Delamain's horizontal quadrant.[20]

date or the zodiac, showing the sun's longitude. Although this might be regarded as an obvious step, it does make Oughtred's instrument more convenient to use and also distinctive.

Richard Delamain's Horizontal Quadrant

The major priority dispute which erupted between William Oughtred and Richard Delamain over the inventions of both the *circles of proportion* and the *horizontal instrument/quadrant* have been extensively investigated and described by Antony Turner.[18] Such is the fame of the dispute that Sawyer conducted a mock trial to examine the cases of the two protagonists at the BSS Annual Conference in 2007. The conclusion reached there, and by most modern authors, is that Oughtred was the true inventor but perhaps Delamain does deserve a little credit for bringing the matter to the attention of the public by 're-inventing' a slightly modified version of the triens, based on what he had learned of the horizontal instrument. Delamain certainly did himself no favours by the manner in which he presented his arguments, as described by Bryden.[19]

Delamain's 'invention', the *horizontal quadrant*, is described in his book *The making, description and use of a small portable instrument…called a Horizontal Quadrant*, published in 1632.[20] The frontispiece of the book is a small (15.5 × 10 cm) copperplate engraving of the quadrant (Fig. 11). The engraving may be attributed to John Allen as the design and engraving style matches his signed quadrant HQ-1. Delamain's description of how to draw and use the quadrant is not easy to follow, even after making allowances for 17th century writing styles. The quadrant is described as fitted with sights along one edge for measuring the altitude of the sun (or stars). This is standard for most quadrants but Delamain's version has a hanging index rather than a string and line. As the index is not counter-poised, it cannot give a true reading of the altitude. Towards the end of the book Delamain describes a second set of (moveable) sights, fitted to the index. The only extant example of these known is on the brass instrument by Francis Pigot (HQ-3). The use of these sights would have been most impractical.

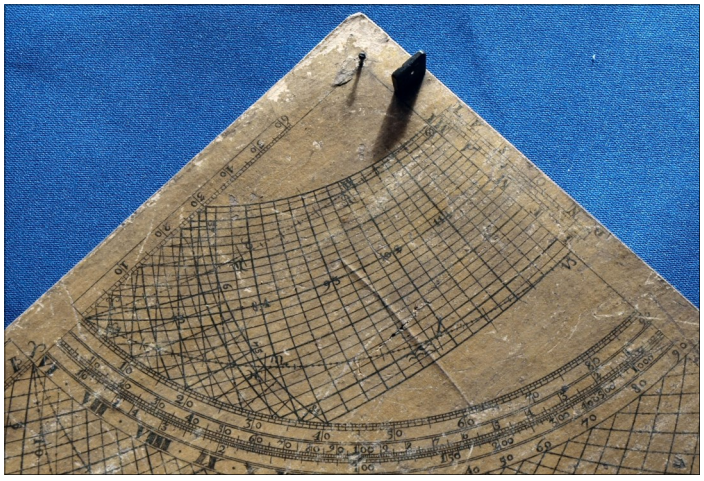


Fig. 12. Prujean's horizontal quadrant HQ-4.

Other Horizontal Quadrants

A description of a horizontal quadrant was published in 1649 by "C.B. Maker of Mathematical Instruments in Metall".[21] This was Christopher Brookes who was actually William Oughtred's son-in-law and whom Brookes credits as the originator of the work. The small booklet contains no plates and so it is difficult to visualize exactly what the instrument would have looked like. The authors know of only one instrument which matches Brookes' description, a paper-on-wood device by John Prujean, Brookes' successor as the incumbent Oxford instrument maker. The quadrant, HQ-4, is shown in Fig. 12 and features a small horizontal stereographic projection and a Gunter's quadrant on one side and a Sutton's (or Collins' or Harvey's) quadrant on the other. Clearly, Prujean engraved plates for these two prints but, whereas the Sutton's quadrant is relatively well-known from other examples, the inverted horizontal device is rare, presumably meaning that it was not popular. It has been described in some museum catalogues as "Allen's quadrant" or "Oughtred's quadrant", perhaps following the item of the latter name in Prujean's 1701 trade list.[22a] References to Allen's quadrant could be either to John Allen as the maker of a brass device (HQ-1) and engraver of Delamain's frontispiece plate, or to his more illustrious and prolific master, Elias Allen.

Fig. 12 shows that Prujean (following Brookes/Oughtred) has constrained the instrument to a true quadrant shape by 'reflecting' the tail about the prime vertical (perpendicular to the meridian). The disadvantage of this is the confusing net of lines which it produces. The design also uses the other half of the full horizontal instrument when compared to Delamain's version, i.e. it places the meridian along the right hand edge. This was probably done to allow the sharing of the same sights with the Gunter's quadrant design on the same plate.

John Collins published small booklet[22] on a *General Quadrant, with the Horizontal Projection, upon it inverted* in 1658, the year before his more well-known book describing the more common quadrant designs by Thomas Harvey, illustrated by plates from Henry Sutton. The quadrant design with the 'horizontal projection inverted' is not illustrated in Collins' tract and only one example of it is known to the authors. This is HQ-2, a paper-on-wood device by Henry Sutton. The theory of this projection is described on p.90. Judging by its rarity, this design also failed to become popular.

From Horizontal Instrument to Double Horizontal Dial

It is unclear when, and by whom, a fixed horizontal dial was added to the stereographic projection of the horizontal instrument to produce the first double horizontal dial. In this case there was no priority dispute. Remarkably, this key development is largely ignored by most modern writers and, in early 20th century sources, the distinction is often ignored or confused, even to the extent of museum exhibits being wrongly described. By adding a second dial

with a polar-pointing gnomon, the portable horizontal instrument was turned into a fixed sundial (although not all examples have been exposed to external conditions for an extended period). There is a gap of four years between publication of *Circles…* (which describes the horizontal instrument but not the DH dial) and the first edition of Oughtred's *Description and Use of the Double Horizontall Dyall*[23] in 1636, so it seems likely that the first DH dial was made during this period. It is quite possible that Elias Allen himself made this development, perhaps even before 1632. He had an established position as a dial maker so it would have been a natural extension for him. Certainly, the earliest known dated DH dial was made by his apprentice John Allen in 1632 (DH-7), so one or more of the numerous Elias Allen examples probably pre-dates this.

The DH dial largely superseded the horizontal instrument in popularity but the latter did continue to be produced: an example is the 1648 instrument HI-2 now in the National Museums of Scotland. However, the design of the horizontal instrument largely stagnated whilst that of the double horizontal dial continued to develop. The dials developed by Henry Sutton around 1660 set a new level in both accuracy and complexity: the typical dial started to get larger and additional scales were added for indicating the time by the moon or the stars, and for trigonometrical calculations by the presence of sector-like scales. Perpetual calendars, epact tables and the times at locations around the globe were also added. All these features culminated in the great dials of Henry Wynne in the last quarter of the 17th century. They were carried on into the early 18th century, though more sporadically, by Rowley, Culpeper and Delander.

Paper Instruments

As well as the large and extremely expensive brass double horizontal dials, paper versions were available from a number of sources. These generally do not survive, at least in a complete form, although uncut sheets are occasionally found (DH-59,61,62). The earliest advertisement for a paper DH dial is that by Adam Ordway (Ref 24 and page 15). As the advertisement is dated 1662, it is tempting to suggest that his prints were produced from engravings made by Henry Sutton who was known to be producing paper instruments of various types at that time (see DH-61 & 62).

Bryden's study of paper instruments[25] refers to the extensive list of a wide variety of paper instruments offered by Philip Lea in the 1680s and 90s.[26,27] Lea was a map maker and publisher who had a large stock of copper plates (valued at £132 8s at his death) from a wide range of sources, including the stock of the more widely-known Joseph Moxon which he acquired in the 1680s. Thus Lea advertised "Prints of....Double Horizontal Dyals" in his 1689/95 broadsheets and in his 1699 catalogue, under "Mathematical Projections" he listed "Horizontal Projections and Double Horizontal Dials of Several Diameters". The fact that a variety of sizes was available is significant because the known prints by Henry Sutton (and his apprentice John Marke) are all approximately 12" diameter. Sutton/Marke could, of course, have produced different sizes as well but another possible engraver is Thomas Tuttell. Tuttell worked closely with Joseph Moxon (for example, on Moxon's *Mathematics made Easie*, published in 1700) and a paper print from a dial by Tuttell is known (DH-48). Moxon himself had advertised a range of paper instruments in 1657. His list includes Oughtred's circles of proportion and Gunter's quadrant: although no double horizontal dials are explicitly mentioned, they could well have been amongst the "divers other Mathematical Instruments,... printed on Papers and exactly pasted on Boards, &c. with Indexes, and other appurtenances proper to each instrument, very commodious for any mans use."

There is confusion in the literature over the fact that some mirror-image prints exist, not just of double horizontal dials but also of various quadrants. Eagleton & Jardine,[28] for example, produce a long and convoluted argument as to why the reversed image can still be used and how it is an artistic representation of the physical brass instrument. The philosophy of the 17th century collectors is built on this existence of mirror-image prints. Bryden, too, puzzles over the existence of these prints.[25] However, a much more straightforward reason for them exists: they are merely the intermediate stage required to produce a normally-imaged *counterproof* from a brass instrument. To produce a counterproof, the brass instrument is first inked-up, quite heavily, as though it was a standard copper printing plate. A proof is then pulled from this and it is immediately laid face down on a piece of pre-dampened paper. The combination is then run through the press so that the image is transferred to the counterproof, leaving the mirror-imaged proof as an unneeded by-product. (In passing, it is worth noting that this process is the basis of the letter-copying apparatus patented by James Watt a century later.) Clearly, the mirror images were sometimes retained – they were too interesting to discard. When only a few prints were required, this double printing process was cost-effective as it avoided the need to engrave a special mirror image copper printing plate. Mathematical instrument makers were not as adept at engraving in mirror image as the engravers for book plates, as is shown by the errors in the illustrations on Delamain's book on his horizontal quadrant.

Who Owned Double Horizontal Dials and Related Instruments?

It seems likely that the early double horizontal dials were owned and used by practitioners of natural philosophy and were very much practical instruments. Later, they became more complex and much larger so that they became items of 'conspicuous consumption', made and bought to display their owner's wealth and knowledge of the natural world, then regarded as essential for any educated man. A list of the known owners of DH dials, mainly commissioned in the late 17th or early 18th centuries, is given in Appendix 2.

The availability of paper dials shows that there was also an

interest in the device for more impoverished mathematical practitioners who could use the dial indoors, perhaps even without a gnomon, to perform useful celestial calculations.

Horizontal instruments and quadrants remained largely in the hands of practical mathematicians and they did not, in general, develop into large and expensive devices in the manner that double horizontal dials did. An exception to this, perhaps, is the horizontal instrument HI-3 which was presented to St John's College Oxford by George Barkham. More typically, horizontal instruments and quadrants were made in brass by amateurs for their own use (e.g. Francis Pigot's HQ-3 or John Holland's HI-5). Alternatively, cheaper paper instruments were made for students' use.

Samuel Pepys

In his famous Diary[29], Pepys wrote on Weds 3 June 1663:

> "Up betimes, and studying of my double horizontal diall against Dean Honiwood comes to me, who dotes mightily upon it, and I think I must give it him."

The following day (Thurs 4 June 1663), at the end of a long entry, Pepys wrote:

> "Home by water, where by and by comes Dean Honiwood, and I showed him my double horizontal diall, and promise to give him one, and that shall be it."

"Dean Honiwood" is Dean Michael Honywood of Lincoln. He had been exiled to Utrecht during the Interregnum and, on going to Lincoln Cathedral at the Restoration, he found its partially ruined medieval library too small for the 5000+ books which he donated to it, including a copy of Fale's 1626 *Horologiographia.* As a result, in 1674 he invited Christopher Wren to design a new Library which still exists. He paid a local builder, William Evison to construct it. Honywood was also probably responsible for the pair of recently restored vertical dials (facing S and E, BSS SRN 2577) on a south-facing buttress of the southeast transept of the cathedral.

It is not clear if Pepys intended to give Honywood his own DH dial or to commission a new one for him. Neither Honywood nor the dial appears again in the diaries. Enquiries at Lincoln Cathedral Library, where they maintain a collection of Honywood's papers, have not revealed any reference to the dial.

We do not know who made Pepys' DH dial. The most likely person is Ralph Greatorex as the two met several times at local alehouses in the period 1660-1663 and Greatorex also took Pepys to Gresham College for the first time (23 Jan 1660/1). Pepys bought a drawing pen and commissioned a weather glass (barometer) from Greatorex so he would be the logical person to approach for a dial. The second most likely maker, being both the most capable and prolific of the time, is Henry Sutton.

Robert Boyle

The two prints and a counterproof of a DH dial engraved by John Marke (DH-59) which are now part of the Boyle Collection strongly suggest that the actual brass dial was owned by Robert Boyle. (See p.200 and Ref 30 for details.) Some uncertainty is caused by the fact that not all of the papers in the Boyle Collection were originally from Boyle himself as they were passed through several hands before being collected together by the Royal Society. The possibility that Boyle owned a DH dial is considerably enhanced by an essay that he sent to Henry Oldenburg in 1688, discussing the purposes of the eye. He wrote:[31]

> Suppose that a Country Man, being in a clear day brought into the Garden of some famous Mathematician, should see there, one of those curious Gnomonick Instruments, that show at once, the *place* of the *Sun* in the *Zodiack*, his *Declination* from the *Æquator*, the *Day of the Month*, the *Length of the Day, &c*. It would indeed be presumption in him, being unacquained both with the Mathematical Disciplines, and the / several Intentions of the Artist, to pretend or think himself able, to discover all the Ends, for which so Curious and Elaborate a Piece was framed. But when he sees it furnished with a Stile, with Horary Lines and Numbers, and in short, with all the Requisites of a Sun *Dial*, and manifestly perceives the Shadow to mark from time to time, the Hour of the Day; 'twould be no more Presumption than an Error in him to conclude, that (whatever other Uses the Instrument is fit, or was design'd for) it is a Sun-*Dial*, that was meant to shew the Hour of the Day.

This can surely only refer to a double horizontal dial and the writer was clearly familiar with its operation. In fact, Boyle had planned this essay many years earlier as he wrote in his work diaries around September 1673:[32]

> "…And further illustrate the same by what happens in a watch clock or double horizontal Dial."

This was around four years after the engraving of the Marke DH plate. It is perhaps significant that the preserved prints in the Boyle Papers consist of two back-to-back (mirrored) prints on one sheet and a single-sided counterproof (normal direction) on another. This could be taken to suggest that two counterproofs were produced and that one was pasted up with a gnomon as a working dial, leaving the other as a spare.

One further intriguing piece of evidence links Boyle with John Marke and that is the presence of an unusual universal altitude dial, signed by Marke, in the Boyle Collection of the London Science Museum.[33] This dial requires knowledge of the sun's declination on a given day in order to allow the time to be found from the sun's altitude. This information could be extracted directly from a print of the stereographic projection, even without a gnomon. We have no evidence that the two Marke dials were designed or

used as a pair in this manner but it is an intriguing possibility.

John Evelyn

The 17th century diarist John Evelyn included William Oughtred as one of the subjects of his famous *Brief Lives*. Turner[18] recounts that Evelyn owned a paper print of a double horizontal dial on which he had written on the back "A Sun diall to be pasted on a board given me by Mr Mol*. 1694". 'Mr Mol*' is likely to be William Molyneux (1656-1698) the noted Irish natural philosopher and astronomer who was the inventor of an elaborate telescopic sundial and correspondent of John Flamsteed on the Equation of Time, amongst other topics.[34] The dial (DH-47) was part of the Evelyn library which was sold by Christie, Manson & Wood in 1977/8. It is believed to be in a private collection in France but has not been seen by the authors so the delineator cannot be stated with any certainty. Turner states that the hour arcs of the projection extend outside the declination arcs for the tropics, a most unusual feature for any double horizontal dial, although sometimes seen on horizontal instruments. This makes it unlikely that the dial is one of the Sutton/Marke designs. The date is rather late for it to be one of the designs advertised by Adam Ordway[24] but it would fit in with the advertisements of Philip Lea.[26, 27] Alternatively, William Molyneux was capable of drawing the dial himself.

Evidently, Evelyn did not paste his dial drawing to a board and 'fit it with a cock'. However, he was not noted as having a major interest in practical natural philosophy, other that the normal requirements of the society of the time.

17th & 18th CENTURY PUBLICATIONS ON THE HORIZONTAL PROJECTION

Instructions on how to draw a horizontal stereographic projection were published in various books during the 17th (and later) centuries so, in principle, any mathematically literate instrument maker could have learned how to produce these rather superior devices. In practice, very few did and only those taught how to delineate them during their apprenticeships acquired the necessary skills. Some examples of publications giving instructions are described below.

Samuel Foster's posthumous *Miscellanies*[35], edited and published by John Twysden in 1659, has a chapter on Projection with the first so-described being the horizontal projection. The intention here is to show how a planisphere can be drawn and the method relies on the calculation, by use of trigonometrical values, of the centres of the declination and hour circles and the positions where they cross the meridian line. Foster gives quite detailed instructions for doing this and also provides tabulated values calculated for the latitude of London (51° 30'). He further gives the method for calculating the altitude ruler.

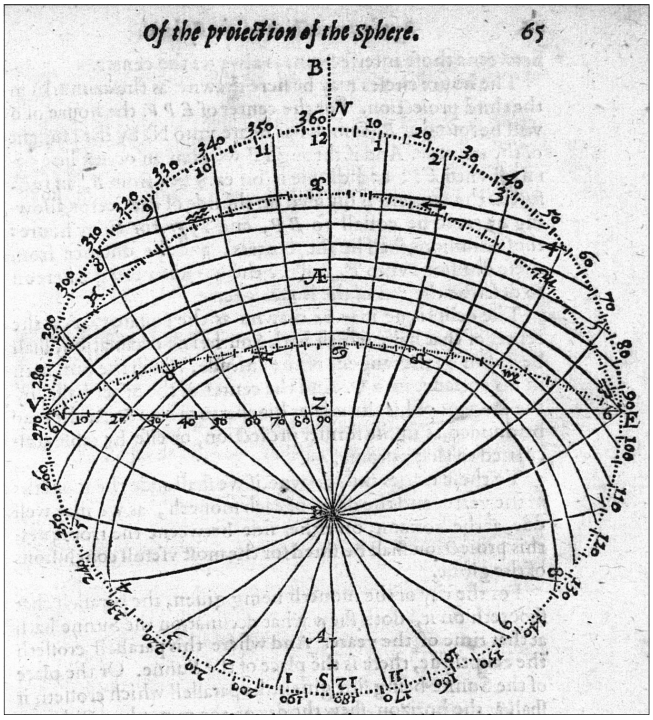


Fig. 13. Gunter's rendition of a horizontal stereographic projection, dating from 1624 and reprinted as late as 1673. Note the hour arcs extending through the pole.

In 1653, Oughtred's leaflet on the use of the DH dial[23] was included as a part of the later editions of Henry van Etten's *Mathematical Recreations*[36] (Oughtred had already made some contributions to the first edition of the book in 1633).

In 1671, John Brown included instructions and a well-drawn diagram on how to use his 'triangular quadrant' to draw a horizontal projection in his book *The Triangular Quadrant*[37] and then to use it to design dials on many planes. In the introduction, describing various approaches to dialling, he describes "Artificial, I call it [dialling] from the lively delineation of the Horizontal projection, the fittest in my opinion for the making plain the mystery of Dialling".

The posthumous *Works* of Edmund Gunter, "carefully revised and somewhat augmented" by the prolific author and publisher William Leybourn (5th edition, 1673)[38] contains a section on projections and provides simplified instructions on how to produce the drawing shown in Fig. 13. In fact, this is the same drawing that Gunter published in 1624. Note that here the hour arcs extend outside the tropics and cross at the Pole and that an altitude scale is drawn along the E-W line. Also, the ecliptic arcs are now included. The method here is to use the tangent scale of Gunter's sector (an example of cross-advertising!). Gunter mentions that the figure is "after the manner of the old concave Hemisphere" and stresses the usefulness of this figure for drawing other plane dials (including vertical decliners) and gives detailed instructions.

William Oughtred's own master-work, *Clavis Mathematicæ*,[39] continued to be re-issued well after his death. In the fifth edition (in Latin) of 1693, the same drawing of the

horizontal instrument as shown in *Circles…* continued to be used in the *Horologiographia* section where the text concentrates on the use of the figure.

John Harris's 1704 *Lexicon Technicum*[40] was one of the first English dictionaries of scientific and technical terms. In it, he gives the following definition:

> DOUBLE *Horizontal Dial*, invented by Mr. Oughtred, and made of *Brass* with a Double *Gnomon*, one to shew the Hour on the outward circle, the other to shew the same Hour in the *Stereographick* Projection, (drawn on the Plate.) This not only finds the *Meridian*, Hour, &c, but shews the Sun's Place, rising and setting, Declination, Amplitude, Altitude ad Azimuth, Diurnal Arch, and many useful Propositions; and may be very well applied to the making of *Dials*.

In the section on the "Projection of the Sphere in Plane", Harris describes stereographic projections on the planes of the meridian, equinoctial and horizon. These variants could possibly be the source for the drawings in the spandrels of the 'Bacon' dial DH-9 (see p. 34). The method described for the horizontal projection is based on first finding the Pole of the World from half the tangent of the co-latitude, then finding the centres of the hour and declination circles from similar trigonometric methods.

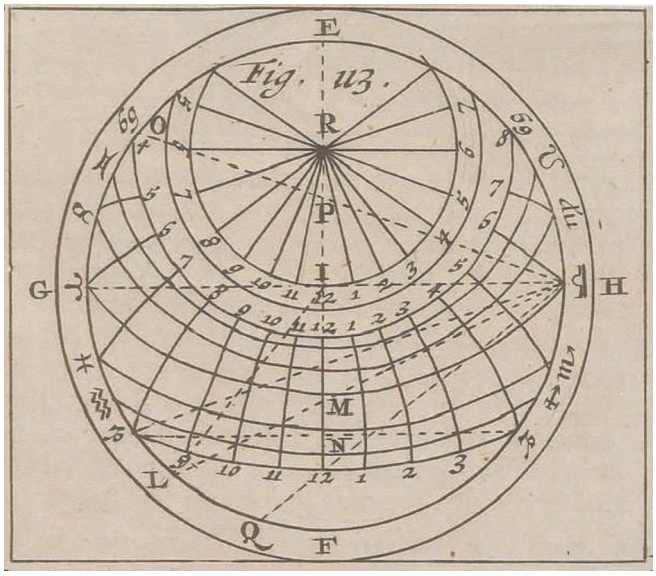


Fig. 14. Ozanam's drawing of a double horizontal dial, showing the internal hour lines of the horizontal dial.[41]

Ozanam's *Cursus Mathematicus*[41] was translated from French into English by John Desaguliers and published in 1712. Part V covers Geography and Dialling and has a short section on "How to describe an Horizontal Astrolabe". The description is purely geometric and quite abbreviated but by following the diagram (Fig. 14) carefully it would be possible for an experienced and mathematically literate dialmaker to produce a double horizontal dial. Ozanam also shows the construction of a double horizontal dial by inscribing a polar-gnomon dial inside the stereographic grid, rather than around it as was the English tradition. This layout was continued by French makers into the 20th century. A further suggestion which Ozanam makes is to position a magnetic compass at the centre of the horizontal dial so that the instrument operates as a magnetic azimuth dial. This is based on the fact that the magnetic deviation in Paris, where Ozanam was based, was essentially zero at the time.

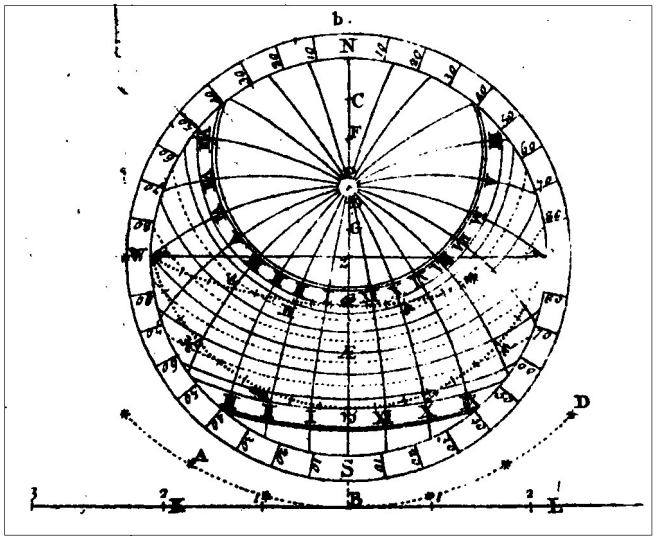


Fig. 15. The stereographic projection in William Hawney's 1725 'Doctrine of Plain and Spherical Trigonometry'.[42]

The Kent mathematician William Hawney published several books to teach mathematics at various levels, from a basic introduction to quite advanced practical topics. His 1725 book *The Doctrine of Plain and Spherical Trigonometry* includes a whole chapter on "The projection of the sphere in plano".[42] A number of projections are described in detail including (in Section II) "how to project the sphere in plano, sutable [sic] to any assigned Horizon, suppose London, whose Latitude is 51° 30' ". The instructions given are comprehensive, being based on tables of the centres of the arcs and their intersection, and they give rise to the projection shown in Fig. 15. It can be seen that this is, in fact, a horizontal instrument but nowhere does Hawney call it this, mention its use for time-telling, or give credit to Oughtred. It seems that the instrument was no longer fashionable.

By 1776, when the fifth edition of James Ferguson's *Lectures on Selected Subjects*[43] was published, the double horizontal dial was completely obsolete and very few, if any, examples had been made for many decades. Nevertheless, Ferguson does briefly mention it and gives a diagram showing how the stereographic projection gives the place of the sun before passing on to Babylonian and Italian dials.

Some memories of the double horizontal dial carried on into the 19th century. The mathematician Charles Hutton, in his *Philosophical and Mathematical Dictionary* of 1815[44], gives an account of Oughtred's life and mathemati-

cal publication. In the dictionary section, he gives a definition of the DH dial:

> "Double Horizontal dial: one with a double gnomon, the one pointing out the hour on the outer circle, the other on the stereographic projection drawn upon it. This dial finds the meridian, the sun's place, rising and setting, &c, and many other problems of the globe."

Whilst this is all true, the reader gets the impression that the entry is for completeness only and that the dial has passed out of common usage – as indeed it had.

REFERENCES

1. Neugebauer (1975).
2. Turner A (1985).
3. Sédillot (1841).
4. Charette (2003).
5. Anon: *Astronomische Zeichnungen* (1508-20). Bavarian State Library Cod.icon 182. The horizontal projection is folio 16r. We are grateful to Nicola Severino for bringing this document to the notice of the dialling community. The document is online at *http://www.digitale-sammlungen.de/~db/0002/bsb00020752/images/*
6. Georg Hartmann (1527/8).
7. Lamprey (2002).

7b. F. Sawyer, J. Schilke & N. Severino: 'Andreas Schöner's Stereographic Sundial Design' *NASS Compendium* 16(4), pp.15-18 (Dec 2009).

8. Zinner (1956) p.362.
9. Apian (1586).
10. Zinner (1956) p.512.
11. Janin (1979).
12. Ward (1981) p.123.
13. Turner G (2000).
14. Dudley (1647).
15. Forster *Circles* (1632).
16. New Oxford Dictionary of National Biography (2005).
17. Gunter (1624).
18. A.J. Turner (1981).
19. Bryden (1974).
20. Delamain *Horizontal quadrant* (1632).
21. C.B. [Brookes] (1649).
22. Collins *General quadrant* (1658).

22a. Bryden (1993).

23. Oughtred *Description & Use* (1st ed. 1632)
24. Adam Ordway (1662) reproduced on p. 15.
25. Bryden (1997).
26. Lea (1685-9).
27. Lea (1699).
28. Eagleton & Jardine (2005).
29. Latham & Matthews (eds.): *Pepys diaries*, (1970-83).
30. Davis (2008).
31. Hunter & Davis (eds.) "Whether and How a Naturalist should Consider Final Causes" Vol. 11, pp.89-90, (1999).
32. Boyle Papers BP17 fol.152v 847 (Sept 1773).
33. Lowne & Davis (2009)
34. Davis (2004).
35. Foster *Miscellanies* (1659).
36. van Etten *Recreations* (1653).
37. Brown (1662 and 1671).
38. Gunter *Works* (1673).
39. Oughtred *Clavius* (5th edition 1693).
40. Harris *Lexicon Technicum* (1704).
41. Ozanam *Cursus Mathematicus* (1712).
42. Hawney (1725). Chapter 5 is on the *Projection of the Sphere in Plano*.
43. Ferguson *Selected Lectures* (1776).
44. Hutton (1815).

THE HORIZONTAL INSTRUMENT AND THE HORIZONTAL QUADRANT

The development of these two instruments was explained in the preceding section: here, their uses and the principles on which they operate are explained. Their principal function was to determine the time of day and the azimuth of the sun from its declination, the measured altitude and the latitude for which the instrument is made.

Horizontal Instrument

The horizontal instrument (HI) is a stereographic projection of the sky on a horizontal plane and carries arcs of time and the declination of the sun, together with means of finding the declination for any day of the year. It operates from a measured altitude of the sun and for this purpose is provided with a pivoted arm (the alidade) which carries a scale of altitudes. A drawn example is given in Fig. 1.

The sun's declination is found from the projections of the ecliptic which show the dates on which the sun has certain declinations, in the same way as is found on some double horizontal dials, as explained on p. 27. The sun's altitude is found by suspending the instrument by the top ring so

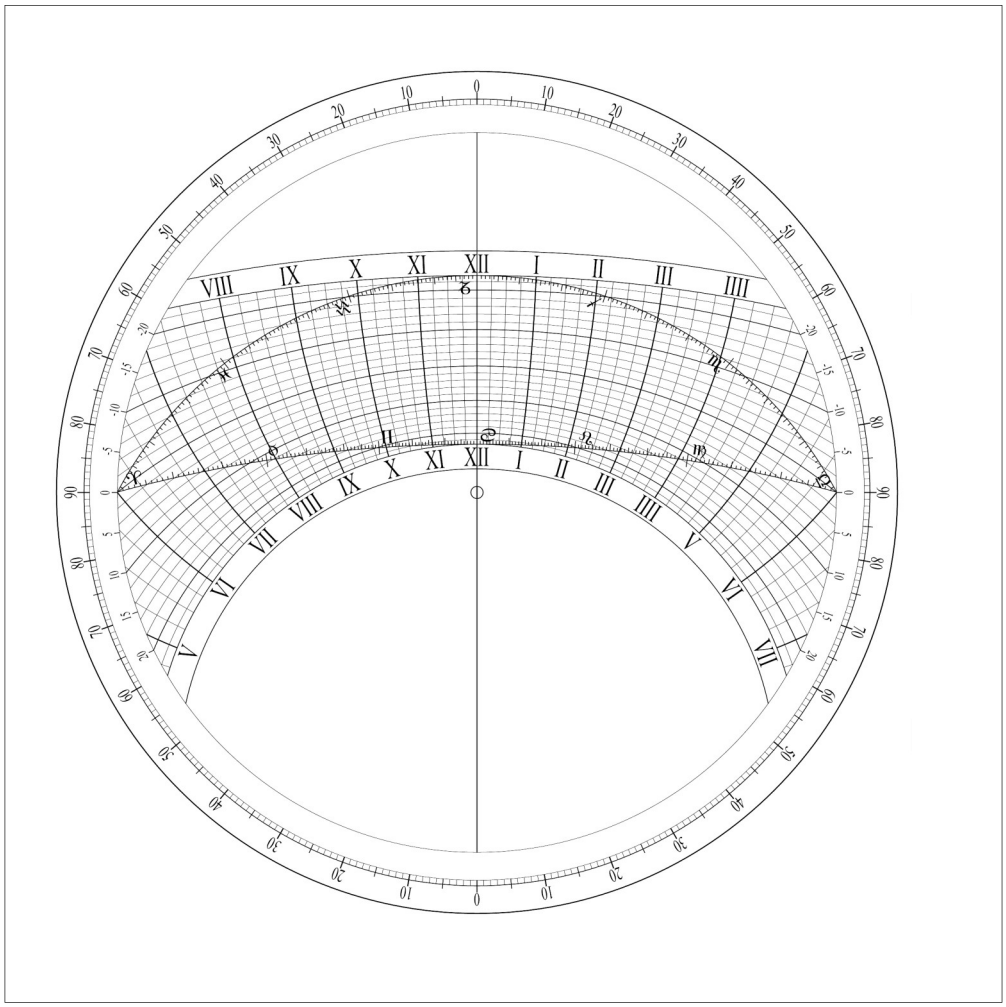


Fig. 1. A schematic horizontal instrument, drawn for a latitude of 38° 42' N. From 'The Astrolabe', courtesy J. Morrison.

that it hangs vertically and with the sun in the dial plane. Two methods were used: on some instruments a central pin (now generally missing) casts a shadow on a degree scale around the rim of the dial (for this the instrument would need to be turned slightly out of the plane of the sun) and on others the alidade is provided with sights, enabling it to be pointed at the sun, and an indicator to show the altitude on the degree scale. The altitude so found is transferred to the alidade scale and the arm rotated to set it to the declination for that day. The time can then be read at this point and the azimuth of the sun will be shown on the outer scale by the alidade pointer. HI-4 and HI-9 are respectively examples of instruments using the shadow method and the sighting method.

The times of sunrise and sunset and the duration of darkness can be determined from a reading from the time arcs at the point where the appropriate declination arc meets the horizon circle.

It would be difficult to hold up the larger examples. One (HI-6) is 775 mm (about 30 inches) in diameter and several are over 300 mm. Probably the optimum size for clarity and for ease of handling is about 200 mm.

The main difference between the double horizontal dial and the horizontal instrument is that the former operates from the azimuth of the sun and the other from the altitude. However, the horizontal instrument can also be used as an azimuth dial if placed horizontally and correctly oriented with respect to the north-south line. The shadow of a central pin (longer than that required for the altitude determination) will indicate the time where it crosses that day's declination line. This method is the same as that used with the stereographic projection on a double horizontal dial. For dials with sights on the alidade, this could be adjusted to the direction of the sun until its shadow is hidden and again the time is read where the line of altitudes intersects the declination, which will also give the sun's altitude.

With care, an accuracy of about two minutes in the derived time can be attained, except near the meridian where the solar altitude changes only slowly with time. There is ambiguity between times before and after noon which can be resolved by taking another reading shortly afterwards: the value which gives a later time is of course the correct one. An advantage of the horizontal instrument over the double horizontal dial is that times near noon are not obscured by the shadow of the thicker gnomon.

Horizontal Quadrant

The horizontal quadrant (HQ) has similar uses and additionally sometimes gives star positions for time-finding at night. The name 'quadrant' refers to the quarter-circular scale used to measure the altitude and does not necessarily describe the form of any particular instrument. Some examples include trigonometric scales for other purposes, including surveying. Fig. 2 is a schematic drawing of a horizontal quadrant.

The operation of the usual form of quadrant does not differ significantly from that of the horizontal instrument described above, in fact the quadrant may be regarded as a horizontal instrument folded in half along the meridian so that the projection represents both halves of the sky superimposed. In this way the declination arcs are identical and the ecliptic arcs are labelled with the zodiacal sigils for signs equally spaced on either side of the solstices. The hour lines represent times at the same intervals either side of 12 noon and are so labelled, for example 9[am] and 3 [pm]. Generally, the morning hours are given in Roman and the afternoon hours in Arabic numerals. One difference from the horizontal instrument is that, instead of dates on the ecliptic arcs, a date scale at the ends of the declination arcs is calibrated for both series of days between the equinoxes. Another is in the method of finding the sun's altitude. A plumb-bob or pivoted alidade arm is suspended from a point directly above the 12 noon line (the centre of the horizon circle) and is allowed to hang freely when the sun is sighted through two small apertures mounted on the body of the instrument. The altitude is indicated on a degree scale around the curved limb. To find the time, the measured altitude is transferred (either by a movable bead on the plumb-bob cord or by a scale on the alidade) to the projection at the declination appropriate for the date and the time read at the intersection point.

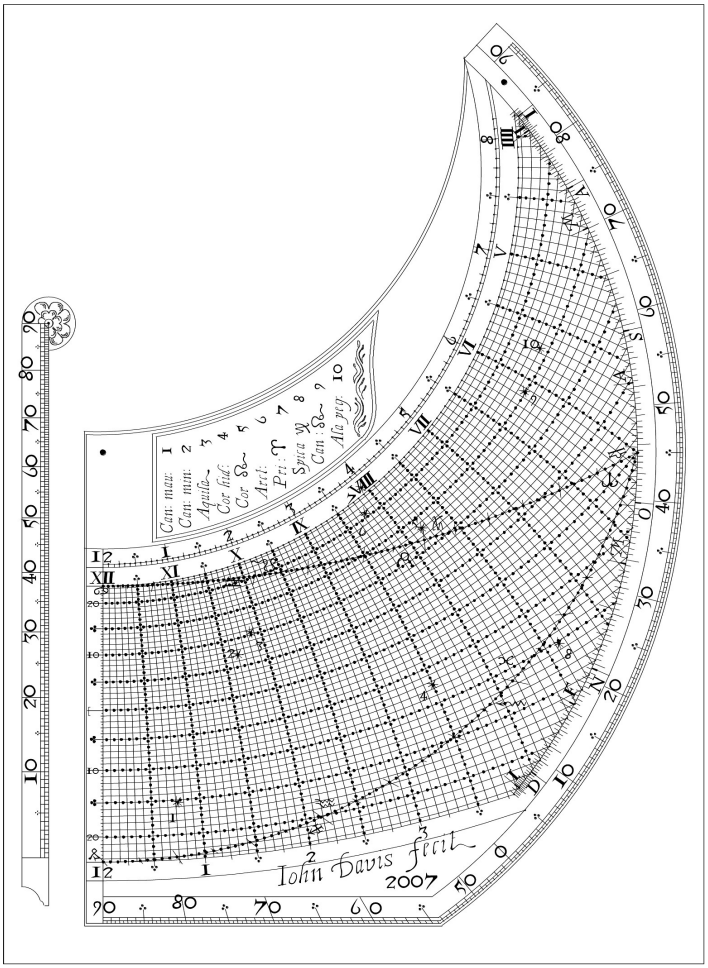


Fig. 2. A schematic horizontal quadrant, drawn for a latitude of 51.5° N.

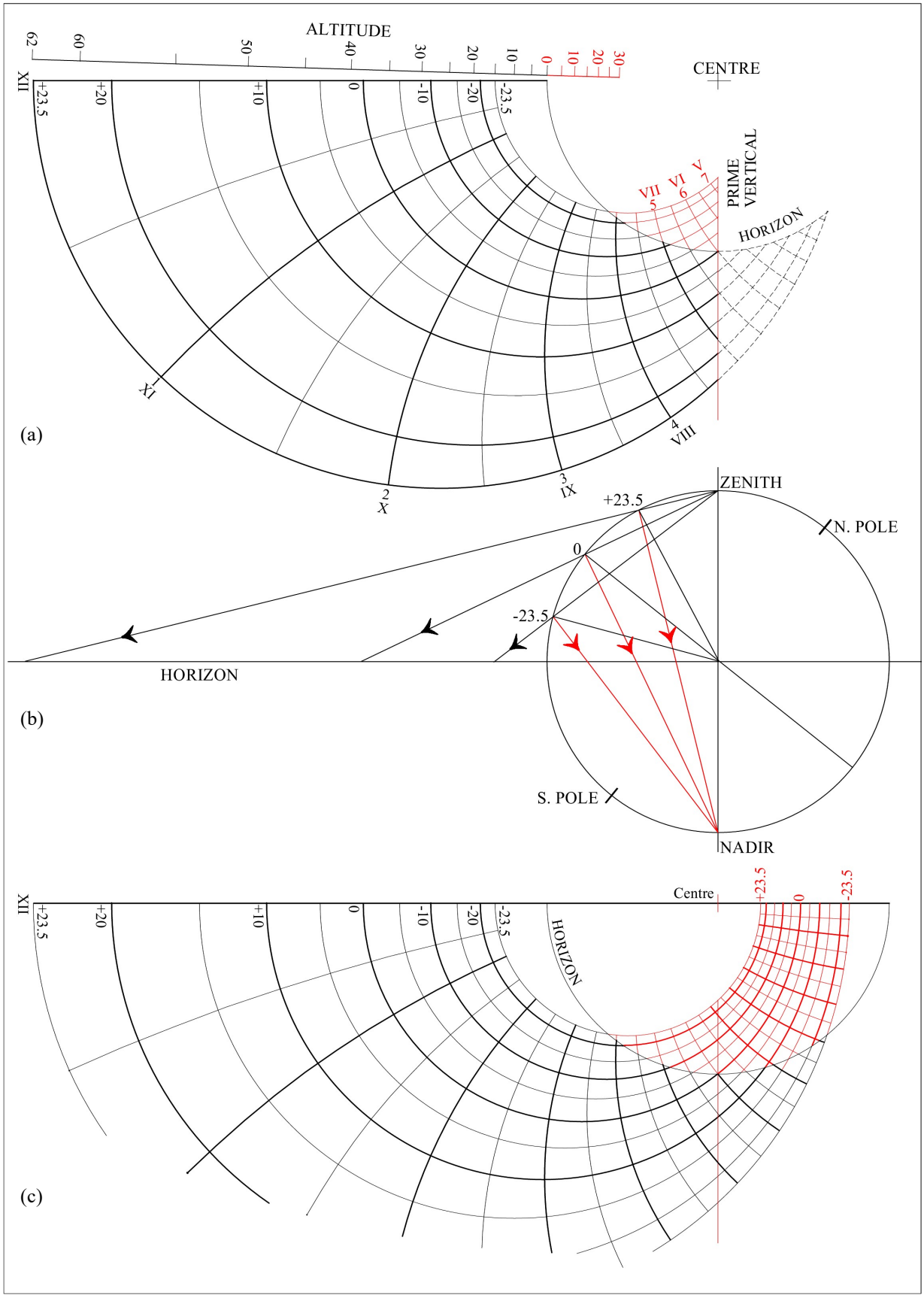


Fig. 3. The 'inverted quadrant'. (a) The device described by Collins with the 'reverted tail' in red; (b) a meridional section showing how the inverted (black) and normal projections (red)are formed; (c) the relationship between the inverted (black) and normal (red) projections. The three figures are drawn for a latitude of 51.5° N and for the same horizon circle radius.

As with the horizontal instrument, the quadrant suffers from reduced accuracy near noon and ambiguities between am and pm times. Its advantage was that it could be made conveniently small, capable of being carried in a pocket.

'Inverted' Quadrant

A different form of projection on a quadrant was described by John Collins (1658) and is called the "horizontal projection inverted". The usual stereographic projection is a view of the sky as seen from the nadir projected onto the plane of the horizon, but in this case the sky is projected from the zenith. In this way the projection is turned 'inside out' so to speak, the declination arcs are interchanged with those for the winter months appearing nearest to the centre of the instrument, and the solar altitudes increase towards the limb. The hour circles are convex to the meridian, not concave. This instrument as described is confined to a quadrant of a circle which would leave unrepresented that part of the projection for the summer months which falls beyond the prime vertical. It is included by continuing the projection into that area which is unused by the winter declinations: this is known as the "reverted tail".

The operation of this design is similar to that of the usual form of quadrant, with sights and a plumb-bob to read the altitude on a scale of degrees around the curved limb. The sun's declination is obtained from date scales on the reverse of the quadrant correlated with a scale of declinations. A bead on the plumb-bob cord is set to the measured altitude on a scale: this is called 'rectifying the bead'.

Collins does not illustrate this quadrant, but Fig. 3a gives a simplified drawing with that part which falls beyond the prime vertical shown in dashed lines and the 'reverted tail' in red. This is used if the bead, when set to the altitude, cannot be matched to the appropriate declination on the main projection, implying that the sun is too low for the time to be in the range 6am to 6pm. The bead is rectified to the altitude on a subsidiary scale (shown in red) and set to the declination (with reversed sign) on the reverted tail where the time can then be read. Fig. 3b is a meridional section showing the inverted projection of the declinations of the tropics and the equator onto the horizontal plane (black lines) and the normal projection in red. Fig. 3c is a comparison of the inverted projection in black and the normal projection in red. This shows that the reverted tail is effectively part of the normal projection and is used in the same way. The reduced scale would have an adverse effect on the precision of reading the time.

Only one instrument of this type is known, by Henry Sutton, HQ-2 (see Catalogue section). The strong curved line on this instrument is "Dary's curve" which can be used in conjunction with additional scales to determine the time at latitudes other than the one for which the instrument is made.

It is difficult to see much advantage in this construction over the normal quadrant. One is that the scale of the divisions is greater for the summer months, which could add precision in the period in which the quadrant is most likely to be used.

Collins also describes (Collins 1659) other inverted projections taken from the north pole of the sky on to the plane of the equinoctial. They are beyond the scope of this work which deals only with stereographic projections on to the plane of the horizon, but are fully discussed by Morrison (2007).

DIAL ANALYSIS

There is often a need to analyse an old dial, of any type, to discover something about its origins. Three key pieces of information which are sometimes – though by no means always – engraved on the dial are its design latitude and longitude and its date of manufacture. Should this data not be engraved, it is usually possible to establish at least some of it by analysing the delineation of the dial, a process sometimes called 'reverse engineering'. A number of techniques exist to do this: a double horizontal dial, with its relatively complex features, offers more possible approaches than other dials. Additionally, the extra features (calendars, stars etc.) often found on a DH dial can also be very useful for determining its origins.

1. LATITUDE

This is usually the only design parameter which can be extracted from the basic delineation of a sundial. Methods appropriate to an ordinary horizontal dial can be used but the stereographic projection of a double horizontal dial offers other alternatives.

1.1 Gnomon Angle

Measuring the angle between the style edge of the gnomon and the horizontal dial plate is the most direct method of establishing the design latitude of a dial. This assumes, of course, that it is certain that the gnomon is original.

There are a number of practical difficulties to be overcome when making the measurement. For example, gnomon supporters buttressing its base often prevent a protractor being placed directly alongside it. One way to avoid this is to take the complement of the gnomon angle, measuring from the part of the dial plate immediately to its south. It is always necessary to establish that the dial plate is truly flat and this is especially the case when measuring from the south. An alternative method is to measure the inclination of both the style edge and the dial plate (dials are rarely set absolutely horizontal!) with a precision inclinometer and to take the difference.

As an alternative to measuring the gnomon angle directly, the length of the style edge (to a well-defined feature on the tip) and its perpendicular height above the dial plate can be measured. The ratio gives the sine of the angle. It is important to check that the gnomon is straight for this method to be accurate.

A simple method of measuring the angle, but one which is remarkably effective, is to place a piece of light card against the side of the gnomon and trace its edge with a sharp pencil. The card can be cut to avoid any gnomon supporter. Care is needed to ensure that the bottom edge of the card is in good contact with the dial plate. The resulting angle can be measured at leisure later, when it will also be apparent whether the style edge is truly straight. If it is not, the bottom part of the profile is likely to give the intended angle, though it cannot be measured to such a good level of accuracy as when the whole gnomon can be used. For large gnomons, the horizontal and vertical distances from the origin to the tip of the gnomon can be measured with a ruler so that the tangent of the angle can be calculated. This avoids the need for a large, finely-divided protractor.

1.2 Horizontal Dial Hour-line Angles

When designing a conventional horizontal dial, the angles which the hour-lines make with the noon line are a function of the design latitude. The relationship is

$$\tan X = \sin \phi \,.\, \tan h$$

where X is the hour-line angle, ϕ is the latitude and h is the hour angle (15° per hour). This equation can be rearranged to give the design latitude as

$$\phi = \arcsin \frac{\tan X}{\tan h}$$

In principle, any single hour-line, with the exceptions of noon and the 6am and 6pm lines, will give the design latitude. (The noon line has an angle of 0° and the 6pm/am lines are at ±90° irrespective of the latitude.) However, the method is most sensitive for hour-line angles of around 45°, i.e. between 9 and 10am and 2 and 3pm in Great Britain. Because it is impossible to measure the angles of a real dial exactly, a more accurate value of the design latitude can be obtained by using many hour lines but weighting the results in favour of those around 9am and 3pm. This can be achieved automatically by the following method.

a) measure the angles of as many hour-lines as possible (but see below) and tabulate them against their hour angles.

b) a first estimate of the design latitude is made and the theoretical angles of all the hour-lines are calculated,

c) for each hour angle, the difference between the measured and the theoretical hour-line angle is calculated: this is the error angle for the line at that time, assuming the dial had really been designed for the estimated latitude.

d) the root-mean-square (rms) of all the errors is calculated, representing the goodness of fit.

e) the first estimated design latitude is now adjusted in such a way as to minimise the rms error. The process is iterative and best performed by computer, for example in a spreadsheet program with a 'Goal Seek' function. The resulting value of the estimated design latitude represents the best approximation to the real value and the final residual value of the rms error is a measure of how nearly the real dial fits a theoretical one of this latitude.

f) a plot of the errors as a function of the hour angle can be made. It is instructive to see if the points are randomly scattered, indicating that they are the result of normal layout and measurement inaccuracies, or show some definite trend which could be indicative of a systematic layout error or a mis-positioning of the measuring protractor.

In step (a) above it is suggested that as many as possible of the hour-lines are measured. It is possible, or even probable, that dialmakers only delineated the major lines from first principles and then simply divided the space between them empirically or by eye. Hours and half hours, and possibly quarter-hours as well, are therefore the best lines to use for the analysis. Including the lines for smaller intervals will not invalidate the result but may not bring any increased accuracy.

An alternative to the above analysis technique is to calculate a design latitude separately from each hour-line, excluding lines within, say, 1 hour of 6am/6pm and noon where a small inaccuracy in the angle will produce an appreciable error in the derived latitude. The mean latitude and rms error can then be extracted and, if necessary, hour-lines producing suspicious differences from the mean can be remeasured to check for errors. If none are found they can be excluded if the stand-off from the mean is greater than twice the rms error. The advantage of this method is that it gives a figure for the rms error of the derived latitude value directly, i.e. the confidence that can be placed in the value. The standard error for the mean latitude is found by dividing the rms value by the square root of the number of individual lines included in the mean.

It is surprisingly difficult to measure the hour-line angles of a real dial to the level of accuracy needed to give a precise latitude – typically, an accuracy of better than ±0.1° is sought. The first difficulty encountered is that the gnomon obstructs the positioning of most designs of protractor. The example measurement which is described below was made on the Henry Wynne double horizontal dial DH

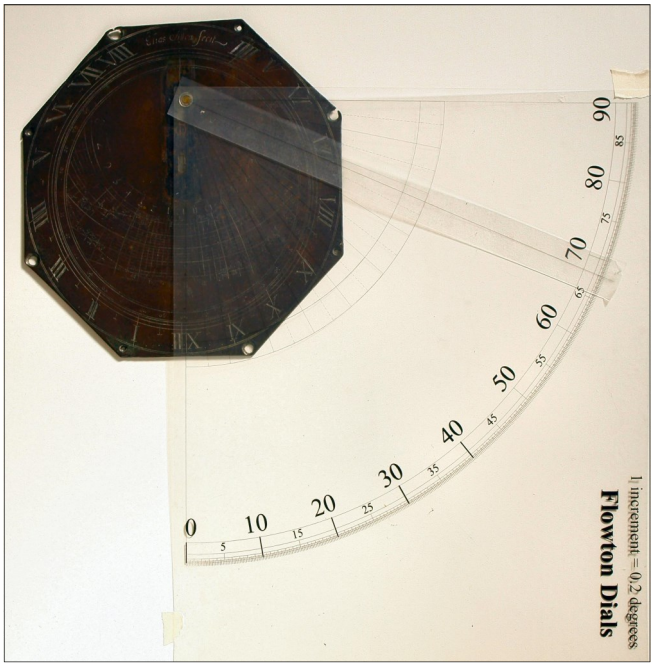


Fig. 1. An A3-sized transparent protractor for measuring hour-line angles on a dial. The 0° is lined up on the right hand side of the noon gap.

-41 which, conveniently, is missing its gnomon. The second difficulty is locating the origins of the delineation accurately and aligning the protractor along the meridian and E-W lines: although these are theoretically at 90° to each other, there is often a slight discrepancy. The protractor must be repositioned to the appropriate origin for each quadrant. The lines for the 'back hours', before 6am and after 6pm, are theoretically just extensions of the complementary lines nearer noon so often it is not necessary to measure them, other than as a check on the maker's method.

A transparent protractor with a swinging rule, purpose-made for dial measurement, is shown in Fig. 1. It may be temporarily fixed to the dial, or the table it is resting on, with masking tape. The error profile for the estimated opti-

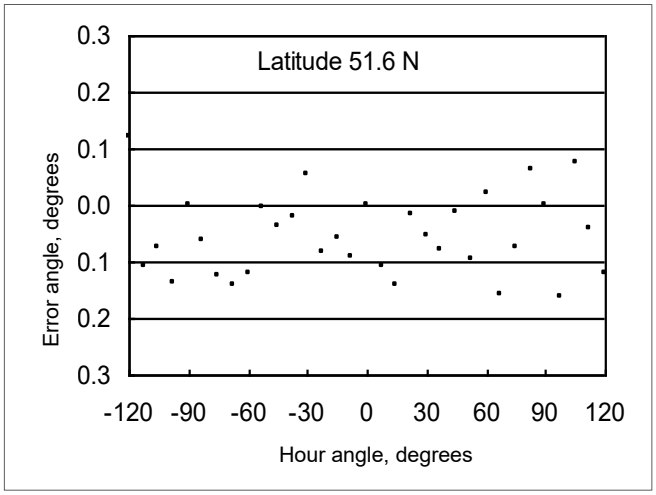


Fig. 2. The error profile of the hour-lines of the Henry Wynne dial DH-41.

mum theoretical design latitude of 51.60° is shown in Fig. 2. The resulting mean error of 0.072° is one of the lowest which has been measured by the authors, indicating the precision to which Henry Wynne worked.

For square or rectangular dials, it is sometimes possible to measure the distances from the point of intersection of the hour-line with the border either to the 6am-6pm line or to the noon line. In Fig 3, for the hours near noon, if A is the distance from the origin to the border along the noon line and B is the distance along the border to the hour-line, then $\tan X = B/A$. Similarly, for hours nearer to 6am or 6pm, measure the distance C of the border from the noon line and D is the distance of the hour-line from the 6am/pm line, then $\tan X = C/D$. This method is effectively the reverse of the dial design method shown by *Waugh*.[1]

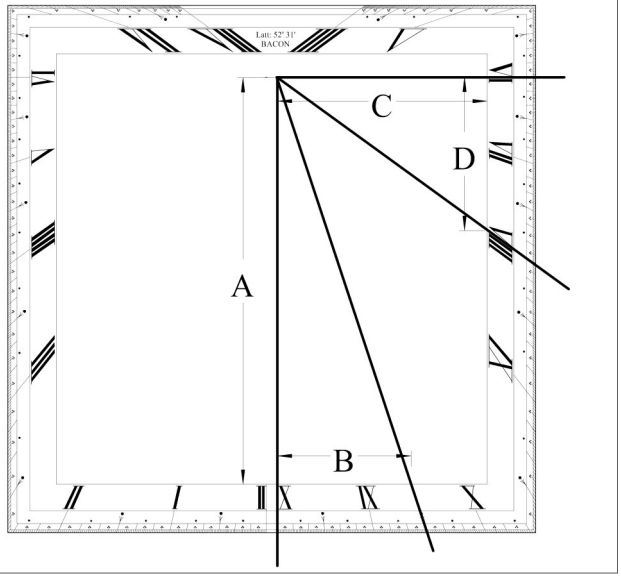


Fig. 3. Measurement of hour angles on a square dial.

For other dial shapes, hour-line angles could be found by taking linear measurements from the dial origin to the position where the line crosses the chapter ring, and then perpendicularly from this point to the noon line. The ratio gives $\sin X$.

1.3 Extreme Hours

Good quality English sundials usually have hour numerals from IIII am to VIII pm. However, the sub-divisions often run slightly beyond these extremes by a few minutes. The best makers calculated the exact range needed to cover the period from the earliest sunrise to the latest sunset, occurring on the summer solstice. These times are latitude dependent according to the relationship

$$\tan\phi = \cos h / \tan\varepsilon$$

For convenience, this is plotted in Fig. 4.

Fig. 5 shows one end of the main hour scale of the Daniel Delander DH-17 which extends from III:48 to VIII:12, appropriate for a latitude of 51.40° (assuming the obliquity

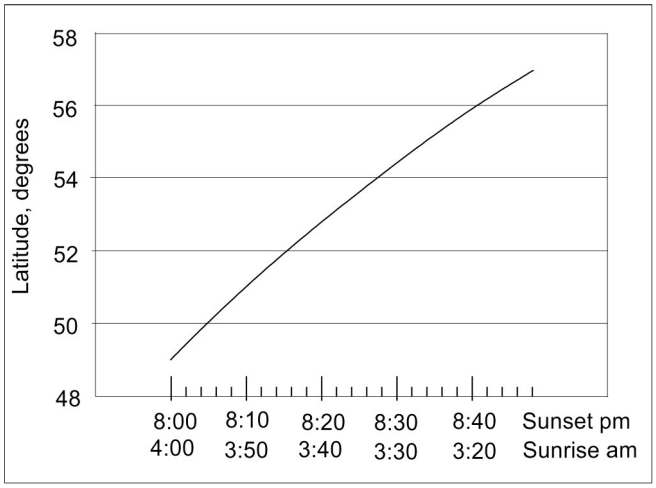


Fig. 4. The relationship between earliest sunrise / latest sunset (at the summer solstice) and the latitude. The obliquity of the ecliptic, ε, is taken as 23.5°.

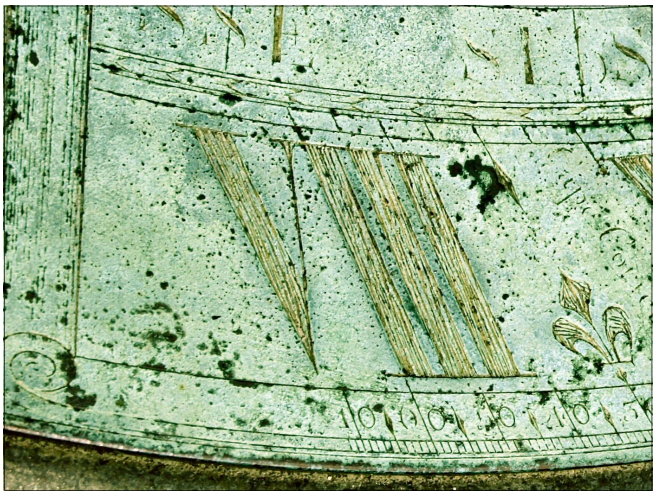


Fig. 5. The end of the hour scale on the Daniel Delander DH-17 showing the latest sunset time of 8:12pm.

is taken as 23½°). Care must be taken with this technique as some very good makers, including Elias Allen himself, did not always engrave the extra minutes beyond IIII am or VIII pm. It is, however, a good method of corroborating other techniques.

1.4 Sunrise & Sunset Azimuths

The stereographic projection of a double horizontal dial presents a number of features which are latitude-dependent. One of the most convenient of these is the azimuths of sunrise and sunset which appear around the horizon circle of the projection. Most DH dials have an azimuth scale in degrees (often to fractions of a degree) engraved very close to the horizon circle and thus they are self-calibrated. This means that a good assessment of the latitude for which the projection was designed can be obtained even from oblique-angled photographs where the perspective error and lens distortion are unknown.

The azimuths of the sun at sunrise and sunset are given by

$$A_{sr,ss} = \mp \arccos\left\{\frac{-\sin\delta}{\cos\phi}\right\}$$

where A_{sr} and A_{ss} are the azimuths of sunrise and sunset, respectively, measured from the south (i.e. sunrise will be at -90° at the equinoxes) and the other symbols have their usual meanings. This expression can be re-arranged to give the design latitude from the azimuth of sunrise or sunset for any date, i.e. any value of the sun's declination. In practice, the method is most sensitive at the solstices (where $\sin\delta$ has its max/min values) and these points are also the easiest to see on a dial. Thus there are four positions on the projection which should each give equivalent results. Any spread in the results represents the inaccuracy in the delineation.

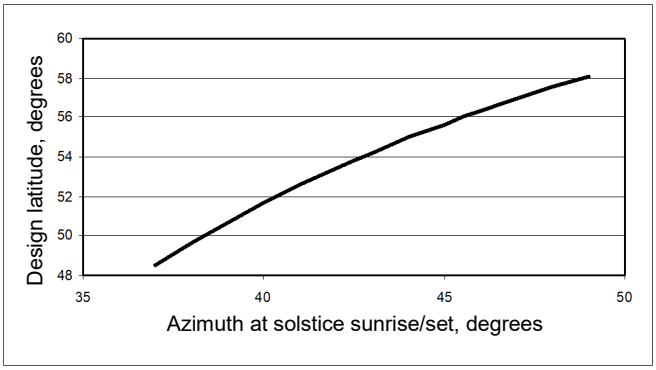


Fig. 6. The theoretical design latitudes of a DH dial as a function of the indicated azimuths of sunrise and sunset at the solstices. Azimuths measured from E or W.

Fig. 6 shows the sunrise/sunset azimuths as a function of latitude, allowing readings from a dial to be converted directly into design latitudes. Some care is needed here as many DH dials have the zeroes of their engraved azimuth scales at the E and W positions, rather than at the N and S. Thus, it is necessary to take the complement of the measured angle.

The curve in Fig. 6 was calculated using a value of ±23½° for the sun's declination at the solstices, rather than the more precise modern value of ±23.44°, as the former is more likely to be the one used by a 17th century dialmaker. In cases where this uncertainty in what value of obliquity has been used is critical, other declination lines, e.g. the ones at ±20° which are easy to see, may be used. For the Henry Wynne dial DH-41, this technique gives a design latitude of 51.60° ±0.05° which is the same as the value obtained from the hourline angle method.

1.5 Hour-arc and Declination Intersections

A variation on the previous method is to find the hour angle, rather than the azimuth, at the points where the declination lines meet the horizon circle of the stereographic grid. This method does not rely on the azimuth scale being engraved immediately adjacent to the horizon circle. Either the declination or the hour must be interpolated between the lines available and then

$$\tan\phi = -\cos h/\tan\delta$$

Several different readings should be taken, avoiding those where the declination is near the equator, say ±10°.

1.6 Sun's Altitude at Noon

The sun's altitude, *a*, is given in general by

$$\sin a = \sin\delta\sin\phi + \cos\delta\cos\phi\cos h$$

At noon, when $h = 0$, this reduces simply to

$$a_n = 90^\circ - \phi + \delta$$

Thus the positions where the declination arcs of the stereographic grid cross the meridian line give the design latitude. Most DH dials have an engraved altitude scale which could, in theory, be used to measure the noon altitude. This would work well if the actual dial is available for study as the distance can be stepped out with dividers. It is not recommended to use the method from photographs because the scale is located away from the measurement position and hence subject to photographic distortions. Instead, if the photograph is taken from the east or the west, the ratio of the altitude distance to the horizon circle radius, *r*, can be used. This radius should be measured along the meridian line so that it suffers the same photographic scaling as the altitude distance measurement. If the linear distance of the noon altitude position from the origin of the grid is r_a, we have

$$\frac{r_a}{r} = \frac{\cos(90^\circ - \phi + \delta)}{1 + \sin(90^\circ - \phi + \delta)} = \tan\left(\frac{\phi - \delta}{2}\right)$$

giving

$$\phi = 2\arctan\left(\frac{r_a}{r}\right) + \delta$$

The calculation is simplest for the equinox line ($\delta = 0$) although using the extremes of the grid as well, when $\delta = \pm\varepsilon$, provides useful extra accuracy.

1.7 Hour-arc Centres Position

The hour arcs of the stereographic grid are struck from centres which lie along an E-W line positioned at a distance

$$y_h = -r\tan\phi$$



Fig. 7. The centres for the hour-arcs on the Elias Allen DH -57, showing their position in a straight line running E-W.

to the north of the origin. (See p.31 for the derivation.) On many DH dials, this row of construction marks can still be seen. The most important one, for the 6am and 6pm arc, is centrally located on the meridian line. Depending on the proportions of the dial, it often falls in the noon gap as the photograph of the Elias Allen DH-57 in Fig. 7 illustrates. Even if only some of the arc centres are still visible, it is possible to reconstruct the position of the line and measure its perpendicular distance y_h from the centre. If the horizon circle radius r is also measured along the meridian, the ratio immediately gives $\tan \phi$ with good accuracy. For the Henry Wynne dial DH-41, this calculation gives a latitude of 51.38°.

2. LONGITUDE

There are no basic features of a horizontal dial (including DH dials) which allow the design longitude to be calculated. However, some high-status dials include the times of noon for various world-wide places as part of their furniture. Some of the double horizontal dials by Henry Wynne and by the 'John Rowley school' are included amongst these. If the longitudes of these places – or the longitudes which the dialmakers believed they had – are known, then the time offset can be used to calculate the longitude of the dial. The method relies on the longitude difference between the dial and the named location being equal to the time offset of noon, in hours, divided by 15.

The drawback with this scheme is that the longitudes of far-away places were known only very inexactly in the 17th and early 18th centuries. The most reliable places to use are those which had astronomical observatories, or European ports visited by skilled navigators. Hence London (i.e. Greenwich), Paris, Dublin, Lisbon and Madrid are probably the best to use. As an example, the dial signed by Daniel Delander, DH-17, has a long list of placenames as shown on p.172. These give calculated longitudes which are typically around 0°, despite the fact that the dial is currently located at around 1° 08' W. Taken with a calculated latitude of 51.4°, it thus seems likely that this particular dial was made for London.

3. DATE

There are no features of an undated horizontal dial which allow its date to be calculated exactly. However, various stylistic features and extra furniture (particularly epact tables, equation of time tables and star data) can give information on the most likely period of construction.

3.1 Calendar

The dates of the equinoxes shown by the stereographic grid of a DH dial show what calendar system was being used when the dial was made. As almost all of the antique dials in this study were made before 1730 and England continued to use the Julian calendar until its adoption of the Gregorian calendar in 1752, this method is of little practical use though. An exception is the Benjamin Scott dial DH-26 which was made for Paris and uses the Gregorian calendar despite being made in c.1713: France had adopted the Gregorian calendar much earlier, in 1582.

3.2 Epact Tables

The most useful dial furniture from a dating viewpoint are tables of *epact* or *golden numbers*. Values for these are sometimes given for a considerable span of years. The first year in the table is usually the date that the dial was made, perhaps plus-or-minus one year. The evidence for this is that makers such as Henry Wynne had a fairly standard tabular layout with seven years to a row but added or subtracted extra cells for dials made in years which did not fit this layout exactly – see, for example, the table on the Staunton Harold dial shown on page 114. Even if the dial is quite severely eroded, such that many of the engraved years cannot be read, the sequence of the table can normally be established by looking at the pattern of the planetary symbols, engraved for the leap years. Being larger than the small year numerals, these often survive the weathering, particularly the simple symbols for the Sun and Moon.

3.3 EoT Tables

In 1672, the development of reliable and accurate tables for the equation of time (EoT) by the Astronomer Royal John Flamsteed provided further clues to the date of a dial. The earliest known appearance of EoT data engraved on a datable sundial is the 1685 Henry Wynne dial for Staunton Harold, DH-36. (Two horizontal dials by Thomas Tompion with EoT tables may be slightly earlier but are not dated.[2]) Thus any dial engraved with EoT data from its original manufacture must be later than 1672 and is probably after 1685 unless it is by Tompion or Wynne. Although it does not necessarily follow that DH dials without EoT data are pre-1685, this does generally seem to be the case for many known examples.

For dials with EoT data, further clues as to the date may be available from the actual values used. Although small changes in the Earth's orbit do cause changes in the EoT over timescales measured in centuries, the changes over the period when DH dials were made are usually too small to be noticeable. But the accuracy with which EoT tables were calculated developed quickly in the decades after 1672 so it is sometimes possible to relate the EoT data engraved on a dial to a particular source (more often than not one of the tables provided by Flamsteed). The analysis is not easy or exact so the reader is referred to Davis[2,3] for further details.

3.4 Star Data

Dials which feature star data in the form of right ascensions and, occasionally, declinations, give the possibility

Maker	Instrument No.	Year	Positions	Number of stars	Derived Epoch
J. Browne	HQ-7	c.1630+	RA, dec	46	1629
Sutton	Gunter's quadrant	1658	dec	21	1652
Sutton	DH-61 & 62	1661	RA	12	1651
Marke	DH-59	1667	RA	12	1651
Wynne	DH-36	c.1685	RA	12	1651
Gray	DH-22	1699	RA	6	1698

Table 1. The epochs of the stars on various instruments.

of identifying which epoch they are for. Care needs to be taken as dialmakers tended to be rather conservative and so could be using data which were significantly out of date. Very few catalogues of accurate star positions were available in the seventeenth century: the best were those of Tycho Brahe (1546-1601) published by Kepler in 1602 and later enlarged editions, and of Hevelius (1611-1681) which may have been available in manuscript form although not published until 1690.

The positions of stars in right ascension (RA, α) and declination (dec, δ) are slowly changed by the precession of the earth's axis. Catalogues of star positions are therefore prepared for a specified epoch, and to derive positions for another epoch it is necessary to correct the published data for precession in the interval. Subsequent workers often published catalogues for other later epochs, based on primary sources such as Tycho and Hevelius. For example, Moxon[4] provides star positions, derived from Tycho's catalogue, for epochs 1600 and 1700, together with values for 100 years of precession which could be used to derive positions at other epochs. Positions are given to degrees and arc-minutes in both RA and dec: for practical use the RAs need to be converted to values in time. Although this particular example, published in 1686, would not have been useful to the majority of double horizontal dial makers, other catalogues of star positions with sufficient accuracy for sundials would have been available.

The rate at which star coordinates are changed by precession is not large. In right ascension the annual change is 3·1 seconds of time per year for a star on the celestial equator and for stars at higher declinations (up to about 50°, say) can vary between about 1·5 and 5s/yr. At higher declinations the change could reach a minute or more per year, but not many dials show high-declination stars. In declination, annual precession can vary between 0 and 20 arc-seconds per year. A simple expression for precession, adequate for sundial purposes, is:

Annual precession in RA, in seconds of time:

$$3{\cdot}073 + 1{\cdot}3362 \sin\alpha.\tan\delta$$

and in declination, in minutes of arc:

$$0{\cdot}334 \cos\alpha$$

On most dials, star positions are given to one minute of time in right ascension, although a few tabulate only to quarter-hours. From the rates of precession given above, it is evident that the star positionson the dial will correspond to the true star positions (to a minute of time) over a range of years, possibly up to twenty years in unfavourable circumstances, and the epoch of a position is uncertain to that extent. Additionally as mentioned above the dial maker may have used out-of-date positions, leading to further uncertainty.

Where declinations are provided, they are usually given to minutes of arc. It is therefore possible that declinations may give a tighter range of possible dates, but only for those stars where the precession in declination is sufficiently large.

By inverse interpolation of the 1600 and 1700 places given by Moxon, epochs for the dial values can be found. The results of analysis of the star positions given on a few dated (or dateable) instruments are shown in Table 1.

Four of these instruments are dated. Delamain published a description of the horizontal quadrant in 1632[5]so 1629 is a plausible date for the star positions although the Browne instrument may have been made later to Delamain's design. As explained earlier, the date of the Wynne dial can be deduced from the calendrical information. For this dial only the stars with given positions were analysed as those of the others are read from a scale with limited accuracy. The dial by Marke duplicates the stars and positions of the Sutton DH dial, and part of the dial face with the positions is shown in Fig. 8. The dial by Stephen Gray includes a calendar date for each star. These are the dates in the Julian calendar on which the star transits the meridian at midnight apparent time.



Fig. 8. Some of the stars listed on the John Marke dial DH-59.

As the RAs are given only to the nearest minute of time, the uncertainty in the derived epochs amounts to about 7 years. In declination, with positions to arc-minutes, the uncertainty is only about 2 or 3 years. It seems most likely that the positions are in fact ten-year values, using positions for 1630, 1650 and 1700. These are well within the uncertainties in the derived epochs.

The stars on individual dials are selected from the fifteen brightest stars visible from Britain, with fainter stars included to improve the distribution in RA. Some makers identify the stars by their proper names, others use their places in the traditional drawings of the mythological constellation figures, as 'Orion's left foot' (Rigel) or 'Oc Tau' (Bull's eye, Aldebaran). A star often included is 'Ala Pegasus' (the 'wing of Pegasus', γ Peg), a third-magnitude star.

From the evidence of these instruments it appears that some makers took trouble to derive positions appropriate to the dates of their instruments but others (possibly copying from one another) were content to use out-dated positions, 35 years or so in the case of the Wynne dial, over which interval precession would have altered them by about two minutes of time. However, the star positions were intended to facilitate finding the time at night, and in view of other uncertainties such an error would not have been significant.

Because of the uncertainty of deriving the epochs and the propensity of makers to use out-dated positions, it must be concluded that star positions cannot be relied upon to provide an accurate date for a dial.

See also page 120 for an analysis of the stars on dials.

3.5 General Style

Engraving styles change over time and can be used as a clue to dating dials. For example, the earlier use of 'I' for 'J' and 'U' for 'V' gradually faded during the 18th century and styles became more formal and less florid. Numerous other small details in lettering and decoration give a general 'feel' of the period when a dial was made but are difficult to codify.

One feature which does have a definite start date is the introduction of outward-facing Roman numerals for the main chapter ring. Prior to around 1710, all dials had their main numerals oriented inwards, like a clock-face, so that they were designed to be read most easily by an observer standing to the south of the dial. With the introduction of larger dials delineated to the minute, it was necessary to look closely at the chapter ring to take a reading, meaning that it was more convenient to stand to the north of the dial and accordingly to have the numerals oriented outwards. It seems that John Rowley, or possibly Thomas Tompion, was the first to realise this and make the change. Three of the set of four Rowley dials at Blenheim Palace, made in 1710, were outward-facing. The style became standard for all dials by London mathematical instrument makers over the next few decades.

The change in engraving orientation affected all the engraving on a dial, with the possible exception of any coats of arms. Reversing the orientation of the lettering in a conventional EoT ring, with the months progressing clockwise around the dial, meant that the reading was done rather awkwardly from right to left. This could provide for some confusion but it was, after a few years, realised that making the ring run anti-clockwise removed any ambiguity. This 'final' form of the EoT ring on English dials was complete by 1713 when Benjamin Scott made his double horizontal dial DH-26.

REFERENCES

1. Waugh (1973).
2. Davis (2003).
3. Davis (2005).
4. Joseph Moxon, *A Tutor to Astronomy and Geography…… and Globes, in Six Books,* London, (1686).
5. Richard Delamain, *The Making, Description and Use of……a Horizontal Quadrant*, London, (1632).

MATERIALS AND METHODS

INTRODUCTION

This chapter deals with how, and from what materials, historic double horizontal sundials were made. The large majority of the dials are of metal, usually described in the literature and auction catalogues as 'brass' or 'bronze', both alloys of copper. In this they are no different to the more common garden sundials and many other mathematical instruments. We will consider here the sources, preparation, working, delineation and other methods used to produce finished dials and touch on the influence of the methods on the survival of the dials when exposed to several centuries of weathering. The information presented here is an extension of an earlier paper.[1]

MATERIALS

By modern definitions, brass is an alloy of copper (Cu) with, predominantly, zinc (Zn). Bronze is similarly an alloy of copper and tin (Sn). Mixed alloys containing both zinc and tin are also possible and are frequently known as gunmetals (see Fig. 1). Small amounts of other metals, particularly lead (Pb), are often added to improve machining or weathering properties. Historically, traces of many other metals such as silver (Ag), iron (Fe) and nickel (Ni) can sometimes be found as these were present in the mixed ores from which the metals were smelted. In the past, the terms bronze and brass did not have their precise modern meanings and were sometimes used inter-changeably so that descriptions in contemporary literature – or even modern literature – are not a reliable guide to the alloys actually used. This can be very confusing. The literature has been reviewed by Manasek[2,3] who concluded that many 18th century dials traditionally described as brass may be of bronze. However, on the evidence presented below, we believe that this is wrong and that sundials were normally produced from alloys which were essentially brasses, albeit sometimes with traces of tin in them.

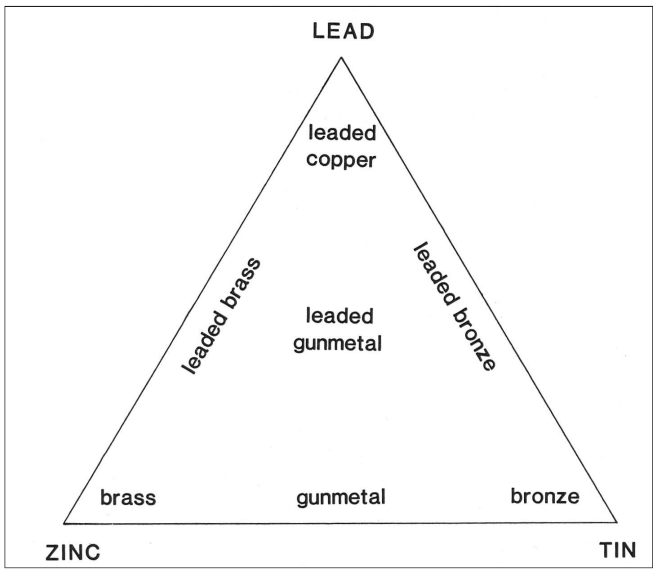


Fig. 1. Diagram of copper alloys and their modern names.

Different alloy compositions of both brass and bronze to optimise them for specific purposes are today often named after the application for which they were developed. These often result in different colours of freshly-exposed metallic surfaces. Fig 2 shows some of these names but it is stressed that these are for modern, intentional, alloys.

Name	Cu	Zn	Sn	Others
Common brass	63	37		
Free cutting (leaded, engraving etc) brass	61	36		3 Pb
Naval (marine, Admiralty etc) brass	61	38	1	
Yellow brass	66	34		
Gilding metal	80	20		
Nickel silver	62	5		33 Ni
Phosphor bronze	95		4	0.35 P
Bell metal	77		23	
Gunmetal	88	2	10	
Leaded phosphor bronze	87	1	7	3.1 Pb; 0.2 P
Speculum metal	68		32	

Fig. 2. Names and compositions (wt.%) of some individual alloys.

Bronze is the oldest alloy known to mankind and has been available since prehistory (note the eponymous 'Bronze Age'). It can be prepared by melting metallic copper and tin together, both metals being extracted relatively easily from their respective ores. Today, it is quite expensive due to the price of tin. It is most commonly used for sculpture, where its abilities to flow accurately into fine moulds and to withstand weathering make it a natural choice. It is, perhaps, these perceived advantages that lead to the assumption that it was used for high quality sundials. Freshly prepared bronze surfaces have an attractive, slightly reddish-yellow colour. Most bronzes have a relatively low concentration of tin (perhaps 5-10%) but the alloys used for making bells ('bell-metal') has a higher tin content of >20%, making it harder and the bell more sonorous.

Brass is a more recent alloy which was not widely known in Europe (although the Romans did have small amounts[4]) until the Middle Ages. This is due to the fact that metallic zinc was only identified and industrially available in the West in the early 19th century. The difficulty is that the temperatures at which zinc is released from its most common ore calamine[5] are above its boiling point and so the zinc comes off as a vapour and much of it is lost. Early production was often known as 'colouring copper' as it was not realised that an alloy was being produced and the resulting brass was much yellower than the original copper which had been heated together with the calamine – the 'cementation process'.[4, 6-8]

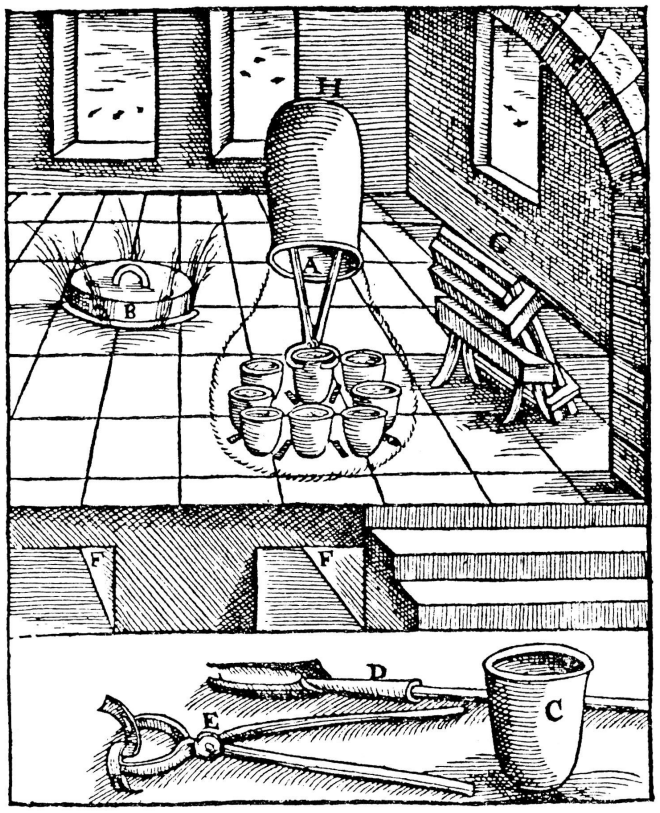


Fig. 3. Ercker's 1574 illustration of a cementation furnace. The eight crucibles must be visualized in the under-floor furnace (F), below the lid (B). Note particularly the "Brittanische steine" (G) for casting plates of brass.

Brass exists in two main metallurgical phases, known as α -brass and β-brass, with different physical properties.[9] Below 32% Zn (by weight) only the alpha phase exists whereas above 45% Zn the material is all beta phase. In between, a mixed (α+β) phase exists. Brass produced purely by the cementation process is all in the alpha phase. The presence of the mixed (α+β) phase which, being harder, is sometimes preferred for very fine engraving, is indicative of the higher zinc concentrations resulting from co-melting zinc and copper. This co-melting technique was not developed in England until after the work of William Champion[4] in the mid-18th century: James Emerson was granted a patent for the industrial process of producing brass from metallic zinc and copper in 1781.[10] Thus dials and other instruments produced in England (and Europe) in the 16th and 17th centuries are invariably of α-brass, sometimes with a zinc concentration much below the 32% maximum. However, 17th century astrolabes from Lahore indicate the availability of high-zinc brasses in the near-East much earlier.[11]

Brass has been used in Europe since medieval times and its adoption by the mathematical instrument making industry was partly on the basis of its availability. Thus monumental brasses[12] and musical instruments[13] were both produced from brass in this period and the materials and methods from these trades were adapted by the mathematical instrument makers. Brass can be a hard-wearing material, especially if it is work-hardened. It cuts very cleanly, making it ideal for applications such as the gear wheels of clocks and for engraved mathematical instruments.

Brass Production and Sources

The *History of Technology*[8] explains that brass was known in Greek times. Early brass making was described by Biringuccio[7] (1530), Agricola[6] and Ercker[14] (1574) but English practice is best decribed by Merrett (1662).[15] The brass makers' cementation furnace (Fig. 3) consisted of a deep conical hole beneath the working floor. At its bottom was a shallow fire containing 8 or 10 relatively small crucibles filled with a mixture of roasted and ground calamine, powdered charcoal and copper scrap. The heating was maintained for between 9 and 20 hours. Excess evaporated zinc not absorbed by the copper could sublime and collect as 'spelter' near the top of the crucibles and may possibly have later been added back into molten brass to increase its zinc content.

The molten brass was poured into moulds to form ingots or between limestone plates (called 'Britannische steine') to create thick sheets which could later be hammered to produce thinner strips. During this process, shown in Fig. 4, the brass would rapidly become work-hardened and required frequent heating in a furnace to anneal it for further working.

European production of brass in the medieval period was centred on the Meuse valley (around Liège) and in the vicinity of Aachen. Metal for use in the monumental 'brasses' found in English churches in the Middle Ages was usually imported from the Low Countries, often in the form of the mixed alloy 'latten' (akin to modern leaded gunmetal) as ballast in the hold of ships working as part of the wool trade.

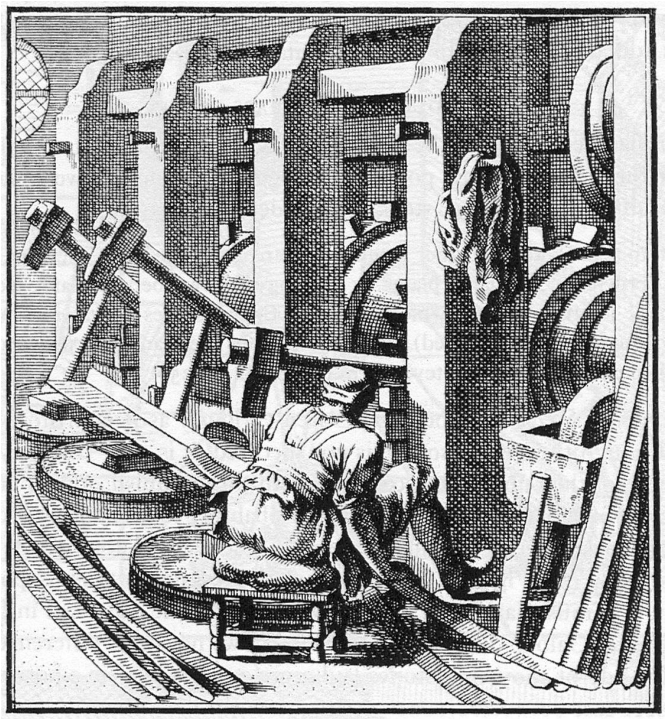


Fig. 4. Christoph Weigel's illustration of beating brass strips with a water-powered trip hammer.

England lacked an indigenous source of brass until the Elizabethan period. In 1565, the Company of Mines Royal was formed with English and German capital and with the help of German technicians. Although the main aim was to mine and smelt copper in Cumberland, a 19-year licence was granted to William Humphey, Assay Master of the Mint, and Christopher Schulz, manager of a calamine mine in Saxony, to mine calamine and make brass. The licence[16] allowed them to "digg and myne for the said calamyne stone in all the lands of our Realm" and for the "making and pounding of Latten and all other mettalls into plate and wyer." One unit of the company, the Mineral and Battery Works, found calamine in Somerset and they hauled it to Tinterne. But they failed to produce usable brass, possibly due to using sulphurous coal as a fuel. When the licence expired, a new one was granted in 1584 to a group including John Brode who set up his manufacturing site at the old monastic mill of Isleworth. Water-power allowed the use of both large bellows for the furnaces and tilt hammers (of up to 4 cwt) to work the brass plate. 'Battery plate' as it is known was around 2 mm thick. Amongst other uses, it was employed for monumental brasses but it was markedly thinner (and hence inferior for the purpose) than earlier imported plate. However, it was ideal for early dial making.

Another source of brass in 16th and 17th century England was from recycled monumental brasses. There were two key periods for this: the dissolution of the monasteries after 1535 and then later during the Commonwealth period when a Parliamentary Ordnance of 1643 required the removal of all "idolatory or superstitious monuments". The sheet or plate brass torn from the tombs in churches and abbeys could be used in two different ways. It could be cut into smaller pieces, turned over and re-engraved on the back, producing 'palimpsests'. Perhaps the main use of this recycled brass sheet was to produce new, more politically correct, monumental brasses of which many are known.[17] Another use was to make sundials with at least one still existing[18] and another recorded but now lost[17]. None of the known DH dials is believed to be a palimpsest. The other way in which recycled monumental brasses were used was to melt them down, possibly with other broken brass, bronze or copper from a variety of sources including bells and domestic wares. The resulting alloys would have very variable compositions which could lie anywhere in the triangular quaternery-alloy diagram.

Brass was an expensive material in the 17th and 18th centuries. Robert Hooke recorded several purchases of it in his diaries.[19] For example, he gives:

> 1676 Sept 18: Bought of ----- brasse plate at 16d. per lb., 2sh.9d. paid. cutt it into instrument joint.

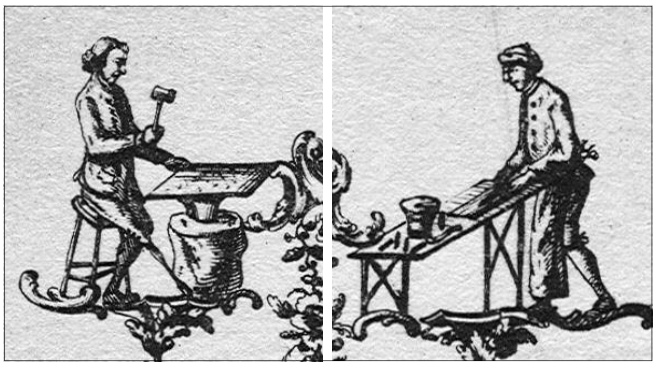


Fig. 5. Illustrations from the18th century tradecard of the platemaker Benjamin Whitton, Shoe Lane, Holborn, showing the process of hammering and scraping plates (copper for printing or brass for mathematical instruments). From the Ambrose Collection, courtesy of The Trustees of the British Museum.

1678 May 14: bought of brasier Cateaten Street 2sh. of Brasse.

1679 May 7: Paid Tod for 2 brasse plates 10sh.

Later, in the mid-18th century, it is recorded that a garden sundial by Thomas Wright was stolen for the scrap value of its brass.[20] The price of around 8 pence per pound (weight) is about half the cost of finished brass plate paid by Hooke. The story also records that the brass foundry to which the stolen sundial was offered was located in Shoe Lane in London, a known centre for brass.

Plate Preparation

Having produced large ingots or sheets of brass, smaller pieces of the appropriate thickness and surface-finish needed for engraving had to be prepared. Even thin (2 mm) brass sheet produced using tilt-hammers required further work. Before the development of rolling-mills in the late 17th century, the preparation of metal plates by hand-hammering and scraping was a specialised craft skill and developed in 16th and 17th century London alongside the printing and mathematical instrument trades (see Fig. 5).

In the 17th century, brass foundries for melting brass ingots into usable shapes could be found in London, particularly in Chancery Lane which was also the centre of the instrument making activities and near to the clockmakers of Fleet Street. The Great Fire of 1666 caused the loss of some of these foundries: it is not clear how quickly the industry recovered.[21] Fig 6 shows the casting process at a rather later date. Casting was a simpler and more efficient method of producing circular plates or complex shapes than by cutting from sheets or blocks of material. The surface would need considerable finishing before it was ready for engraving.

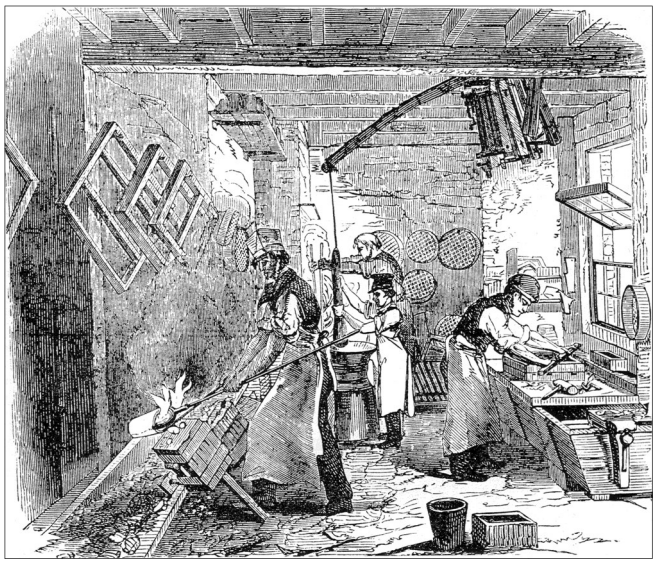


Fig. 6. Brass foundry work. This illustration from the London Illustrated News of 20 Sept 1851 shows the process at the clockmakers of J Smith & Sons, Clerkenwell. Brass ingots, smelted elsewhere, are melted and poured into moulds.

METALLURGICAL STUDY OF DH DIALS

It has been possible to perform some metallurgical studies of a small number of the double horizontal dials listed in this study.[22] The method of compositional analysis used was energy dispersive analysis of x-rays using a Leo 1450VP scanning electron microscope interfaced with an Oxford INCA energy dispersive x-ray analysis (EDAX) suite. The microscope has a backscatter electron detector to provide atomic number contrast as well as secondary electron detector to provide surface topography. Primary electron energies in the range 15-20keV were used. Using internal standards the instrument is capable of quantifying elements above oxygen in the Periodic Table. When used in this way the limit of detection is 0.1% by weight. The analysis of alloys of copper, zinc, tin, lead and iron do not present problems in terms of overlapping peaks.

In principle, the x-ray analysis technique is non-destructive but the limited size of the specimen chamber meant that only samples removed from dials were used. The technique essentially probes the surface of the specimen to a depth of less than 3 microns (around a ten-thousandth of an inch). Since the dials examined were invariably covered with a patina with a thickness of much more than this, and because the surface regions of the dials could well have a different alloy composition to that in the bulk ('de-zincification' due to preferential loss of zinc at the surface), analysing the freshly-exposed surfaces of samples cut from the dials allowed reliable and representative results to be obtained.

Conscious of the need not to introduce significant damage to valuable antiques, the specimens used were very small, typically $1 \times 0.5 \times 0.2$ mm. Small slivers were cut, using a very sharp hardened steel lettering chisel, so that they did not cause any visible impairment to the dials, from locations on the back of the dialplate such as the insides of the tenon slots, and the burrs around screwholes. In addition to analysing dialplates, the gnomons were also

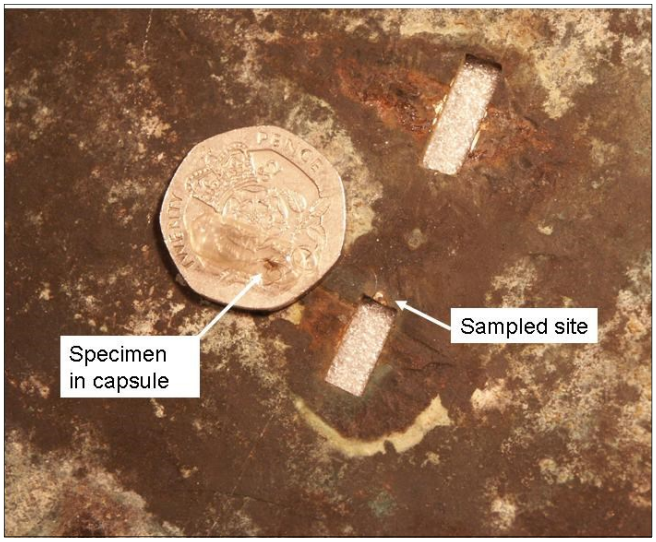
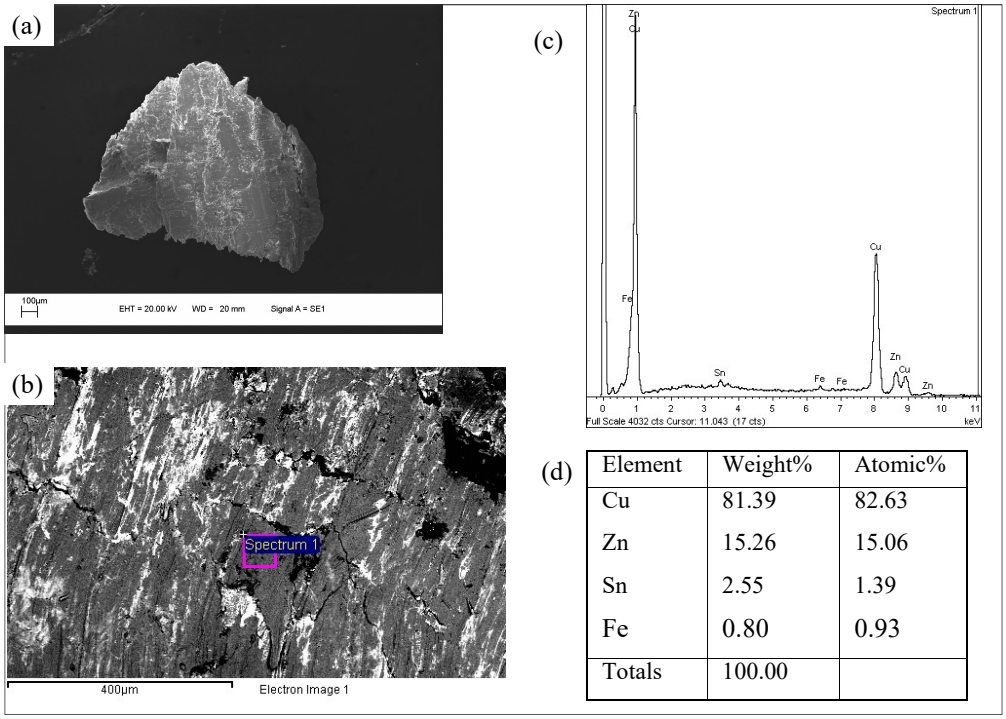


Fig. 7. Specimen taken from the back of an Elias Allen dial, inside a transparent capsule laying on a 20p piece.



(d)

Element	Weight%	Atomic%
Cu	81.39	82.63
Zn	15.26	15.06
Sn	2.55	1.39
Fe	0.80	0.93
Totals	100.00	

Fig. 8. Analysis of a specimen from the dial plate of Henry Wynne's DH-36. (a) Overall electron micrograph of specimen. (b) Close-up showing the area analysed. (c) Resulting spectrum. (d) Compositional analysis.

This area shows lower than average concentrations of tin but trace amounts of iron, in comparison to other areas of the same specimen.

sampled wherever possible, usually from the hidden underside or the tenon. An optical photograph of a typical sample is shown in Fig. 7.

After x-ray analysis, some specimens were prepared for high-power optical examination by embedding, polishing and grain-boundary etching. (See Greaves & Wrighton[23] for details of the techniques employed.) The purpose of this was to investigate if evidence of the plate preparation and machining treatments could be observed in the microstructure of such small specimens.

A typical set of results is shown in Fig. 8. The electron micrograph shows the region of the specimen sampled and the table gives the output from analysing the spectrum from the x-ray analyser.

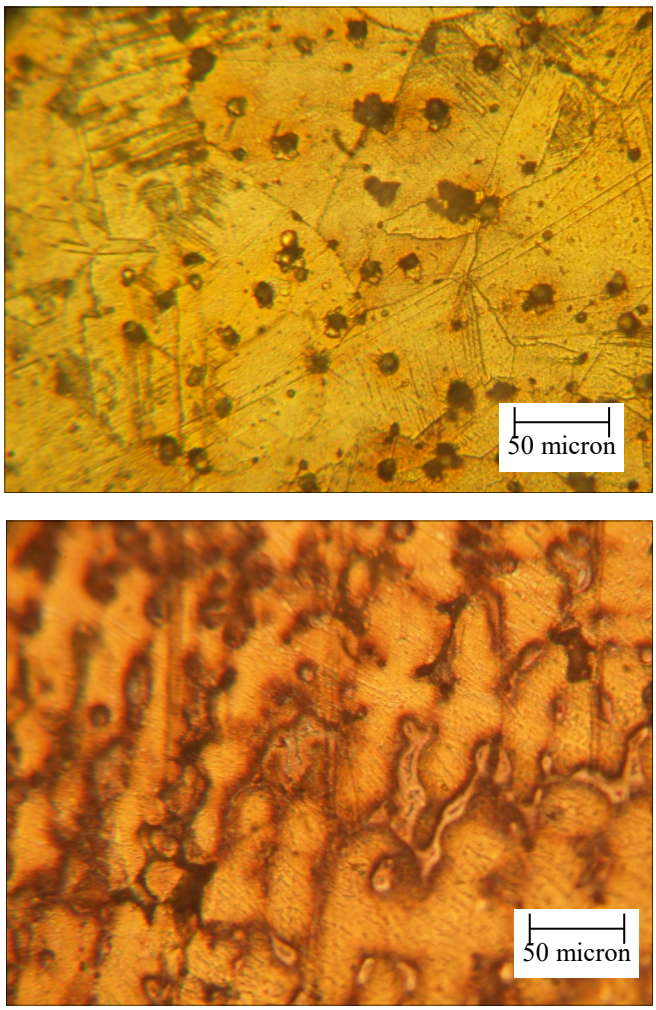
A summary of all the specimens examined is shown in the table of Fig. 9. The specimens are arranged in the order in which the dials were made. There is no chronological trend in the results: individual dials must be considered separately in relation to the development of metallurgy at the time.

Elias Allen: dials DH-8 & 57, plus 'John Seller' DH-27. These instruments represent the earliest double horizontal

Maker	Date	Dial	Sample	Cu	Zn	Sn	Pb	Others	Comments
Elias Allen	c.1630	DH-8	dialplate	66.1	33.9				
Elias Allen	c.1630	DH-57	gnomon tenon dialplate	68.1 68.1	26.3 31.9	1.1	<3.9 locally <<17 locally	Fe 0.5	
Elias Allen (Seller)	c.1630	DH-27	dialplate gnomon	63.3 60	36.7 40				 modern replacement
Henry Wynne	1685	DH-36	dialplate N dialplate S gnomon tenon	80 80 80	15 15 15	5 5 5	Trace	Fe trace	
John Rowley	c.1700	DH-25	dialplate gnomon	69.4 83.7	26.2 14		2.9	Fe 1.5 Si 2.3	 Cast

Fig. 9. Summary of analytical results. Elemental compositions are in weight %.

dials and have thin dialplates. It can be seen from Fig. 9 that the plates are all from brass with no tin detected. The zinc content is very high for the cementation process, at over 30%, showing that the process was run to completion using an ore with a high zinc content. Bearing in mind Allen's connections through his master Charles Whitwell back to Humphrey Cole of The Mint, it is suggested that he was probably using brass which had come directly from indigenous sources with no recycled component. Cameron[12] has shown that these relatively high zinc concentrations with virtually no tin and moderate lead components are characteristic of monumental brasses from English plate of the late-16th and early-17th centuries.



Figs. 10 &11 Optical micrographs showing the structure of Elias Allen DH-57 after selective etching to reveal the microstructure. Top: dialplate. The black spots are Pb precipitates; the long parallel lines show twinning. Bottom: gnomon, showing a cast structure with very little cold-working.

Fig. 10 is an optical micrograph showing the crystalline structure of the dialplate of Allen's DH-57. It shows well-formed equiaxed grain and a significant amount of precepitated lead (the average concentration was difficult to measure because of the small sample size). There is considerable twinning visible which is good evidence of the annealing step after cold-working.

None of the Allen dials examined had its original gnomon intact. However, on DH-57 the broken-off tenon was found still in its slot underneath a replacement gnomon, providing an opportunity for analysis. As Allen's gnomons are of a thickness very similar to his dialplates, it had been expected that they would have been cut from the same source material. The analysis proved this not to be the case. The brass has a lower zinc concentration of around 26% and there is now a tin content of around 1%. In addition, there is a trace (0.5%) of iron. The optical micrograph of Fig. 11 shows a different structure to the dialplate – it has a much coarser grain structure, there is no evidence of cold-working and there are numerous inclusions. In addition, there are signs of 'dezincification' of the surfaces, i.e., preferential loss of zinc to the atmosphere leaving a slightly porous copper matrix. All these features point to the gnomon having been cast and receiving relatively little working afterwards. This would account for the extreme fragility of Allen's gnomons. The tin content may be the result of the foundry incorporating various mixed-alloys into the melt, perhaps intentionally to improve the flow into the mould.

Henry Wynne: DH-36. The dialplate of this 1685 dial was sampled at two points on opposite sides of the disc. The composition was the same in each case: a 'gunmetal' with 15% zinc and 5% tin. In this case there only trace amounts of lead. The optical micrograph (Fig. 12) shows that this is a cast plate with some 'coring' (the preferential rejection of zinc as the melt solidifies). There was little evidence of any cold-working of the cast disk – note that surface preparation by scraping and filing, as opposed to hammering, would not alter the microstructure.

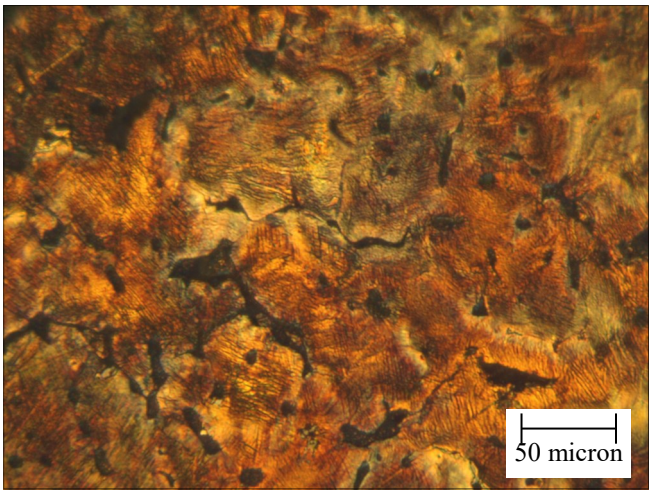


Fig. 12. Optical micrograph showing the structure of the alloy of the dialplate of Henry Wynne DH-36.

The gnomon tenon of the Wynne DH-36 has the same composition as the dialplate and thus it is highly likely that it was cast at the same time. In fact, this is just the same procedure that was used to make the modern replica (see page 55) although the composition was rather different.

John Rowley: DH-25. This undated double horizontal sun - and moon-dial is considerably smaller than Rowley's 1710 DH dial for Blenheim Palace and is thought, on stylistic grounds, to be rather earlier. The dialplate is of intermediate thickness (around 3 mm) between the Elias Allen dials and the large plates used by Henry Wynne and so could conceivably be either from a worked sheet or a casting. The analysis shows it to be a leaded brass with a 'medium' zinc concentration of 26% and a relatively high 1.5% of iron.

The Rowley dial has an unusual gnomon which appears to be cast with integral mounting feet: examination of its fixing to the dialplate shows this to be original although the upper section has been replaced. It has a slightly porous surface texture. The compositional analysis shows an unusually low zinc concentration of only 14% with an unexpected 2.3% of silicon. This may have resulted from overheating of the melt during casting and a consequent loss of zinc by evaporation. The silicon content may have resulted from the sand (silica) used as the mould. Overall, the impression is of a surprisingly poor-quality item from such an eminent maker.

DIAL MAKING METHODS

Dialplates

Early DH dials were generally small, square and had thin dialplates, of the order of 2 mm thick. This is in line with other contemporary mathematical instruments and reflects the cost and availability of brass at the time. (Note in passing that a few of these early dials were octagonal though some existing octagonal dials are likely originally to have been square but have since been trimmed to remove corners damaged by fixing holes.) Brass of this thickness would have been relatively easy to work and all the dials of this period show hammer marks on the backs from the preparation process.

Later dials (from Henry Wynne onwards) were much larger and designed to impress so naturally the dialplates needed to be much thicker, 6 to 10 mm being typical. The analysis above shows that these plates were made by casting. The back of Wynne dial DH-34 uniquely shows signs of being turned on a lathe of some form (Fig. 13). Other circular dials will have been turned to produce a clean edge. Turning was an accepted trade at the end of the 18th century but it would have required a very large lathe (such as were used for wood by wheelrights) to turn a 30" diameter dialplate. An alternative method could have been that described by Moxon[21] (Fig. 14) which would have also been used to prepare the edges of circular dials then in fashion.



Fig. 13. The back of Henry Wynne's Wrest Park dial DH -34 showing lathe marks and gnomon tenons with retaining wedges.

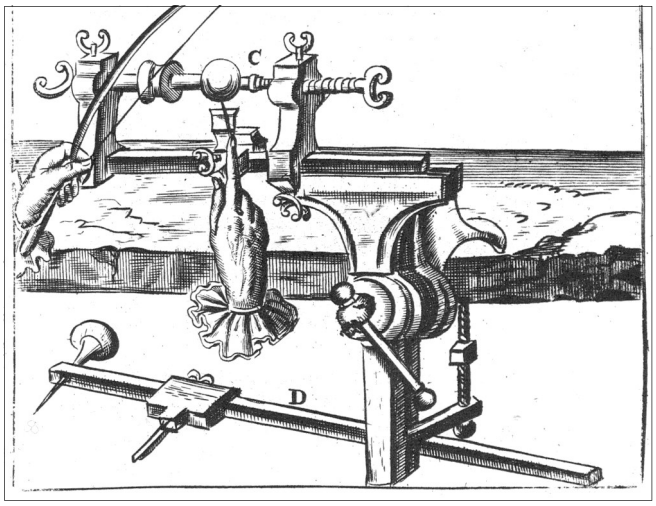


Fig. 14. A hand lathe or tramel (D) illustrated by Joseph Moxon.

Two Henry Wynne dials (DH-37 & 40) feature laminated dialplates with a very thin surface sheet, carrying the engraving, being fixed to a much thicker backing sheet. The method of fixing is a number of concentric rings of rivets. There could be as many as 6 rings with rivets about 1 inch apart, all carefully flattened to allow their heads to be engraved during the dial delineation. It is unclear exactly why this form was used. It may have been simply



Fig. 15. The rim of Henry Wynne's Clarence House dial DH-40 showing the thin laminated surface sheet rivetted onto a thicker backing piece but now cracking and wearing away.

because it was not possible at the time to produce a large flaw-free plate of brass and so a thinner sheet – which could be hammered more easily – was fixed to a low-quality cast backing plate. This structure was not entirely satisfactory as is seen by the cracking of DH-40, now at Clarence House (Fig. 15). This 'season cracking' is due to internal strain along the grain boundaries and preferential loss of zinc.[23]



Fig. 16. The underside of John Rowley's Blenheim Palace dial DH-24 showing the cast ring forming a deep rim to the dial.

A further development of the laminated dialplate is the form where a flat dialplate of around ¼" thickness is attached to a cast rim of perhaps 2" depth. (Fig. 16.) This structure is seen on dials signed by John Rowley, Thomas Tompion and Daniel Delander. It makes the dials appear far more substantial and impressive whilst also providing a solid structure to keep the dialplate flat. The rings, which have complex double-ogee shapes, would have been cast and then turned. (It has not so far been possible to perform a compositional analysis.) The dialplates are attached using a ring of rivets or screws around the rim. The construction produced a dial which was hollow underneath and this made mounting it on a pedestal difficult. Sometimes, as in the case of the non-DH Rowley companion dials at Blenheim Palace, the cavity was simply filled with a lime-mortar mixture, producing a flat base to the dial, level with the bottom of the rim. However, neither the Blenheim DH dial nor the Hampton Court one (which may also have been made by Rowley) has been treated like this.

Engraving

The techniques of engraving metals with a sharpened steel burin or graver to produce printing plates was developed in the Low Countries, normally on copper plates. The same techniques can be used on the harder brass plates to produce scales for scientific instruments. It is believed that the method, for both copper printing plates and brass mathematical instruments, was introduced into this country by Gemma Frisius. The line passed though Humphey Cole to Charles Whitwell and then to Elias Allen. Although the

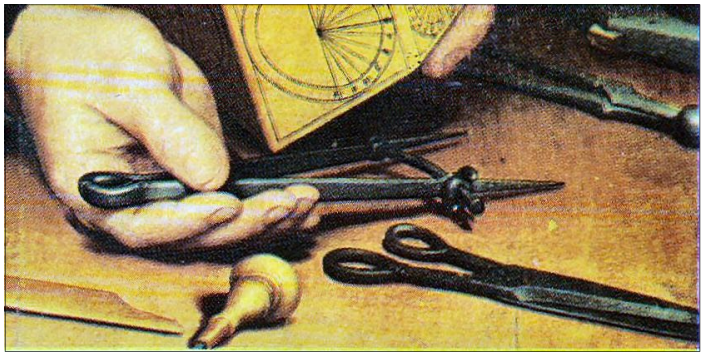


Fig. 17. Close-up of a section of Holbein's famous portrait of Nicholas Kratzer showing a selection of hand-tools of the mid-16th century. Courtesy The Louvre, Paris.



Fig. 18. Close-up of a section of the Elias Allen portrait (see page 138) showing the tools—mainly burins and files—on the rack behind him.

skills and techniques for engraving brass instruments developed markedly during the 16th to 18th centuries in London, the tools changed very little. The burins or gravers seen in the portraits of Nicholas Kratzer (Fig. 17) and Elias Allen (Fig. 18) look remarkably modern and the methods for sharpening them given in 1701 (Fig. 19) are still usable. The major requirement for the burin was that it should be made from a high-quality tool-steel that would take and retain a good edge. Although the details of the

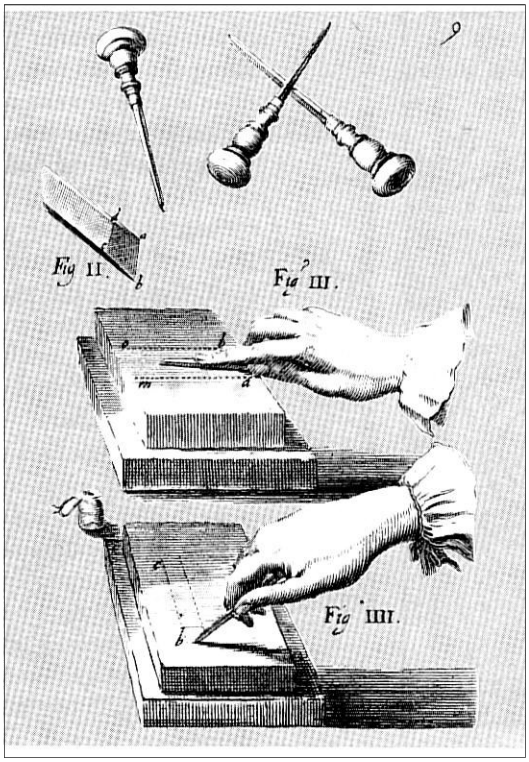


Fig. 19. Use of a burin or graver, from Abraham Bosse's 1701 Traieté des Manières de Graver en Taille-Douce. *Courtesy Bodleian Library, Oxford, Douce B 678.*

metallurgy were largely unknown at the end of the 17th century, Moxon[21] describes various steels depending on their country of origin and recommends Venice or Damascus steel as particularly good for gravers. Dial-makers would often check their gravers by making small test engravings on the backs of the dials.

The engraving of plates for printing or mathematical instruments is in many ways a finer version of the engraving of monumental brasses. The much deeper engraving (often called chasing) required for this earlier profession was achieved using a hammer to drive the graver or chisel, as is shown in Fig. 20. This would leave a characteristic serration to the line which is not seen on the early dials with their relatively shallow lines. Some dials (not double horizontals) which were reworked in the 19th century do show the much deeper incisions – 1 mm or more – which would have required this technique. Other trades which required the engraving of metals included die-making for coins and the decorative engraving of the goldsmiths. It is thus no coincidence that Humphrey Cole worked in The Mint and that some early dialmakers were members of the Goldsmiths' Company.

Unlike the ivory dialmakers of Nuremburg, the London makers had relatively little use for punches to form their lettering. An exception to this is the number '0' which was routinely punched rather than engraved. The number was invariably completely circular in form (Fig. 21). Although most makers had a selection of sizes (perhaps three or more), there was often a mismatch when they were combined with other, hand-engraved, numbers, e.g. to produce multiples of 10. Sometimes the number '8' was produced by two '0's which resulted in an oversize number unless a particularly small punch was available. Elias Allen often did this. The production of a set of punches was part of the masterpiece of a Nuremburg apprentice and it may be that London makers also produced their own punches. Moxon recommends Flemish steel, imported via Cologne, for making punches.

Other Tools

Dialmakers had a relatively small repertoire of tools. The most common and frequently-used were files, varying from the "rough-tooth'd file" (or "Rubber") through bastard to the fine file.[21] A selection can be seen in the rack behind Elias Allen. Compasses were essential both for setting out the pattern and for engraving circular arcs.



Fig. 20. Incising or chasing a monumental brass. From a manuscript illustration c.1320. Courtesy the Trustees of the British Museum.

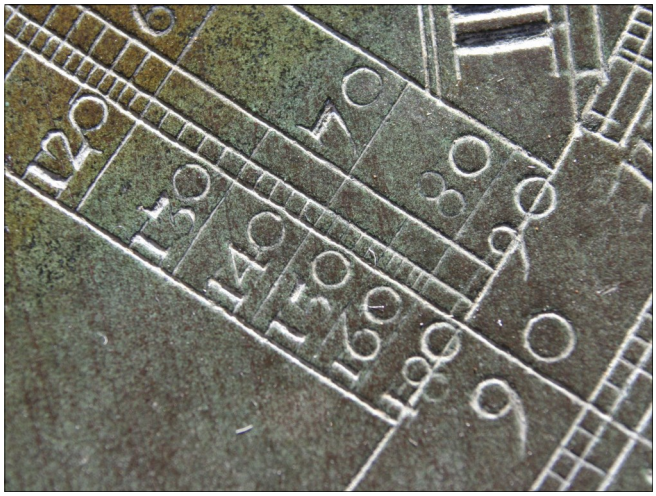


Fig. 21. Several punched numeral '0's amongst other, engraved numbers (example from the anonymous dial DH-42). Note the '8' and probably the '6' and '9' are also based on punched circles.

Hammers and burnishers were used to flatten and smooth the brass plates. Chisels and tin-snips seem to be the most popular tools for cutting plates: the pictures of workshops show a notable absence of metal-cutting saws, though a variety of types for woodworking was available. Holes were produced by a bow-driven drill.

It is likely that dialmakers would have made some of their tools themselves. However, in 16th century Nuremburg, the toolmaker (Fig. 22) was already a well-known profession so it is likely that a similar trade existed in London.

Layout Methods

Delineating a DH dial requires the same set of basic skills as for other mathematical instruments. One extra requirement, besides the accuracy needed, is a method to produce circular arcs with very large radii. Beam compasses could have been used for radii of around a metre but for the hour arcs near noon on a stereographic projection, the much larger radii required may have been produced by putting a smooth arc through a set of calculated points along it, as was described by Oughtred in *Circles of Proportion…* (see page 4). The arc may have been achieved by eye or with the aid of a slightly springy strip of brass or wood. Tools based on this technique were available later in the 18th century, with the degree of bow controlled by a number of screws.[24] The more complicated tool shown by Blagrave (see illustration on page 43) might have been used but there is no evidence and it would certainly have been difficult to position on a sheet of brass.



Fig. 22. A 16th-century toolmaker. After Amman.



Fig. 23. The two gnomon registration holes and origins of delineation on the John Rowley dial DH-25.

The standard horizontal part of a DH dial was produced by the same methods as any ordinary dial. Most quality dials have two small holes at the origins of the polar-gnomon delineation, such that they are one-quarter covered by the 'toe' of the gnomon when the dial is assembled. Elias Allen and John Rowley were two of the makers who did this – see the example in Fig. 23. It is highly likely that these holes were to accept the pivoted ruler which would allow the hour lines to be quickly marked on the dial from a template aligned to this point. No direct reference to the method has yet been found but Fig. 24 shows the concept.

Gnomon Fixings

The methods by which the gnomons of DH dials were attached to their dialplates developed during the 17th century in line with other dials and clockmaking techniques. Because of the need to allow the sun's rays unrestricted access to the vertical knife-edge, the gnomons of a DH dial often dispensed with any side supports or buttressing, making it more difficult to achieve a secure fixing. Restored dials with replacement gnomons do sometimes have added support at the base of the gnomon.

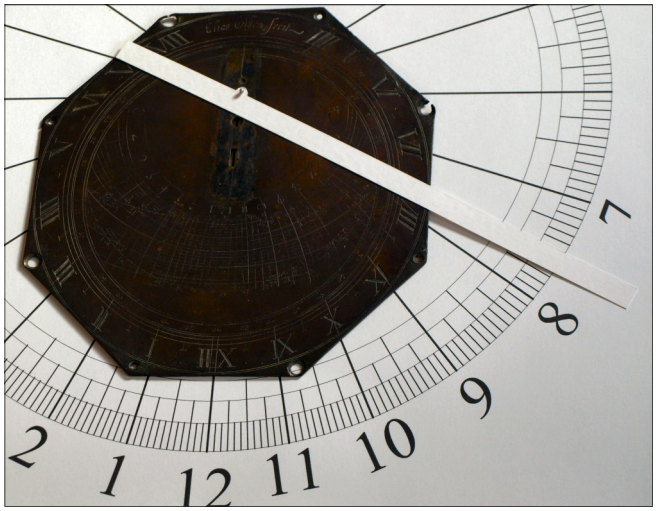


Fig. 24. The suggested method by which horizontal dials were laid out, using a paper template and a ruler pivoted on one of the two origins of delineation.

All of the Elias Allen DH dials which have been examined use the same simple gnomon fixing method. A pair of short tenons pass through slots in the dialplate and are then hammered or peened over to form a permanent fitting. Despite the apparent crudity of the technique, it worked well and some examples still have the gnomon firmly in place, even if the tail is now broken off. (Fig. 25).

The DH dials from Henry Sutton (and also his apprentice John Marke) usually had small side supports as part of the gnomon, presumably a part of a single piece casting. This allowed the gnomon to be screwed on. The early John Rowley dial (DH-25) analysed above also demonstrates this technique (Fig. 26).



Fig. 25. The back of Elias Allen dial DH-4 showing the original gnomon still firmly held in place by the hammered -over tenons. The two delineation centres can also be seen penetrating through the plate.



Fig. 26. The repaired gnomon on John Rowley's DH-25. The lower, original, section has a pair of feet cast in and attached to the dialplate with handmade screws.

The gnomons on Henry Wynne's dials are much more massive. They still use a pair of tenons but these now have rectangular holes in them to accept iron or brass wedges. (see for example, Fig. 13). This same technique can also be found on dials by John Rowley (e.g. at Blenheim Palace) and Thomas Tompion.

PATINAS ON DIALS

One of the delights of antique garden sundials is the range of patinas they develop after centuries of exposure. These can range from turquoise blues through apple greens and browns to completely black. The colours come mainly from the development of complex copper compounds which gradually develop on the surface, although there is undoubtedly some influence from the other alloying metals. The influence of atmospheric conditions and airborne contaminants is also likely to be significant, but the authors have not found the detailed relationships described in the literature.

The development of verdigris on copper has been recognised for centuries and for a long period of time it was used to produce a pigment for green paint. Patinas can also be introduced artificially and the standard texts on the subject[25,26] give literally hundreds of recipes (chemical mixtures plus application methods) for producing interesting patinas on various metals, mainly for sculptures and decorative metalwork. Freshly-exposed brass and bronze surfaces take on a brown colouration after a few months of weathering and this darkens with time. The more interesting patina colours only develop naturally after many years of exposure.

Some of the likely constituents of patinas are listed in Fig. 27.[27] It can be seen that they are all copper compounds though it might be expected that the other metallic

Colour	Material	Compound
Olive green	Malachite (hydrated copper carbonate)	$Cu_2CO_3(OH)_2$
Blue	Azurite (copper carbonate)	$2CuCO_3.Cu(OH)_2$
Blue verdigris	Copper acetate	$Cu(CH_3COO)_2.CuO.6H_2O$
Green verdigris	Copper acetate	$2\ Cu(CH_3COO)_2.CuO.6H_2O$
Neutral verdigris	Copper acetate	$Cu(CH_3COO)_2.H_2O$
Black	Copper sulphide	CuS and Cu_2S
Brown	Cuprous/Cupric oxides	Cu_2O and CuO

Fig. 27. Table identifying some of the common copper patina.

elements in the alloys could contribute to the colouring. For example, an early yellow paint pigment was lead stannate (Pb_2SnO_4). However, the limited range of specimens examined in this study has not produced an obvious correlation between alloy composition and patina colour. Atmospheric conditions probably contribute considerably to patination colours.

Many double horizontal dials have been cleaned at some stage in their life and hence it is difficult to tell just how original their patinas are. Clearly, any dial showing a 'brassy' appearance has been cleaned, and probably protected with wax or lacquer, in the relatively recent past. Some dials, such as the Wynne dial DH-36 and the W. Croft DH-15, have been chemically treated and so their current colour is not representative. A selection of other dials are listed in Fig. 28 but it is not clear at present if the patina colours described are due to the alloy composition, atmospheric conditions, or other factors.

REFERENCES AND NOTES

1. J.R. Davis, T.M. Brown & I. Brightmer: 'Brass or Bronze?', *BSS Bulletin,* 19(ii), pp.50-55, (June 2007).
2. F.J. Manasek: 'What was brass?', *SIS Bulletin*, 91, pp 18-19, (Dec 2006).
3. D. Pantalony, R.L. Kremer & F.J. Manasek: *Study, Measure, Experiment – stories of scientific instruments at Dartmouth College*. pp.33-34, Terra Nova Press, Vermont (2005).
4. J. Day: 'Brass and Zinc in Europe from the Middle Ages until the nineteenth century' in *2000 Years of Zinc and Brass*, P.T. Craddock (Ed.), British Museum Occasional Paper No.50 (1998).
5. Calamine is a mixture of zinc spar, $ZnCO_3$ (smithsonite in the US) and zinc silicate, $Zn_4Si_2O_7(OH)_2$ (hemimorphite).
6. Georgius Agricola: *De Re Metallica*, (1556). Translated into English by H.C. Hoover & L.H. Hoover, Dover Publications, New York (1950).
7. Vannoccio Biringuccio: *De La Pirochtechnia*, (c.1530). Translated into English by C.S. Smith & M.T. Gnudi, Dover Publications, New York (1990).
8. Singer et al: *History of Technology* (1954-84).
9. Alpha phase brass has a *face-centred cubic* molecular structure and beta phase brass is *body-centred cubic*.
10. Wikipedia at *www.wikipedia.org.*
11. B.D. Newbury, M.R. Notis, B. Stephenson, G.S. Cargill & G.B. Stephenson: 'The Astrolabe Craftsmen of Lahore and Early Brass Metallurgy', *Annals of Science*, 63(2), pp. 201-213, (April 2006).
12. Cameron: Medieval Brasses.
13. R.L. Barclay: *The art of the trumpet-maker – the materials tools & techniques of...* OUP, (1992).

13a. G. White, *English Lantern Clocks*, Antique Collectors Club, Woodbridge (1989). See Appendix IV.

14. Ercker (1560).
15. Merrett (1662). See under Neri (1612).
16. BL. Sloane MS 2483 (1565).
17. Page-Phillips: *Palimpsests* (1980).
18. A. James: 'A happy ending – the Preston Gubbals sundial', *BSS Bulletin*, 20(iv), p.144-7, (September 2008).
19. Robert Hooke's diaries (see Robinson & Adams).
20. J. Davis: 'A Just Punishment?', *BSS Bulletin*, 17(ii), p. 65, (June 2005).
21. Moxon: *Handyworks* (1700).
22. The analytical investigations were performed at Derby University by T. Brown and I. Brightmer and the optical investigations were led by D. Hulse.
23. R.H. Greaves & H. Wrighton: *Practical Microsopical Metallography*, Chapman & Hall, London (1967).
24. H. Dawes: *Instruments of Imagination* (2009). See p.56 for an illustration of an example by Thos mas Heath.
25. R. Hughes & M. Rowe: *The Colouring, Bronzing and Patination of Metals*, Thames and Hudson (1991).
26. A.L. McMullen: *Architectural metalwork in copper and its alloys*, Copper Development Association, London (1963).
27. M.V. Orna: 'Chemistry, color, and art', *J Chem Ed*, 78(10), p.1305 (October 2001).

Dial	Maker	Patina colour	Notes
DH-4	E Allen	Pale blue-green	Possibly original
DH-7	J Allen	Tan / dark brown mottled	Cleaned?
DH-11	H Bedford	Olive green & brown	
DH-16	E Culpepper	Pale blue	Possibly original
DH-17	D Delander	Green-blue	
DH-24	J Rowley	Black-brown	Cleaned 1960s
DH-26	B Scott	Bright brass	lacquered?
DH-36	H Wynne	Black	Cleaned 1960s
DH-40	H Wynne	Pale blue-green	Developed since 1968
DH-53	J Marke	Bright blue-green	
DH-64	H Sephton	Mid brown	

Fig. 28. Table showing some of the dials with old (though not necessarily original) patinas.

THE PERPETUAL CALENDARS ON DOUBLE HORIZONTAL DIALS AND OTHER INSTRUMENTS

Several dial makers (notably Henry Sutton and Henry Wynne) included perpetual calendars on their instruments, enabling the date of a weekday to be found for the current or indeed any other year. The set of four dials made by John Rowley in 1710 for Blenheim Palace (including a double horizontal dial) has a calendar on the moondial. The known English-made DH dials were all constructed before the 1752 change in Britain to the Gregorian calendar (New Style, NS) and therefore refer to the Julian calendar (Old Style, OS). One exception is the one made for Paris by Benjamin Scott, which does use the Gregorian calendar. Matters were complicated by the start of the civil year being taken as March 25 so that January, February and most of March were actually part of the previous year. One occasionally sees a date prior to March 25 given as two years. Fig. 1 shows a memorial tablet to Nathaniel Collier in Jevington church, giving the year of his death as 1691/2, implying 1691 OS and 1692 NS. In Scotland, however, January 1 was the first day of the new year from 1600.

Starting the new year on March 25 had other curious consequences. The leap day of February 29 fell, not in years which were divisible by four, but in the previous year. In leap years March 25 falls on the same weekday as January 1. As the date of Easter Sunday can range from March 22 to April 25, it was possible occasionally to have two Easters in one year and none in the next. In the year called 1667 Easter Days fell on April 7 and March 22, and the next was April 11, 1669. The next occurrence was in 1694 when Easter Days were April 8 and March 24.

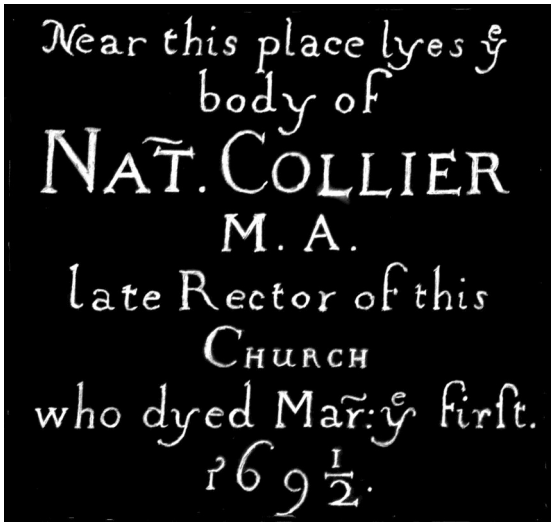


Fig. 1 A memorial tablet showing a date in both Old Style and New Style.

For their perpetual calendars, dialmakers adopted a year starting on March 1, thus reverting to the ancient Roman calendar which still survives in the names of the months September to December, implying the seventh to the tenth months. For both dialmakers and ancient Romans this had the advantage that the leap-year intercalary day came at the end of the year. However, Ordway[1] and other workers take February 29 as the first day of leap years, which may simplify the procedure.

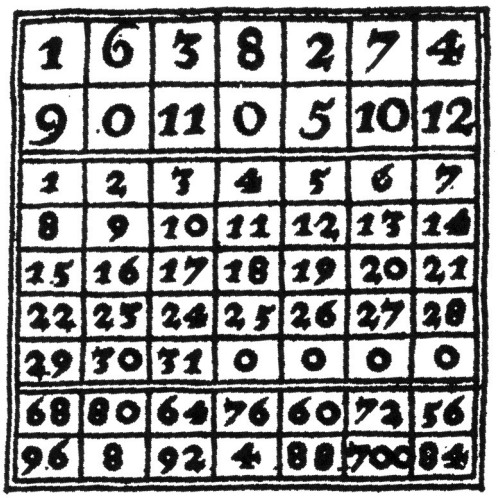


Fig. 2 The perpetual calendar on a Henry Sutton sector.

A perpetual calendar needs knowledge of two parameters. In any year, it is necessary to define some date and the corresponding weekday to be taken as a starting point, which is then applied to a table relating the weekdays to the dates. This table must account for the incommensurability of the week and the month and the varying number of days in the months.

An example of a perpetual calendar (from a quadrant of 1658 by Henry Sutton) is shown in Fig. 2, arranged in seven columns and nine rows: instructions for using it were given by Collins.[2] The numbers in the first two rows are

Weekday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Planet	Sun	Moon	Mars	Mercury	Jupiter	Venus	Saturn
Symbol	☉	☾	♂	☿	♃	♀	♄

Fig. 4 The planetary symbols and the days of the week.

the months numbered from March as 1, April as 2, and so on, January and February being 11 and 12. The next five rows are the dates in groups of seven arranged horizontally and stepping down for the next week. The bottom two rows are every fourth year from 1656 to 1708 which follow the leap days of February 29.

The sequence of the months in the first two rows is explained as follows: starting with March as month 1 in the first column, count columns forward by the number of days by which March is short of 35, i.e. 4 days. This arrives at the fifth column, which is that for April, month 2. April is short of 35 days by 5 days: count on another 5 columns to arrive at the third which is that for May, month 3. Continue this way for the remainder of the year, always subtracting the number of days in the previous month from 35 to locate the column for any month. The logic behind this is that the dates of the weekdays in any month are greater than the same weekdays in the previous month by the number of days by which the previous month was short of 35 days or 5 weeks.

The pattern of numbering now becomes clear. Except for those of August and October each column has two months at its head, for example 1 and 9 (March and November) in the first column. These are the months in which the dates of the month repeat on the same weekday: if March 1 falls on a Tuesday so will November 1.

The next step is to find what week-day March 1 falls on in the year of interest. This can be obtained for those years in the two rows at the foot of the table by noting in which column the quoted year falls. If the year is under the first column March 1 is a Sunday, if under the second a Monday and so on. For years not given add one day for every year after the quoted one up to the next. For example, in 1664 March 1 is a Tuesday and in 1665 it is a Wednesday. Collins gives an arithmetic rule for finding the day of March 1 in any year: add to the year one-quarter of it (ignoring any remainder) and two, divide the result by 7 and take the remainder from this division. This is the weekday of March 1: remainder 1 represents Sunday, 2 Monday and so on. No remainder signifies Saturday. In modern terms we have for the remainder:

$$7.\text{fpart}\{[\text{ipart}(\text{year} \times 5/4 + 2)]/7\}$$

where fpart is the fractional part and ipart is the integer part.

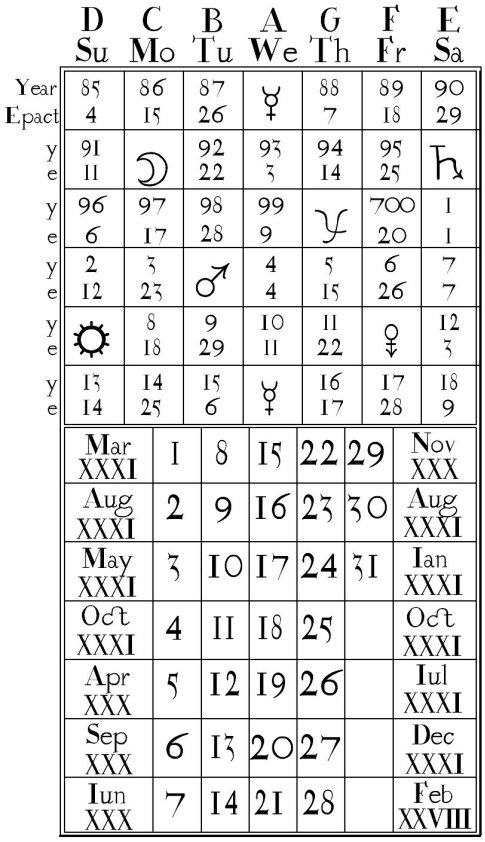


Fig. 3. A portrait of Samuel Morland.

Referring now to the table of months and dates, the week-day found for March 1 is used to find other dates by taking the column for any month as that day also. For example, if March 1 is Thursday, days 8, 15, 22 and 29 are also Thursdays, 7 to 28 are Wednesdays, and 9 to 30 are Fridays. In this way the calendar for the month can be derived. Then taking the column for April (month 2) as Thursdays, it is found that 5 to 26 are Thursdays, 6 to 27 are Fridays, and so on for the other months. It would probably help to prepare a loose piece of card bearing the weekday names which could be positioned appropriately above the dates, enabling the day of any date to be readily found. It should be mentioned that this method will be valid only for the Julian calendar and for a March 1 start of the year.

Calendars on instruments by other makers follow the same general method but with detail differences in the layout of their tables. The invention of this type of calendar table is attributed by Turner[3] to Sir Samuel Morland, whose portrait is shown in Fig. 3.

Some calendars use the planetary symbols to denote the days of the week. These are shown in Fig. 4, giving the day, the planet name (the sun and moon are taken as planets) and its astrological symbol. Those for the sun and moon are stylised pictures, the others represent: for Mars, a shield and spear; Mercury, a winged staff and serpents (the caduceus); Jupiter, a lightning bolt; Venus, a hand mirror; and Saturn, a scythe. The use of these symbols originates in the Babylonian system (c.3000 BCE) in which the 24 equal hours of the day were ruled by the planetary deities in decreasing order of the period taken for each planet to complete a circuit of the heavens. Using the English equivalents of the Babylonian names the sequence was Saturn, Jupiter, Mars, Sun, Venus, Mercury and



	D Su	C Mo	B Tu	A We	G Th	F Fr	E Sa
Year	85	86	87	☿	88	89	90
Epact	4	15	26		7	18	29
y	91	☽	92	93	94	95	♄
e	11		22	3	14	25	
y	96	97	98	99	♆	700	1
e	6	17	28	9		20	1
y	2	3	♂	4	5	6	7
e	12	23		4	15	26	7
y	☼	8	9	10	11	♀	12
e		18	29	11	22		3
y	13	14	15	☿	16	17	18
e	14	25	6		17	28	9

Mar XXXI	1	8	15	22	29	Nov XXX
Aug XXXI	2	9	16	23	30	Aug XXXI
May XXXI	3	10	17	24	31	Ian XXXI
Oct XXXI	4	11	18	25		Oct XXXI
Apr XXX	5	12	19	26		Iul XXXI
Sep XXX	6	13	20	27		Dec XXXI
Iun XXX	7	14	21	28		Feb XXVIII

Fig. 5. Part of the calendar from Henry Wynne's Staunton Harold dial (DH-36).

Moon. The day commenced at sunrise and the day was ruled by the deity of the first hour. Starting with Saturn as the first hour (Saturday), the hours ran three times through the sequence of seven and three extra hours so that the last hour was Mars. Continuing the sequence the first hour of the next day would be Sun and the day was called Sunday. Another seven plus three makes the first hour of the following day Moon (Monday). This continues for the seven weekdays, but in the English language the names of the other four weekdays for Mars, Mercury, Jupiter and Venus are derived from their Anglo-Saxon equivalent planetary deities Tui, Woden, Thor and Freya.

Some large dials by Henry Wynne comprehensively expand the year-weekday table to include every year over a certain range. Part of such a table, reproduced from a modern replica of a Wynne dial[4] is shown in Fig. 5, running on from 1685, the probable date of the original dial. Here it is seen that a day in every year associated with a weekday. There is a gap at every fourth year when a day is given by both its name and its symbol. The significance of this arrangement is that the weekdays with a year are those of March 1 and the intervening days without a year represent the leap day of February 29, 'between the years' as it were. The method of obtaining the day of any date is the same as that already explained.

Other information is given by Wynne's table. The capital letters at the head are the *dominical letters*: if the sequence of days in a year is cyclically labelled A to G starting on January 1, the letter which stands against Sundays is the dominical letter for that year. The dominical letter steps back by one letter from year to year, but no letter is placed against February 29 in leap years. If such a year is taken to start on January 1 it therefore has two letters, the first for use in January and February and the second for the succeeding months. By starting the year on March 1, dialmakers have avoided this complication and the first letter is omitted. The dominical letter can also be used to determine weekday dates, although Wynne has not used it in this way. He does however use it to find the date of Easter.

The lower figures given for each year are the *epacts*, a device for finding the age of the moon. After a period of 19 years the phases of the moon fall on the same day of the year or one day earlier, depending on whether the interval includes 4 or 5 leap years. The Greek astronomer Meton is credited with this discovery in about 433 BCE and the relationship is called the *Metonic cycle*. It arises because 19 Julian years of 365.25 days are nearly the same as 235 lunations of 29·530589 days: the difference over 19 years is about 1½ hours. Before the 1582 Gregorian reform of the calendar, the moon's age was derived from the *Golden Number*, obtained by adding one to the remainder after dividing the year by 19. Tables were prepared giving the dates of new moon depending on the golden number but the relationship was fixed, making no allowance for the small error in the Metonic cycle. One of the uses of this was to determine in advance the dates of Easter, but due not only to the errors of the Julian calendar but also that of the moon's age from the golden number (about one day in 300 years) Easter was progressively drifting from the correct date. The Gregorian reform corrected the calendar and revised the means of finding the moon's age by the method of epacts: for any year the epact is the age of the moon on January 1 less one day. From year to year the epacts increase by 11: twelve lunations of 29½ days are 354 days, 11 short of a year. The complete series of epacts has 30 entries (0, 11, 23, 4, 15….19), adding 11 to the preceding epact and subtracting 30 if the sum exceeds 30. From this series, a sequence of 19 is selected so that the epacts also operate on a 19-year cycle, but periodically another sequence is chosen to keep in step with the true moon. Necessary changes are made in centennial years and were made in 1700 and 1900. The next one will be in 2200. The dates of new moons can be tabulated from the epacts but the rules are too complex to be simply expressed on a sundial. For his purpose Wynne adjusts the epacts by applying the correction back to the Julian from the Gregorian calendar and then gives the simple rule of adding together this modified epact, the date of the month and one extra day for every month starting with one for March, two for April and so on, then subtracting 30 or 60 days if necessary to find the age in the range 0 (new moon) to 29 days. About half the ages so found are correct and half are one day wrong. A few can be two days in error.

References and Notes

1. Ordway (1662).
2. Collins (1659).
3. Anthony Turner (1987).
4. Davis & Lowne (2003). Reprinted on p.41 of this monograph.

AN UNUSUAL DOUBLE HORIZONTAL SUNDIAL

GENERAL DESCRIPTION

Although this instrument (AD-1) may certainly be classed as a double horizontal sundial because it has a polar gnomon dial and an azimuth dial using a stereographic projection, the method of obtaining the azimuth of the sun differs from the conventional instruments as devised by William Oughtred. Instead of a vertical gnomon to give a shadow indicating the azimuth, it has two rotatable alidades (one east and the other west of the gnomon) which can be pointed at the sun. Then the time can be read at the point where the edge of the alidade intersects the declination line for the current date, in the same way as for the shadow of a vertical gnomon. The alidades are calibrated for the sun's altitude, which may also be read at the intersection point.

One obvious difference of the dial from the usual instruments is that the stereographic projection is in the same orientation as the sky, instead of turned through 180º. This arises because the alidades are directed to the sun, not opposed as with the gnomon shadow.

From the gnomon angle and analysis of the stereographic grid, the dial is made for a latitude of 51º 30'. Taylor[1] has given a description of the dial which has been of use in the preparation of this note.

DETAILS

A photograph of the dial on its pedestal (which now leans slightly from the vertical) is shown in Fig. 1 and a closer view in Fig. 2. A plan view of the dial plate with the gnomon removed is in Fig. 3. The dial is octagonal, about 590 mm between corners. It is oriented so that angles of the octagon are north-south and east-west, rather than the more usual position with the sides towards these directions.

From the periphery inwards the features are:

A polar dial graduated IIII-XII-VIII hours divided to 3- and 5-minute intervals, numbered in 10s with half-hours identified by an attenuated fleur-de-lis. The numerals are oriented to be read looking from the centre.



Fig. 1 (left). The dial on its slightly leaning pedestal.

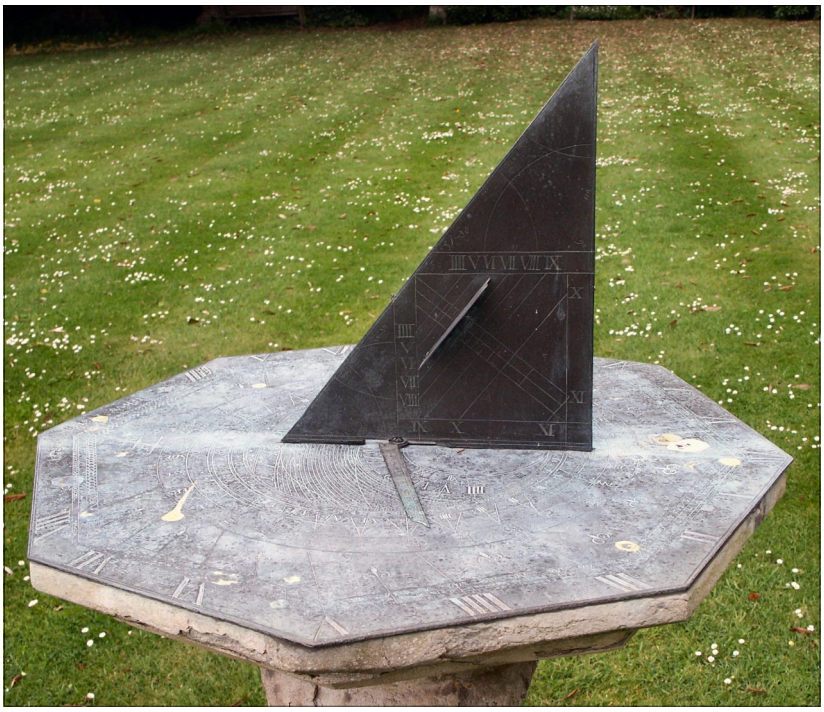


Fig. 2. A close-up of the dial from the east.



Fig. 3. The dialplate with gnomon removed.

Next inward comes a 32-point compass rose, with each point labelled. Transversals divide the points into quarters, thirds and halves. Radial lines at each point are accompanied by a calibration which effectively divides the circle into 24 parts, numbered in a 2×12-part sequence. For this there is an inelegant mix of Roman and Arabic numerals which run from XII at the north and south points and then increase clockwise by increments of three-quarters of a unit at each point so that they read XII, ¾, I½, II¼, III….. to XI¼ and start again at XII. The purpose of this scale is not clear: superficially it seems like a time scale but the only locations where the time of day would nearly correspond with the bearing of the sun would be at very high northern latitudes (not at the pole itself, where every direction is south!). The azimuth circle comes next, graduated in degrees numbered in 10s with zeroes at the east and west points and 90º at the north and south. An elaborate fleur-de-lis is at the north point.

The stereographic projection has unlabelled lines of declination at 2° spacings, (1½º for the 22-23½ interval). Hour lines are labelled IIII-XII-VIII on the tropic of Cancer and IX-XII-III on that of Capricorn. Only lines for integral hours are shown on the grid, but a scale outside the Cancer labels is divided to quarter-hours. Ecliptic arcs cross the projection from east to west, giving calendar months and marks for individual days with fifth and tenth days identified. Zodiacal sigils are shown at the commencement of each sign and the dates of the solstices and equinox are appropriate to the Julian calendar. The March equinox is at the west side and the September one at the east. Fig. 4 shows parts of one of the alidades, the compass rose, the azimuth circle and the stereographic projection.



Fig. 4. Parts of an alidade, the compass, the azimuth circle and the stereographic projection.

Place	No.	Noon	Time on grid	Implied Longitude	Actual Longitude
Bantam	59	XII	V	105° E	106° E
Surrat	54	XII	VI¾	79° E	73° E
Jerusalem	-	XII	IX½	37° E	35° E
Tenarif	22	XII	I½	22° W	16° W
Port Royal	4	XII	V	75° W	77° W
Mexico	47	XII	VI½	98° W	96° W

Table 1. The inscriptions on the centre of the dial.

At the centre of the area not occupied by the stereographic projection is a small unlabelled 16-point compass rose, part of which is under the gnomon. Just outside this are six place names, three on each side of the gnomon with Arabic numerals adjacent, then a ring of numerals XII in line with each name. These line up with the hour calibrations on the stereographic grid. The interpretation of these is that the times following the XIIs are the local times at the named places when it is noon at the dial location, depending on the longitude difference. Table 1 shows in sequence from the centre: the names, the numbers, the XII numbers, the times on the grid, the corresponding longitudes and modern longitudes for comparison.

Bantam is now Banten in Java and Surrat is Surat, India. Mexico is taken to mean a coastal port, perhaps Veracruz. Four of the longitudes are a reasonable match to the modern values. An error of 6º is not surprising for Surat, but Tenerife ought to have been better.

There is no obvious explanation for the figures which follow the place names. If the figure of 4 for Port Royal is a mistake for 40, the values correlate approximately with distances from England. It may be significant that the one inland location (Jerusalem) does not have a figure, suggesting a nautical connection for the others. One possibility which has been considered is that they are intended to represent the durations in days of sailing to or from England, excluding intermediate stops. On this assumption the average speed to the eastern ports would be about eight or nine knots, too fast for a merchant ship of the period, and to the western ones about four knots, probably still too fast. When Edmond Halley travelled to St Helena in 1676 the journey on an East India Company vessel took three months, an average speed allowing for stops of less than three knots. Another explanation could be that the figures are the expected duration in weeks of round voyages to those places and back to England. Assuming that perhaps a quarter of the total time of absence would be spent at intermediate ports and the destination, the average sailing speed is about three knots for the eastern ports but only two knots or less for the western ones. This is perhaps a better agreement with the speed of Halley's journey, but the figures remain a mystery.

The nautical connection is continued by some designs on the dial face, shown in Fig. 5. There is a cross-staff with a hand and a profile of the face of an observer using it. The instrument is shown with three cross-staves in use: in fact only one would be used at any one time. Curiously, the observer is shown wearing a conical hat with a tassel, rather like a night-cap or jester's hat. The motto 'TEMPVS FVgIT' (with a small g) is accompanied by an hour-glass with wings: time caught in the act of flying! Sand-glasses of appropriate periods were used to time the watches on shipboard and also in streaming the log-line to determine the speed by counting the knots on the line which pay out in the timed interval. The first owner of the dial was perhaps a merchant trading to the named places, or a retired sea captain nostalgic for places he had visited in his career.



Fig. 5. Details of the cross-staff area.

The two alidades pivot at the centre of the stereographic projection, underneath the polar gnomon, as can be seen in Fig. 3, and are divided to one degree intervals. It seems unlikely that an alidade could be pointed accurately at the sun's bearing: this could only be done by noting the coincidence with its own shadow. With the blade nearly in contact with the dial surface, this would not be a precise indication. It is possible that they are intended to derive the altitude and azimuth of the sun by setting the edge of the blade to the intersection of the vertical gnomon's shadow and the appropriate declination line. The altitude is read at the intersection and the alidade points to the azimuth.

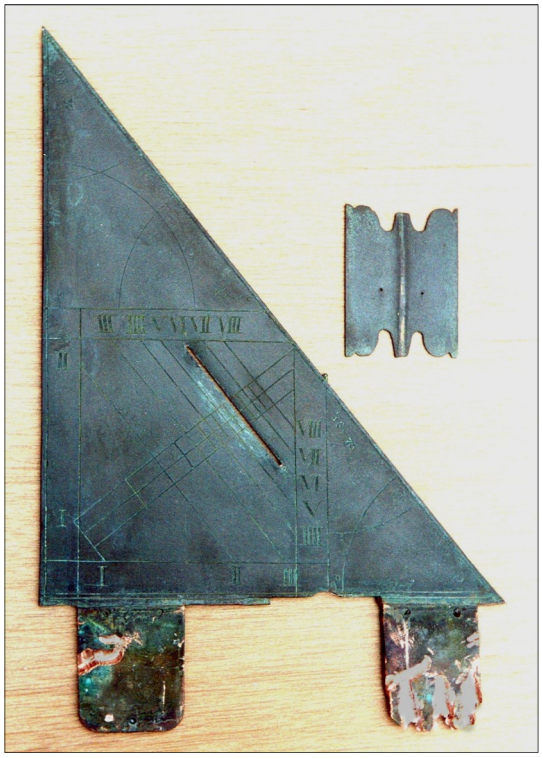


Fig. 6. The west face of the gnomon.

The gnomon is a right-angled triangle, length 385 mm along the hypotenuse. It carries figures indicating the latitude of 51º 30' and the co-latitude (38º 30'). On the sides of the gnomon are direct east and west polar dials divided to half-hours, the east one graduated IIII-XI and the west I-VIII. The west face of the gnomon is shown in Fig. 6, together with the dismounted small gnomons for the polar dials which fit in a slot visible in the figure. The rebate to allow the alidades to pivot under the gnomon is visible, and the two tenons to secure it to the base plate.

The dial appears to have been in its present location in the Maidstone area for at least a hundred years and possibly longer. It is of early seventeenth century appearance, but no date or maker's name is given; the only indication is the letters 'J L' visible in Fig. 5, which are perhaps more likely to be the original owner's initials. Without this information, it is not possible to say whether the dial was a precursor of the usual double horizontal dial, the maker's idea of an improvement on it, or an independent development.

A Similar Dial

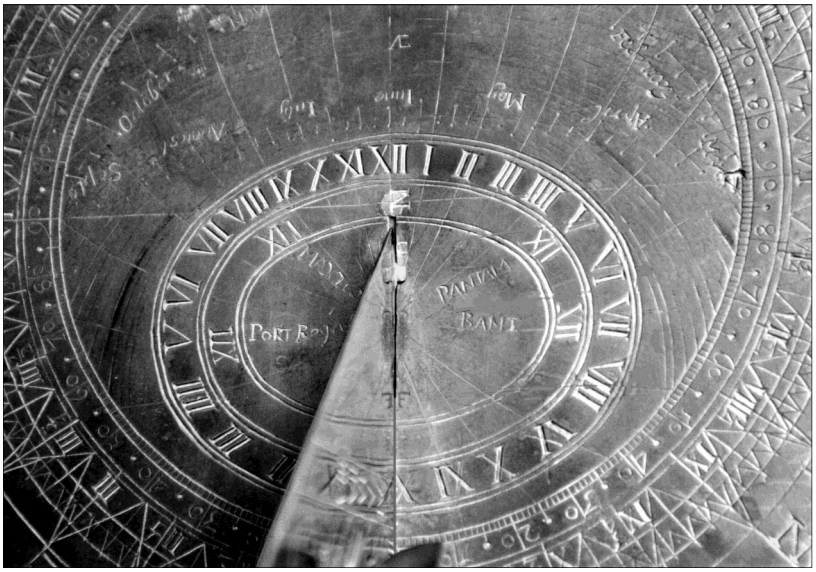


Fig. 7. A similar dial in the West Country (AD-2).

A similar although slightly smaller dial, AD-2, (partly shown in Fig. 7) is at a location near Bath. It has many features in common with the other dial: horizontal polar and azimuth dials, compass rose, azimuth circle, some place names and east and west polar dials on the gnomon. There are differences in detail. The polar dial chapter ring is divided to 3 minutes and 7½ minutes (⅛ hour) and the zeroes for the azimuth circle are at the north and south points with 90° at east and west. There is no separate scale to sub-divide the stereographic projection hours, which are labelled only along the tropic of Cancer. Rather curiously, the Roman numerals for this run through the full 2×12-hour sequence, although only IIII-XII-VIII are needed. Four place names are shown in the dial centre, three of which (BANTAM, PORT ROYALL and MEXICO are common to the other dial. The fourth place (BANT or BA-NI) is not identifiable.

Presumably alidades were fitted but are now missing. Their probable pivot location is indicated by an apparent filled hole on the dial-plate near the gnomon point which carries a letter Z or a sideways N.

The available photographs of the dial do not include that area where the other dial has the nautical symbols. The absence of any maker's name or date again precludes any conclusions about its origin or whether one dial was copied from or influenced by the other.

REFERENCE:

1. G. Taylor J. Brit Astr. Ass. 84,8 (1974).

THE STAR PLACES ON DOUBLE HORIZONTAL DIALS AND OTHER INSTRUMENTS

Some of the instruments described in the monograph carry the names of stars and their celestial coordinates, in Right Ascension (RA) and declination (dec). The primary purpose of these appears to be for time-finding at night but they may have had other uses, for example in surveying or navigation. Eleven instruments (eight double horizontal dials and three horizontal quadrants) have legible star names, with variable numbers of stars listed, ranging from 46 on HQ-7 to only 6 on DH-22. They are identified either by their proper names or by their positions in the mythological depictions of the constellations, in Latin (sometimes abbreviated) or English.

Table 1 lists the eleven instruments and the fifteen stars which are most commonly used, occurring on four or more instruments. The first column is the modern designation of each star and its magnitude, the second the proper name, the third the RA and dec for epoch 1650. Each instrument is identified by the maker's name and the serial number in the Catalogue and notes the coodinates which are given, followed by the star names or identities transcribed from the instrument.

The star designation comprises a Greek character and a three-letter abbreviation for the constellation name. The Greek letters were assigned by Johannes Bayer (1572-1627) in 1603 and generally but not always follow the alphabetical sequence in order of decreasing brightness. Their convenience meant their rapid adoption by astronomers but not, it would appear, by dial-makers. Of the star identifications, 'Os Ceti' is the 'jaw of Cetus', 'Oculus Tauri' is the eye of Taurus, 'Cingulum Orionis' is the central and brightest star of Orion's belt, 'Lucida Lyræ' is the brightest star in Lyra (Vega) and 'Ala Pegasi' is the wing of Pegasus, the flying horse. The last row of Table 1 shows the number of stars (those with three or fewer occurrences) which have been omitted: to include them all would have made the Table unwieldy. Six of the eight DH dials have twelve stars, mostly selected from the fifteen stars shown in the Table.

All the stars used are plotted in Fig. 1, in order of their RA, with the number of entries shown by the height of the lines. The brightness of the stars is colour-coded, red for the brightest (brighter than magnitude 1.5), green for stars

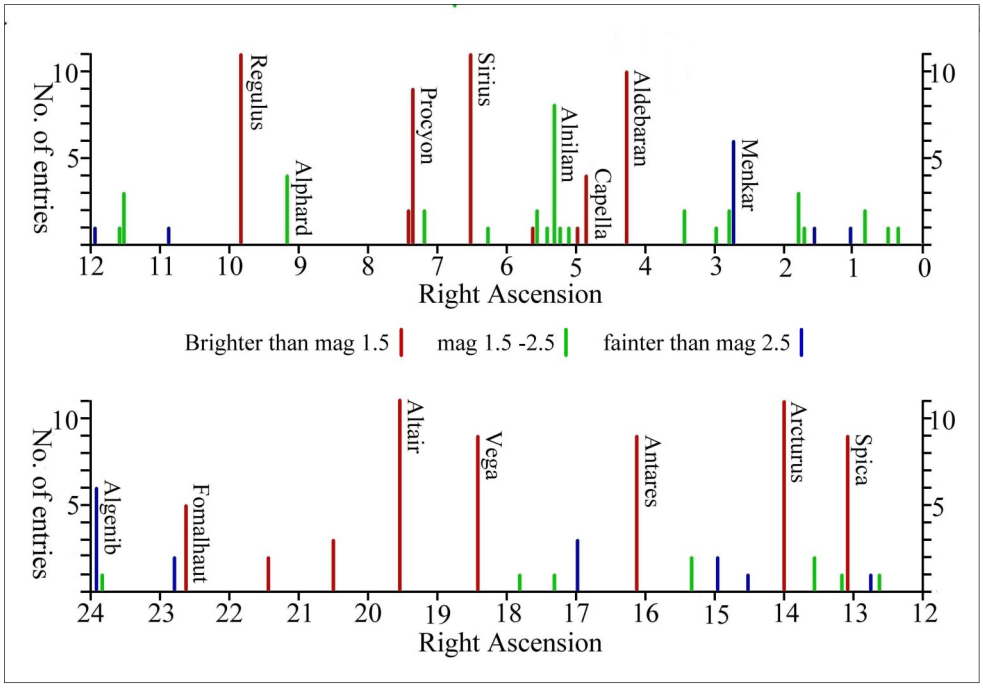


Fig. 1. The Right Ascensions of all the stars used.

Desig[nation] Mag.	Proper name	1650 RA/Dec Coord.	E.Allen DH-3 RA	Gray DH-22 RA	Wynne DH-34 RA	Wynne DH-36 RA	Wynne DH-37 RA	Anon DH-42 RA	Marke DH-59 RA	Sutton DH-61, 62 RA	J.Allen HQ-1 RA, dec	Sutton HQ-2 dec	Brown HQ-7 dec,PD,RA
α Cet 2.5	**Menkar**	**2h:44m +2°:42'**			Os Ceti	Os Ceti	Os Ceti	Os Ceti	Os Ceti	Os Ceti			
α Tau 0.8	Aldebaran	4:16 +15:46	Bull's Eye	Aldebaran	Oculus Tauri	Oc Tau	Oc Taur	Oc Taur	Oc Taur	Oc Taur		Oculus Tauri	Bulles Eye
α Aur 0.1	Capella	4:51 +45:35	the Goate			Hircus						Hircus	Goate star
ε Ori 1.7	Alnilam	5:19 -1:27			Cingulum Orionis	Cm Ori	Cin Orio	Cin Ori	Cin Ori	Cin Ori		Med in Cing Orion	Orions girdle
α CMa -1.5	Sirius	6:30 -16:13	Great Dog	Sirius	Canis Major	Can Maj	Can Maj	Can Maj	Can Maj	Can Maj	Can mai	Canis Major	Great dogge
α CMi 0.4	Procyon	7:21 +6:06			Canicula	Canicul	Canicul	Canicul	Canicul	Canicul	Can min	Canicula	Lesser dogge
α Hya 2.0	Alphard	9:11 -7:08				Hidra					Cor hid	Cor Hydr	Hydra brightest
α Leo 1.4	Regulus	9:50 +13:39	Lion's heart	Cor Leonis	Cor Leonis	Cor Leo	Cor Leon	Cor Leo	Cor Leon	Cor Leon	Cor ♌	Cor Leon	Lion's heart
α Vir 1.0	Spica	13:07 -9:16			Spica Virginis	Spic Vir	Spic Vir	Spic Vir	Spic Vir	Spic Vir	Spica ♍	Spica	Virgins Spike
α Boo 0.0	Arcturus	14:00 +21:04	Arcturus	Arcturus	Arcturus	Arctur	Arctur	Arctur	Arctur	Arctur	Arct	Arctur	Bootes thighs
α Sco 1.0	Antares	16:08 -25:34	♏ heart		Cor Scorpy	Cor Scor	Cor Scor	Cor Scor	Cor Scor	Cor Scor		Cor Scorpy	Scorpions heart
α Lyr 0.0	Vega	18:25 +38:30	Harp Star		Lucida Lyræ	Lu Lyr	Lu Lyra	Lu Lyra	Lu Lyra	Lu Lyra		Lyra	Harpe brightest
α Aql 0.8	Altair	19:34 +8:00	Vultur	Altair	Cor Vulturis	Cor Vult	Cor Vult	Cor Vult	Cor Vult	Cor Vult	Aquila	Cor Vulturis	Eagles heart
α PsA 1.2	Fomalhaut	22:38 -31:23	Fomahaut		Fomahant	Fomalha		Fomaha				Fomahaut	
γ Peg 2.8	Algenib	23:55 +13:15		Ala Peg			Ala Peg		Ala Peg	Ala Peg	Ala Peg	Ala Pegasi	
		No. other stars	3			8					2	9	34

Table 1. The eleven instruments and the fifteen stars most commonly used.

of magnitude 1.5 to 2.5 and blue for stars fainter than magnitude 2.5. The fifteen stars of Table 1 are identified by their proper names. Ideally, of course, the dial-maker would have liked his selection of stars to be uniformly distributed around the sky (the use of twelve stars needs spacings of two hours in RA) but the brighter stars are not so conveniently placed. Around 4 to 7 hours RA, the constellations of Taurus, Orion, Canis Major, Canis Minor and Gemini provide many bright stars, but in other areas bright stars are sparser and unevenly distributed. Nevertheless, makers have in general managed to achieve good coverage with no unduly large gaps. The faint stars with only one entry shown are mostly the 34 unlisted stars on HQ-7.

The choices of some of the fainter stars seem to have been determined by ease of identification on the sky. For example, Alnilam is readily picked out by its central position in the distinctive pattern of the line of three stars in Orion's belt, and Algenib is the lower left star in the Square of Pegasus. Menkar is the brightest star in a quadrilateral and Alphard has no comparable star nearby (its name means 'the solitary one').

It is difficult to understand why stars at high or low declinations were included on the quadrants. Capella, Antares and Fomalhaut have declinations which place them outside the tropics and therefore cannot be plotted on or used with the stereographic grid. Possibly they were intended for some unknown purpose.

Time Determination from the Stars on Horizontal Quadrants

The primary purpose of the stars on the horizontal quadrants appears to have been for finding the time at night. One method of achieving this is given by Delamain (1632) which in modern terms is

$$\text{Local solar time} = (\text{RA}_{\text{star}}) \textit{ minus } (\text{RA}_{\text{sun}} \pm 12^{\text{h}}) \textit{ plus or minus } (\text{hour-angle}_{\text{star}}).$$

At midnight, the sun is at its lower meridian transit (below the horizon due north) and adding 12^{h} to its RA gives the sidereal time at midnight. Subtracting this from the star's RA (the sidereal time when the star will be at upper transit) gives the time interval between midnight and star transit which (disregarding the 4^{m}/day acceleration of sidereal time over solar time) is the solar time of star transit. If $(\text{RA}_{\text{star}})$ is less than $(\text{RA}_{\text{sun}} \pm 12^{\text{h}})$ add 24^{h} to $(\text{RA}_{\text{star}})$. In the final step, if the star is east of the meridian it has not reached transit and the hour-angle is subtracted to derive the local solar time. If west, the meridian has been passed and the hour-angle is added.

All the required quantities can be derived from the instrument. RA_{sun} is read from the hour lines at the position on the ecliptic corresponding to the current day on the date scales. To find $(\text{hour-angle}_{\text{star}})$ it is necessary to know the star's declination as well as the RA which are either engraved or plotted on the grid. The hour-angle (measured in time units east or west of the meridian) is found from the observed altitude of the star in conjunction with its coordinates.

As the quadrant effectively folds the whole sky into four, prior knowledge of the approximate RA of sun or stars is needed to determine this coordinate correctly. The rules to give RAs in the 24-hour system are:

RA 0^{h}-6^{h} (Mar11-Jun 11): read the positions right-to-left on the Roman numerals and subtract 6^{h}.
RA 6^{h}-12^{h} (Jun 11-Sep 13): read the positions left-to-right on the Arabic numerals and add 6^{h}.
RA 12^{h}-18^{h} (Sep 13-Dec 11): read the Roman numerals and add 6^{h}.
RA 18^{h}-24^{h} (Dec 11- Mar 11): read the Arabic numerals and add 18^{h}.

In the case of the sun, confirmation can be obtained from the zodiacal sigils which are generally engraved along the ecliptic. Near the solstices, it would be difficult to obtain the accurate RA of the sun because the daily change of declination is small. It could be estimated by taking the RA to be 6^{h} on June 11 and 18^{h} on December 11 and subtracting four minutes for every day before, or adding four minutes for every day after, these dates.

The time-finding procedure is:

1. Measure the altitude by sighting the star through the apertures in the sights, allowing the plummet to hang freely.

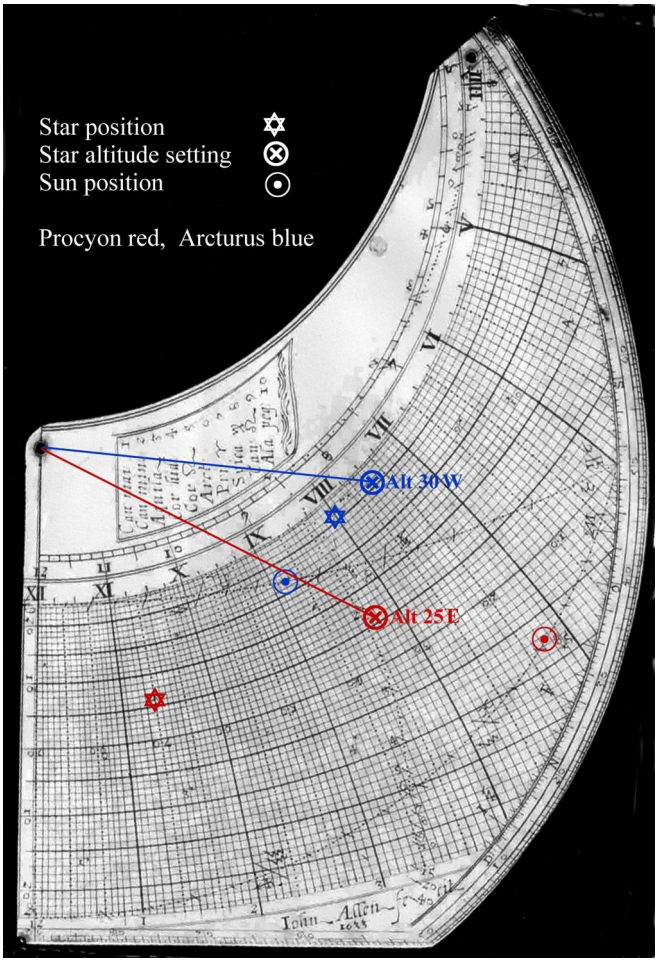


Fig. 2. Quadrant by John Allen with star and sun positions.

2. Transfer the altitude reading to the grid using the plummet, matching the altitude scale to the declination of the star, either as it is plotted or found from the given places. Read the time scale at the intersection point, using the Arabic numerals. This is (hour-angle$_{star}$).
3. Find RA$_{star}$ from the position given or plotted on the grid.
4. Find RA$_{sun}$ by locating the required date on the calendar scale and following the declination on which this falls to meet the ecliptic. Add or subtract 12^h as necessary to keep the midnight sidereal time within 0-24^h.
5. Subtract the result of step 4 from RA$_{star}$ and add or subtract to the result (hour-angle$_{star}$) from step 2. The sum (diminished by multiples of 24 hours if it exceeds this) is the local solar time in the 24-hour system. For time in the 2×12^h am-pm. system, subtract multiples of 12^h.

Although the finding of the star's altitude can be done in darkness, the remaining operations would need to be done in artificial light. It would also be advisable to write down the three derived values to facilitate the arithmetic!

In Fig. 2 and Table 2, the quadrant by John Allen (HQ-1) is used to illustrate the method. In this instrument the star coordinates are not given but their positions are plotted on the grid. The symbols on Fig. 2 show the derivation of the various values.

Symbols	Red	Blue	Blue
Date	October 1	July 27	April 27
RA$_{sun}$	13:10	9:08	2:52
Star	Procyon	Arcturus	Arcturus
Altitude	25°, E	30°, W	30° W
RA$_{star}$	7:20	14:01	14:01
RA$_{star}$ + 24^h		38:01	38:01
RA$_{sun}$ ± 12^h	1:10	21:08	14:52
Difference	6:10	16:53	23:09
Hour-angle$_{star}$	-3:47	+4:32	+4:32
Local solar time	2:23	21:25	3:41
Calculated time	**2:27**	**21:29**	**3:36**

Table 2. Derivations of solar time from the John Allen quadrant.

The agreement between derived and calculated times is much as expected, in view of the possible errors in setting and reading the quadrant and the fact that the sun's RAs are average values over the leap year cycle. The two columns for Arcturus are complementary in the sense that the declination of the sun is the same on both dates and therefore the sun symbol on Fig. 2 serves for both, but the values of RA$_{sun}$ are different.

Time-Telling from Stars on a Double Horizontal Dial

In this case the instrument is not adapted for measuring the star's altitude to derive the hour-angle. For those dials on which star RAs are given, these can be used for time-telling, if one of the given stars is on or near the meridian. In this case there is no correction for the star's hour-angle and the equation becomes:

Local time = (RA$_{star}$) *minus* (RA$_{sun}$ ±12^h)

If the star is not quite upon the meridian the time difference can be estimated and subtracted from the local time if east or added if west.

The sun's RA is derived from the dial in much the same way as outlined above but here east and west directions from the meridian are depicted separately and it is easy to see from the zodiacal sigils which value is required. One method of finding the sun's RA is to ignore the time figures and count hours forward from the March equinox to September and then back to March. The time values on the dial can also be used to derive the RA:

RA 0^h-6^h (Mar11-Jun 11): subtract 6^h.
RA 6^h-12^h (Jun 11-Sep 13): subtract from 18^h.
RA 12^h-18^h (Sep 13-Dec 11): add to 6^h.
RA 18^h-24^h (Dec 11- Mar 11): add to 18^h.

On dials of the Allen type, finding the RA is straightforward since the RA will correlate with the date scale on the ecliptic. Several dials (even some without star places) carry the RA of the sun engraved in small figures along the equatorial line. Part of the dialplate of DH-3 (by Elias Allen) showing the small RA figures is given in Fig. 3.



Fig. 3. Part of double horizontal dial DH-3 by Elias Allen, showing Right Ascension values along the equatorial line.

Clearly, the dial figures could not be read by starlight, but it would be possible to memorise the midnight sidereal time and the RAs of a few stars visible at that season.

DIALS WHICH APPEAR TO HAVE THE STEREOGRAPHIC PROJECTION

The early dialling literature contains mentions of dials with diagrams which appear misleadingly like the stereographic projection at first inspection.

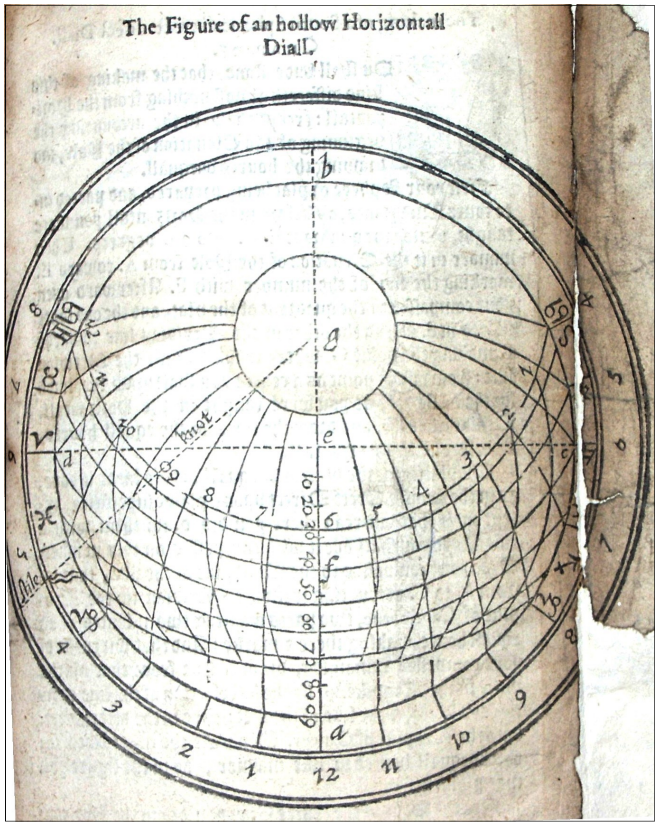


Fig. 1. Drawing of a horizontal scaphe dial from Fale.[1]

A drawing by Fale[1] (Fig. 1) seems to show a stereographic projection but the accompanying text makes it clear that this represents a horizontal hollow hemispherical scaphe dial and is a schematic view of the interior, from a point vertically above the centre of the horizon circle. The differences from a stereographic projection are that there is no radial change of scale, as is shown by the evenly-spaced solar altitudes which are marked along the meridian, and the declination lines do not meet the hour lines at right angles. If the view had been taken from a point at a distance equal to the dial radius above the centre of the horizon circle it would have been a stereographic projection! Fale also shows a vertical scaphe dial (Fig. 2). Both dials include hour lines for the equal Babylonian hours starting at sunrise.

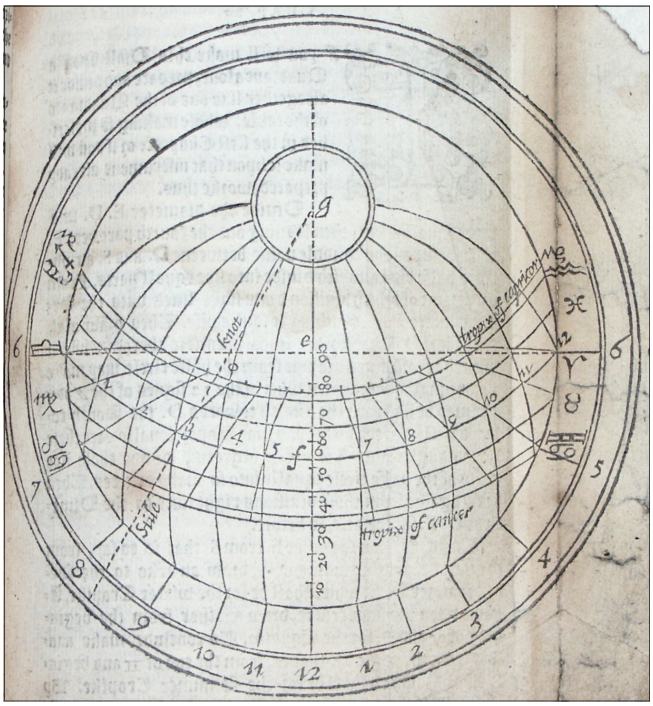


Fig. 2. Drawing of a vertical scaphe dial from Fale.[1]

Fig. 3 is a drawing from a manuscript which was found in the collections of Lund University Library, written in Latin by an anonymous author (possibly based in Nuremburg or Vienna) and dated 1477-1505.[2] There is a resemblance to a stereographic projection but it is only superficial. The hour lines are straight, not curved, lines for times 12 hours apart are not continuous through their origin, and the declination

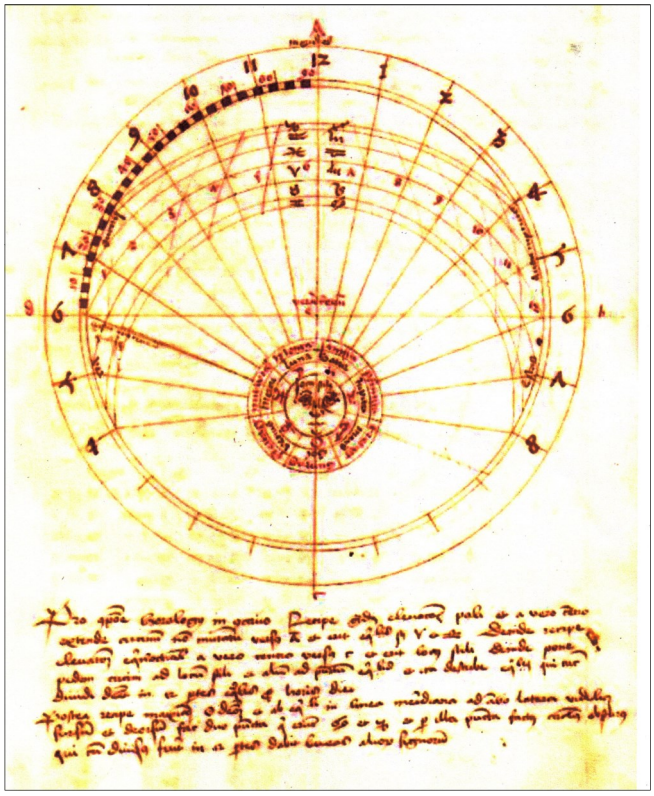


Fig. 3. The drawing from the Lund library MS Medeltidshandskrift 47.

lines are concentric with the origin of the hour lines. Apparently the hour lines were drawn by connecting equally-spaced intervals of 15º of azimuth on the horizon to the pole, which has caused their spacing to increase at angles further from the meridian. Alternate declination arcs were drawn from the intersection points of hour lines with the horizon, which has given horizon azimuths approximately correct for a latitude around 49º. The diagram is unlikely to be a representation of a plane sundial and it is most probably a highly schematic view of a horizontal scaphe dial. It too has lines for the Babylonian hours.

REFERENCES

1. Thomas Fale: *Horologiographia – The Art of Dialling*, London (1593).
2. Anon.: 'Early dialling manuscript found', *BSS Bulletin* 18(iii) p.138 (September 2006).

THE 'TRIENS' BY CHRISTOPHER SCHISSLER

The sixteenth-century instrument-maker Christopher Schissler (c.1531-1608) of Augsburg produced many different scientific instruments in his working life: over one hundred examples of his prolific output are known. The example considered here, HQ-8, is called a 'triens' and is in the Germanisches Nationalmuseum, Nuremburg. It is an altitude dial using an unusual means of time-telling, and is based on a design by Peter Apian (see p.79). Signed and dated "CHRISTOPHORUS SCHISSLER FACIEBAT AUG ANNO 1569", the two faces are shown in Figs. 1 and 2. Both sides carry a note of the design latitude "PRO ELEVATIONEM POLI 47·48·49 GRADUS": Augsburg is 48° 26′. Don't overlook the charming engraving of an astronomer with outlandish headgear making measurements on a celestial sphere by moonlight. The side shown in Fig. 2 has scales which are beyond the scope of the current study. The sighting apertures for finding the sun's altitude are positioned on one of the straight edges.

The name 'triens' comes from the angle of the arc of the calibrations which occupies about 120 degrees or one-third of the complete circle. In Roman currency, the triens was a bronze coin worth one-third of the copper *as*.

Fig. 1 shows the side of the instrument to be used for finding the time. It would have originally been fitted with a plumb-bob and cord passing through the aperture at the centre of the projection and fitted with a sliding bead indicator. This is a stereographic plan of the sky but, whereas the usual type of altitude dial would carry hour lines and arcs of declination, here the hour lines are replaced with arcs which (on the sky) represent arcs of constant radii from the east or west points of the horizon. These arcs are drawn for every third degree and numbered both from the horizon point and in the reverse direction from the meridian. The angular distance of an arc from east or west point is referred to by Janin[1] as 'distancia' for which the symbol D is adopted here. The relation of D to the latitude, φ; the sun's declination, δ; altitude, a; and hour-angle, h, is expressed, using a subsidiary quantity P, by the equations:

$$\tan P = \cos\varphi.\sin\delta/(\sin a - \sin\varphi.\sin\delta)$$

$$\sin D = \sin a/\sin(90+P-\varphi) \quad (1)$$

$$\sin h = \cos D/\cos\delta \quad (2)$$

Eq. 1 derives D from the local circumstances of latitude, declination and altitude and Eq. 2 relates the hour-angle and hence the time to D and declination. Note that latitude does not enter into Eq. 2 as the east and west points of the horizon are common to all latitudes. On the projection, the distancia arcs are drawn centred on a line perpendicular to the meridian, passing from the centre through the east and west points. The distance of the centre of an arc from the projection centre is given by $R/\cos D$ and the radius r by $r = R\tan D$ where R is the triens radius from centre to horizon.

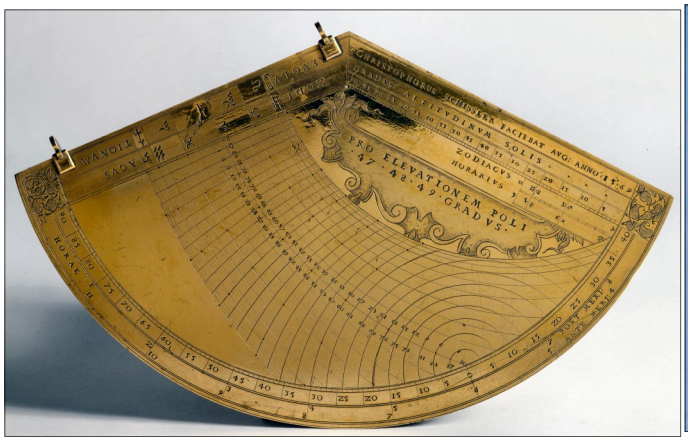


Fig. 1. The altitude dial.

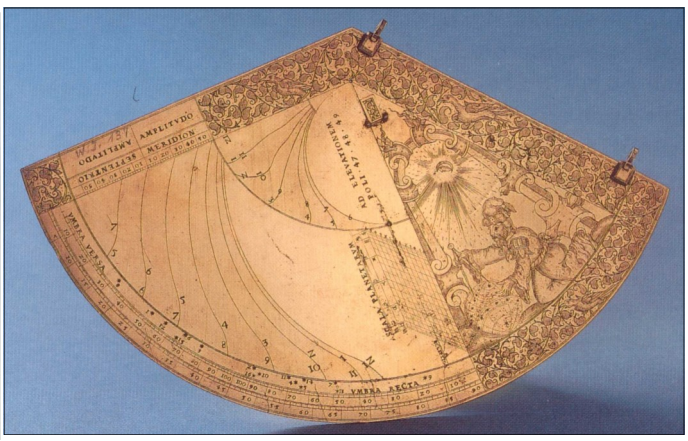


Fig. 2. The reverse side.

The declination arcs are drawn for the declination of the sun at its entry into each sign (ZODIACUS REVOLUTIONUM) and are divided into thirds (intervals of ten degrees of solar longitude or approximately ten solar days). Other scales include one for the altitude of the sun (GRADUS ALTITUDINUM SOLIS) and below this is another scale of signs of the zodiac (ZODIACUS HORARIUS) folded back upon itself at the equinoctial signs. The time scale is around the periphery, labelled with both morning and afternoon hours (HORAE ANTE MERI, HORAE POST MERI), uniformly spaced about the centre of the projection. Inside this is the altitude scale of degrees with zero at the 6am–6pm point. It is read from the cord hanging freely when sunlight is allowed to pass through one of the sighting apertures and fall on the other.

The method of use is given by Janin. It involves two settings of the bead on the cord.

1. The altitude as measured by the quadrant is transferred to the altitude scale and the sliding bead on the cord is set accordingly. The current position of the sun is selected on the arcs of the zodiacal signs, and the cord moved around until the bead rests on it. The calibration of the distancia arc at that position is noted.
2. In the second setting the cord is moved to the ZODIACUS HORARIUS scale and the bead set at the position of the current sun's sign.
3. The cord is stretched out straight and moved around until the bead rests on the distancia arc previously found.
4. The time is read on the hour scale around the periphery. Although the time scale is calibrated only in hours it is possible to obtain greater precision by reading the angle on the altitude scale, subtracting from 90º, converting to time and applying as an hour angle to 12 noon.

In step 1, the centre of the projection is the zenith but in step 2 it represents the pole of the sky. The steps correspond to Eq.1 and Eq. 2.

Fig. 3 shows an example of the dial in use. Suppose the sun's altitude is measured as 20° when the sun is just entering the sign of Taurus. The red symbols show the settings of the sun's altitude with the bead set on the altitude and meeting a distancia arc. The blue symbols indicate the bead set to the appropriate zodiacal position for sun's entry into Taurus and placed on the distancia. The indicated time is about 7:10am or 4:50pm The calculated times for these conditions are 7:07 and 4:53 at a latitude of 48º.

There is ambiguity in the positioning of the bead in step 2. The bead will meet the distancia arc in two places, as indicated by the smaller blue dot on Fig. 3, so that two time readings are possible, equally spaced either side of 6am or 6pm. In this instance it should be apparent which one is correct but at smaller values of *D* (shown by two green dots), it may not be obvious. The ambiguity is only present in summer months: from autumn equinox to spring equinox time values later than 6am or earlier than 6pm are the only ones possible. The ambiguity could be resolved by taking another altitude reading a few minutes later. The derived time value which gives a later time is the correct one.

Another difficulty can occur at low declinations of the sun and times within about three hours of noon. In step 2, it is possible for the bead to fall in the area of the projection where the distancia arcs are not drawn. They should have been continued out to the horizon circle.

Both this instrument and the more usual altitude dial procedure (of reading the time directly from hour lines at the intersection of the altitude and declination) suffer from increasing uncertainty around noon when the altitude changes only slowly with time, and are ambiguous between morning and afternoon times.

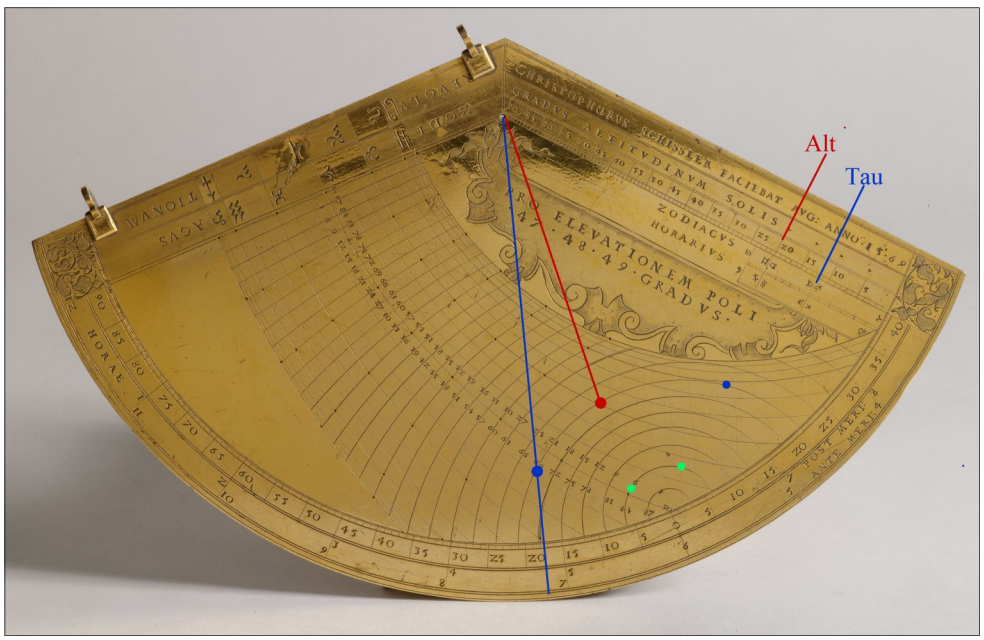


Fig. 3. Altitude dial with example of use.

REFERENCE

1. Janin (1979).

THE DOUBLE HORIZONTAL DIAL IN THE 20TH AND 21ST CENTURIES

After its heyday in the 17th and early 18th centuries, the double horizontal dial largely disappeared from the range of dials offered by mathematical instrument makers. The dials by Benjamin Scott (DH-26), Jonathan Gill (DH-19), Edward Hatton (DH-23) and Henry Sephton (DH-64 & 65) were made in the second and third decades of the 18th century and are the last of the great dials which can be confidently dated. One anonymous slate dial (DH-45) is probably of the 19th century and made by an amateur. During the 19th century, descriptions of the double horizontal dial disappeared from the literature even when the stereographic projection was explained for other purposes. It was not until the 20th century that there was a significant interest in old scientific instruments – particularly astrolabes – and the double horizontal dial began to make a comeback.

The Double Horizontal Dial in 20th Century Literature

The first signs of a revival of interest came with Robert Gunther[1] in the 1920s. In studying the *Early Science of Oxford*, he examined the instruments in the colleges there. Unfortunately, he is one of a number of authors who muddles the horizontal instrument with the double horizontal dial, describing the fine example of the former, then still at St John's College (HI-3), as a double horizontal.

In Cambridge, Robert Whipple (founder of the Whipple Museum) put together a significant collection of scientific instruments of all types, including horizontal instruments. In his 1930 paper,[2] he references Oughtred's instruction leaflet for the double horizontal dial.

In France, the great collector and writer on early instruments Henri Michel included the double horizontal dial and the horizontal instrument as part of his study of astrolabes. His *Traité de l'astrolabe*,[3] first published in 1947 and reprinted in 1976, explained the use of horizontal instruments and showed as examples a double horizontal dial by Henry Sutton (DH-49) and a Delamain's horizontal quadrant (HQ-1) which was described as "Allen's quadrant" on account of its signature. Again, the distinction between the horizontal instrument and the double horizontal dial was not made clear. Many of Michel's instruments eventually found their way, via Lewis Evans, to the Oxford Museum of the History of Science. However, his Sutton DH dial is not in the collection and its whereabouts have not been established.

In 1979, Louis Janin wrote[4] on astrolabes and sundials using the horizontal stereographic projection and used the Benjamin Scott dial (DH-26) as an example. He also pointed out the earlier use of the horizontal stereographic projection for time-telling instruments by Hartmann and Apian. Janin also illustrated what may be the first reconstruction of a double horizontal dial in modern times. This was by E Rouanet (M-20). It featured separate wire gnomons for the vertical and polar styles together with four levelling screws and a bubble level and was probably designed for indoor use. It also shows the design variation originating with Ozanam, common on many French reconstructions, that puts the polar-gnomon dial inside the stereographic grid rather than around the outside.

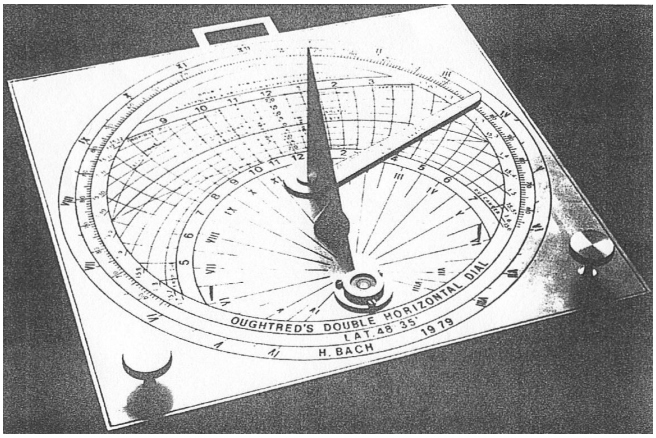


Fig. 1. A modern French double horizontal dial by H. Bach (after Rohr 1986).

René Rohr, in a French edition of his popular book *Sundials – history, theory, practice*,[5] also shows a demonstation version of a DH dial (M-1). It was made by H. Bach in 1979 for a latidude of 48° 35' N and is very similar to the Rouanet one as it features a central polar-gnomon dial, a rotating altitude alidade and levelling screws (Fig. 1).

A number of other publications in the second half of the 20th century mention "Oughtred's dials" either as parts of treatises on sundials or in catalogues of museum collections of dials and astrolabes. For example, Denis Savoie's 1997 *Gnomonique Moderne*[6] gives the basic equations for drawing a stereographic projection and D'Hollander's 1999 *L'Astrolabe, Histore, Théorie et Practique*[7] briefly mentions "Oughtred's double sundial" although he does manage to mis-attribute John Allen's horizontal quadrant HQ-1 to Elias Allen. James Morrison's comprehensive 2007 book *The Astrolabe*[8] gives full details on how to draw the horizontal instrument and the double horizontal dial as well as many other devices: it also shows a number of demonstration instruments (M-18, 26 & 27).

Of the books dealing largely with instruments in museums, Anthony Turner's *Early Scientific Instruments, Europe 1400-1800*,[9] and his catalogue of the now sadly dispersed Time Museum collection,[10] also have some illustrations, as does *Scientific Instruments*[11] jointly authored with Harriet Wynter.

The rise in interest in double horizontal dials right at the end of the 20th century (at least outside France) can be largely attributed to the papers by Sawyer[12] and Lowne[13]. These are republished elsewhere in this monograph.

Modern Dials

Modern DH dials generally fall into three categories. First, there are wood-and-paper models designed as demonstrators to show the principles of the device. These include the example by Lowne (M-3) shown on page 31 and those in Morrison's book.[8]

Then there are replicas or facsimiles of historic dials made to allow the valuable originals to be protected from weathering and theft. The two main methods of making replicas are either to make an exact facsimile from a silicone mould formed on the original, or to engrave a copy of the original into a brass blank. For the silicone mould method, the mould can either be used to produce an 'electrotype' by depositing copper in an electrolytic bath, or the dial can be made from resin loaded with very fine brass or bronze powder – a method sometimes called cold-cast bronze. An example of the former is the dial on public display at Wrest Park (M-6); the first replica of Henry Wynne's Staunton Harold dial (M-7) is an example of the resin technique. All examples of brass replicas (or 'reconstructions') currently known have used photo-chemical etching processes to engrave the design: examples are the 'Bacon' dial M-5 and the Henry Wynne second replica M-12, both described in detail in this monograph. It is proposed to complete (eventually!) the replica Tompion dial M-14 at Hampton Court Palace by hand engraving.

The third category of modern DH dials is for new designs made for use in gardens or other display purposes. These may be in the traditional material of brass but using modern engraving methods, or in totally different materials. A slate dial by David Brown Sundials is currently being planned (M-29).

All the dials known to the authors are catalogued in Part 4 of this monograph. Of particular significance is Joanna Migdal's 2009 dial M-23, believed to be the first hand-engraved double horizontal dial for nearly three centuries. Also, Malcolm Barnfield's M-15 is the first southern hemisphere double horizontal and also the first located within the Tropics.

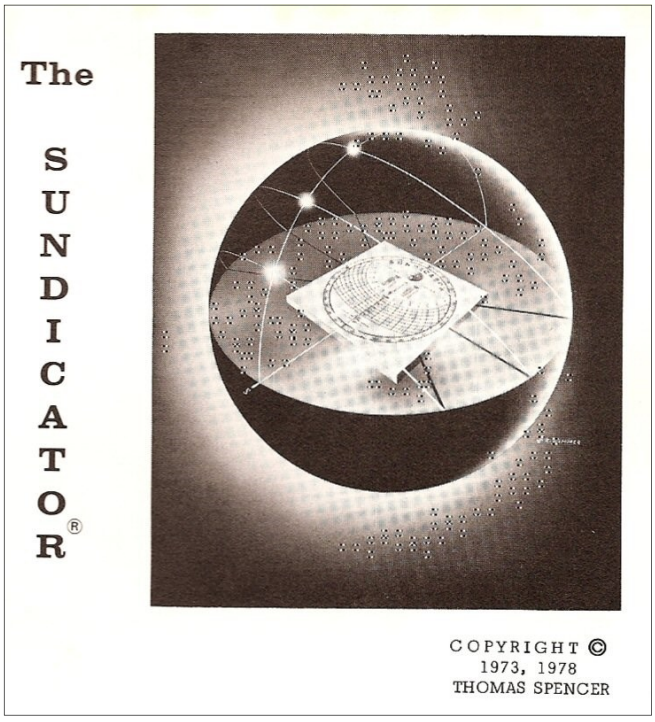


*Fig. 2. The **Sundicator** (M-28) as shown on the cover of its instruction manual.*

Other Instruments

The horizontal stereographic projection has found use in some modern instruments, particularly those used by architects, gardeners or photographers requiring a visible demonstration of the sun's course during the day at different seasons on the year. One instrument of this type is the ***Sundicator***® (M-28, Fig. 2).[14] This device was patented (1973) by Thomas Dickinson Spencer (d.1995), a retired US naval attaché, who produced a version in Plexiglass and distributed it commercially. Essentially it is a horizontal instrument with a clear rotating altitude index and a removable brass pin gnomon. One noteworthy point is that the declination lines (a total of 9) were drawn for pairs of calendar dates chosen to make the arcs approximately equi

-spaced. The resulting choices mean that the extreme values of declination shown are ±22.5° rather than the solstice values. Different versions were sold with inset magnetic compasses (and a table of the magnetic variation in a number of US cities) and as a 'Planetfinder', for use in conjunction with almanac tables. Sundicators are now rather rare.

Modern Developments

There have recently been some developments to Oughtred's original design. These have generally become possible only with modern computer design and drawing methods, or with modern machining. For example, the design by Jean Michel Ansel for Ludiver Observatory (M-25), replaces the traditional knife-edge vertical gnomon with a vertical cylinder of non-negligible diameter. As a result, the style edge casting the shadow moves around a small circle during the day so the lines of the grid – which now includes a noon gap – are no longer the simple circular arcs of a stereographic projection but require numerical calculation.

A dial by Tom Kreyche (M-8) also replaces the stereographic projection, this time with an azimuthal-equidistant one. Amongst the advantages claimed for this is the ability to display the periods of twilight when the sun is a known distance below the horizon (Fig. 3). Other developments, particularly focussed on showing the profile of the visible horizon, have been promised.

A Java program by Bradley Lufkin[15] includes the Oughtred dial amongst many other projections. The plotting routine includes a world map, also with a choice of projection,

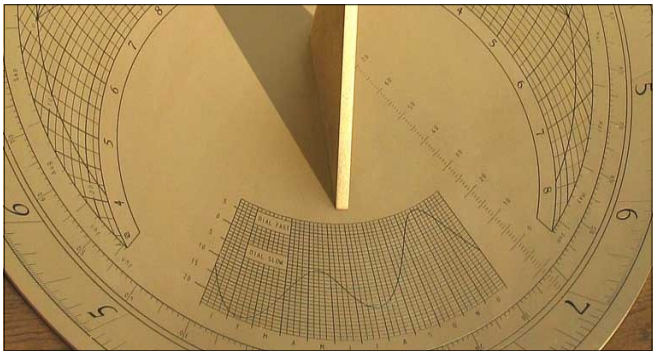


Fig. 3. Part of the projection of M-8 by Tom Kreyche, showing the extension of the projection (no longer stereographic) below the horizon.

so that a variety of 'geographic dials' can be drawn. The program allows the projection to be drawn either as a standard Oughtred dial or as a 'reverse Oughtred' so that it appears similar to the unusual designs AD-1 & 2 described on page 116. With this form, the location on the globe where the sun is directly overhead at any instant is directly displayed. The format opens possibilities for an interesting new class of 'geographical dial': two examples are shown in Fig. 4. Other options in the program allow the hour lines to be corrected for the equation of time, longitude, refraction and daylight saving time. Alternative hour lines for Italian or Babylonian hours can be produced so that the program reproduces the 16th century drawings of Georg Hartmann.

A very exotic development on the Oughtred theme has been described by Fer de Vries [16], reporting on an idea by Yvon Massé of France.[17] The design starts by projecting from the zenith instead of the normal nadir, i.e. it is like

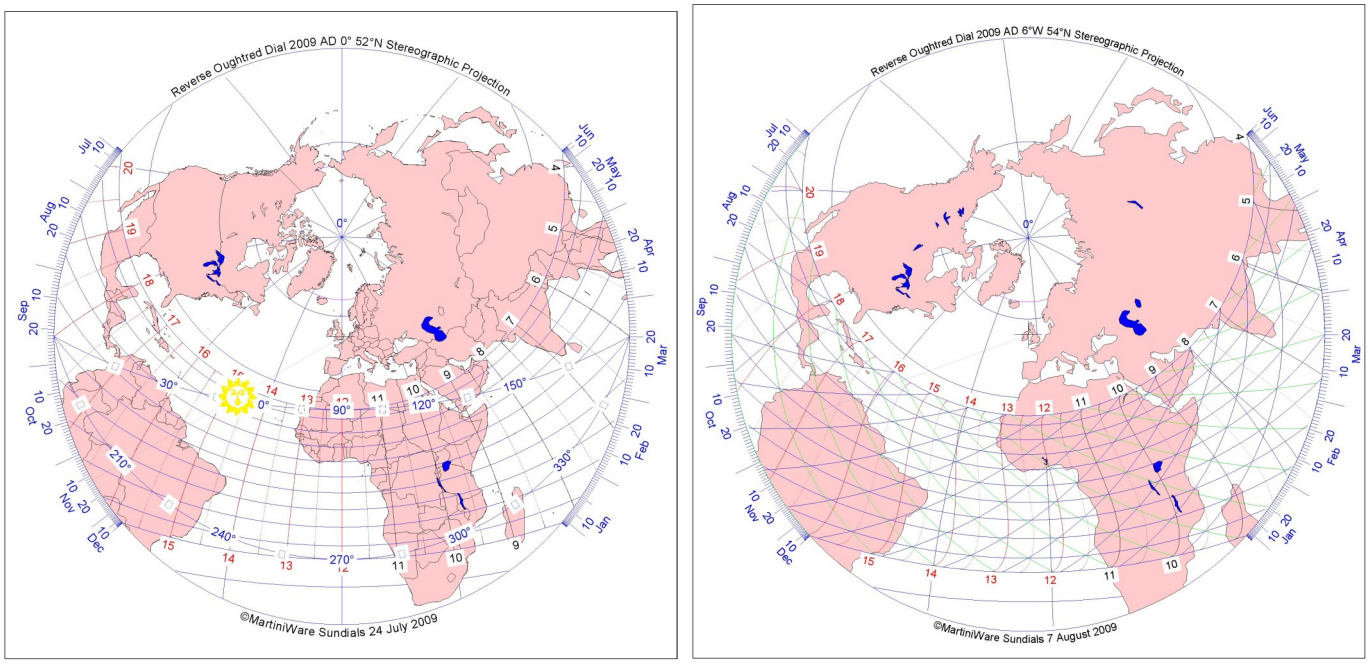


Fig. 4. Oughtred plots produced by Bradley Lufkin's Java-based routines. Left, a reverse (i.e. rotated by 180°) stereographic projection centred at 52° N on the Greenwich meridian and showing the sun's position on July 24. Right, projection centred on a location in Northern Ireland (54° N, 6° W), showing civil time (longitude and EoT corrections), plus Babylonian hours (blue) and Italian hours (green).

the "stereographic projection inverted" described by John Collins in 1658. It is then developed further by using an arbitrarily-sloped gnomon (in the meridian plane) whose angle is chosen, for example, to change the equinoctial arc into a straight line. It is unclear if any practical dials have been built using these schemes.

Conclusion

It is clear that the double horizontal dial is a very long-lasting device, being both practical and aesthetically attractive. It is pleasing to see the modern revival of interest in it and the many forms it is now taking. Traditionalists may prefer the early forms of the instrument lovingly hand-made by Elias Allen and his followers, but we also look forward to future developments!

REFERENCES AND NOTES

1. Gunther (1922).
2. Whipple (1930).
3. Michel (1947).
4. Janin (1979).
5. Rohr (1986).
6. Savoie (1997).
7. D'Hollander (1999).
8. Morrison (2007).
9. A. Turner (1987).
10. A. Turner (1985).
11. Wynter & Turner (1975).
12. Sawyer (1997). Reprinted p.20.
13. Lowne (2001). Reprinted p.25.
14. A scan of the instruction booklet for the *Sundicator* is currently online at the website of Dick Koolish, *http://www.dickkoolish.com/rmk_page/suncalc.html* where a Postscript program for plotting similar devices can also be found.
15. Lufkin, unpublished but distributed to members of the online Sundial Mailing List, (2009).
16. de Vries (2000).
17. see online article by Y. Massé: 'Un cadran horizontal à tracer à la règle et surtout au compass', at *http//pagesperso-orange.fr/ymasse/gnomon/hori2prc.htm*, (February 1999).



A portrait of William Oughtred by Wenceslaus Hollar (who also engraved the original portrait of Elias Allen). This engraving was used as the frontispiece of later editions of some of Oughtred's mathematics books and is also the basis of the later portrait of Oughtred shown on p.148. Compare this with the version shown as the frontispiece of this monograph.

THE
MAKERS AND THEIR DIALS

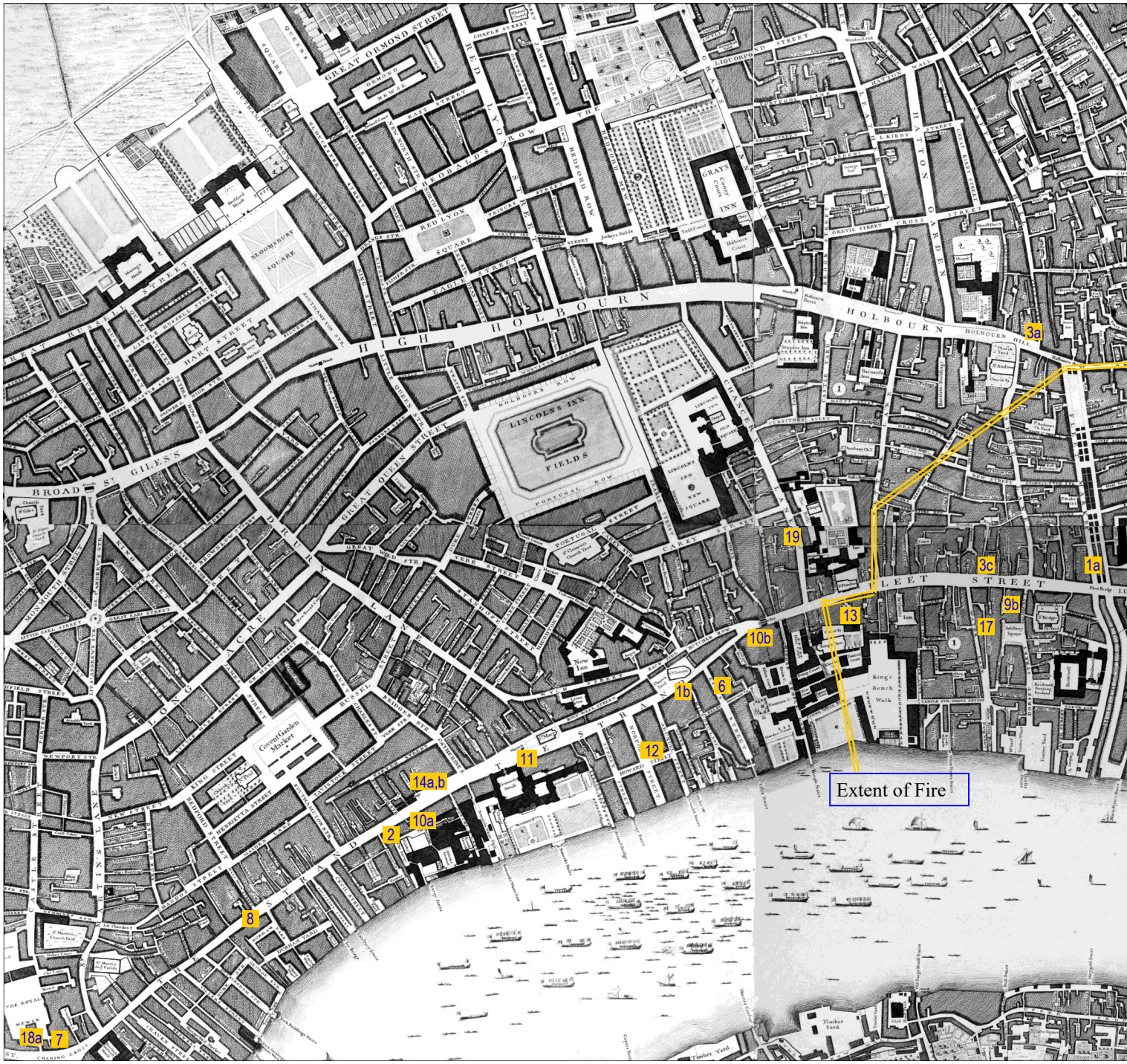
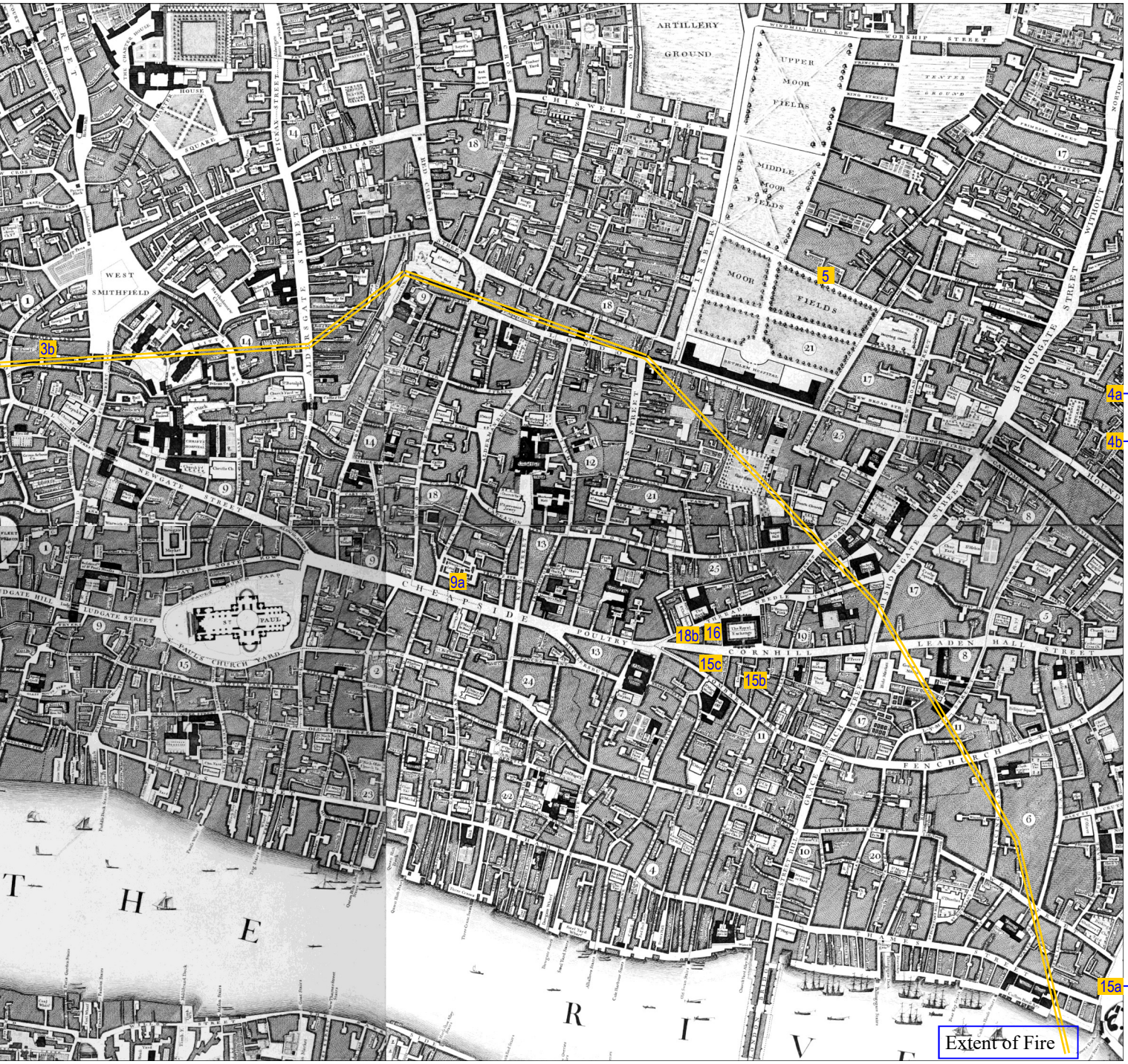


Fig. 1. Map of London, showing the locations of mathematical

The addresses shown below are based on contemporary advertisements, books etc. Some makers had more than one set of premises, usually sequentially but occasionally concurrently. Some addresses which appear to be separate locations are actually different descriptions of the same premises, e.g. the multiple description of Elias Allen's premises near St Clement's church (1b). The addresses are plotted here on a map of London first published by John Rocque in 1746. Exact locations of some addresses of the form 'At the sign of...' are shown only approximately.

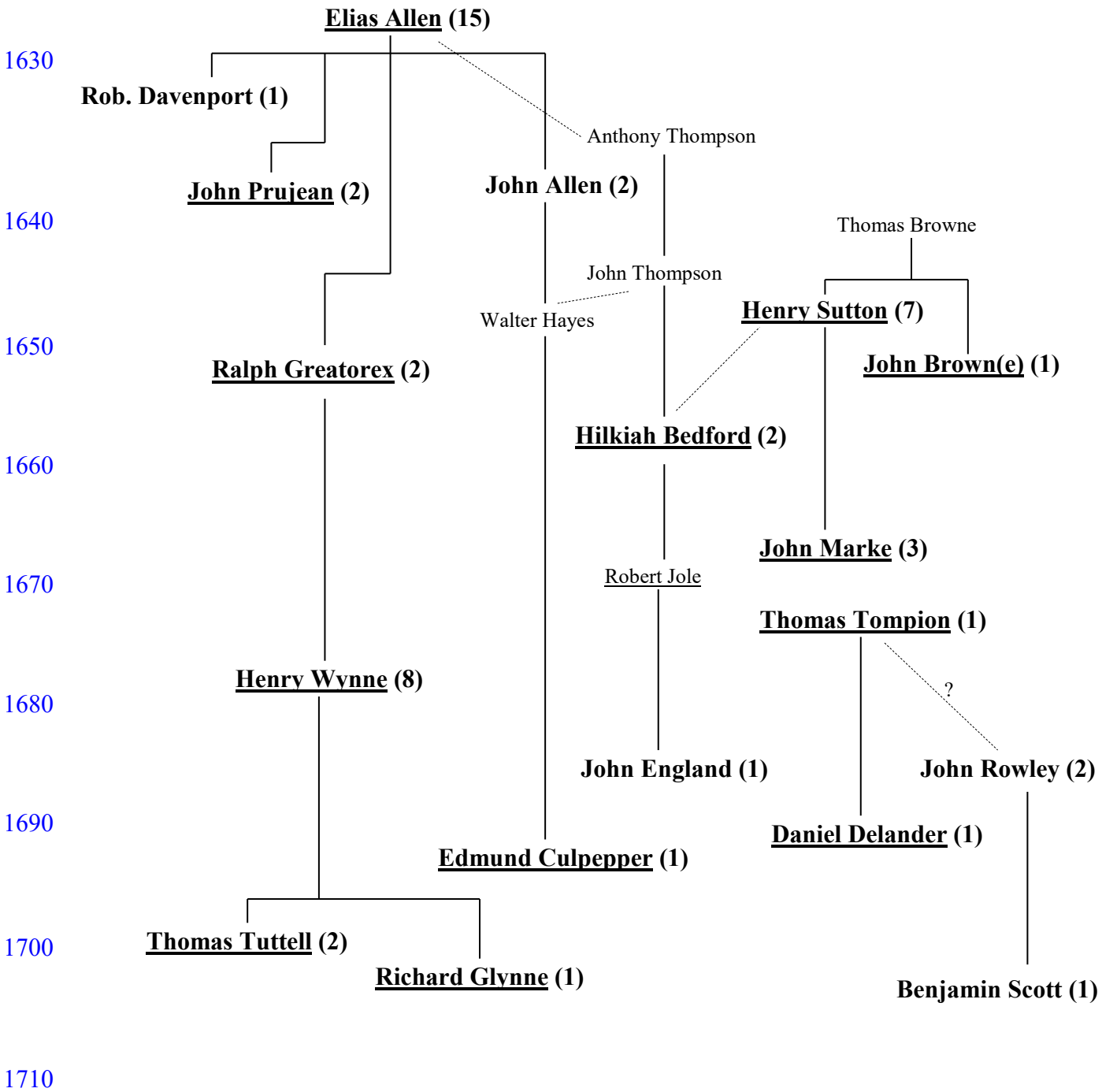
The extent of the Great Fire of 1666 is also shown. The mathematical instrument makers generally escaped the effects of the Fire as they were mainly clustered to the west of the destroyed zone by 1666. This contrasts to the clockmakers, whose district of Lothbury was devastated. Henry Wynne was particularly lucky as he saw the fire come to within yards of his premises (19).

1. Elias Allen: (a) 'Blacke Horse ally neere Fleetbridge'; '(b) At the Bull's Head over against St Clement's church, Strand', 'Without Temple Bar' and 'Without Temple Bar near St Clement's church'.
2. John Allen: 'Near the Savoy, Strand'.
3: Hilkiah Bedford: (a) The Globe near Holborn Conduit; in 1663 he moved to (b) Hosier Lane, the address of the Thompsons. (c) Fleet Street in 1666, presumably having been burnt out in the Great Fire.
4. Thomas & John Brown(e): (a) Dukes Place, Aldgate; (b) Sphere & Sundial, The Minories.
5. Edmund Culpepper: Sign of the Crossed Daggers, near Moorfields.



instrument makers. From the map of John Rocque 1746.

6. Daniel Delander: Devereux Court, Strand; Temple, Fleet Street and Within Temple Bar (same location?).
7. John England: Charing Cross.
8. John Gill: The Strand.
9. Richard Glynne: (a) Sign of Atlas and Hercules, Cheapside and then, from 1718 (b) 'opposite Salisbury Court, Fleet St'.
10. Ralph Greatorex: (a) Adam & Eve, Strand; (b) Temple Bar.
11. John Marke: His premises were at the Golden Ball in the Strand, near Somerset House.
12. William Oughtred /Earl of Arundel, Arundel House, The Strand.
13. John Rowley: 'Sign of the Globe' near St Dunstan's in Fleet Street.
14. Benjamin Scott: (a) Exeter Change, Strand and, until 1733, (b) at the Mariner and Globe, Exeter Exchange.
15. John Seller: (a) Hermitage Stairs, Wapping (sometimes Mariner's Compass & Hourglass; (b) Exchange Alley, Cornhill; (c) Pope's Head Alley, Cornhill.
16. Henry Sutton: "Behind the royall exchange" on Threadneedle Street.
17. Thomas Tompion: Water Lane (various buildings).
18. Thomas Tuttel: (a) 'King Arms and Globe at Charing Cross' and (b) 'Against the Royal Exchange in Cornhill'.
19. Henry Wynne: Chancery Lane, variously given as "at the Pope's Head", "Next the Sugar Loaf in Chancery Lane" (1682), "over against the Rolls" (1700), "Near Sergeant's Inn" (1707). Probably all the same location.



* Numbers in brackets are the number of instruments known using the horizontal stereographic projection (DH, HI or HQ).
* Names underlined were members or brothers of the Clockmakers' Company.
* Names in bold are known makers of stereographic projection devices; for others, none are yet known.
* Solid lines show master-apprentice links.
* Dashed lines show trade relationships.
* Dates show very approximately when makers gained their freedom.

Fig. 2. The Major Double Horizontal Dial Makers in London.

THE MAKERS AND THEIR DIALS

This section gives some biographical details of the known makers of double horizontal dials (and horizontal instruments) and describes their dials in some detail. The makers are arranged alphabetically with the exception of anonymous dials which come at the end.

A Note On Dial Numbering

All of the instruments described in this monograph have been given a unique reference number. The first two letters describe the type of instrument:

DH Double horizontal dials
HI Horizontal instruments
HQ Horizontal quadrants
AD Associated dials (mainly with stereographic projections)
M Modern dials and replicas (post 1900)

The numerical part of the reference has been assigned simply in the order that the instruments became known to the authors. There are some missing numbers in the sequence because some dials turned out to be double reporting of ones already known (such as when a dial in an auction catalogue later appeared in a museum collection).

London Instrument Makers

The majority of the double horizontal dials of the 17th and early 18th centuries were made by London mathematical instrument makers. Many of these makers, over several generations, worked in a small area of the city centred around Chancery Lane and Fleet Street. A contemporary map showing this area is given in Fig. 1.

Prior to 1631, instrument makers could have been members of any of the city guilds. After its establishment in 1631, the Clockmakers' Company (CC) claimed the rights over this trade and tried to force dialmakers to join. This control was never total and members of other guilds continued to produce dials. Double horizontal dials, produced by only the best-trained and most skillful makers, were thus the preserve of members of relatively few guilds and the techniques were passed from master to apprentice over several generations. Some earlier papers postulated that the making of a DH dial represented the 'master-piece' produced by an apprentice to prove his abilities before being admitted as a Freeman of his guild. This was on the basis that most makers known at the time had only one dial attributed to them. The increasing numbers of known dials, with several makers having a significant number of dials to their names, makes this theory less likely—though this does not preclude the instrument still being an appropriate test for the end of a seven-year apprenticeship. A chronology of the most prolific makers is shown in Fig. 2.

ELIAS ALLEN

DH-1, 2, 3, 4, 5, 8, 50, 51, 54, 57, 58; HI-1, 2, 3.
See also DH-27.

Elias Allen (c.1588-1653) is one of the most important of all the mathematical instrument makers. Very unusually for an artisan, we have a portrait of him (Fig. 3).[1] Not only was he a personal friend of William Oughtred, making the first brass horizontal instruments and double horizontal dials directly to his instructions, he was also the most productive of all the DH dial makers with, currently, 11 extant dials to his name. He trained several apprentices who later went on to produce DH dials of their own and so, after Oughtred himself, he is the most important figure in the history of the double horizontal dial.

Elias Allen was born in Ashurst, Kent. (He later made a small horizontal dial for the churchyard there.) He served his apprenticeship in London under Charles Whitwell who

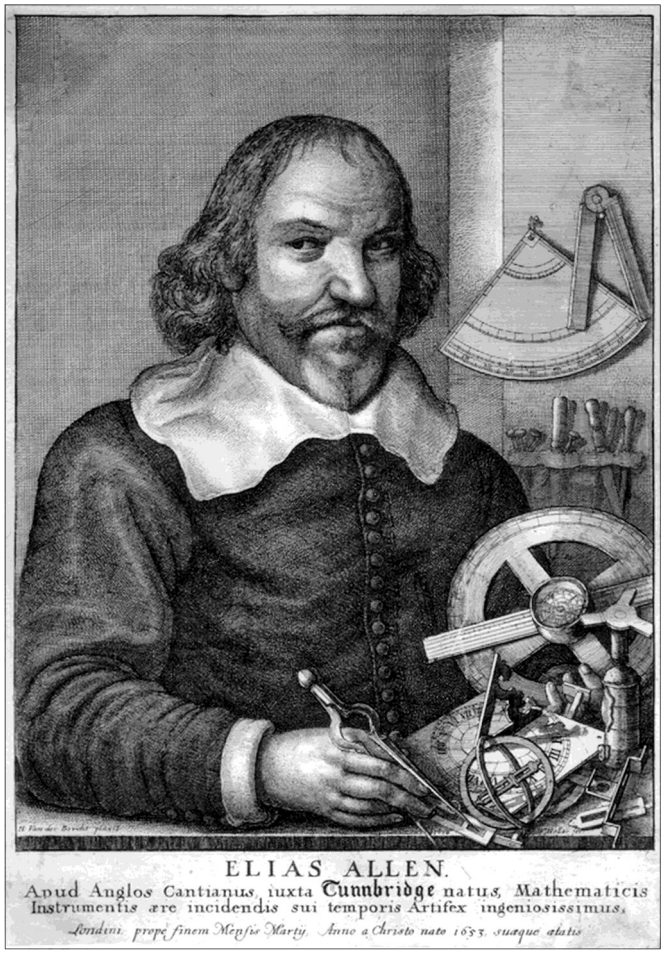


Fig. 3. Portrait of Elias Allen, from an engraving by W. Hollar and based on an original painting now lost.

was the leading mathematical instrument maker of the day. When Whitwell died in 1611, Allen took over his shop in the Chancery Lane area, variously referred to as 'Blacke Horse ally neere Fleetbridge', 'At the Bull's Head over against St Clement's church, Strand', 'Without Temple Bar' and 'Without Temple Bar near St Clement's church'. These addresses may or may not all be the same building but they would certainly have all been within a couple of hundred yards. Allen took his freedom of the Grocers' Company on 7 July 1612 but later joined the newly-formed Clockmakers' Company, becoming their Warden in 1635/6 and Master in 1637. As a result, his early apprentices (and their resulting dynasties) were in the Grocers' and the later ones were in the Clockmakers'.

Allen did not date his instruments but it is believed that he made the first horizontal instruments around 1625 and the first double horizontal dials around 1630. He usually signed them simply 'Elias Allen fecit'. With the exception of the double horizontal and moon dial (DH-3) in the London Science Museum, all the dials follow very closely the same pattern based, not surprisingly, on his earlier horizontal instruments. They vary in size from about 190 mm (7½") to around 350 mm (14") with most being octagonal although two are circular and two are (or were originally) square. The dial plates are typically around 1.5 to 2 mm thick. See *Materials Analysis* section for a metallugical description.

There is no consistency in the diameter of the horizon circle (the key parameter in drawing the stereographic grid) so it seems that Allen did not have a standard template of the pattern, delineating the grid from scratch each time. The key features of this pattern are as follows.

* A polar dial from IIII-XII-VIII with the numerals on the periphery and oriented inwards. Note the rather wide angle of the 'V' and 'X' numerals. Divided to 5 minutes on the inside of the chapter ring. Half hours marked with a simple 'T-bar' marker.
* Around the outside of the stereographic projection is an azimuth scale, 4× [0]-90° by 1° with the zeroes E & W. On a small number of dials (e.g. DH-2, 58) there is also a set of compass directions (e.g. SEBE) between the chapter ring and the azimuth scale. These directions are rotated 180° from their normal geographical positions so that they indicate the Sun's azimuth from the shadow of the vertical style edge.
* The stereographic projection has no date scale around its outer, horizon circle. The declination arcs are typically for 2° intervals with the 10° steps engraved heavier. The hour arcs are subdivided to quarter-hour intervals.
* The hour arcs are labelled on their inner (summer) ends only, in Arabic numerals oriented to be viewed from the south (or inside).
* The ecliptic arcs have dots for individual days numbered 10, 20, 29/30/31 and labelled with the months. These are usually in full (e.g. **Februari**) but sometimes with just the initial letters.
* A simple altitude scale, divided to degrees, runs from the centre towards the SW.
* The signature, **Elias Allen fecit** , is in the empty southern sector of the chapter ring, oriented inwards.
* On dials which are not too badly weathered, the row of centres for the declination arcs can be seen running south from the gnomon. Also, the centres for the hour arcs are sometimes visible running E-W through the noon 'XII'.
* The typical thickness of the gnomon on Allen's DH dials is only around 3 mm. They are thus rather fragile and many have been broken. The normal fixing was a pair of tenons passing through slots in the dialplate with their ends peened over. Despite this seemingly crude method, some gnomons (eg DH-4) are still upright and tight after 350 years.

Small variations from the simple layout do occur. The octagonal dial DH-54 has N and S marked and also, unusually, the latitude is marked as "51 20". Most of the other dials seem to have been made for London at 51½° N although DH-2 in the National Maritime Museum has a calculated latitude of 52.6° ±0.1°. DH-54 now features a well-made replacement gnomon of the correct profile (except for the decorative tip) with a protective brass plate underneath the dial. Two carefully filled circular holes near

the north edge of the dial and symmetrical about the noon mark suggest that at one stage in its life a brass wire hoop was fitted to support the gnomon tip. The 'Geneva' dial (DH-50) has Roman instead of arabic hour numerals on the stereographic grid.

The dial in the Adler Planetarium (DH-5, previously in the Time Museum) is circular and has a ring divided to minutes arount the periphery. It also features a gnomon with cast-in feet. It is tentatively speculated that this dial may be a late example of Allen's output.



Fig. 4. Part of the Elias Allen DH-3, showing the additional moondial ring just inside the main hour numerals.

The Science Museum DH and Moondial (DH-3)

The double horizontal dial part of this instrument closely follows the pattern of Allen's other examples.

The moondial This has a separate time scale of hours labelled with small Arabic numerals running between the main chapter ring and the azimuth scale: part of this from 8 to 12 can be seen in Fig. 4. The values do not correspond with the main Roman numerals: they are four hours less starting 12 at IIII am, 8 at XII, 12 at IIII pm and concluding 4 at VIII pm. Inwards from the stereographic projection is a table of time corrections corresponding to ages of the moon in days, starting at 5 and concluding at 25, omitting days near new moon when it is too faint to provide a gnomon shadow. To compensate for the four-hour change in the time ring, the corrections are increased by four hours. Part

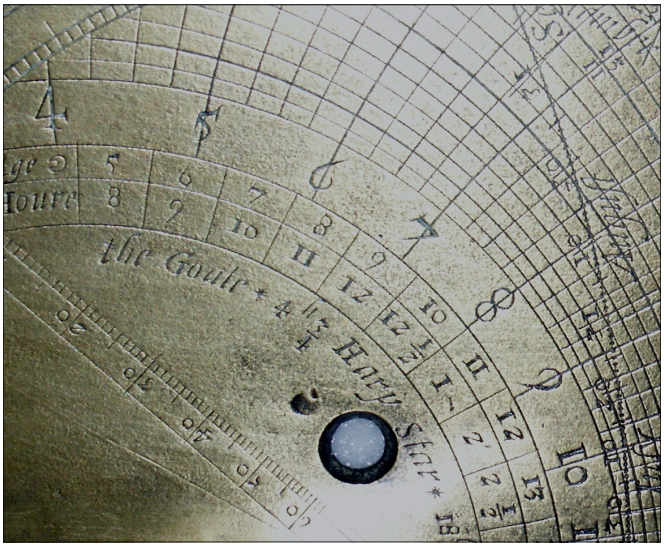


Fig. 5. The lunar time offset ring on DH-3.

of this area of the dial is shown in Fig. 5 and the full table is given in Table 1. For comparison, the corrections from the famous Cambridge Queens' College moondial with 4 hours added to the values are given. It is seen that the Allen values mostly agree within about half an hour except for three values which are too large.

To use the dial, the time is read from the gnomon shadow on the moondial scale and the correction from the table is applied to give the approximate solar time. As has been explained elsewhere[2] the error in times found from the moon by the use of such tables can be considerable. There is no obvious reason why Allen adopted this method of off-setting the time scale by four hours and adjusting the corrections to suit. The small numerals of the hour scale are only about 4 mm high and those of the correction table are even smaller: all would be difficult to read under moon-light.

The star names The names and right ascensions of twelve stars are given in two arcs running to the north and south of the stereographic grid. Some of these can be seen in Figs. 4 & 5. The full list is given in Table 2.

The right ascensions given on the dial agree very well with those of 1650 (which have been derived from a modern catalogue) rounded to the nearest quarter-hour, except for Vindemiatrix which should be 12¾. The star positions could be used to derive the time at night, possibly with greater accuracy than the moondial is capable of providing. Details of the method are given on p.120.

Age	5	6	7	8	9	10	11	12	13	14	15
Hours	8	9	10	11	12	12½	1	2	2½	3	4
Qn Co	8:00	8:48	9:36	10:24	11:12	12:00	12:48	1:36	2:24	3:12	4:00
Age	16	17	18	19	20	21	22	23	24	25	
Hours	5	6	6½	7	8	9	10	11	12½	1	
Qn Co	4:48	5:36	6:24	7:12	8:00	8:48	9:36	10:24	11:12	12:00	

Table 1. Moondial corrections on DH-3 by age. Qn Co refers to the table on the Queens' College, Cambridge, vertical moondial.

Name on dial	RA on dial	Modern name	Designation	True RA (1650)
(a) to North of grid				
Pleides	3½	Pleiades (Alcyone*)	η Tau	3^h 27^m
Bull's eye	4¼	Aldebaran	α Tau	4 16
Great Dog	6½	Sirius	α CMa	6 30
Lion's Heart	9¾	Regulus	α Leo	9 50
Vindemiatrix	12¼	Vindemiatrix	ε Vir	12 45
Arcturus	14	Arcturus	α Boo	14 00
[Scorpion's] heart	16	Antares	α Sco	16 08
(b) to South of grid				
The Goate	4¾	Capella	α Aur	4 51
Harp Star	18½	Vega	α Lyr	18 25
Vultur	19½	Altair	α Aql	19 34
Fomahaut	22½	Fomalhaut	α PsA	22 38
Marchab	22½	Markab	α Peg	22 47

Table 2. The star names and right ascensions on DH-3. (indicates the brightest star).*

Horizontal Instruments

It is presumed that the earliest of the three known Allen horizontal instruments was made before the earliest of the double horizontal dials. The very earliest instrument may be one (now lost?) described by William Oughtred in his *Apologeticall Epistle*.[3] This was in 1627 and was being made by Allen, under Oughtred's instruction, as a New Year's gift for the King. The back of the instrument was to carry "the theories of the Sun and Moone" but it is not known if it was actually completed and presented to the King. It was the letter that Oughtred wrote to Allen describing the constructional details of these instruments which was seen by Richard Delamain and was at the heart of the priority dispute.

Uniquely, HI-2 is dated 1648 which is late for a horizontal instrument. HI-3 was presented to St John's College, Oxford, in 1635, probably when new. It features an elaborate coat of arms which are not thought to be in Allen's hand. The instruments have quite a wide range of sizes (270 mm to 450 mm diameter) and all have the circles of proportion on the reverse. The layout of the instruments is quite standard and follows closely the illustrations in *Circles of Proportion...*[3]

JOHN ALLEN

DH-7; HQ-1. See also DH-30 & 60 (attrib).

John Allen was the first of Elias Allen's apprentices (bound in 1617) and hence was a freeman of the Grocers' Company. It is likely that he was a kinsman of the more illustrious Elias though he was not his son: possibly he was a nephew. He continued to work in the same workshop after his normal seven year apprenticeship and he did not take his freedom until 1631/2, the same year that he took Walter Hayes as his apprentice. It seems that he did not want to pay the higher dues of a Freeman until he needed to do so in order to take an apprentice.

John Allen's only known double horizontal dial (DH-7) is in Maidstone Museum & Bentlif Art Gallery. It is signed 'Iohn Allen fecit 1632' which makes it the earliest known dated DH dial although some of Elias Allen's dials must surely be earlier. Not surprisingly, John Allen's engraving style is very similar to his master's. The format and structure of his DH dial are also very similar: for example, the time divisions for the main horizontal dial remain around the inside of the chapter ring, and the half-hour markers are the same simple 'T-bar' design. The most significant difference is that the ecliptic arcs are marked with the zodiac symbols and dotted for the degrees of solar longitude. He has moved the date scale to the outside of the horizon circle, a format which became standard for virtually all later dials. The months run clockwise round the circle with the spring equinox on the afternoon side of the dial. The months are indicated with their initial letter (using I for January, June and July) and sub-divided to individual days. The azimuth scale, immediately outside the date scale, is numbered in 10s of degrees with 'E' and 'W' in the zero positions indicating the sun's direction.

A smaller change is the addition of the hour numbers, still in Arabic numerals, on the winter side as well as the summer side of the stereographic grid. It also has a N-S meridian engraved across the whole dial.

John Allen also made one of only two known brass Delamain's quadrants (HQ-1), now in Brussels. (Note that Joyce Brown's paper[4] on the Grocers' Co. wrongly describes it as a double horizontal dial, as did the museum's

catalogue.) The quadrant is dated 1633, just one year after his DH dial. Thus it seems that he was heavily involved in the priority dispute between Richard Delamain and William Oughtred, being in a position to provide Delamain with the letter from Oughtred to Elias Allen explaining how to draw the stereographic grid. The diagram in Delamain's book[5] (see p.81) illustrating his quadrant is so similar to the Brussels instrument that it is almost certain that the copper plate for it was engraved by John Allen: note that the diagram also includes an advertisement for both John and Elias Allen. The instrument has an error in the positioning of one of the stars (Spica, no.8, has the wrong sign for its declination) on the stereographic grid and also has what appears to be a secondary hour scale, with arabic numerals, inside the main Roman numeral one. However, the spacing of the scale is not correct for this.

See below under unsigned dials for DH-30 & 60.

BACON

DH-9.

The dial signed simply "Bacon" is described in detail elsewhere in this monograph.[6] At the time that article was written, it was not known if 'Bacon' referred to the maker or owner. It now seems likely that the dial was made by the clockmaker William Bacon of Colchester (working c.1648 – c.1680). Two clocks by him are signed "Guilielmus Bacon, Colcestria fecit' and 'William Bacon, Colchester'.[7] The latitude of Colchester is 51° 53' N, very similar to that on the dial.

HILKIAH BEDFORD

DH-10, 11.

Hilkiah Bedford (c.1632-1689) was a Quaker and the son of Thomas Bedford, a 'gent.' from near Boston in Lincolnshire. He was bound to the London instrument maker John Thompson in 1646, becoming a Freeman of the Stationers' Company in 1654. He later (1667/8) became a Brother of the Clockmakers' Co. Both John Thompson and Anthony Thompson are associated with Elias Allen (and later Walter Hayes) though common advertising. Bedford's premises were initially The Globe near Holborn Conduit but in 1663 he moved to Hosier Lane, the address of the Thompsons. As this was the year that John Thompson died, it is likely that Bedford took over his shop. He moved westwards to Fleet Street in 1666, presumably having been burnt out in the Great Fire.

DH-10, signed "Hilkiah Bedford Londini fecit", is in the Museum of St Andrews University and is one of the instruments which James Gregory (Regius Professor of Mathematics) commissioned for the St Andrews Observatory when he visited London for that purpose in 1673. He had been empowered by the University to "goe to London" to buy "such instruments and utensils as he with the advice of other skilful persons shall judge most necessary and useful for the above mentioned design" [providing an observatory]. It was initially in St Salvator's College and then for many years it was in the garden of St Mary's College, where the plinth is still in place. The actual dial remains attached to the capital of the pedestal. It is a fairly standard design, largely following John Allen's format, but rather larger and using Roman numerals for marking the hour arcs on the stereographic grid. It has declination lines for every degree (5°s dotted) and hour arcs for 5 minute intervals (half-hours dotted). There is a single altitude scale running to the southwest.

DH-11 is signed "Hilkiah Bedford in Fleet street" but is otherwise very similar to the St Andrews dial (DH-10). Its gnomon has suffered the common fate of being snapped off just above the vertical edge, the bent end showing it received a downward blow.

The two Hilkiah Bedford dials are very proficiently and neatly delineated but are lacking any extraneous decoration or unusual features.

CHARLES BLOUD

DH-12.

Charles Bloud is unique amongst the early makers of double horizontal dials in that he was French rather than English. He was working in Dieppe in the second half of the 17th century, usually in ivory. He is best known for his form of magnetic azimuth dial.

Bloud's double horizontal dial DH-12 is unusual on several fronts: it is a portable dial and it is constructed of ivory with silver fittings. It is a diptych construction with a string-gnomon horizontal dial surrounding a recessed stereo-graphic dial which forms the card of a magnetic compass. It is actually a form of 'compast' with the hour numerals running counter-clockwise. The stereographic grid is read not by a shadow but by the position of the magnetic needle, having first aligned the dial with the shadow of the string gnomon on the 12 of the horizontal dial. This alignment assumes a magnetic variation of zero, approximately correct for Dieppe in the mid 17th-century. There does not appear to be any adjustment for other variations.

THOMAS & JOHN BROWNE

HQ-7 (attrib).

John Brown(e) (fl. 1648-1695) was the son of his master, Thomas Browne, and apprenticed alongside Henry Sutton. Although he was freed in the Joiners' Company, he was also a Brother Clockmaker, becoming their Master in 1681. He described himself as a 'philomath' and, as well as an instrument maker, he was also an author and publisher, in this latter field being associated with John Seller (see below). His first publication is the short booklet *The Triangular Quadrant*,[8] first published in 1662 and co-authored by Henry Sutton. A much longer version was published in 1671 and bound with it, is a second book, *Horologriographia or the art of dyalling…by the use of the triangular-quadrant*.[9] In this, he describes how to draw a

horizontal (stereographic) projection from the data on the sector, and then to use the projection to design dials on many planes.

Although no double horizontal dials are known by Thomas Browne, a spiral logarithmic scale by him is known amongst the papers of the mathematician John Pell (1611-85).[9a] This seems to be the 'circles of proportion' which is invariably found on the back of the Elias Allen horizontal instruments so there does seem to be a connection between Browne and the Oughtred designs.

In his *Apologeticall Epistle*,[3] Oughtred describes the link between Thomas Browne and Richard Delamain so this may relate to the design of the Delamain's quadrant HQ-7 which is attributed to John Brown. It is most unlike the other known examples, being both in wood and also much larger. The design is unusual in that the declination lines extend outside the Tropics. Also, it uses a plumb-bob and bead (now missing) rather than a swinging index with altitude scale and hence it avoids the problem of the offset centre of gravity of the index giving an error in the altitude.

JAMES CLARK

DH-13, 14.

James Clark, sometimes Jacobus Clerk, (c.1650–1718) was a London-trained copperplate engraver who moved to Scotland around 1690.[10] The first record of his work is from 1671 when he cut for John Seller a pirated version of Sir Jonas Moore's manuscript chart of the Thames Estuary. He is known to have been a "Printseller and engraver in Gray's Inn" from the inscription under a c.1675 map by W. Hollar. Clark's name appears on twelve charts commissioned by Seller for his *English Pilot* series, though some of these were merely re-workings of Dutch plates which Seller passed off as new work (see p.69).

When Clark moved to Edinburgh around 1690 it was as a die-engraver for the Scottish Mint. It seems that some of the dies and punches actually came from the London Mint with Clark subcontracting the work. He also continued engraving maps (e.g. John Adair's coast of Scotland, published 1703) and portraits (e.g. George Buchanan in 1711).

Given Clark's background as an engraver and the absence of an extensive portfolio of instrument making, it is surprising that of the three instruments signed by him two are double horizontal dials, the peak of the genre generally only produced by the very best mathematical instrument makers of each generation. Both these dials are delineated for Scotland, with a calculated design latitude of 56.5° N. One, DH-13 in the National Museums of Scotland, is signed "Jacobus Clark fecit Edenbugi". Thus its design latitude is about half a degree north of Clark's home in Edinburgh. It is a fine, elegant dial very crisply engraved and in good condition although without its gnomon. The layout is quite simple and sparse: indeed, the minute scale for the polar dial is divided to individual minutes but these are not numbered giving the dial an unfinished look. It

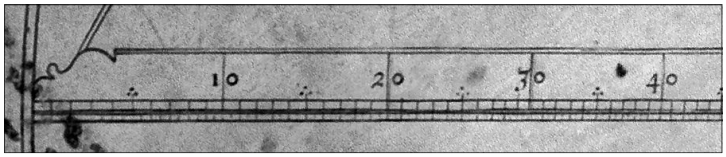


Fig. 6. The altitude scale on the dial plate of DH-13. Note the end decoration which probably takes the form of the gnomon tip (missing).

does, though, carry the initials TH and MD together with a thistle, presumably for the first owners. One point worth noting is that the outer end of the altitude scale, running southwest from the gnomon, is decorated with the shape of a gnomon tip, Fig. 6. This shape is very reminiscent of Henry Wynne's gnomons.

The second dial (DH-14) is quite different. It is signed "Ja Clark Dudonis fecit" and its design latitude of 56.5° N is indeed appropriate for Dundee. The dial, in Liverpool Museum, is in a rather corroded condition and without its gnomon but its many features can still be seen. As well as the basic double horizontal dial (with the stereographic grid divided to 5 minutes of time and 1° of declination) it has:

* An epact table running from 1679/80 to 1718,
* A perpetual calendar of the Henry Sutton form,
* A moon's age time offset scale in an arc around the inside of the stereographic grid,
* The RAs of some prominent stars (not readable),
* Two pairs of trigonometrical scales, running SE and SW from the gnomon,
* A full-circle azimuth scale with compass points for the sun's azimuth.

These features and their layout were first introduced by Henry Sutton (see DH-49), then used by his apprentice John Marke (DH-59), and brought to a peak by Henry Wynne. One other dial shares these features, the anonymous DH-42.

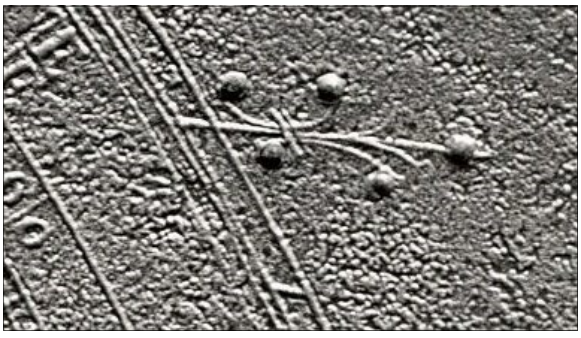


Fig. 7. The half-hour marker from DH-14.

It is also worth noting that the half-hour markers in the main chapter ring of the 'Dundee' Clark dial are the same distinctive 'five-dot' pattern favoured by Wynne and his apprentice Thomas Tuttell (see Fig. 7). It thus seems possible, perhaps even likely, that the majority of the engraving on this dial was not actually performed by Clark who simply added his name to an otherwise unsigned dial. He came from a background in John Seller's employment

where plagiarism was not unknown and old DH dials were available (note that Clark did not move to Scotland until 10 years after the design date for the dial). He certainly had the engraving skills even if he was not a trained mathematical instrument maker. That stated, the differences between the two 'Clark' DH dials are so marked that it seems unlikely that they were produced by the same man.

W CROFT

DH-15.

W. Croft of Ilminster, Somerset, is known to us only through his one double horizontal dial. He does not appear in Taylor as a mathematical practitioner, Loomes as a clockmaker, Wallis as a mathematician or Clifton as a mathematical instrument maker. Nevertheless, his dial is a very competent piece of work even if it falls short of the high standards of the London makers and the liklihood is that he was a local clockmaker. The dial was restored in 2002 with a new gnomon fitted to replace a totally inappropriate earlier replacement and the very light blue encrusted patina removed to leave a brown oxidised surface, revealing much more of the engraving.

The dial plate is quite thin (brass was expensive!). The stereographic grid is delineated to 5 minutes of time and to 1° of declination with the 10°s being more deeply cut and the quarter hours and 5°s being dotted, all in the best London tradition. There is an "Inequalities of Natural Days" scale in an arc around the centre of the dial, in the form developed by John Rowley, showing that it dates to after the 1680s at the very earliest. On the other hand, the main Roman numerals are orientated to be read from the centre of the dial, suggesting that it is not later than the second quarter of the 18th century. The half hour fleur de lys, which are quite ornate, are placed on the inside of the chapter ring rather than the outside as had become standard by that period.

EDMUND CULPEP(P)ER

DH-16.

Edmund Culpep(p)er snr. (c.1670 – 1737) was trained by the much-respected Walter Hayes, being bound in 1684 but not being made a Freeman in the Grocers' Company until 1713/14. This was possibly when he took over the business, at the Sign of the Crossed Daggers, near Moorfields, from the infirm Hayes. Although there are no double horizontal dials currently known by Walter Hayes, as he had earlier served his apprenticeship under John Allen there is a clear case for the passing down of the design methods.

Edmund snr's son, also Edmund, was a prolific instrument maker in his own right and so it is sometimes difficult to assign instruments unambiguously to either of them. In the case of the only known Culpeper double horizontal dial (DH-16), it is clear that the maker was the older man because of the date, 1708. The dial is a fine one, including both a moondial and a 'geographic' ring although, surprisingly for the date, it lacks an equation of time scale. Some of the engraving, which is very fine (e.g. quarter-degree divisions of the azimuth scale), is now suffering the effects of weathering. The gnomon has an immensely long 'tail', due to the relatively small offset of the polar dial origin from the centre, with, on its underside, the fixing holes for a plummet. This seems to have been merely for levelling the dial, rather than for facilitating use at different latitudes, as on the Greatorex dial DH-21. At the south of the dial is a fine armorial for Richard Hill who had been deputy Paymaster to the army during the 1690s.

ROBERT DAVENPORT

HI-4.

Robert Davenport was the second of Elias Allen's apprentices, bound in the Grocers' Company in 1623 and freed in 1635. Initially working in London, by 1647 he had relocated to Edinburgh. Not many instruments by him are known but one is a universal equinoctial ring dial which appeared on the *Antiques Roadshow*.

Davenport's little horizontal instrument, which features Oughtred's circles of proportion on the back, is in the National Museums of Scotland collection and it seems it was made for a Scottish location. Not surprisingly, his engraving hand shows great similarities with those of both Elias and John Allen so it is difficult to tell them apart. Even characteristic features such as the open-topped 'p' are present, though perhaps Davenport's '2' is rather less angular.

RICHARD DELAMAIN

HQ-5 (tentative).

Although Delamain was one of the combatants in the priority dispute with William Oughtred over the invention of both the circles of proportion and the horizontal instrument/quadrant, it is very uncertain whether he actually made a real instrument himself. In his Oxford DNB entry, Higton states that "it is probable that the silver sundial sent to the Duke of York by the King just before his death was one of Delamain's horizontal quadrants" and it is on this basis (only) that the catalogue entry HQ-5 is based. No silver Delamain's quadrant is currently known and, if one was made it is likely that John Allen would have been the maker, based on his association with Delamain.

According to Oughtred, Delamain began his career as a master of a writing-school and attended lectures at Gresham College, being taught astronomy by Edmund Gunter from 1616 to Gunter's death in 1626. He was a mathematical student of Oughtred and established himself as a mathematics teacher in the late 1620s. It was his publications in 1631 of *Grammelogia, or, The Mathematical Ring* (a circular slide rule) and *The Making, Description and Use of ... a Horizontall Quadrant* which brought him into conflict with Oughtred. However derivative Delamain's instruments were, his publications did at least ensure that

Oughtred responded by publishing his *Circles of Proportion ... and the Horizontal Instrument* (translated by his student William Forster).

Bryden[38] has shown that *Grammelogia* is at best a confusing book, and the *Horizontal Quadrant* (both as a book and the actual design of the instrument) also has significant faults. Nevertheless, and despite Oughtred's higher social standing and being a staunch royalist, Delamain managed to obtain the post of quartermaster-general and tutor to the King, and oversaw the making of a number of mathematical instruments for the King. With his early death, believed to be in 1644, the priority dispute came to an end.

DANIEL DELANDER

DH-17.

Daniel Delander (c.1678 – 1733) was a London clockmaker (he was made a Freeman of the Clockmakers' Company in 1699) who trained under Thomas Tompion, perhaps the greatest of all English clockmakers. His premises, variously described as Devereux Court, Strand; Temple, Fleet Street and Within Temple Bar, were in the heart of the clock- and instrument-making quarter of London. As well as being a prolific clockmaker he is also known to have sold a barometer.

Only two sundials signed by Delander are recorded in the BSS Register of Fixed Dials, one of which is the fine double horizontal DH-17. Interestingly, the other, which was sold from Hampton Court to a private collector complete with a Van Nost 'kneeling blackamoor' pedestal, features a gnomon which at first sight appears to belong to a DH dial. In fact, the vertical northern edge of the gnomon is not in the centre of the dial and serves to cast a shadow over a sun's azimuth scale. Both Tompion and Rowley have signed similar azimuth dials, for Hampton Court and Blenheim Palace respectively.

The Delander DH dial is a large instrument which was stolen from a private garden in 2008. The actual brass dial plate is attached to a cast brass/bronze ring with a depth of about 50 mm. This ring is very similar to those on the Rowley, Scott and Tompion dials but set upside down so that the bottom diameter, in contact with the pedestal capital, is greater than the actual dial diameter. In layout, the dial is very close indeed to that produced by Benjamin Scott, who in turn inherited his style from his master John Rowley. Hence it is reasonable to speculate the existence of a trade relationship between Delander and Scott similar to the one which seems to have existed between their respective masters, Tompion and Rowley.

JOHN ENGLAND

DH-18.

John England (c.1676 – after 1708) was a London mathematical instrument maker who held the appointment of Instrument Maker to Queen Anne. He served his apprenticeship under Robert Jole, being made a Freeman of the Stationers' Company in 1702/3. Jole is not recorded as a DH dial maker but his master was Hilkiah Bedford who has two DH dials to his name. England is perhaps best known for the series of instruments he made for the new Plumian observatory at Trinity College, Cambridge in 1703.[11] These instruments include the complicated mechanical horizontal dial known as the 'sciothericum telescopicum' invented by the astronomer William Molyneux, as well as a sector, a universal ring dial and a dual analemmatic/horizontal dial in the style of that popularised by his contemporary Thomas Tuttell. (Note in Fig. 1 that England's premises at Charing Cross, as were Tuttell's.) Taylor[17] suggests that England came to the notice of Christopher Wren and Isaac Newton when producing the Trinity instruments, thus securing his royal appointment.

The John England DH dial (DH-18) is most unusual in that it is in copper rather than brass. Consequently, it is now very worn but it is possible to see that, even when new, the dial was not up to the standard of the other known England instruments. It is very tempting to suggest that it was an early practice piece made in a material which was relatively easy for a learner to engrave.

Like John Rowley, who also produced several instruments for the Trinity Observatory, John England had two forms of signature for his instruments. Both read 'John England [or Rowley] fecit' but one was in a rather florid cursive script and the other a much more formal, upright form. The former has the look of a 17th century style, while the latter seems more in keeping with the elegant 18th century. Thus it could be suggested that the script form, which is what is found on the England DH dial, came earlier in the careers of both men. Unfortunately, both forms are found on the instruments from both men in the Trinity collection which suggests that either they used the two forms interchangeably or that the changeover in style was currently in progress.

The fundamental problem with the England DH dial is that the maker has not offset the origin of the polar-style dial sufficiently far to the south. As a result, it has not been possible to fit a sensible height of the vertical style, at the centre of the plate, under the style edge. It seems that England realised this mistake part-way though the work. The remaining stub of the gnomon has the vertical edge in the wrong place, merely to give it sufficient mechanical strength; the central part of the dial cannot therefore operate correctly and England abandoned engraving the stereographic grid part-way through. The hour arcs are engraved and numbered (Arabic numerals) but the sub-divisions have not been put in. The instrument would still have operated correctly as a standard horizontal dial.

This faulty instrument is interesting because it shows that, even for a properly trained instrument maker, the design of the double horizontal dial presented a number of potential pitfalls. The most surprising feature is that it was allowed to escape from the workshop.

JOHN GILL

DH-19.

John (or Jonathan) Gill was the son of the blacksmith Edward Gill of St Andrew, Holborn, and became a London clockmaker working from the Strand. He was apprenticed to John Barrow, gaining his freedom in the Clockmakers' Company in 1707. Barrow was an important clockmaker, being Master of the guild in 1714. Relatively little is known of Gill although one ordinary horizontal dial (in addition to DH-19) is attributed to him and recorded as BSS SRN 2911.

Gill's 1716 double horizontal dial is unusual in that it has a copper dial plate, perhaps because this material was readily available for making clock dials. It also has a motto – Pereunt, sed Imprantur (sic) – which is not common on horizontal dials of any sort at this period. It has a small compass rose around the base of the vertical gnomon but no altitude scale. Strangely, the outer chapter ring is divided down to 3 minute intervals instead of the more usual 1, 2 or 5 minutes. The half-hour marks are very much of the design expected on a clock dial. The stereographic grid is well-drawn and divided to 10 minutes of time and 2° of declination, dotted on the half-hours and the 10°s. The azimuth scale, placed around the outside of the date scale, is divided to 1° intervals but places the zero at the N of the dial, rather than at the more common E and W points. Quite why a London clockmaker made such a sophisticated sundial for a location with a latitude appropriate for York, and how it found its way to America, is a mystery.

RICHARD GLYNNE

DH-56.

Richard Glynne (1681–1755) is a well-known and well-respected mathematical instrument maker who was apprenticed to Henry Wynne towards the end of his illustrious career. After gaining his freedom in the Clockmakers' guild in 1707, Glynne worked from the sign of Atlas and Hercules, variously described as Cheapside and then, from 1718, as "opposite Salisbury Court, Fleet St". Many instruments are known including portable and fixed dials, armillary spheres, compasses and, after 1712, he also sold globes in collaboration with his mother-in-law, Ann Lea. He lived for a considerable period after retiring and selling off his stock in 1730.

Glynne's recently re-discovered double horizontal dial (DH -56) means that he is the second of Henry Wynne's apprentices known to have made them, placing him in the fourth generation of makers in a direct line from Elias Allen. The dial is in a terrible condition and very little can now be deciphered although it was once clearly a fine instrument. At 18" diameter and with a half-inch thick gnomon, it was obviously quite substantial, even if not on the scale of Wynne's. Like some of his master's, it features a 15-ring moondial around the outside of the stereographic grid. A coat of arms to the south of the gnomon has so far



Fig. 8. Two trial fleur-de-lys engraved on the back of Glynne's DH-56. The one on the right was chosen as the half-hour symbol for the dial.

defeated the College of Heralds. The back of the dialplate features two trial fleur-de-lys designs, both very crisply cut and still in good conditions (Fig 8). One of these is the design actually used as the half-hour marker and the other is rather more curvy: neither is like the complicated 'H' form used by Wynne.

The date of the dial has not so far been discovered. It must be after Glynne obtained his freedom in 1707 but it still uses the inward-facing form of hour numerals and the coat of arms has rather loose floriate decoration more common in the 17th century. Thus it is likely to have been made quite early in Glynne's career.

STEPHEN GRAY

DH-22.

Stephen Gray (1666-1736) was born in Canterbury, Kent, the son of a dyer.[39] He entered the family business but it was a poor and hard trade and his health suffered. He was apprenticed to the London-trained Canterbury watchmaker Charles Annott in 1682.[39a] His elder brother married well, becoming Mayor of Canterbury in 1692, and possibly helped to support him though he remained poor. He corresponded with members of the Royal Society, including the first Astronomer Royal, John Flamsteed, and was eventually elected as a Fellow. He was clearly well-regarded as a practical astronomer and made observations both in Cambridge and at Norton Court near Cambridge, the home of John Godfrey, possibly a cousin of Flamsteed. From about 1715 he seems to have stayed in London with Dr Desaguliers before entering Charterhouse as a pensioner in 1719. Here he conducted the experiments in electricity which later earned him the unofficial title 'the father of electrical communication' (see Fig. 10).

As a poor 'scientist', Gray would have made his own instruments and equipment. The double horizontal dial (DH -22) which he made in 1699 appears to be delineated for the Sayer family's country property of Pett Place near Charing, Kent.[39b] The latitude engraved on the dial, 51° 15' N, is quite close to the modern value. The standard of engraving is quite competent even if not up to the best London standards and the dial is clearly a 'working' one, being devoid of decoration. It includes an equation of time scale

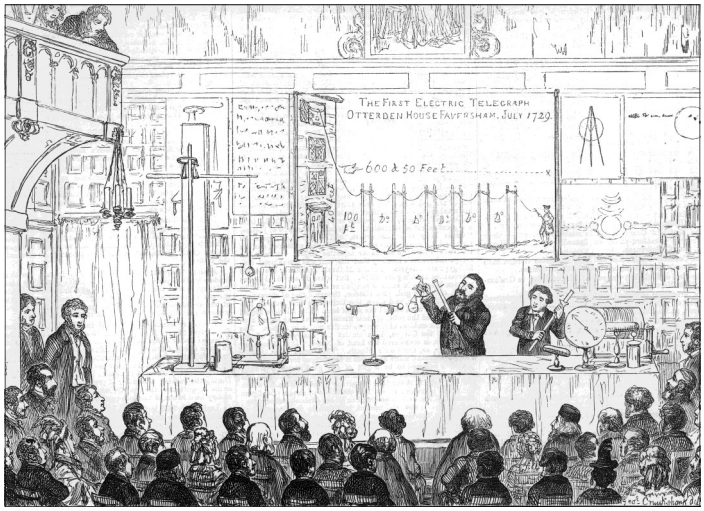


Fig. 9. A re-creation of a lecture at the Charterhouse on Stephen Gray's experiments on electrical conduction from the London Illustrated News.

in a circular arc inside the stereographic grid, making it very similar to the W Croft dial (DH-15). In this case, though, we have the addition of the RAs of some prominent stars engraved around the inside of the southern part of the azimuth scale.

The unique feature of the dial is that it has a small pivot at the plate centre and a retaining clip which would originally have been to hold a rotating altitude index in place. The foot of the knife-edge is lifted slightly off the dial surface to allow access to the pivot point. Whilst the gnomons on some other DH dials, particularly those of Henry Wynne, also have this adaption, the Stephen Gray dial is the only one where it can be stated with certainty that a rotating index was used. The dial also shows that a plumb-bob could be suspended from the gnomon tip, registering against a mark on the dial plate. Unlike the Greatorex example, though, this was only to ensure that the plate was level.

RALPH GREATOREX

DH-20, 21.

Ralph Greatorex (c.1625-1675) was the first of Elias Allen's apprentices to have been bound in the Clockmakers' Company (1639) although he did not take his freedom until 1653 when he took over from Allen. Like Allen, he was a personal friend of William Oughtred. He is best known through the many mentions of him in Pepys' *Diary*:[12] he was obviously a drinking companion who took him to Gresham College[13] and supplied him with several instruments. It is possible that Greatorex also made Pepys' double horizontal dial (see p.84). Very few instruments by Greatorex are known but one which has been described in detail[14] is an equinoctial ring dial, another of Oughtred's inventions. He seems to have left his address in The Strand in 1663 and it is probable that his mathematical instruments predate this. After this date Greatorex moved more towards larger mechanical engineering and surveying work, being involved with vacuum pumps and early 'fire engines' (i.e. steam engines) and in a project to fortify the harbour at Tangiers, for which he provided a diving bell. He had many contacts within the scientific and social communities and is mentioned by Robert Boyle and John Evelyn.

The smaller of Greatorex's two DH dials, DH-20, is quite standard for the time (c.1660). The other, DH-21, is 18¾" square, which is large for the period though it still uses the thin brass plate of the Elias Allen dials. It is expertly engraved and the stereographic grid occupies a high proportion of the area of the dialplate, allowing the azimuth scale to be finely divided to quarter-degree divisions. The dial features a well-executed coat of arms for Bolles of Scampton.

The most intriguing feature of the dial is a (unique) unlabelled scale running along the meridian line. This is in the form of a series of dots which are numbered in 10s and run from 61 nearest to the dial centre to 30 near the noon numeral (Fig. 9). The scale would have operated in conjunction with a plumb-bob which would have hung from the tip of the gnomon, where a pair of orthogonal intersecting holes show its suspension point. The scale is to allow the dial to be used at locations other than its design latitude of 51.5°. The plate would simply have been elevated at the southern or northern edge until the plumb-bob hung over the appropriate latitude marking. Additional

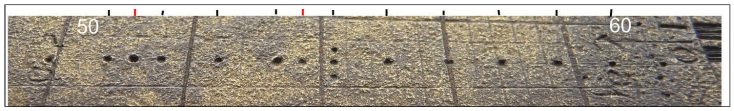


Fig. 10. Part of the dotted latitude scale along the meridian line of the Greatorex DH-21. The 10s are numbered and the 5s are triple-dotted. Extra points (marked red in the top margin) are for key latitudes.

points are provided on the scale for 51.5°, 48.5° and 54.5°, the last two latitudes presumably being for places of particular interest to Greatorex or his client Bolles, though they do not correspond to any known Bolles properties. The ability to tilt a normal polar-gnomon dial to suit a location other than the one for which it was delineated is quite well-known but the fact that the process also works for the stereographic projection, where the knife-edge is moved out of verticality, is not obvious. Whether Greatorex solved this mathematical puzzle himself or whether a mathematician (perhaps even Oughtred) provided him with this unique design is not known.

EDWARD HATTON

DH-23

Edward Hatton (fl. 1696-1719) was not a mathematical instrument maker. Taylor[15] records that he kept a mathematical school at Stourbridge, Worcs., but was chiefly interested in commercial arithmetic and gauging. He produced a new edition of Robert Recorde's *Ground of Artes* – by then 150 years old – and dedicated it to the young Duke of Gloucester. The double horizontal dial (DH-

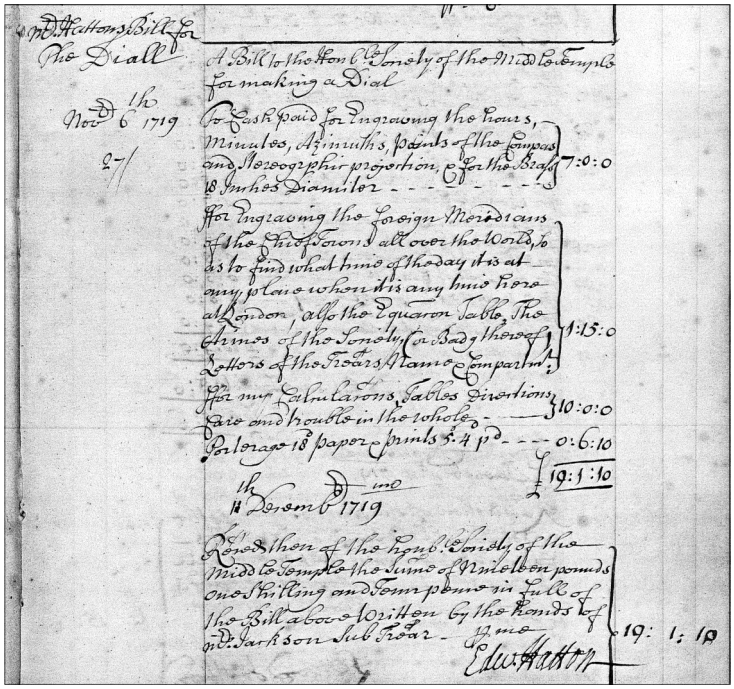


Fig. 11. "Mr Hatton's Bill for the Diall, 6 Nov 1719" from the Middle Temple Account Books.

23) which he designed for the Middle Temple in London is now missing and no image of it exists. It is known only through the very clear description in the Middle Temple accounts,[16] shown in Fig. 11 and transcribed here:

Mr Hattons Bill
for the Diall
Nov^{ber} 6th 1719
A Bill to the Honb^{le} Society of the Middle Temple
for making a Dial
To cash paid for engraving the hours
Minutes, Azimuths, points of the Compass
and Stereographic projection & for the Brass
18 Inches Diameter……...7:0:0
Ffor Engraving the foreign Meridians
of the Chief Towns all over the World, so
as to find what time of the day it is at
any place when it is any time here
at London, also the Equation Table, The
Armes of the Society (or Badg thereof)
Letters of the Trears^{sur} Name & Compart??.....1:15:0
Ffor my Calculations, Tables, Directions
Care and trouble in the Whole…….10:0:0
Porterage 18^{d} paper & prints 5^{s} 4^{d} pd..……..0:6:10

£19:1:10

11th Decemb^{r} 1719

Rec^{d} then of the Honb^{le} Society of the
Middle Temple the Sum of Nineteen pounds
one Shilling and Tenn pence in full of
the Bill above Written by the hands of
Mr Iackson Sub Treas^{r}

[signed] Edw. Hatton 19.1.10

Thus we can see that it was a large and sophisticated dial with an Equation of Time table and geographical place-names as well as the basic stereographic grid. We do not know who actually made the dial. At this relatively late date the principle makers with this style would be the apprentices of either Henry Wynne or John Rowley – perhaps Benjamin Scott – but they would surely be capable of producing a design without Hatton's help. It is interesting that his charge for the design was more than the total cost of materials and labour in making it. The total bill (£19 1s 10d) is considerably less than the £50 which John Rowley had charged nine years earlier for the only slightly larger Blenheim DH dial. There is no record of what happened to this dial – there is an ordinary horizontal dial by Cary in more or less the same location today.

JOHN MARKE

DH-53, 59, 63.

John (Johannes) Marke (c.1641- after 1673) was originally from Northampton and was apprenticed to the great Henry Sutton. He started his apprenticeship in 1655 in the Joiners' Company although he also became a Brother Clockmaker in 1667. Like his master, from whom he eventually took over, he could work in brass, silver, ivory or wood and he made the whole range of mathematical instruments of the time. His premises were at the Golden Ball in the Strand, near Somerset House. He made instruments for both Robert Hooke and John Flamsteed but he is probably best-known for the instruments he made for James Gregory to equip the new St Andrew's Observatory when he came to London in 1673 on a purchasing expedition. These included a new plate for the latitude of St Andrews (56° 25') to fit to the Humphrey Cole astrolabe (already a century old) which is still in the St Andrew's Museum. The stereographic projection on that instrument is a testament to Marke's skills.

A double horizontal dial by Marke is at Newchurch, Isle of Wight (DH-63). It was made in 1678 for 50° 40' (the local latitude) and was originally at nearby Knighton Manor, then owned by Sir Robert Dillington. The family died out in 1721 and when the manor was eventually demolished, Squire Bissett gave it to the local church in 1815. Like the dials produced by Marke's master, Henry Sutton, it is characterised by a rather narrow main chapter ring.

The second extant example of a double horizontal dial by Marke (DH-53) has only recently come to light, still in a private garden. It is not in good condition as it now has a thick blue-green patina though it does still have its gnomon intact and was clearly once an excellent instrument. The original gnomon has integral cast supporters ('feet') and the sides show faint traces of engraving in the form of one or more globes. These might possibly have been similar to the various projection diagrams seen in the spandrels of the later 'Bacon' dial.

An engraving of a Marke dial (DH-59) is in the archives of the Royal Society as part of the Robert Boyle Papers (vol. 35). Folio 201 shows the dial and folio 219 is a mirror image. It is probable that the mirror image was pulled directly from an inked dial plate and that this was then used, with the ink still wet, to reverse image again for a normal view. The great scientist Robert Boyle (1627-1691) moved from Oxford to his sister's (Lady Ranelagh) house in Pall Mall in 1668, (on the present site of the Royal Automobile Club) where he lived until his death. Boyle also had a retreat in the City—'my Messuage or Dwelling House in St Michael Crooked Lane London'. The dial's recorded latitude, 51° 32', is the conventional value for London and so it seems quite possible that the actual dial was made for either of these locations.

The engraving shows that the dial was very similar to those of Sutton, particularly DH-49. It features a curved scale of the time offset of the moon's shadow and a perpetual calendar and epact table for the years 1668 to 1707. Underneath the perpetual calendar is a small linear scale running from 50 to 60 [degrees?] subdivided to 15' increments. The purpose of this scale, which has not been seen elsewhere, has not been determined. Between the moon arc and the sector scales, Marke has placed the names of twelve prominent stars and their RAs. This data is the same as that found on some of Sutton's double horizontal dials and quadrants.

Like Sutton's dials, the zeroes of the azimuth scale (4× 0 -90°, subdivided to 30') are at the N and S points rather than the more conventional E and W. The fixing holes for the gnomon show that it was retained by screws rather than tenons and that it had side supports, probably like those of Marke's extant dial DH-53. The origin for the outer horizontal dial has been positioned quite close to the southern edge of the dial plate, thus allowing a more robust gnomon with a good height to the vertical style edge but at the expense of a rather cramped time scale in the early morning and late evening.

ADAM ORDWAY

DH-55.

Very little is known of Adam Ordway. He is not listed in Taylor's Mathematical Practitioners[17] or in Clifton[18]. In fact, he is known only through the leaflet describing the uses of a double horizontal dial, as reproduced on p.14. This suggests perhaps that he was a printer or bookseller, working in the middle of the 17th century and exploiting the demand for mathematical instruments. Although no example of the paper DH dial which he describes in his 1662 leaflet is currently known, the likelihood is that it was taken from the design by Henry Sutton.

WILLIAM OUGHTRED

William Oughtred (1575-1660) was one of the most important mathematicians, and mathematical writers, of the 17th century. His life has been extensively described and his influence analysed: see, for example, the major biography by Florian Cajori,[19] his entry in the *Oxford Dictionary of National Biography* or the writings of Frances Willmoth.[20] Only a brief resumé is given here. Several portraits of Oughtred exist – see for example the frontispiece and Fig. 12. It is unclear how Oughtred actually pronounced his name. Rather unusually for the period, his own spelling was quite consistent and hence gives no phonetic clue. The most likely pronounciation is perhaps 'Ow-tred' though it could also be 'Ooh-tred'.

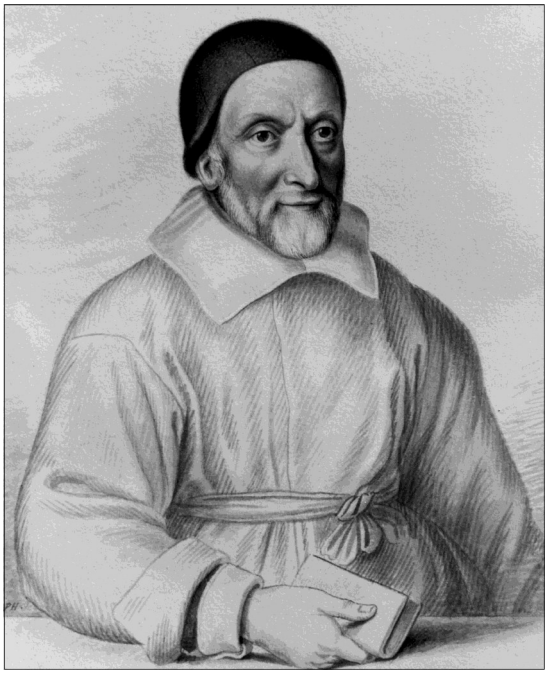


Fig. 12. William Oughtred by George Perfect Harding, after an engraving by Wenceslaus Hollar (1646).

The son of an Eton writing master and 'registrar', Oughtred was educated first at Eton and then at King's College, Cambridge, taking his MA in 1600. He was ordained and became the vicar of Shalford in Surrey in 1603, moving in 1610 to nearby Albury where he remained as rector until his death. Although by profession a priest he spent his time writing and teaching mathematics. He gained the patronage of Thomas Howard, second earl of Arundel, being granted a room in his London house in The Strand. This was conveniently close to Elias Allen's workshops. Oughtred taught mathematics to the Earl's second son, William, prompting him to write his classic textbook *Clavis Mathematicæ* in 1631, reprinted in many editions for decades after Oughtred's death.

Much has been made of Oughtred's apparent disdain for the use of mathematical instruments without first gaining a full grounding in the mathematical principles upon which they were based. This was expressed most strongly in his *Apologeticall Epistle* against Richard Delamain, and his references to 'Juglers'.[41] Notwithstanding this, he was the inventor of three types of mathematical instrument: the universal equinoctial ring dial which became the most popular pocket dial of the 18th century, the straight sliderule, to become the constant companion of engineers

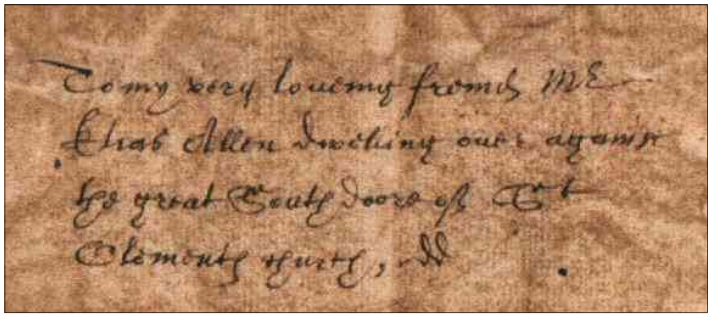


Fig. 13. The address on the back of a letter from Oughtred to Elias Allen dated 20 Aug 1638. It reads 'To my very loving friend Mr Elias Allen dwelling over against the great South door of St Clements church'. Courtesy CUL.

and scientists until the development of the electronic calculator towards the end of the 20th century, and the double horizontal dial which had a relatively short period of popularity but is now experiencing a small revival. Oughtred did not seek to gain financially from these inventions and passed their constructional details to the instrument makers, particularly to Elias Allen and, later, Ralph Greatorex. A letter from Oughtred to Allen in 1638 (Fig. 13)[21] – not unfortunately about the DH dial – starts "Good Mr Allen" and gives detailed instructions to delineate a gauging rod which shows just how much assistance he would have given in the drawing of the first horizontal instruments and, later, double horizontal dials.

Although he had a long life, surviving sequestration during the Commonwealth for his royalist views and seeing the Restoration of the monachy, Oughtred's contributions to mathematical instruments were all made during his early career. One other contribution, though, was the marriage of one of his daughters to Christopher Brookes. Brookes was an apprentice of Elias Allen and later edited some of Oughtred's books, notably on the horizontal quadrant[40] and on spherical trigonometry.

FRANCIS PIGOT

HQ-3.

Very little is known of Pigot and it seems that he was not a professional instrument maker. The horizontal quadrant HQ -3 which bears his name is the only known example of his work. Its engraving is of a reasonable quality but not to the standard to be expected of a London maker. Taylor[17] describes him a mathematical practitioner (fl. 1653-66) who lived at Cleobury Mortimer, Shropshire, and published an almanac for Ludlow. He advertised that he could teach the use of mathematical and surveying instruments. The design latitude of the quadrant is about 52.4° which would be a good match for Ludlow (actually 52° 22'). It somehow found its way into the collection of Sir Roger Newdigate (1719-1806), the 5th Baronet of Arbury Hall in Warwickshire.

The quadrant largely follows the original design of Delamain though it uses zodiac symbols for the ecliptic rather than calendar date. A separate table give the dates for the beginning of each sign. One feature which Delamain described but is not seen on other extant instruments is a second set of pinnules (sights) mounted on the rotating index or plummet. Whether Pigot was able to make use of them is doubtful.

JOHN PRUJEAN

DH-6 (tentative); HQ-4.

John Prujean (c.1630-1706) was an apprentice of Elias Allen in the Clockmakers' Company (although he had been bound to Thomas Lacock for eight years prior to being turned over to Allen in 1646). By 1664, Prujean had moved to Oxford where he gained the right to trade as a mathematical instrument maker by being matriculated as a non-academic member of the university. He lived and worked in New College Lane for the rest of his life. He may have been attracted to Oxford by reports from Christopher Brookes, an earlier apprentice of Allen's and William Oughtred's son-in-law, who had been given a position at Wadham College in Oxford. Prujean is associated with the Oxford mathematicians Richard Holland and Thomas Edwards through advertisements in their publications. (Note that the amateur horizontal instrument HI-5 in the Whipple Museum is signed John Holland who may be related to the former mathematician.)

Several of the known instruments by Prujean are of paper-on-wood, suggesting that he was aiming at the 'poor scholar' market. He published a list of about twenty instruments which he could produce in 1701.[22] These included "*Oughtred's* Quadrant", "His [Oughtred's] double Horizontal Dial" and "*Collins's* Quadrant". 'Oughtred's quadrant' is probably the design described by Christopher Brookes based on a horizontal stereographic projection folded twice so that it fitted into a quarter of a circle. The only known example of this design is on the wood-and-paper instrument HQ-4 by Prujean, now in the Newdigate Collection. The instrument also features Sutton's (or Collins') and Gunter's quadrants. The Prujean design has the 'reverted tail', i.e. the section of the projection for the summer months before 6am and after 6pm is reflected along the quadrant edge as described by Brookes. Although this produces a compact design it produces a complicated

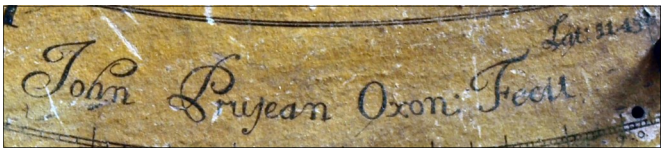


Fig. 14. John Prujean's signature on HQ-4.



Fig. 15. The signature on DH-6, tentatively identified as John Prujean.

net of lines. Another unique feature is that Prujean (or Oughtred) has chosen to put the meridian line on the right-hand edge of the quadrant, perhaps merely to differentiate it from Delamain's design.

The double horizontal dial DH-6, at the Beamish Museum, may also possibly be by Prujean: it is very badly weathered but it is suggested that the signature see Figs. 14 & 15) includes his characteristic forms of the letters I (or J) and P. The dial is quite small and in the simple form known from the Elias Allen workshop.

JOHN ROWLEY

DH-24, 25.

John Rowley (1668-1728) was a country lad (the son of a sword cutler in Lichfield, Staffs) who rose to become Master of Mechanics to King George II and who counted the heads of many European states as his patrons. He was renowned for the accuracy of his instruments, the inventiveness of his designs and for their artistic presentation. He undertook his apprenticeship in London as a mathematical instrument maker under Joseph Howe of the Broderers' Company, being made a Freeman in 1690. Howe and his 13 apprentices are not known as great dialmakers so it is not clear how Rowley obtained his designs. He worked from the "Sign of the Globe" near St Dunstan's in Fleet Street and quickly established a good reputation and the patronage of the Prince of Denmark (Queen Anne's husband). Thus, by 1708 he was making astronomical instruments for the new observatory at Trinity College, Cambridge, and a few years later he was at Greenwich Observatory advising John Flamsteed, the first Astronomer Royal, on instruments. He is best known for his orreries – he made the first so-named for the Earl of Orrery – and for his elaborate mechanical equinoctial ring dials which were used as gifts to the royalty of Europe and beyond. He was equally at home making exquisite silver portable dials and controlling large civil engineering works providing water supplies to Hampton Court, Windsor Castle and similar locations. Rowley trained a number of apprentices who themselves became great dialmakers, particularly Benjamin Scott, Thomas Wright and William Deane. It is also possible that he had a trade connection to the great clockmaker Thomas Tompion (see below).[23,24]



Fig. 16. John Rowley's signature from his indenture as an apprentice (top), and from his small DH-25.

The smaller of Rowley's two known double horizontal dials, DH-25, is undated but is thought to date from relatively early in his career as the form of the signature is in a rather florid script similar to that of the handwritten one on his indenture, Fig. 16. The dial was at one time at Bilton Hall, near Rugby, the home of the poet and essayist Joseph Addison (1672-1719). However, its design latitude of around 51.5° shows that it was not made for that location though it is possible that it was made for Addison's London home. The dial has been in private hands since being sold from Bilton Hall.

Although not now in good condition, it is clear that the dial was very finely engraved as it features a full moondial, with 15 chapter rings, as well as the stereographic projection. The bottom section of the gnomon, which is thought to be original, is a casting with an integral pair of supporting feet. Metallurgical analysis (see page 106) of this gnomon suggests that the casting process was not fully under control, supporting the view that Rowley was experimenting at the beginning of his career.

The larger of Rowley's double horizontals, DH-24, is one of a set of four large (20" diameter) and imposing dials made in 1710 for Blenheim Palace, then still under construction. The bill to the 1st Duke of Marlborough for this dial, described as "one large horizontal Dial with the projection of the sphere in plano and a Brass Cornish" was £50 0s 0d. This made it the cheapest of the four as the others each cost £10 more, presumably because they had elaborately pierced gnomons. We also know that Rowley and Henry Banks, the carver of the pedestals, were paid £5 "for a journey to Woodstock to sett up the dialls and taking several levels". The "Brass Cornish" (cornice) which is referred to is a cast and turned ring with a double-ogee profile on which the dial plate sits, attached with a ring of screws around the periphery. The ring is about 80 mm high. It gives the dial a more imposing presence and also helps to prevent the relatively thin dial plate warping. Similar rings can be found on the other Blenheim dials, on Tompion's dials, and on some by Rowley's apprentices. The dial was believed lost for many years in the late 20th century but was actually in an unopened packing case at Blenheim after being returned from restoration work in the 1960s and was 'rediscovered' for the BSS Oxford Conference of 2004.

The stereographic grid on the dial (to 5 minutes of time and 1° of declination) is quite conventional and includes values of the sun's RA, (0)-24 hours, along the equinoctial line. The azimuth scale, divided to half-degrees, places the zeroes at E and W and actually labels them so. There is an "Equation of Natural Days" scale in an arc inside the grid, giving values of "Watch Faster/Slower" to half-minutes for each day of the year. There is a symmetrical pair of altitude scales either side of the gnomon. That to the west is labelled *Altit: Solis* and runs 0-62(?)° whilst that to the east is not readable. To the south of the gnomon is a coat of arms for the 1st Duke of Marlborough featuring his twin

eagle supporters and the motto *Honi Soit Qui Mal Y Pense* for a Knight of the Garter.

The main hour numerals are oriented inwards (or towards the south). This was the standard direction until the end of the 17th century but on the other three Blenheim dials Rowley reversed the direction and placed them facing outwards. This later became the standard direction for large, high-quality dials. Together with the fact that the DH dial was £10 cheaper than the others, this suggests that it was made slightly before them. The outside of the main chapter ring is divided to minutes, numbered in 10s as standard. The inside of the ring is divided into fractional hours, first to halves with a fleur-de-lys, then to quarters (with a 'three-arrow' symbol) and eighths.



Fig. 17. The 'truncated pyramid' gnomon supporters on Rowley's DH-24, similar to those on Thomas Tompion's dials, and those of Rowley's apprentices.

The gnomon of DH-24 features a pair of supporters in the form of 'truncated pyramids' (Fig. 17). This shape became something of a trademark for Rowley's dials and those of his followers. The gnomon fixing has been altered during restoration but this is only visible from underneath the dial.

The possible link between John Rowley and Thomas Tompion is explored under the latter's entry, below.

BENJAMIN SCOTT

DH-26.

Benjamin Scott (c.1688-1751) was John Rowley's first apprentice, being turned over to him in 1706 having originally been bound to James Anderton in the Grocers' Company in 1702. As a result, Scott became a Freeman of the Grocers', rather than the Broderers', in 1712 and was later able to train several important dialmakers in that guild. His address in London was in the Strand, first at Exeter Exchange and, until 1733, at the Mariner and Globe. By 1747, he was working at the St Petersburg Academy of Sciences in Russia, where he remained until his death. His master Rowley had already made and/or supplied numerous instruments to Peter the Great, so it is likely that this served as an introduction for him to be recruited there.

Scott's only known double horizontal dial (DH-26) was made for Paris and is now in the Musée des Artes et Metiers there. What are almost certainly the instructions for it, handwritten by Scott in English, are in the British Library Sloane collection, MS 2040, and transcribed here on page 16. The link between the dial and the MS is that the calculations of the longitude correction use Paris as the example. The date of 1713 on the instructions is just a year after Scott gained his freedom which gives some credence to the commonly suggested hypothesis that the manufacture of a double horizontal dial could represent the master-piece for an apprentice.

The dial has very strong similarities to the Rowley one for Blenheim Palace (and also the Daniel Delander one). It is essentially the same size and also has the double-ogee cast ring to form a deep support. Actually, it is 14 mm greater in diameter but that can be accounted for by an extra profiled edge to the dial plate, overhanging the ring. The substantial gnomon has the characteristic Rowley 'truncated-pyramid' supporters. There is an EoT ring, now labelled *Equation de Jours Naturels* and with the times *avant/retard la montre*, inside the stereographic projection. It uses the Gregorian calendar which was adopted in France well before it was accepted in England. The symmetrical double altitude scales in the form of a sector are also present. The same fractional-hour chapter ring format is also present but, as the dial is three years later than the Blenheim one, the main Roman numerals are now arranged in the new, outwards-facing direction. Scott has also reversed the orientation of the names of the months on the calendar ring around the outside of the stereographic grid. In order to maintain the natural left-to-right reading direction, this has caused him to change the direction from clockwise to anticlockwise and, at the same time, to move the first point of Aries on the ecliptic to the west side of the dial.

One feature on DH-26 which does not appear on the Rowley dial is the set of world-wide place names engraved radially in the main chapter ring, positioned so that the gnomon shadow shows when it is noon at those places. This format for a 'geographical' dial was first introduced by Henry Wynne (see below). Wynne also had dials with separate rings for the place names and it is this style which Rowley had used on his non-DH Blenheim dials, and others. Scott, and later on his apprentice descendents Thomas Heath and George Adams, introduced the efficient scheme with names in the main ring to the Grocers' Company makers. The actual place names which Scott uses are, of course, in French and include *Londres* at about 9 minutes before noon.

JOHN SELLER

DH-27 (resigned).

John Seller snr. (c.1640–1697) sold nautical instruments (particularly compasses), maps and charts, and globes. An article describing his life and showing that he did not actually make DH-27 but merely added his name to a dial by Elias Allen, already several decades old, is reprinted on p.69.

HENRY SEPHTON

DH-64, 65 (attrib.).

Henry Sephton (c.1686-1756) was not an instrument maker but a master mason and the leading architect in the Liverpool area in the second quarter of the 18th century.[42] His most important work was Ince Blundell Hall, a handsome Georgian house with a façade derived from that at Buckingham House. A drawing for the Hall signed "Henry Sephton Invenit & Delin" exists. The double horizontal dial DH-64 which bears his signature was made for Lord Richard Molyneux (5th Viscount) of Woolton Hall. It is the latest (1722) known DH dial and it seems that Sephton may actually have engraved it personally (it is inscribed "fecit") as there are small features of the design which are not quite what would be expected of a professionally engraved instrument. Alternatively, he may have produced the design and had a local engraver (or perhaps a clockmaker) engrave it for him. The signature on the back of the dial is in a different, amateur, hand compared to that on the front and may have been Sephton experimenting. The stereographic grid is not as detailed as contemporary London dials; for example there are no ecliptic arcs or altitude scale. Also, the engraving of the coat of arms lacks finesse. Nevertheless, it is a good dial. It is on an elaborate pedestal for which Sephton may also have been responsible.

The Molyneux family of Woolton Hall were related to the Irish branch of the family, notably William, his brother Sir Thomas, and William's son Samuel, all noted scientists and politicians. William Molyneux is believed to have given a drawing of a DH dial to John Evelyn and spent some of his professional life at Chester, not far from Woolton. He died in 1698 so could not have been directly connected to Sephton's dial. Samuel worked with James Bradley on observations at Kew House, which led to the theory of nutation of the earth and was a noted practical astronomer. The location is now commemorated by a (replica) Tompion sundial. Thus is seems possible that he influenced the choice of a dial for Woolton.

HENRY SUTTON

DH-28, 29, 46, 49, 61, 62; HQ-2.

The instrument maker Henry Sutton (c.1624-1665) is known as one of the most talented artisans of the 17th century. In 1758, long after Sutton's death, Edmund Stone paid him the following praise:

> "Mr Sutton's Quadrants, made above one hundred Years ago, are the finest divided Instruments in the World; and the Regularity and Exactness of the vast Number of Circles drawn upon them is highly delightful to behold."

Details of his life are sparse. He was apprenticed to Thomas Brown(e) in the Joiners' Company, being bound in 1638. He married twice and died of plague, a fact which "troubled" Robert Moray in a letter he wrote to the Secretary of the Royal Society, Henry Oldenburg. Many of his instruments carry the names of his collaborators and customers. This suggests that Sutton was a highly active member of the mathematical community. For example, a dialling scale on a Sutton instrument features the name Euclid Speidell, a London-based mathematics teacher.[25] Sutton was also associated with Sir Samuel Moreland for whom he made parts of his calculating machine and who invented a form of perpetual calendar which appeared on several of Sutton's instruments.

His place of work and the range of his stock can be determined from the following advertisement, which is written on a quadrant dated 1658: "This Instrument or any of the Mathematiques are made in Brass or Wood by Henry Sutton Instrument maker behind the royall exchange". The Royal Exchange, which is now a shopping complex, was a major landmark in mid 17th century London, having been built in the 1560s as a centre for merchants and tradesmen to do business. Sutton's shop on Threadneedle Street behind the Exchange would have been an important location for mathematical practitioners; not only did he make and sell instruments, he also collaborated on their design and sold mathematical books.

Sutton was a prolific instrument maker with six double horizontal dials and a horizontal quadrant to his name as well as many other complicated quadrants with projections of the sphere. One such is the eponymous Sutton's quadrant featuring a 'southern astrolabe projection', a variant of the stereographic projection. (Sutton's quadrant, described by Collins in *The Sector on a Quadrant…*[26] was really invented by the mathematican Thomas Harvey but Sutton was sufficiently competent to work out its details himself.)

In the 1630s and '40s, the design of the double horizontal dial had rather stagnated in Elias Allen's workshop but, towards the end of Allen's career and after his death, Sutton took it forward and developed the style that would be the basis of all the best dials for the next 50 years.

Sutton's double horizontal dials are predominantly on square plates, a shape which was beginning to go out of fashion in favour of circular ones. With his background in astronomy, quadrants and sectors, Sutton made several new features a standard part of the DH design. These are best seen on his 1660 dial DH-49, once in Henri Michel's collection, and on the similar engraving in the Byrom Collection, DH-61. The first of these was the relatively minor addition of the sun's right ascension, running across the equatorial arc from [0] at the First point of Aries (E on the dial) to 12 at Libra (W) and then back to 24 at Aries. (Note that this scale does occur on one Elias Allen dial, the Science Museum moondial DH-3, but it was not a regular feature.) Next, he added a curved scale around the inside of the stereographic projection, giving the offset of the moon's RA for the 29.5 days of the lunar month. This ran 2× 0-12 hours, typically subdivided to 7½ minutes, for the moon's

age in quarter-day increments. The accuracy of the time shown by the moon's shadow, using the data from moon RA scale, has been discussed by Lowne.[27]

Sutton's experience with sectors is shown by his introduction of additional trigonometrical scales alongside the one showing the sun's altitude. This simple scale, running from the dial centre towards the southwest, is now paired with a second scale running (0)-45° for

$$r = r_0 . \tan z$$

where r is measured from the dial centre, r_0 is the radius of the horizon circle and z is the zenith angle. In addition, a second pair of scales running towards the southeast (and hence at an exact right angle to the first pair), runs (0)-90° showing $\sin z$ and (0)-180° showing $\sin(z/2)$.

Sutton's double horizontal dials have a full circle azimuth scale but the zeroes of the scale (4× 0-90°, subdivided to 30') are at the N and S points rather than the more conventional E and W. In addition, DH-49 (at least) has a subsidiary scale in the southern quadrant running (0)-90 and 90-(0) with the 45° points in the centre, aligned due south. This scale, together with the two linear trigonometrical rules at right angles, form a simple quadrant on the dial.

Several of Sutton's DH dials have calendrical tables on them, another feature which first appeared on his quadrants and was copied by later DH dial makers. On DH-49 these take the form of two square tables, one a perpetual calendar and the other tabulating the value of epact for the years 1657 to 1690 (see p.112).

There are several paper versions of Sutton's DH dials, e.g. DH-46, 61 & 62. It seems likely that they are either proofs (reversed images) or counterproofs made from the plate of real dials. The designs are very similar but differ in small details, such as the date (1660-1662) and the calendrical tables, so it is not simply a case of multiple prints made from the same plate. This design is also shown by the brass dial DH-49, although in that case the star RAs were absent. The paper dial DH-61 in the Byrom Collection[28] is typical. The collection is named after John Byrom (1691-1763) but, since the dial is dated 1661, clearly he was collecting older printed material and it is not a dial which he owned personally.

The two paper images (DH-62) in the British Library were deposited as part of the Thomas Birch (1705-66) collection but it is thought[25] that he acquired them from John Pell (1611-85).[9a]

THOMAS TOMPION

DH-31.

Thomas Tompion (1639-1713) is generally regarded as the father of British clockmakers and his signed clocks make extraordinarily high prices (Fig. 18). It is less well known that he made, or at least supplied, a number of sundials.[29] He arrived in London from Ickwell Green in Bedfordshire in 1671 at the age of 32: details of his apprenticeship are unclear. He was befriended by the scientist Robert Hooke and worked with him to produce one of the earliest spring-driven watches, as well as astronomical quadrants and the two Great Clocks for the new Greenwich Observatory. As well as being a good craftsman and a very inventive engineer, he was also a very successful businessman so that, by 1695, he was employing 14 men at his premises in Water Lane (and an unknown number of outworkers) and he went on to produce at least 800 clocks. His ten known signed sundials comprise five portable dials, a large 'equation' horizontal dial for Wrest Park, two other smaller horizontal dials and a pair of large horizontal dials for Hampton Court Palace, one of which is a double horizontal (DH-31).

The matching pair of dials at Hampton Court stand on very imposing pedestals attributed to Van Nost. The dials are believed to date from 1702 and to have been made for the King, bearing his monogram. They are both 523 mm diameter (20½") with the approximately 3 mm thick dialplates attached by a ring of 9 slot-headed screws to a supporting cast brass ring with a double-ogee based profile 65 mm deep. The dial which accompanies DH-31 is an 'azimuth and equation' dial. Both original dials are now in a very worn and rubbed state and were removed from their pedestals in the 1990s, being replaced on the terrace by new replicas. (An earlier replica of the azimuth dial, made in 1959, is in Kew Gardens.) The double horizontal replica (M -14) is unfinished, consisting just of an unengraved machined bronze facsimile. At the time of writing (2009), the original azimuth dial is on public display in a glass case in the garden gift shop but the double horizontal is in store.



Fig. 18. Thomas Tompion. Courtesy of the Trustees of the British Museum.

The Hampton Court double horizontal dial has suffered from the effects of the corrosive London atmosphere, which has caused severe erosion, and also from millions of inquisitive fingers which have so polished the periphery of the dial that the minutes ring is completely worn away and the edge is significantly rounded. Nevertheless, it was once

a fine dial. The gnomon, which was broken and separated from the dial for some time, is original and well restored.[30] It is buttressed by a pair of truncated pyramid supports exactly in the style used by John Rowley and his apprentices.

There are a number of reasons to believe that the horizontal sundials supplied by Tompion and signed "Tho Tompion Londini" (not, note, "Tho Tompion *fecit*") were actually made in Rowley's workshop, probably personally. Although it might be argued that Tompion had sufficient skills and knowledge to make a one-off double horizontal dial, he was 63 years old at the time and in charge of a large and busy business – even clocks which he was perfectly capable of making were produced by his workmen. There are a number of stylistic features which point to Rowley as the high quality maker to whom Tompion would have entrusted his reputation. As well as the gnomon supporters and cast supporting ring for the dialplate, noted above for their double horizontal dials, there is a common use of transversals (though not on DH dials) to provide an accurate method of reading to one minute. Transversals are quite common on astronomical instruments but very rare on sundials. Both Rowley and Tompion would have observed them on the instruments at the Greenwich Observatory. The other dials at Blenheim Palace and Hampton Court, which Rowley and Tompion respectively supplied as partners to the DH dials there, are believed to be the first occurrence of transversals on sundials. Most other English examples are by Rowley's apprentices. Another common feature between these two makers is sundials with a vertical northern edge to the gnomon casting a shadow onto a scale of the sun's azimuth, again a rare design feature.

It is believed[29] that the pocket universal ring dial signed by Tompion was probably made by Richard Whitehead. Whitehead was an apprentice of Henry Wynne but he died in 1696 so could not have made the Hampton Court dials. It is suggested that Tompion chose the up-and-coming Rowley (29 years his junior) to be his dial supplier and that, as a result, Rowley developed his reputation sufficiently to supply sundials to the heads of many European states under his own name.

THOMAS TUTTELL

DH-32, 48, 66 (attrib.).

Thomas Tuttel(l) (c.1674-1702) was apprenticed to Henry Wynne in 1688 and was thus a fourth generation double horizontal dialmaker. He was the second of Wynne's apprentices, gaining his freedom in the Clockmakers' Company in 1695 and setting up businesses at the 'King Arms and Globe at Charing Cross' and 'Against the Royal Exchange in Cornhill'. He was a very fine engraver and clearly destined to become a great maker. He was appointed to be "Hydrographer and Mathematical Instrument Maker to the King" (William III) in 1700. Tragically, however, he lost his life by drowning in the Thames Estuary on 22 January 1702 while undertaking a survey with two colleagues. Although no portrait of him is known, we do have a good description from an advertisement that his widow published in the *Post Boy* of 31 January to 3 February 1702, appealling for his body to be discovered. It says:[31]

> "He was of Middle Stature, fair Light Hair but his Head newly shaved, his Coat a Gray Cloath napped, trimmed with Black Buttons, his Wastcoat Gray, Breeches a light Colour; and his Linnen marked with a red T."

Tuttell is perhaps best known for his portable, self-aligning combination analemmatic and horizontal dials, of which he made several and also published a descriptive leaflet.[32] Despite the title of his pamphet - *The Description and Uses of a New Contriv'd Eliptical Double Dial* – he did not actually invent the format though he is generally recognised as popularising it. Like the double horizontal dial, its self-aligning properties are generally overstated.

Only one signed brass DH dial by Tuttell is currently known (DH-32) but a print of a second dial also exists (DH-48). These dials are very similar in design although the paper dial is smaller in size and differs in some minor details, such as the type of fleur-de-lys used for the half-hour markers and the spelling of 'excellent' in the signature. However, they have quite different coats of arms and so clearly they were for different clients. Both dials carry the same unusual motto (which Tuttell also used on one of his portable analemmatic dials). It reads "Preteritum Nihil, Praesens Instabile, Futurum Incertum." (*The past is gone, the present transient, the future uncertain*). Similar sentiments, phrased slightly differently, are expressed by the Silesian poet and emblematist Nicolas Reusner (d. 1602) in a book of epigrams published in 1593,[43] but it is not known if this was the first occurance of the phrase.

HENRY WYNNE

DH-34, 35, 36, 37, 38, 39, 40, 41.

Henry Wynne is second only to Elias Allen as the maker of the largest number (8) of recorded double horizontal dials. He was born c.1640 and bound as an apprentice to Ralph Greatorex in 1654, thus making him a third generation DH dialmaker. He gained his freedom in the Clockmakers' Company in 1662 and only a year later he took his first apprentice, Richard Whitehead. (Whitehead himself became a highly respected instrument maker though no DH dials by him are currently known.) Of Wynne's later apprentices, Richard Glynne and Thomas Tuttell both have extant DH dials.

Wynne was very lucky when the Great Fire of London in 1666 came within a couple of hundred yards of his premises in Chancery Lane (Fig. 19) variously given as "at the Pope's Head", "Next the Sugar Loaf in Chancery Lane" (1682), "over against the Rolls" (1700), and "Near Sergeant's Inn" (1707). He operated there as both an instrument maker and a seller of scientific books. As a result, he was later recorded merely as a 'bookseller' in an

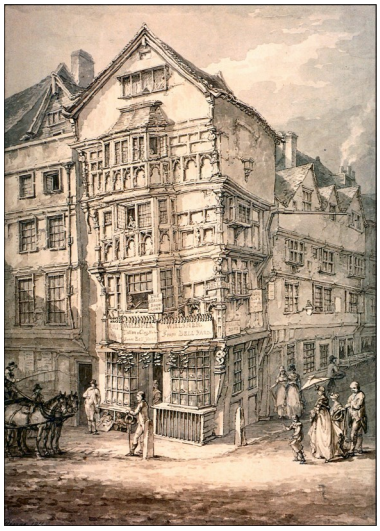


Fig. 19. View from Fleet St, looking north up Chancery Lane, very close to Wynne's premises. This building, which survived the Great Fire and was demolished in the 18th century, is sometimes called Izaac Walton's shop but that was actually three doors to the west and he had left before Wynne's period. Courtesy Guildhall Library, Corporation of London.

edition of Robert Hooke's diaries.[33] The *Diary* refers to Wynne (variously spelled Win, Wynn, Winn etc.) at least 27 times between 28 September 1672 and 8 November 1680. On one occasion (18 May 1678) Hooke visited Wynne along with Samuel Pepys (who is known to have had a double horizontal dial). Pepys clearly knew Wynne well as he had described him as a " 'prentice of Greatorex" as early as 4 February 1669 and reported that he had bought a "parallelogram of brass" from his "shop in Chancery Lane".

Wynne was involved in all aspects of instrument making and is believed to have made barometers ('weather glasses') for Hooke: he co-authored a leaflet on the subject during the 1680s. He also co-authored a leaflet on the equinoctial ring dial, presumably to accompany instruments which he made. By 1690 he had risen in the heirachy of the Clockmakers' Company and was Master for the year. He was clearly a trusted member of the scientific fraternity in London. An example of this is that when William Leybourn, who lived in the east of London, delineated the vertical dial for Brick Court of the Middle Temple (very near to Wynne's Chancery Lane premises) in 1695, it was Henry Wynne who collected and signed for the £2 2s 0d fee.[34] One of Wynne's last known dials was a large horizontal dial made for the Inner Temple in 1707, just two years before his death in 1709. In his will,[35] signed on 7 November 1708, he is described as being "sick and weak in body but sound of mind and memory". It was witnessesed by one Elizabeth Read and by John Coggs, an independent journeyman who later worked for Thomas Wright, amongst other makers. Wynne left the majority of his estate to his nephew.

Wynne's double horizontal dials are mainly undated. Some can be dated by the calendrical information on them (see page 96) or by documentary evidence. For example, the Windsor Castle accounts book for 1677/8 records the items:

> "Henry Wynne for Materialls and Workmanship in making a Large Double Horizontal Dyall set in the Southest Terras Walke at Windsor Castle, according to Contract for the same £25."

and

Dial Ref	Description	Date
DH-41	Hotham Park	1660s ?
DH-37	'Cornwallis' (Brome)	1667/8
DH-40	Windsor Castle (Clarence House)	1677/8
DH-39	'Earl of Lauderdale'	1679
DH-35	Powys Castle	1680 ?
DH-34	Wrest Park	1682/3
DH-36	Staunton Harold	1685
DH-38	Drumlanrig Castle	1692

Table 3. Tentative chronology of Wynne's DH dials.

> "Henry Wynne for his journey and Charges from London to Windsor for setting y^e^ great Horizontal dyall on y^e^ Terras Walk^e^".

The dial referred to is believed to be DH-40, now at Clarence House (a sister dial – an ordinary horizontal – by Wynne is still at Windsor Castle). This dial was moved slightly in 1968 to its current position in front of the main entrance at the insistence of the Duke of Edinburgh, who had noticed that it was being damaged by drips from an overhanging tree. It seems likely that it was also cleaned at that time as photographs show it without the heavy blue-green verdigris which it now has, obscuring almost all the details of the engraving. A 1968 photograph (see Catalogue) shows that it would originally have looked very similar to the 'Cornwallis' dial DH-37.

A tentative chronology of Wynne's DH dials is given in Table 3.

Relatively little is known of the last dial on this list. For the others, there is a marked tendency for them to get larger and more sophisticated as time progresses. The Drumlanrig dial is the largest known of any maker. The form and layout of the stereographic projection is already determined for the smallest (and presumed earliest) dial, DH-41 at Hotham Park. It is not known who actually commisioned this dial. It is extremely well executed but is devoid of 'extra' furniture which would help to place it. Both the 'Cornwallis' and the Clarence House dials are larger and have more features added to the basic DH dial. For example, the Cornwallis dial has a table of epacts and star data, aranged in the form developed by Henry Sutton three decades earlier. It is interesting to note that Tompion made a tower clock for the Cornwallis estate of Brome Hall in c.1690, perhaps to accompany the sundial.

The Clarence House and Cornwallis dials are unusual in that they have laminated dialplates, consisting of a thin engraved sheet rivetted to a thicker, underlying sheet. This construction should be contrasted to the Rowley and Tompion dials where a much thicker dialplate is screwed to a deep, cast rim. This construction is discussed further in the section on *Materials and Methods*, p.106.

The Wrest Park dial (DH-34) is well preserved and shows Wynne experimenting with extra features around the

stereographic projection, partly to produce a more balanced design by allowing the stereographic projection to be smaller for a given dial size. In this case, the multiple chapter rings are for different locations around the world, a layout he has used on at least one non-DH dial (such as that at Euston Hall, Norfolk).

For the Staunton Harold dial (DH-36, described in detail on p.41), Wynne has chosen to put 'moon rings' i.e. complete chapter rings for pairs of days in the lunar month, around the stereographic projection. This dial is also the first to feature equation of time data though its position, along the style edge of the gnomon, looks very much like an after-thought.

Eleven of the twelve stars which are engraved with their right ascensions are the same as those shown on Sutton's and Marke's dials (see p.120). The exception is that Wynne replaced *A la Peg* (with an RA of $11^h\ 55^m$) with *Fomalhaut* possibly because, although it is much further south, it is brighter. Also, two stars are usually drawn in the 'wing of Pegasus' which could lead to confusion.

The Drumlanrig dial (DH-38) is the latest Wynne dial that has been examined in detail and shows that he has continued to develop and improve his style. The inside of projection is now filled with a large equation of time table for every day of the year, in the style of those seen on Tompion's dials. The geographical place names are positioned in two rings with a XII to show the times of their local noons: this was the style used later by John Rowley and Thomas Wright.

UNSIGNED DIALS

DH-42.

This unsigned dial has the appearance of a Henry Sutton or John Marke design – it is about 1 foot square, features sector-type scales and a curved lunar scale inside the projection, a standard set of stars with their RAs and so on. However, the epact table (another Sutton/Marke feature) indicates a date of 1680 which is too late for Sutton and probably Marke too. It could possibly have come from Henry Wynne's workshop as he (and his apprentices) continued the use of these features. It is a puzzle why a dial of this quality should be unsigned, against the rules of the London guilds. Another possiblity is that it was made by someone copying a paper version of a Sutton dial, though they would have had to have been a very competent engraver.

DH-44.

This dial was originally signed in the southern sector of the chapter ring but this has been erased. It was once at the Time Museum and was subsequently sold by Sotheby's New York. It is a good dial (though lacking its gnomon) with several mysteries: who made it; who erased the signature and why; and where is it now?

It has the dedication, added in a different hand at a much later date: "The Gift of Eliza Hayton from Bledlow House Bucks" and the motto "From the Rising of the Sun THE LORD'S NAME IS TO BE PRAISED unto the going down of the same", (Psalm 113:3, Gatty[37] no. 321). Bledlow House, Bucks., which is probably the design location of this dial, did not belong to the Hayton family in the 17th century but was acquired by Henry Cross in the 18th century. His son, Thomas, owned the manor by 1745 and his heiress was the Elizabeth (1702-88) who married William Hayton of Ivinghoe.

The altitude scale, which unusually runs from the gnomon towards the SE rather than to the SW, is divided from 0° to 90° whereas on most dials it only runs to the maximum solar height at noon on the summer solstice.

DH-45.

This is the only known double horizontal dial made in slate and it is only known through its entry in a Christies auction catalogue. It is thought to be from the 19th century and certainly the outward-facing Roman numerals indicate that it must be after around 1750 at the very earliest and the general style points to it being later. It is a slightly idiosyncratic design with, for example, the altitude scale positioned along the southward meridian and with very long hour divisions. The dial is probably best described as 'decorative'. The projection appears to be properly delineated although it does not have an ecliptic.

DH-52.

This dial follows closely the style used by Elias Allen, both in general layout and in detailed features. As examples, the ecliptic is labelled with calendar dates rather than zodiac sigils and solar longitudes, the angles of the Xs and Vs are quite wide, (though the width of the broad strokes is wider than Allen's hand) and so on. A minor difference is that Allen's characterisic 'T-bar' half-hour mark has been replaced by a different 'rosebud' symbol. One unique feature is the divisions on the altitude scale which run obliquely rather than perpendicularly to the edge, a feature seen elsewhere on the Greatorex dial DH-20 and the Dudley azimuth dial AD-3. The dial may have been made in Allen's workshop though not by Elias or John Allen. It could possibly be by Greatorex (though some features of the lettering do not match examples of his hand on other dials) but it could possibly be a slightly later copy.

DH-30 and DH-60.

These two small (105 mm square) printed engravings of a DH dial are identical. They include features such as a reversed '4' on an altitude arc and a reversed 'N' in the motto: clearly the engraver was not accustomed to engraving in mirror image. This conclusion is strengthened by the fact that the dates run anticlockwise around the horizon circle with Aries on the west, a configuration not usual until nearly a century later.

DH-30 is in the London Science Museum and is a single sheet of paper as part of the collection of tradecards described by H.R. Calvert.[36] It was originally tentatively ascribed to Henry Sutton simply because it had been filed adjacent to Sutton's tradecard. However, it bears no resemblence to any of Sutton's dials. The other known example of this design, DH-60, is bound at the end of a copy of Richard Delamain's 1632 book on his horizontal quadrant, with no supporting text. This is extremely strange, especially in the light of Delamain's claim that he invented his device without using knowledge of Oughtred's DH dial.

Close inspection of the engravings shows a high probability that the copper printing plate was the work of John Allen, who also engraved the horizontal instrument which forms the frontispiece of the book, and also the similar instrument (HQ-1) in Geneva. Points of similarity are the flourishes after the latin words in the spandrels, the forms of the lower case 'c' and 'p', and the overall layout. Two parts of the design are not in Allen's hand. These are the latin motto to the south of the gnomon and the profile of the gnomon itself. It is unusual to see a double horizontal gnomon engraved at all and the one here, with its strange Elizabethan-style piercing, is unlike that seen on any known DH dial. The engraving hand of the motto is a very good match to that on the title page of the book but it is not known whose work this is.

The mottoes on the dial start with a latin hexameter around the circumference:

Perpetuus Solis Distinguit Tempora Motus

(*The continuous motion of the Sun marks out times.)*

Then at the north and south:

VIGILANTE	QUAERE UT INVENIas
(*Keep watch*)	(*Seek in order that you may find*)

The emended script in the second hand reads:

Cunta sciatheri solaria ducta figaris
Cernitur hoc variis exsuperare modus:
Solis et ascendens, occasus et ortus et auster,
Azimuth. Hinc mensis longa videnda dies;
Horaque solaris via sol quodcunque per umbras
praestitit, Horologi mobilis orbis habet.

This section forms three elegaic couplets and may tentatively be translated as:

(Seek and you shall find)
all the solar lines drawn with diagrams in the plane of the shadow-dial. This is perceived to excel in various methods; there are the climbing of the sun and his sinking and his rising and the meridian to the south and the Azimuth. Hence the long[est] day of the month is to be seen. The hour and the path of the sun ensures through the shadows, all these the sphere of the moving sundial includes.

Thus it appears to be a description of the capabilities of the instrument.

DH-66.

It is surprising that this large and impressive dial apparently has no signature. Its coat of arms, for the Earl of Northampton, is also seen in reduced form (without supporters and crest) on Thomas Tuttell's DH-48, now in the National Maritime Museum. Some features of the dial, such as the 'H' form of the half-hour fleur-de-lys and the pennant ends of the azimuth scale, are reminiscent of Tuttell's style. The large Equation of Time table is in the form introduced by his master, Henry Wynne, and the data in it comes from the earliest table published by Tompion in 1683 (Davis (2003 & 2005)). In addition, the physical structure of the dial, with a dialplate riveted to a cast rim, is characteristic of only a small number of makers, particularly Wynne and Tompion and, slightly later, John Rowley.

DH-66 has its main hour numerals arranged to be read from the south or inside of the dial, as was conventional until around the first decade of the 18th century. However, the two signed DH dials by Tuttell (DH-32 & 48) are both very early examples of the new style of outward-facing numerals. Hence if Tuttell was the maker of DH-66, then it must pre-date his other two dials.

HQ-7

See John Brown(e).

REFERENCES AND NOTES

1. The portrait is discussed in detail in H. Higton: 'Portrait of an instrument-maker: Wenceslaus Hollar's engraving of Elias Allen', *Brit. Soc. Hist. Sci.,* 37(2), pp.147-166 (June 2004).
2. Lowne (2005).
3. W. Forster: *Circles of Proportion...* (1632).
4. Joyce Brown (1979).
5. R. Delamain (1632).
6. Davis & Lowne (2001).
7. B. Loomes (1981).
8. John Brown (1662).
9. John Brown (1671).

9a. British Library, Add MS 4473 has a selection of Pell's papers including engravings of Sutton's quadrants.

10. Bryden (1998-9).
11. Davis (2004).
12. R. Latham & W. Matthews (eds.): *The Diaries of Samuel Pepys*, (1970-83).
13. Ibid., entry for 23 January 1660/1.
14. Simcock (1993).
15. Taylor (1966).
16. Middle Temple Accounts MT. 2 TRB/77 1718/19 Item 27.
17. Taylor (1954).
18. Clifton (1995).
19. Cajori (1916).
20. Willmoth (1993), Chapter 2.
21. Letter from William Oughtred to Elias Allen, 20 August 1638. MS Add 9597/13/5/215, Cambridge University Library.
22. Bryden (1993).

23. Appleby (1996).
24. J Davis: *John Rowley – Master of Mechanicks*. Presented at the BSS Annual Conference, Latimer, (April 2008).
25. Eagleton & Jardine (2005).
26. Collins (1659).
27. Lowne (2005).
28. Hancox (1992).
29. Evans (2006).
30. Daniel (1995).
31. Extract from *Post Boy*, 31st January to 3rd February 1702. (No. 1048). Copied from Heal Collection 105.104, British Museum.
32. Tuttell (1698).
33. Robinson & Adams (Eds) (1935).
34. Middle Temple MT2/TRB/No.53 p.72 (1695).
35. Henry Wynne's will is in the National Archives, Perogative Court of Canterbury, Prob 11/505/152.
36. Science Museum inventory 1934-122/38 (Colv. 386).
37. Gatty (Eden & Lloyd eds.) (1900).
38. Bryden (1974).
39. Daniel (2000).
39a. M. Pearson: *Kent Clocks and Clockmakers*, Mayfield Books (1977).
39b. For a discussion of 1718 probate inventory of George Sayer, including his six clocks and barometer, see C.H.K Williams: 'The Church Clocks of Charing, Kent', *Antiquarian Horology*, 29/3, p.390 (Mar 2006).
40. C.B. (1649).
41. Hill (1998).
42. H. Colvin: *A Biographical Dictionary of British Architects, 1600-1840,* Yale University Press (1954).
43. Nicolas Reusner: *Epigrammatum Graecorum Liber Singularis*, Strasburg (1593).

APPENDIX 1

CONCORDANCE

1. Turner (1981)

One of the earliest lists of double horizontal dials, horizontal instruments and horizontal quadrants is that published by Anthony Turner in his 1981 article. The list below shows the correspondence of the instruments described there with their references in this monograph.

Turner (1981)†	Maker	This Monograph
A.1	[Whitwell]	AD-3
A.2	E. Allen	HI-3
A.3	E. Allen	HI-1
A.4	Holland	HI-5
A.5	Davenport	HI-4
A.6	Anon	HI-6
B.1	Sutton	DH-28 or ?
B.2	Anon	DH-44
B.3	Sutton	DH-46
B.4	Wynne	DH-39
B.5	Scott	DH-26
B.6	E. Allen	DH-1
B.7	E. Allen	DH-2
B.8	E. Allen	DH-3
B.9	Greatorex	DH-20
B.10	Wynne	DH-30
B.*	(Evelyn)	DH-47
B.11	Tuttell	DH-48
C.1	J.Allen	HQ-1
C.2	Sutton	HQ-2
C.3	Pigot	HQ-3
C.4	Prujean	HQ-4

† Reprinted in A.J. Turner: *Of Time and Measurement – studies in the history of horology and fine technology*, pp. 99-125, Variorum, Aldershot (1993).

PART FOUR

CATALOGUE OF DIALS

and

OTHER INSTRUMENTS

CATALOGUE OF DIALS

KEY

SRN indicates the BSS Register serial number.

A.J. Turner no. x indicates a dial listed in Turner (1981).

Latitude: in [square brackets] indicates calculated from dial delineation. In “inverted commas” – as engraved on dial.

Dial features have been obtained either by inspection of the dial or from photographs. Missing entries imply that the dial or photographs were not available, that the dial is too badly eroded to show detail, or that the photographs were of low resolution.

Where reference is made to identifying symbols or numerals (dots, crosses, fleur-de-lys, thicker, etc) it implies that every such numeral or multiple of numerals is so identified.

DOUBLE HORIZONTAL DIALS

Record no.	**DH-1**
Signature	Elias Allen fecit
Date	c. 1630
Dimensions	315 mm (12⅜ ins) diam. circular.
Material	Brass.
Condition	Fair/good. Worn, polished. Original(?) gnomon.
Latitude	[51.0° N ?]
Features	Polar dial: IIII-XII-VIII, inward-facing. Two scales of minutes, outer divided 5 min, 10s extended and numbered: inner divided 15 min, alternate quarter-hours hatched. Stereo grid: IIII-XII-VIII, divided 15 min. Dec arcs: 2 deg intervals, 10s thicker. Ecliptic arcs: barely visible. Date scale: on ecliptic, unreadable. Azimuth scale: unreadable. Altitude scale: none visible. Compass scale inside polar dial chapter ring, 32 labelled points, oriented to relate to shadow of vertical style. Dial plate laminated from two sheets of brass.
Location	Oxford Museum of the History of Science.
Provenance	Purchased, 1943. Inventory No. 35515
Reference	A.J.Turner no. B6.
Notes	Some detail appears to have been lost by wear and in the polishing.



Record no.	**DH-2**
Signature	Elias Allen fecit
Date	c. 1630
Dimensions	300 mm (11¾ ins) a/f octagonal.
Material	Brass.
Condition	Good – polished. Gnomon may be a replacement?
Latitude	[52.6° N]
Features	Polar dial: IIII-XII-VIII, inward-facing. Two scales of minutes, outer divided 1min, 5 and 10 extended, 10s numbered: inner divided 15 min, 30 extended and crossed. Stereo grid: IIII-XII-VIII, divided 15 min. Dec arcs: 2 deg intervals, 10 thicker. Ecliptic arcs: March equinox at east side. Date scale: on ecliptic, months, single days dotted, 5 and 10 crossed, numbered 10, 20, 28/30/31. Azimuth scale: single deg, 40-(0)-90-(0)-40, 5 and 10 extended, 10s numbered omitting zeroes at E and W. Altitude scale: to SW, single deg, 10s numbered. Compass scale inside polar dial chapter ring, 32 labelled points, oriented to relate to shadow of vertical style.
Location	National Maritime Museum, Greenwich.
Provenance	AST0232.
References	A.J.Turner no. B7; Higton (2002) p.58.
Notes	Centres for dec arcs visible.



Record no.	**DH-3**
Signature	Elias Allen fecit A Moone diall
Date	c. 1630
Dimensions	258 mm (10⅛ ins) a/f octagonal. Gnomon 3.5 mm thick.
Material	Brass.
Condition	Good.
Latitude	“Latitude 51½ deg N”.
Features	Polar dial: IIII-XII-VIII, inward-facing, divided 3 min, 15, 30 and 45 extended, 30 crossed. Stereo grid: 4-12-8, divided 15 min. Dec arcs : 2 deg intervals, 10s thicker. Ecliptic arcs: March equinox at east side. Date scale: on ecliptic, months, single days dotted, 5 and 10 extended, numbered 10, 20, 28/30/31. Azimuth scale: complete circle, single deg (0)-90-(0)-90-(0), 5 and 10 extended, 10s numbered omitting zeroes at E and W. Altitude scale: to SW, single deg 0-62, 10s numbered. ‘Moone dial’: separate hour scale inside main chapter ring, hours only, 12-8-12-4, 4^h slow with respect to polar dial. Moon correction table: ages of moon, days 5-25, time scale in hours and half-hours, 4^h fast to compensate readings from moon time scale. See also p.139. Names of 12 stars and their RAs. See also p.140. RA of sun in small Arabic figures along equator.
Location	Science Museum, South Kensington (in store)
Provenance	Acquisition no. T1921-613
Reference	A.J.Turner no. B8.
Notes	Centres for dec arcs visible. This is the only known Elias Allen DH dial with moon dial and star places.

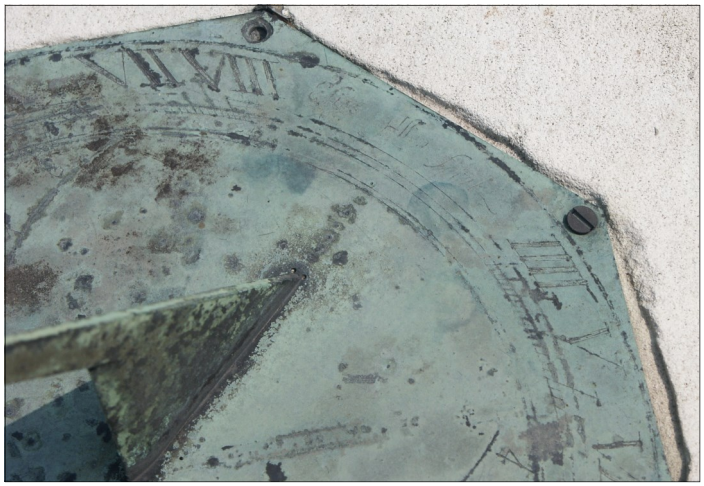




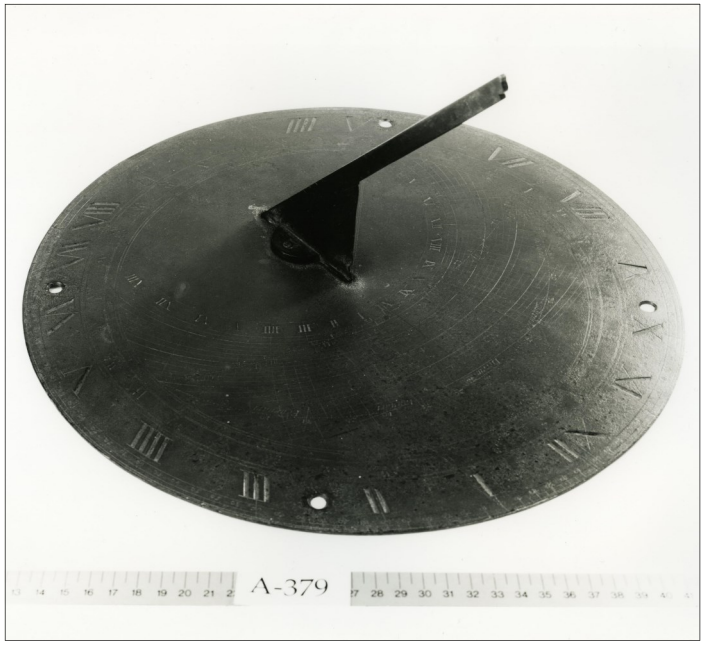


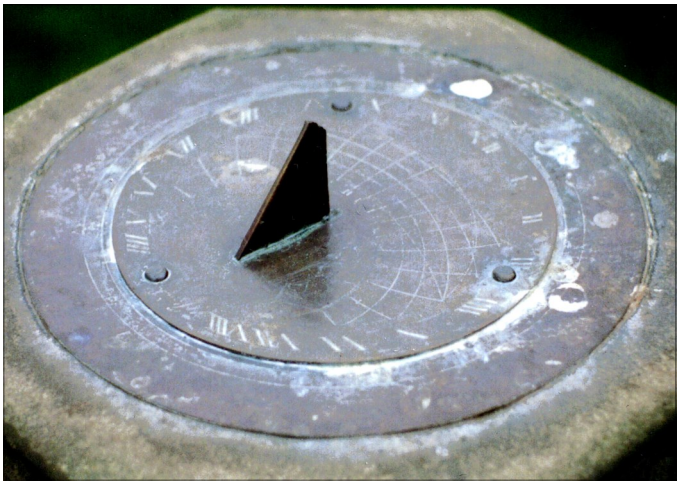
Record no.	**DH-4**
Signature	Elias Allen fecit
Date	c. 1630
Dimensions	216 mm (8½ ins) a/f octagonal. Gnomon thickness 2.5 mm. Horizon circle 169 mm diam. Offset of polar style 59.5 mm to S.
Material	Brass.
Condition	Poor – badly worn and encrusted with patina. Original gnomon.
Latitude	[51.5° N]
Features	Polar dial: IIII-XII-VIII, inward-facing, divided 5 min, 15, 30 45 extended, 30 crossed. Stereo grid: 4-12-8, divided 15 min. Dec arcs: 2 deg intervals, 10s thicker. Ecliptic arcs: March equinox at E side. Date scale: on ecliptic, months (initials only), single days dotted, 5 and 10 crossed, numbered 10, 20, 28/30/31. Azimuth scale: single deg, 45-(0)-90-(0)-45, 10 numbered omitting zeroes at E and W. Altitude scale to SW, single deg, 10s numbered.
Location	Private collection, England.
Provenance	Bought from a Bury St Edmunds antique shop in the 1960s, complete with original (?) pedestal. Dial now indoors.
Reference	BSS SRN 5291.
Notes	Centres for dec arcs visible.



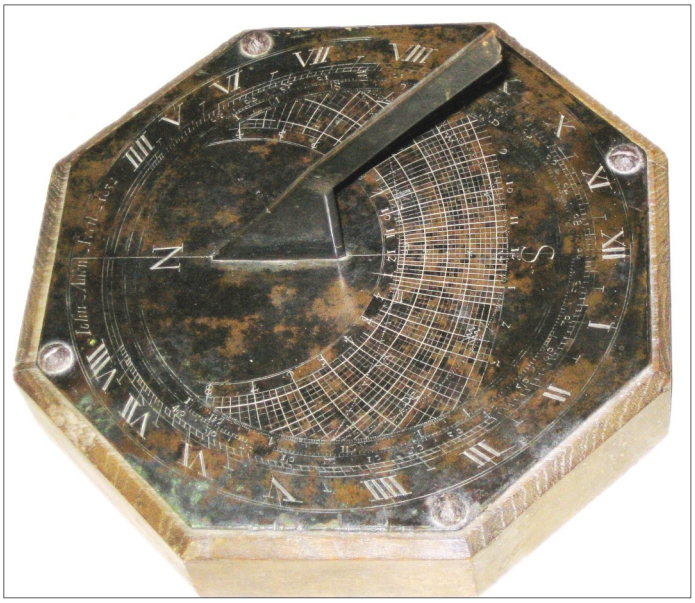


Record no.	**DH-5**
Signature	Elias Allen fecit
Date	c. 1630
Dimensions	350.5 mm (13¾ ins) diam. circular.
Material	Brass.
Condition	Poor, eroded.
Latitude	
Features	Polar dial: IIII-XII-VIII, inward-facing. Stereo grid: 4-12-8, divided 15 minutes. Dec. arcs: 2 deg intervals, 10 thicker. Ecliptic arcs, March equinox at E side. Date scale on ecliptic arcs, months, single days. Azimuth scale. Altitude scale to SW. Compass scale inside polar dial chapter ring, 32 labelled points, oriented to relate to shadow of vertical style.
Location	Adler Planetarium, Chicago.
Provenance	Shown in Tesseract catalogue 51 in 1995/6. Acquisition no. A-379
Reference	*BSS Bull* 13(iii) p.111; Christies sale catalogue 29 Sept 1994 p.31.
Notes	Circular gnomon supporter.





Record no.	**DH-6**
Signature	I (or J)...P... (?) [tentatively attrib. to John Prujean].
Date	
Dimensions	205 mm dia (inner) 290 mm dia (outer).
Material	Brass
Condition	Poor – badly worn, gnomon snapped.
Latitude	Unknown
Features	Only the major lines of the projection are still visible.
Location	Beamish Museum, Stanley, Co. Durham
Provenance	
Reference	BSS SRN 0846.
Notes	Original dial mounted on a larger circular plate with additional scales (not legible).



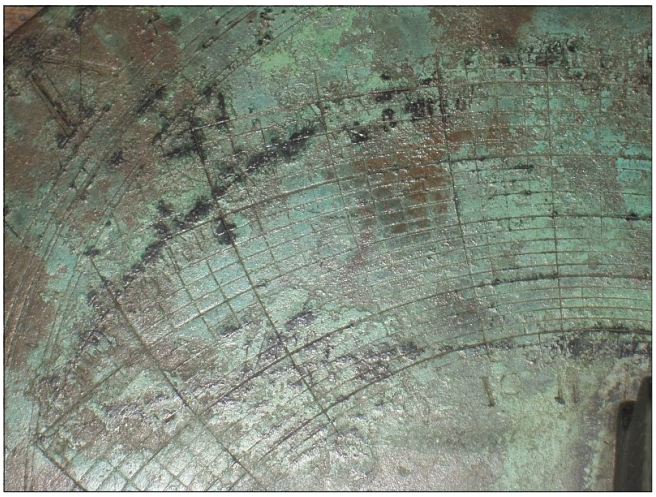
Record no.	**DH-7**
Signature	John Allen fecit 1632
Date	1632
Dimensions	190 mm (7¼ ins) a/f octagon.
Material	Brass.
Condition	Excellent. Gnomon slightly bent.
Latitude	[51.3° N]
Features	Polar dial: IIII-XII-VIII, inward-facing, divided 5 min, 15, 30, 45 extended, 30 crossed. Stereo grid: 4-12-8 at inner ends of hour lines, 9-12-3 outer, divided 5 min. Dec arcs: 2 deg intervals, 10s thicker Ecliptic: March equinox at E side, zodiacal sigils, single deg of longitude dotted, 5 and 10 crossed. Date scale: at ends of dec arcs, months (initials), single days, 10 extended. Azimuth scale: 40-W-90-E-40, numbered in 10s. Altitude scale to SW: indistinct but appears to be single deg. Meridian marked N, S: these and E, W in azimuth scale oriented to relate to shadow of vertical style.
Location	Maidstone Museum and Art Gallery
Provenance	Donated c.1956.
Reference	BSS SRN 6035.
Notes	Earliest dated double horizontal dial known.



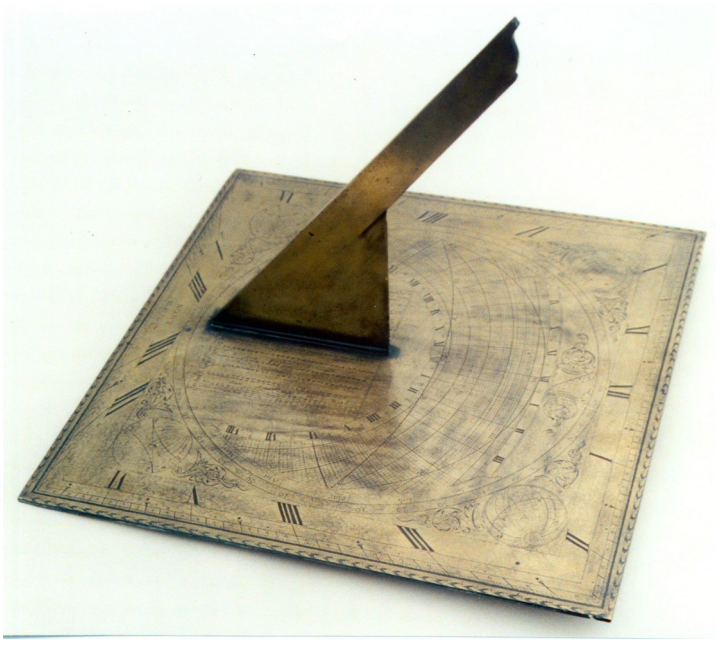


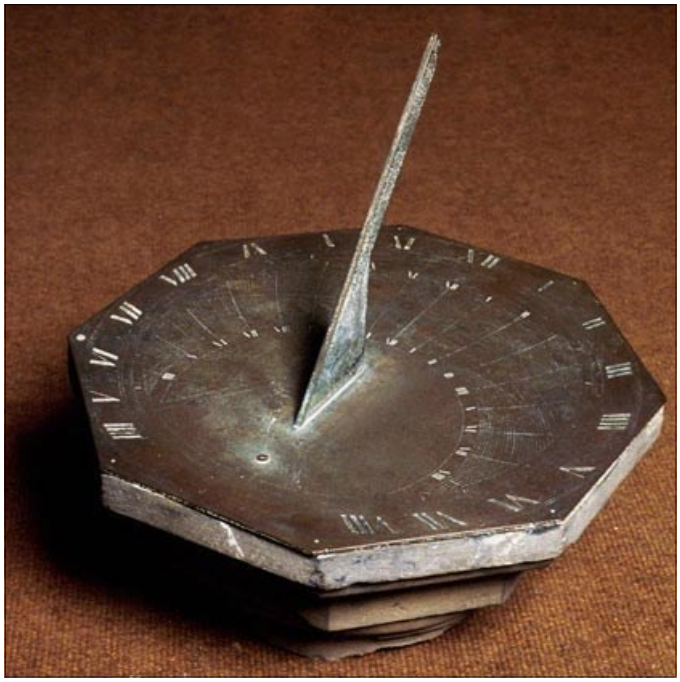
Record no.	**DH-8**
Signature	Elias Allen fecit
Date	c. 1630
Dimensions	194 mm (7⅝ ins) a/f octagon. c. 2 mm thick. Horizon circle 148 mm diam. Offset of polar style 50.2 mm to S.
Material	Brass.
Condition	Poor – badly worn, heavy blue-green patina. Much fine detail has been lost or obscured. Was fitted with inappropriate modern gnomon, now replaced with a better replica.
Latitude	[51.5° N]
Features	Polar dial: IIII-XII-VIII, inward-facing, divided 5 min? Stereo grid: 4-12-8, divided 15 min. Dec arcs: 2 deg intervals, 10 thicker. Ecliptic arcs: Individual days, months. Azimuth scale: 40-(0)-90-(0)-40, 10s numbered, omitting zeroes at E and W. Altitude scale: unreadable.
Location	Private collection, England.
Provenance	Bought from Principia Fine Arts, Hungerford, November 2006. (c. £1600?)
Reference	
Notes	



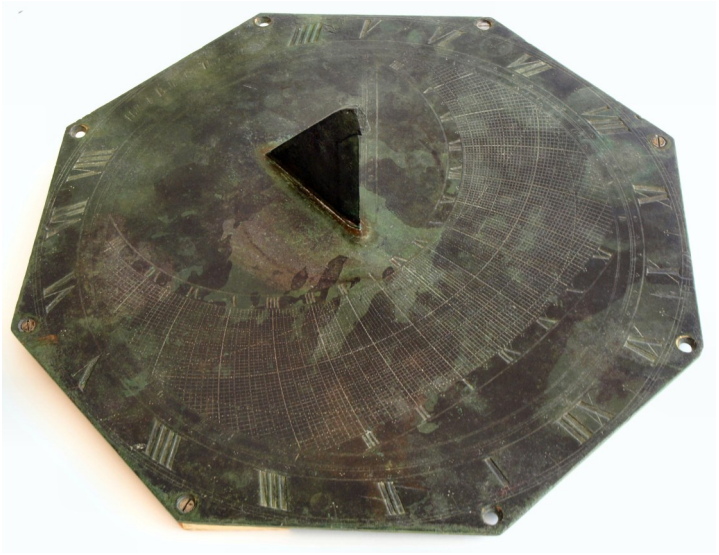


Record no.	**DH-9**
Signature	“Bacon”
Date	c. 1700
Dimensions	330 mm (13 ins) square.
Material	Brass.
Condition	Good. Surface slightly scoured.
Latitude	“51° 56′ ”
Features	Polar dial: IIII-XII-VIII, inward-facing, divided 1 min with 5, 15, 30 identifiers. There is no discontinuity at noon to allow for the gnomon thickness. Stereo grid: IIII-XII-VIII at inner ends of dec arcs, IX-XII-III outer, divided 5 min, 15, 30, 45 dotted. Dec arcs: single deg, 10s dotted. Ecliptic arcs: March equinox at E side, zodiacal sigils, single deg of longitude, 10s crossed. Date scale: at ends of dec arcs, months, single days, three dots at 5. Azimuth scale: 0-90-0-90-0, divided deg and ½ deg, zeroes at E and W. Altitude scale: none. Equation of time table. Coat of arms, unidentified. Designs in spandrels, uncertain purpose. See detailed description in reference.
Location	U S A.
Provenance	Sold by Tesseract, USA in 2000.
Reference	J. Davis & C.M. Lowne, *BSS Bull* 13(iv), 2001 (reprinted p.34).
Notes	It is uncertain whether the name ‘Bacon’ is that of the maker or original owner.





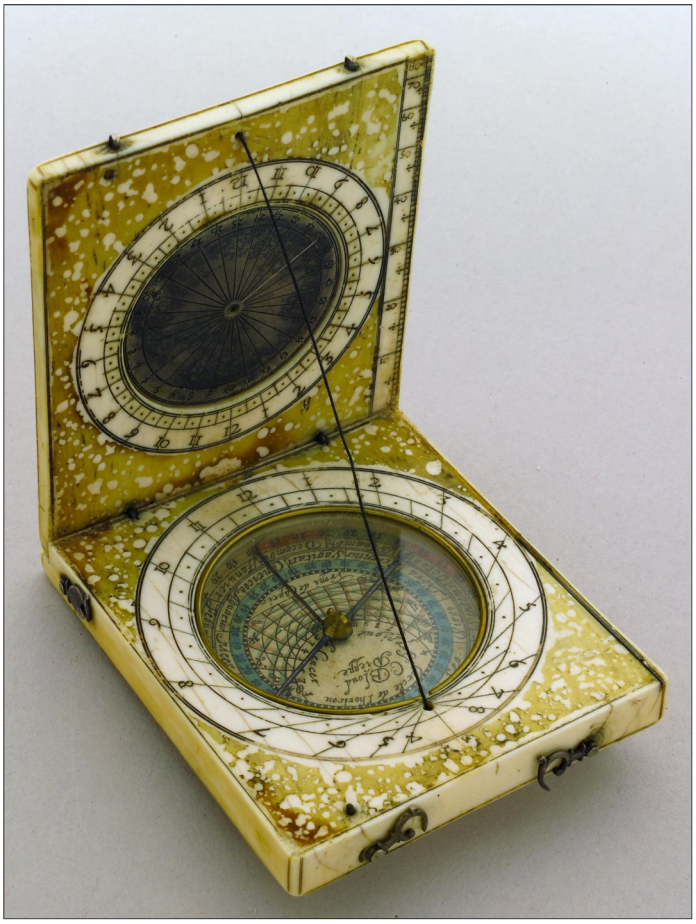
Record no.	**DH-10**
Signature	Hilkiah Bedford Londini fecit
Date	1673
Dimensions	355 mm (14 ins) a/f octagon. Approx 3 mm thick.
Material	Brass (on stone capital).
Condition	Badly worn. Brown patina. Original gnomon.
Latitude	[56.5° N] St Andrews is 56° 21'.
Features	Polar dial: IIII-XII-VIII, inward-facing. Stereo grid: IIII-XII-VIII inner ends of hour lines, X-XII-II outer. Dec arcs: 2 deg intervals. Ecliptic arcs: Date scale: Azimuth scale: Altitude scale to SW
Location	St Andrew's University Museum, Scotland.
Provenance	Originally acquired by James Gregory for St Andrew's Observatory. Accession no. PH209. Knocked off its pedestal in the University grounds by a German bomb in 1940.
Reference	
Notes	





Record no.	**DH-11**
Signature	Hilkiah Bedford in Fleet street.
Date	[1666-1689]
Dimensions	314 mm (12⅜ ins) a/f octagon. 3 mm thick. Gnomon 3.5 mm thick. Base of knife-edge with small flange. Horizon circle 119.5 mm radius. Offset of style from centre 68.2 mm.
Material	Brass.
Condition	Fair. Olive green & brown patchy patina, some fine detail lost. Gnomon tail snapped off.
Latitude	[51.5º N] based on gnomon & hour arc centres.
Features	Polar dial: IIII-XII-VIII, (actually 3:45 to 8:15) inward-facing, divided 5 min, 15, 30, 45 extended, fleur-de-lys at 30. Stereo grid: IIII-XII-VIII at inner ends of hour lines, IX-XII-III outer, divided 5 min, fleur-de-lis at each end of 30. Hours and halves dotted, quarters crossed. Dec arcs: single deg, 10s dotted, 5s crossed, 0 thicker. Ecliptic arcs: March equinox at E side, zodiacal sigils, deg of solar long dotted. Date scale: months, single days. Altitude scale to SW: single deg, 10s numbered, zeroes at E and W. Azimuth scale 40-0-90-0-40, divided to ½º, 5s triple-dotted.
Location	Private collection (England).
Provenance	
Reference	BSS SRN 6793.
Notes	Centres of declination and hour arcs visible. Origins of polar dial and stereographic grid penetrate plate. Small '0's and '8's are punched.

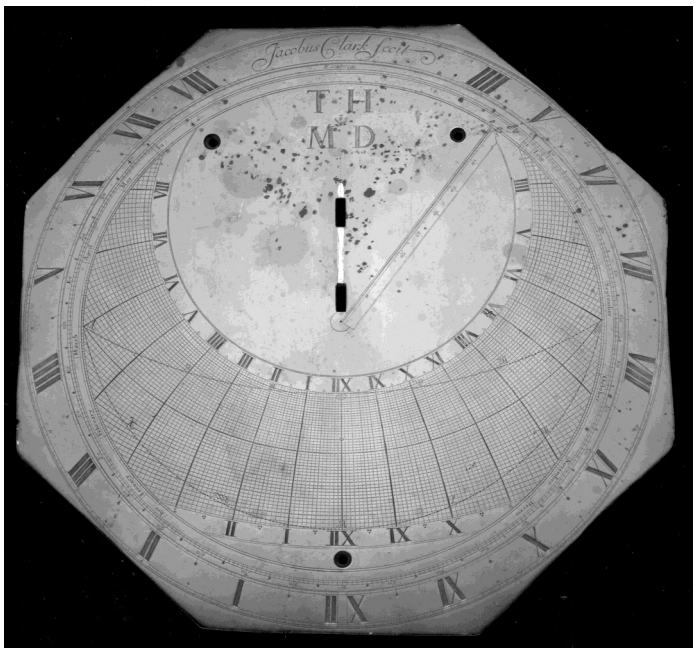
Record no.	**DH-12**
Signature	C[harles] Bloud à Dieppe.
Date	[1653-80]
Dimensions	81 mm H (open); 64 mm W; 78 mm D (2¾, 2½, 3 ins).
Material	Ivory with silver fittings. Case of blind-stamped leather and paper on a wood core.
Condition	Fair/good. Case and hinge broken.
Latitude	50° N? (Dieppe).
Features	Polar dial: 4-12-8, divided 30 min (radial lines), 15 min (dots). String gnomon. Stereo grid: 4-12-8, hours only, numbered counter-clockwise. Dec arcs: for entry of sun into each zodiacal sign, 'Tropique de Cancer' and Tropi de Capri' labelled, others with zodiacal sigils. Azimuth circle: complete, divided 2 deg, alternate intervals blacked, 10s numbered. Scale of zodiacal names correlated with months and days 10, 20, 28/30/31, e.g. for most of January sun is in Capricorn but passes into Aquarius on or about January 20. Altitude arcs: circular concentric with projection centre, joining hours on the tropic of Cancer to the corresponding hour on the other side of noon: 5-7, 6-6, 7-5, 8-4, 9-3, 10-2. Compass needle pivoted centrally on the stereo projection. Moon time conversion dial on inside of lid, 2×12 hour time scale and rotating scale of moon's age.
Location	Adler Planetarium, Chicago.
Provenance	Accession number DPW-19
Reference	
Notes	Effectively a form of 'compast' (see p.78) or magnetic azimuth dial using the horizontal stereographic projection. A fuller description is in the *Makers and their dials* section. Unique (?)

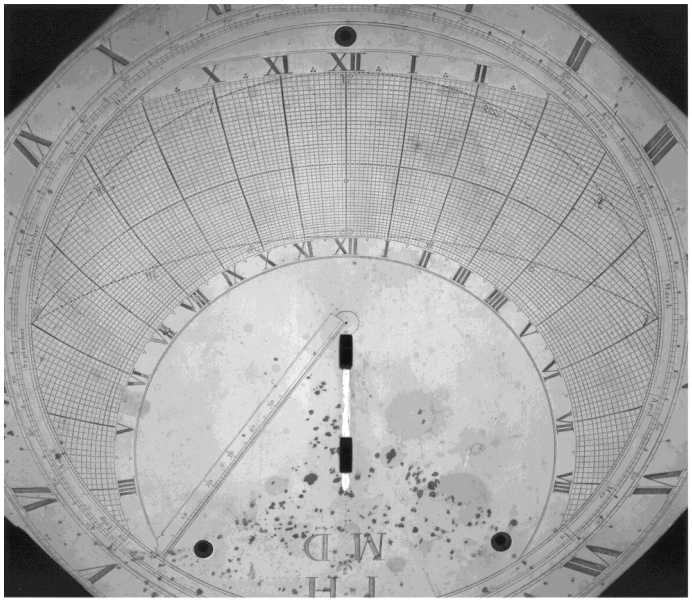




(Perspective corrected)

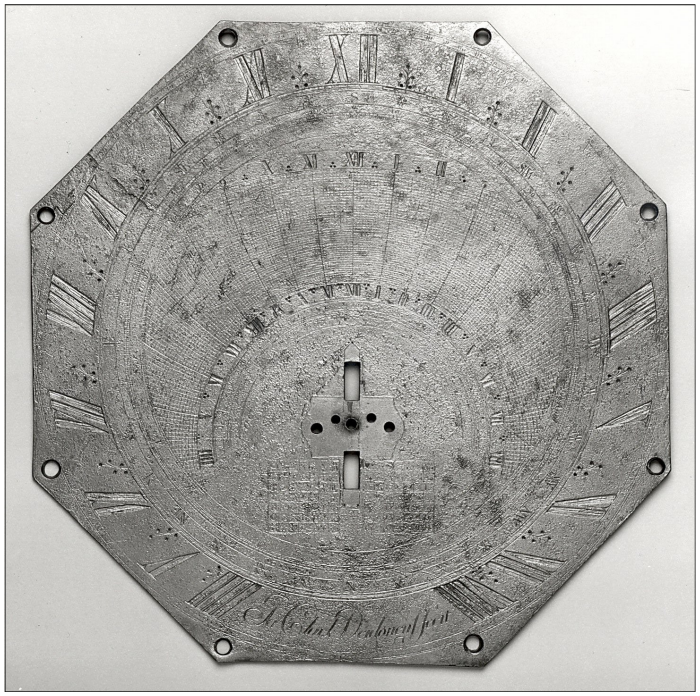
Record no.	**DH-13**
Signature	Jacobus Clark fecit Edenburgi.
Date	[c.1680?]
Dimensions	345 mm a/f octagonal, 3 mm thick.
Material	Brass.
Condition	Dialplate in very good condition. Gnomon missing.
Latitude	[56.5° N] based on sunrise azimuths.
Features	Polar dial: IIII-XII-VIII inward-facing, engraved from 3:15 am to 8:45 pm. Two minute scales, outer divided 1 min, 5 extended, 30 triple-dotted: inner 15 min, 30 extended and dotted. Stereo grid: IIII-XII-VIII at inner ends of hour lines, 9-X-XII-II-3 outer, (3, 9 in small Roman numerals), engraved from 3:15 am to 8:45 pm, divided 5 min, 30 extended and triple-dotted. Dec arcs: single deg, equator thicker line. Ecliptic arcs: March equinox at E side, zodiacal sigils, single deg dotted, 5s crossed. Date scale: at ends of dec arcs, months and single days, 5s and 10s extended. Azimuth scale: single days to 46° (NE and NW), numbered 40-0-90-0-40, zeroes at E and W. Altitude scale: single deg to 57°, 10s numbered. Outer end has shape of a gnomon tip.
Location	National Museums of Scotland, Edinburgh.
Provenance	Purchased from a local antique dealer in the 1980s. Accession no. T.1988.19.
Reference	Bryden (1998/9) “Mr Clerk the graver”.
Notes	Includes the initials TH MD with a thistle. The ranges of the time delineations and azimuth scale are appropriate for the high latitude. A simple but elegant dial.



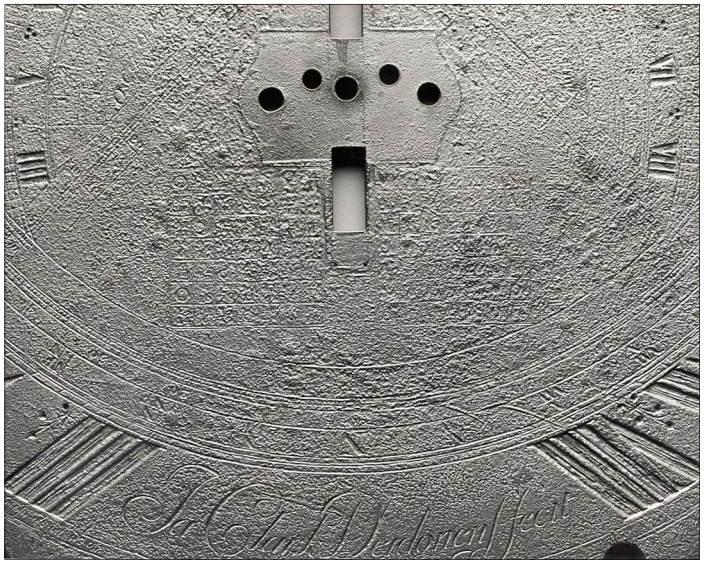


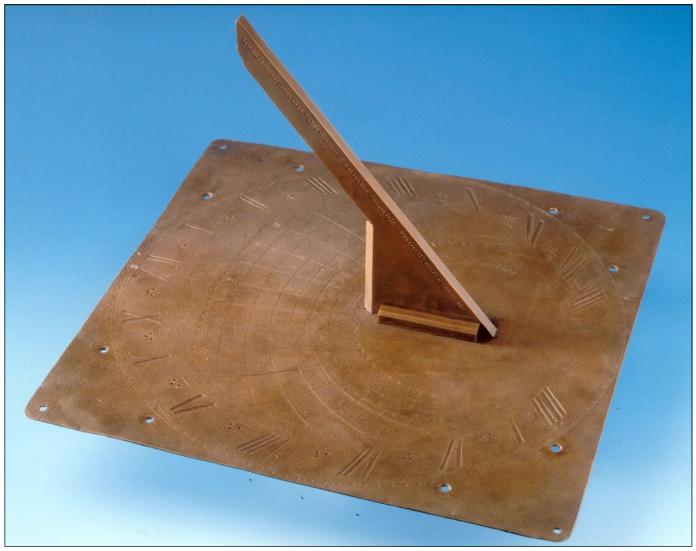


Record no.	**DH-14**
Signature	Ja Clark Dudonen fecit
Date	[1680] based on epact table
Dimensions	434 mm (17⅛ ins) a/f octagon, 5 mm thick, Weight 9 kg.
Material	Brass.
Condition	Poor – badly corroded and gnomon missing.
Latitude	[56° 30' N] Made for Dundee?
Features	Polar dial: IIII-XII-VIII, inward-facing. Two minute scales, outer divided 1 min, 10s extended and numbered: inner 15 min, 30s extended with 5-dot symbol. Stereo grid: IIII-XII-VIII inner ends of hour lines, outer 9-X-XII-II-3 (9, 3 small Roman numerals), divided 5 min, 30 triple-dotted. Dec arcs: single deg. Ecliptic arcs: March equinox at E side, zodiacal sigils. Date scale: at ends of dec arcs, months, single days, 5s and 10s extended. Azimuth scale: single deg, 90-0-90-0, zeroes at N and S, with an additional scale centred with S as 45°, running 0-90° both ways. Altitude scale to SW, and four ‘sector’ trig scales to SW and SE. Compass: 32 labelled points, oriented to relate to shadow of vertical style. Epact table and perpetual calendar. Moon time conversion scale. RAs of prominent stars.
Location	National Museums and Galleries of Merseyside, England.
Provenance	Purchased in 1987 from Roy Sim Antiques, 21 Allen Street, Blairgowrie. Accession no. 1988.379.
Reference	Bryden (1998/9), “Mr Clerk the graver”.
Notes	









Record no.	**DH-15**
Signature	W Croft Ilminster
Date	[c. 1700?]
Dimensions	355 mm (14 ins) square.
Material	Brass.
Condition	Fair. Light blue patina removed 2002. Modern gnomon.
Latitude	[51.2° N] Probably made for Ilminster.
Features	Polar dial: IIII-XII-VIII, inward-facing. Stereo grid: IIII-XII-VIII at inner ends of hour lines, IX-XII-III outer ends. Dec arcs: single deg, 10s thicker. Ecliptic arcs: Date scale: Azimuth scale: Altitude scale: Equation of time table.
Location	Private garden, England.
Provenance	
References	BSS SRN 3949. Daniel, *Clocks*, Dec 2002.
Notes	Restored C Daniel & J Davis, 2002.



DH-16 features an extraordinarily-long gnomon.



Record no.	**DH-16**
Signature	EDMVND CVLPEPER fecit 1708
Date	1708
Dimensions	435 mm diam. (17 ins) circular, 4.5 mm thick. Polar gnomon length 425 mm, 11 mm thick, base 86 mm. Horizon circle diameter 212 mm.
Material	Brass. Gnomon retained by two iron wedges through tenons.
Condition	Fair – light blue patina, some lines worn away. Surface recently 'scoured' exposing brass in some engraving features. Original gnomon, tail slightly bent towards E.
Latitude	[51.6° N]
Features	Polar dial: IIII-XII-VIII (3:47am to 8:13pm), inward-facing. Two scales of minutes, outer divided 1 min, 5s and 10s extended, 10s numbered: inner divided 7½ min, 30 with fleur-de-lys based on three deep dots. Stereo grid: IIII-XII-VIII at outer ends of hour lines, IX-XII-III inner ends, divided to 5 mins, 15 min dotted. Dec arcs: single deg, 10s thicker, 5s dotted. Ecliptic arcs: March Equinox at E side, zodiacal sigils, single deg of longitude dotted. Date scale: at ends of dec arcs, months, single days. Azimuth circle: 0-90-0-90-0, divided to ¼ deg, zeroes at N and S. Altitude scale: none. Compass scale: 32 labelled points, cardinal points spelt out in full, oriented to relate to shadow of vertical style. Moondial: 15 concentric rings identified by moon's age 1-15 and 16-30, containing hours (Roman numerals), half- and quarter -hours. Geographic place names, with XII figures to indicate noon at each locality. Running counter-clockwise from S: Mexico, Charles Town, Port ?, Barbadoes, Cape

	Farewell, Tenerif, Dublin, ??, ??, Constantinople, Jerusalem, Ba?, Fort St George, Batam, Peking. Coat of arms, believed to be for Richard Hill, Bart., MP. A short straight line, labelled E and W on its ends, runs across the base of the knife-edge. Three small holes on the underside of the gnomon tail, vertically above the horizon circle, believed to be for mounting a plummet.
Location	Private garden, England.
Provenance	Believed to have been made for Richard Hill of Hawkstone Hall, Shropshire.
Reference	BSS SRN 5343.
Notes	Richard Hill (1654-1727) was Deputy Paymaster to the army during the Dutch War in the 1690s and inherited Hawkstone in 1700.

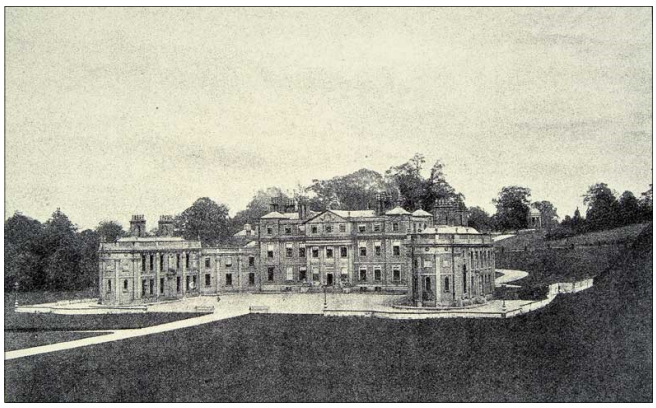






The underside of the gnomon features a mounting for a plummet, positoned to hang above the horizon circle.





Hawkstone Hall, original location of DH-16 after Leach, 'Country Seats of Shropshire', 1891.

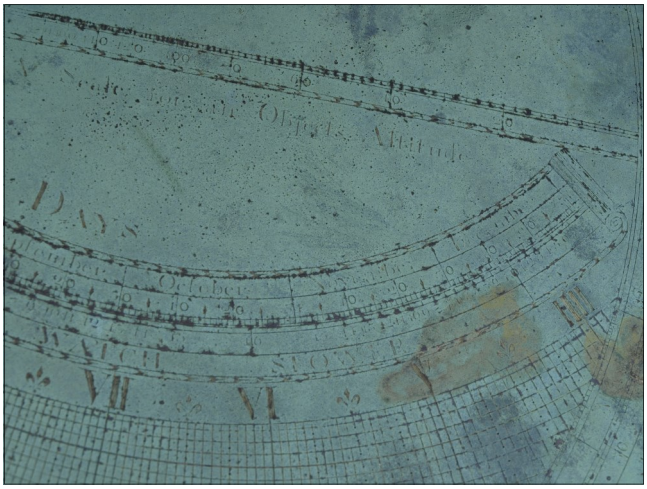


Richard Hill, original owner of DH-16, by Charles d'Agar (Shrewsbury Museum & Art Gallery).

Record no.	**DH-17**
Signature	Daniel Delander LONDON
Date	c. 1715?
Dimensions	613 mm (24 ins) dia., circular dialplate 4.8 mm thick on 37 mm high cast ring, o/all diam. 688 mm. Gnomon 16.5 mm thick, 351 mm tall. Knife-edge 135 mm. Origin offset 153 mm.
Material	Brass.
Condition	Fair/good. Blue patina. Original gnomon.
Latitude	[51.3° N]
Features	Polar dial: IIII-XII-VIII, outward-facing. Two scales of minutes, outer divided single min, 10 numbered with fleur-de-lys at 30: inner divided 7½ min, 15, 45 extended, arrow-head at 30. Stereo grid: IIII-XII-VIII inner ends of hour lines, IX-XII-III outer, divided 5 min, 15, 30, 45 dotted, fleur-de-lys at 30. Dec arcs: single deg, 10s thicker, 5s dotted. Ecliptic arcs: March equinox at W side, zodiacal sigils, single deg of longitude. Date scale: anticlockwise at ends of dec arcs, months, single days, 5s and 10s extended. Azimuth scale: 40-0-90-0-40, ½ deg, 5s extended with arrow-head, 10s numbered, zeroes at E and W. Altitude scale to SE: 'A Scale for the Sun's Altitude', ½ deg 0-90, 10s numbered. Altitude scale to SW: 'A Scale for the Objects Altitude', 2 deg intervals 0-180, 20s numbered. Compass scale: SSE to SSW, labelled single points, correctly oriented. Equation of Time scale: 'THE INEQUALITY OF NATURAL DAYS', months and single days numbered 10-20-28/30/31, time corrections single min individually numbered, 'WATCH SLOWER, WATCH FASTER'. Coat of Arms, unidentified. Place names within chapter ring, some illegible, including: ?, Siam, Jalinoi?, Prideir?, Surat, Dird?, Ispahan, Bagdad, Hafeppi, Alexandria, Constantinople, Candia City, Dantzick, Vienna, Leilon?, Strasburg, Marseille, Paris, The Start, The Lizard, Lisbon, Madiera, T..?, Cape Blanco, Cape Frio, Bell Isle, Bermudas, Cape de Vetta, Ambroso Isles, Cape Corrientes.
Location	Stolen from Stanford Hall, Leics, October 2008 but later recovered. Now kept indoors.
Provenance	
Reference	BSS SRN 3607
Notes	Fitted on a cast ring. The W position for the March equinox is unusual.







Record no.	**DH-18**
Signature	John England
Date	[c.1700]
Dimensions	300 mm (12 ins) diam. circular. About 2.5mm thick.
Material	Copper.
Condition	Poor – badly worn, centre of dial barely legible. Original gnomon broken, modern replacement fitted.
Latitude	[Probably 51.5° N]
Features	Polar dial: IIII-XII-VIII, inward-facing: Two scales of minutes, outer divided 5 min, 30s extended with single dot: inner 15 min, 30s extended, triple-dotted. Long lines for hours, extending inward to about ⅓ dial radius. Stereo grid: 4-12-8 at inner ends of hour lines, 8-12-4 (?) outer ends. Apparently divided hours only with short lines for 15 min intervals. Numerals do not appear to line up with hour lines. Dec arcs: apparently none, scale of single deg on XII line. Ecliptic arcs: March equinox at E side, zodiacal sigils, single deg of longitude, 10s crossed. Date scale: appears to be absent. Azimuth scale: 0-90-0-90-0, single deg, 10s numbered, zeroes at E and W.
Location	Private collection, England.
Provenance	Bought from an antique dealer in the 1960s
Reference	BSS SRN 5306.
Notes	Wrongly delineated, unfinished.



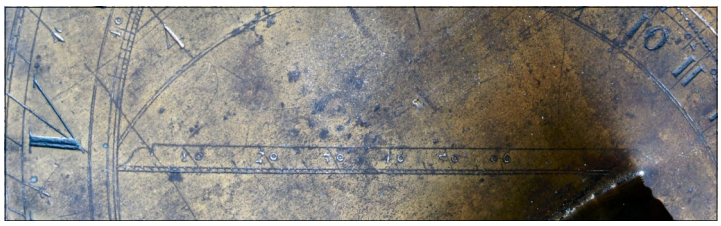
Dusted with talc

Record no.	**DH-19**
Signature	Jn°: Gill Lat: 54° 00' 1716
Date	1716
Dimensions	206 mm (8 ins) a/f unequal octagon (or clipped square).
Material	Copper, brass gnomon.
Condition	Good, original gnomon.
Latitude	"54° 00' ". [Designed for York?]
Features	Polar dial: IIII-XII-VIII, inward-facing, divided 3 min from 3:33 to 8:27, 15, 30 extended, 30 with fleur-de-lys. Stereo grid: IIII-XII-VIII at inner ends of hour lines, IX-XII-III outer, divided 10 min from 3.40 to 8.20, 30s extended with triple dots at outer ends, arrows at inner. Dec arcs: 2 deg intervals, 10s dotted. Ecliptic arcs: March equinox at E side, zodiacal sigils. Date scale: months (abbreviated), 2-day intervals except 1 day at ends of February (29 days) and of 31-day months, 10 extended. Azimuth scale: single deg 24-90-0-90-0-24, 10 numbered, zero at N. Small 8-point compass at base of vertical style, E, SE, SW, W labelled, N with fleur-de-lys, true orientation. Motto: 'Pereunt, sed Imputantur'. Elaborate decorative scroll.
Location	Adler Planetarium, Chicago. Acq. no. W-96
Provenance	
Reference	Shown in Tesseract, USA, cat. D, p.26, 1983.
Notes	One-off design. Centres for dec arcs and hour lines visible.



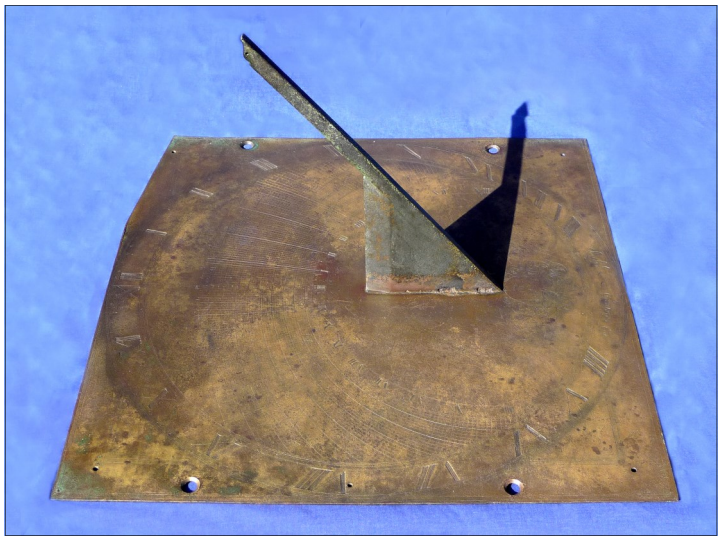








Record no.	**DH-20**
Signature	Ralph Greatorex fecit
Date	c. 1660
Dimensions	252 mm (10 inches) square. Plate 2.1 mm to 2.8 mm thick. Gnomon base (offset of polar gnomon) 64 mm; style length 203 mm; thickness 3.4 mm. Horizon circle diameter 204.2 mm.
Material	Brass
Condition	Good. Original gnomon was straightened slightly in a mild restoration, 1960s.
Latitude	[51.5° N]
Features	Polar dial: IIII-XII-VIII inwards-facing. Divided to 5 mins, outside of numerals with ‘rosebud’ half-hour markers. Stereographic grid: 4-12-8 hours numbered inside, divided to 15 mins. Declination arcs in 2°, 10s heavier. Ecliptic dotted for days, numbered 10, 20, 28/30/31, labelled with months (in full), oriented to be read from the N. Azimuth scale, [45]-00 (sic) -90 twice with 90 at N, outside horizon circle, divided to ½°. Altitude scale to SW, 0-62° by 1°, numbered by 10 (60 written as ‘06’). Divisions are drawn in E-W direction, oblique to scale edge. Scale end shaped to match gnomon tip. May have had a thin, rotating altitude rule. Dot on meridian line at dec of +3° but no visible suspension point for a corresponding plumb-bob. Back of dial has two large engraved circles and pair of dots as alternative origins (?) for polar dial.
Location	Private collection, England.
Provenance	Purchased from a London dealer, 1960s.
Reference	A.J. Turner no 9
Notes	



Record no.	**DH-21**
Signature	Ralph Greatorex fecit
Date	c. 1660
Dimensions	475 mm (18¾ in) square. 1.8–2.5 mm thick. Polar gnomon length 335 mm, 8.5–9.2 mm thick, base 124.5 mm. Horizon circle diameter 399 mm.
Material	Brass. Gnomon retained by one brass wedge and two iron wedges through tenons. The iron wedges correspond to iron tenons dovetailed into the base of the gnomon.
Condition	Fair. Mild removal of patina by West Dean in 2008. NE corner has been cut off in a triangle about 26 mm on E side and 153 on N side. Original gnomon. Two iron sections have long ago been dovetailed into the base of the gnomon towards the S

end. These and their wedges are considerably corroded. Gnomon tail is bent slightly downwards by about 4 mm at the tip.

Latitude [51.5° N] Apparently made for London.

Features Polar dial: IIII-XII-VIII (4:00am to 8:00pm), inward-facing. Outer scale of minutes, divided 1 min, 5 and 10 extended, 10s numbered: 30s with 'rosebud' fleur-de-lys; 15, 45 extended. Hour lines engraved through the Roman numerals the full width of the chapter ring.
Stereo grid: IIII-XII-VIII at inner ends of hour lines facing inward, outer ends not numbered, divided to 5 mins, 30 and 15 min dotted, 30 with small fleur-de-lys pattern.
Dec arcs: single degrees, 10s and 5s thicker.
Ecliptic arcs: March Equinox at E side. Dotted for single days, numbered 10, 20, 28/30/31. Month names in full read from North side of dial.
Azimuth circle: 0-90-0-90-0, degrees, ½º and ¼º, 5º points marked with three dashes (fleur-de-lys), numbered every 10º, zeroes at E and W.
Altitude scale: SW of dial centre, along 50º line of azimuth. Degrees and half degrees, 5º points marked with three dashes (fleur-de-lys), numbered from 10 to 60 every 10. Extends up to 62 and appears to be graduated down to 0, but outermost divisions below 10 particularly unclear from weathering. Divisions are perpendicular to scale edge (unlike DH-20).
There is a thin flat foot to the gnomon knife-edge and a definite hole below it at the centre of an engraved circle about 13 mm diameter perhaps indicating that a thin pivoted scale (now missing) was fitted.
Compass scale: none.
Coat of arms for Bolles of Scampton (baronets): 'Out of three standing cups or, as many boar's heads erect couped argent. Crest: A demi-boar wounded in the left breast with a broken spear shafted or headed argent. Three drops gules.' The hand as mark of a baronetcy.
Three small holes near the tip of the gnomon, vertically above the horizon circle, believed to be for mounting a plummet. Two (1 mm) are normal to the gnomon edge; one passes through the thin part of the gnomon tip ornament; the second runs from the underside of the ornament into a third larger (2 mm) transverse hole.
Other scale: A latitude scale runs North from the dial centre, from 61 nearest the centre to 30 at the North, numbered every 10 with degrees dotted and 5º points triple dotted transversely, and additional single dots at or about 51.5 (the design latitude for London), 48.5, and 54.5. In conjunction with a plumb-bob hung from the hole in the gnomon this would allow the dial to be tilted to work correctly at any latitude from 30 to 61 degrees North.









Spandrels are decorated by two pairs of straight lines engraved parallel to the dial edges.

Location Private collection, England.

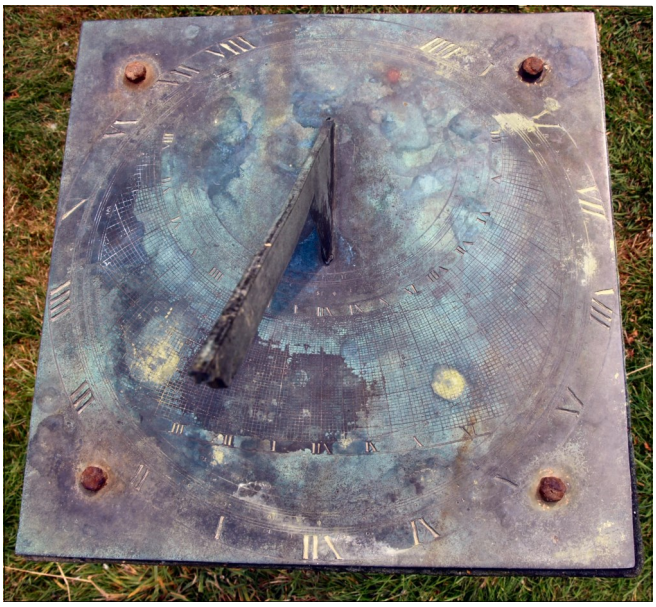
Provenance Purchased on eBay in 2006.

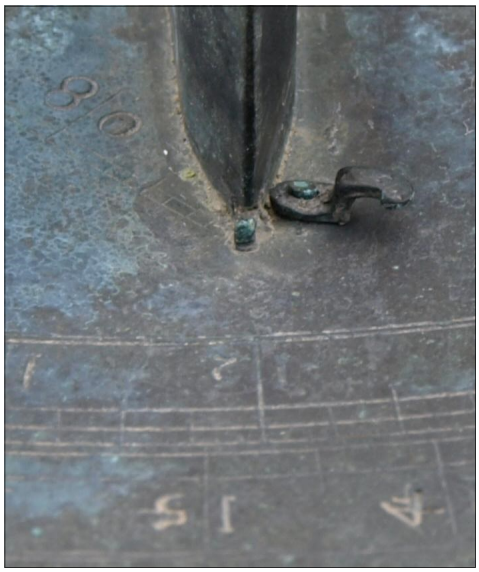
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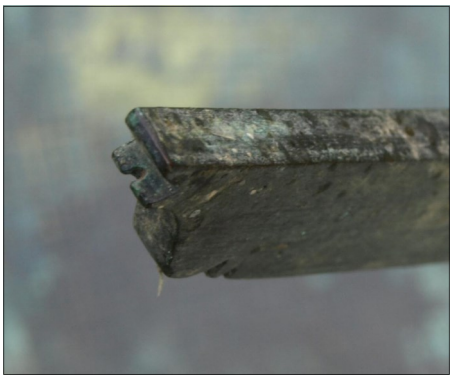
Notes

Record no.	**DH-22**
Signature	STEPHEN GRAY FECIT CANTERBURY 1699
Date	1699
Dimensions	300 mm (12 ins) square.
Material	Brass.
Condition	Fair/good.
Latitude	“51° 15' ” Made for Charing, Kent.
Features	Polar dial: IIII-XII-VIII inward-facing, divided 5 min, 15, 30 & 45 extended, 30s crossed. Stereo grid: 4-12-8 divided 15 min. Dec arcs: 2 deg intervals, 10s thicker. Ecliptic arcs: March equinox at E side. Date scale: on ecliptic arcs, months, single days. Azimuth scale: 45-0-90-0-45, 10s numbered, zeroes at E and W. Altitude scale to SW, unreadable. Equation of Time table Names of 6 stars and their RAs see Table p.121.
Location	Private garden, England.
Provenance	Believed made for Sayer family, Pett Place, Charing, Kent.
Reference	Daniel, *Clocks*, Dec 2000. BSS SRN 4123
Notes	Uniquely, there is a pivot pin at the dial centre and a retaining clip for a rotating altitude alidade (missing). Also, a rare suspension hole for a plumb-bob at the tip of the gnomon.







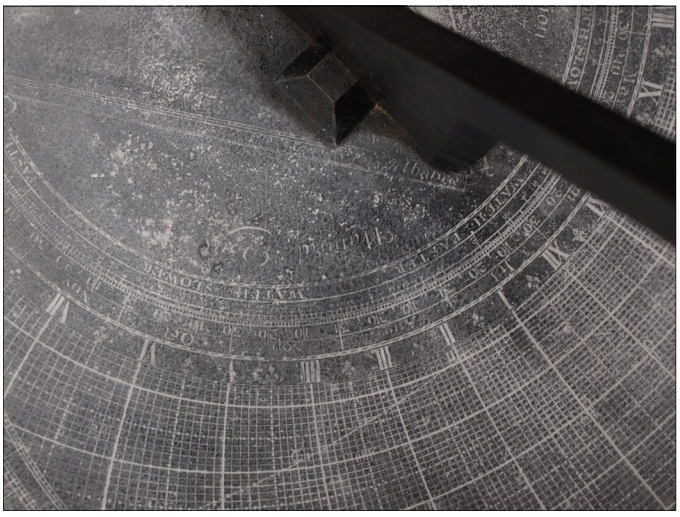


Record no.	**DH-23**
Signature	[Edward Hatton designer]
Date	1719
Dimensions	460 mm (18 ins) diam. circular.
Material	Brass.
Condition	No longer existing.
Latitude	[51.5° N]
Location	Unknown—made for Middle Temple, London.
Provenance	Detailed records in Middle Temple accounts. See p. 147 for an image and transcription.
Reference	MT. 2 TRB/77 1718/19 Item 27
Notes	Included EoT, Coat of arms for the Middle Temple, geographical details.

No image known

Record no.	**DH-24**
Signature	IOHN ROWLEY *Londini*
Date	1710
Dimensions	506 mm (20 ins) diam., circular. On a 80 mm high double-ogee ring.
Material	Brass.
Condition	Fair. Restored in 1960s. V. dark patina, some erosion. Original gnomon (refixed)
Latitude	[52.0° ± 0.2° N] Blenheim Palace is 51.9°.
Features	Polar dial: IIII-XII-VIII, inward-facing. Two scales of minutes, outer divided single min, 10s numbered: inner divided 7½ min, 15 and 45 triple-dotted, 30s with fleur-de-lys. Stereo grid: IIII-XII-VIII at inner ends of hour lines, IX-XII-III outer, divided 5 min, 30s dotted with fleur-de-lys at each end. Dec arcs: single deg, 10s thicker, 5s dotted. Ecliptic arcs: March equinox at E side, zodiacal sigils, single deg dotted. Date scale: at ends of dec arcs, months, single days, 5s extended. Azimuth arc: 40-0-90-40-0, deg and ½ deg, 10 numbered, zeroes at E and W. Altitude scale to SW, divided single deg 0 -61, 10s numbered. 'Altit: Solis'. Altitude scale to SE, uncertain due to erosion, but may be logarithmic. Equation of time scale: "Æquation of Natural Days", months, single days numbered "WATCH SLOWER / WATCH FASTER". Coat of arms for Duke of Marlborough.
Location	Blenheim Palace – still in design location (though not exact position)
Provenance	Made for 1st Duke of Marlborough.
References	BSS SRN 5352. Bills for dial are in British Library, Add. MS. 19527 (ff.51v, 114v), May & Dec 1710. Also David Green *Blenheim Park and Gardens* Oxford, (1992). Davis (BSS Conference 2008).
Notes	One of a set of four dials made to accompany a tower clock by Langley Bradley. Original cost of dial £50.





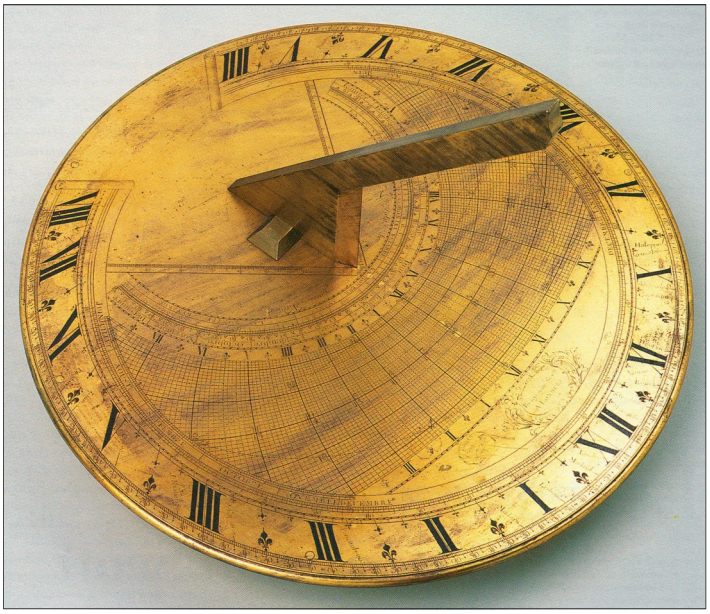




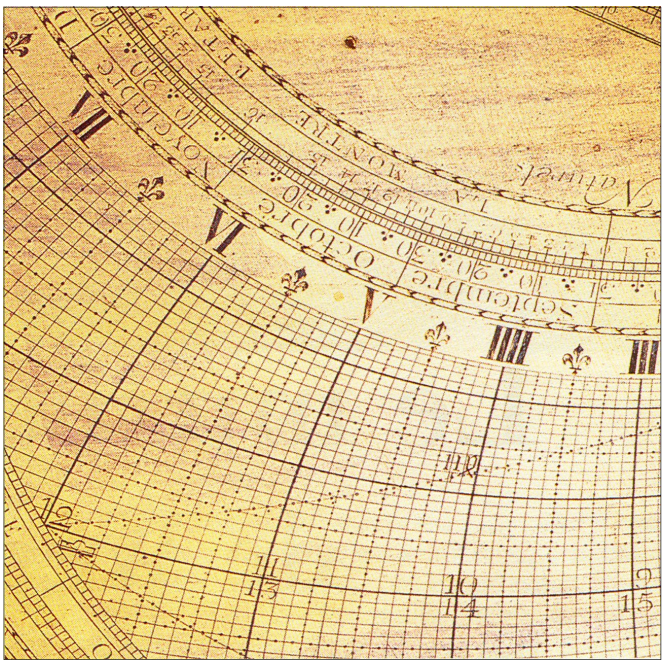


Record no.	**DH-25**
Signature	John Rowley Fecit
Date	c.1700
Dimensions	387 mm (15¼ ins) a/f octagon. Radius of horizon circle 93.1 mm. Thickness approx. 3 mm.
Material	Brass – see Materials Analysis p.106.
Condition	Poor – surface eroded. Top part of gnomon replaced. Mounted on part of a pedestal.
Latitude	[51.6° N]
Features	Polar dial: IIII-XII-VIII, inward-facing, inner ring divided to ⅛ hours, fleur-de-lys half-hours, ‘spade’ quarters; outer to 1 min (10s numbered). Stereo grid: IIII-XII-VIII at inner ends of hour lines, IX-XII-III outer, divided 5 min, 15 & 45 dotted, 30s crossed with fleur-de-lys at each end. Dec arcs: single deg, 10s thicker, 5s dotted. Ecliptic arcs: March equinox at E side, zodiacal sigils, single deg of longitude dotted. Date scale: at ends of dec arcs, months, single days, 10 extended and dotted. Azimuth scale: 0-90-0-90-0,deg and ½-deg, 5 and 10 extended, 10s numbered, zeroes at E and W. Altitude scale: to SW, deg and ½-deg, 10s numbered 0-60. Moondial: direct reading, 15 concentric arcs, hours (Roman numerals), divided 5 min.
Location	Private collection, England.
Provenance	At one time was at Bilton Hall. Sold from there to Sir Peter Smithers. Sold by Sotheby’s to Canon D.G. Galliford (£150) in March 1970. Sold again by Sotheby’s in 2004 (£1200).
Reference	
Notes	Gnomon has two integral circular support brackets, bolted to base.

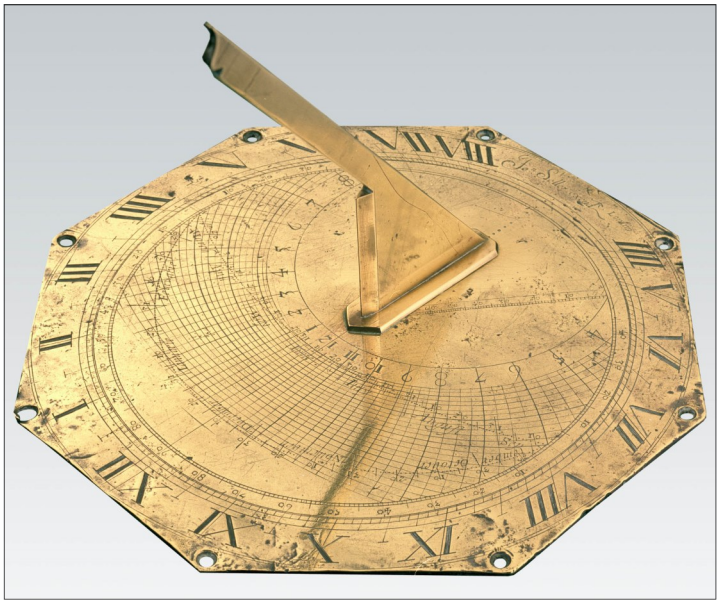
Record no.	**DH-26**
Signature	Benjamin Scott À LONDRES
Date	c.1713
Dimensions	520 mm (20½ ins) diam. On a 80 mm high double-ogee ring.
Material	Brass.
Condition	Excellent – bright brass, original gnomon. No weathering, lacquered(?)
Latitude	[49° ±0.1° N]
Features	Polar dial: IIII-XII-VIII, outward-facing. Two minute scales, outer divided 1 min, 5s extended, 10s numbered, fleur-de-lys at 30: inner divided 7½ min, 3-dot symbol at 15, 30 & 45s. Stereo grid: V-XII-VII outer ends of hour lines, IX-XII-III inner, divided 5 min from 4:05am to 7:55pm, 15, 30 & 45s dotted, fleur-de-lss at each end of 30. Dec arcs: single deg, 10s thicker, 5s dotted, scale of sun's RA on equatorial line. Ecliptic arcs: March equinox at W side, zodiacal sigils, single deg of longitude, 10s triple dotted. Date scale: at ends of dec lines, months in French running anticlockwise, single days, equinoxes at March 21 and September 23 to conform to Gregorian calendar. Azimuth scale: 40-0-90-0-40, deg and ½ deg, 10s numbered, zeroes at E and W. Trig. scales to SE and SW: SE is altitudes, single deg 0-60, 10s numbered. Equation of time scale for Gregorian calendar: "Equalite de jours Naturels", months, single days, 5 triple-dotted, numbered in 10, 20, 28/30/31, min of EoT, "La Montre avant, La Montre retarde." Place names within chapter ring include Lisbon, Madrid, Londres, Marseille, Strasburg, Rome, Dantzick, Constantinople, Alexandria, Jerusalem, Haleppe, Ispahan etc.
Location	Musée des Artes et Metiers, Paris
Provenance	
References	A.J. Turner no. B5. Benjamin Scott treatise on the Double Horizontal dial, British Library Sloane MS 2040 (transcribed on p.16), (1713). BSS SRN 5352.
Notes	Follows Rowley pattern.



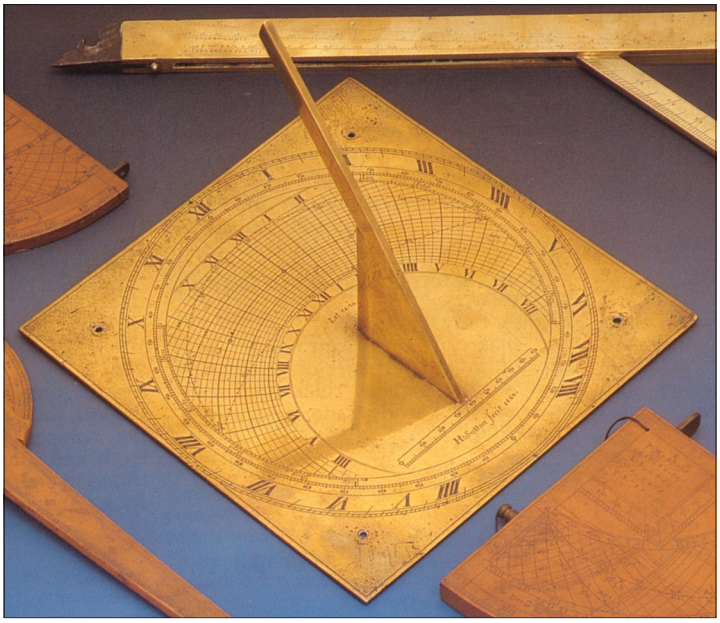




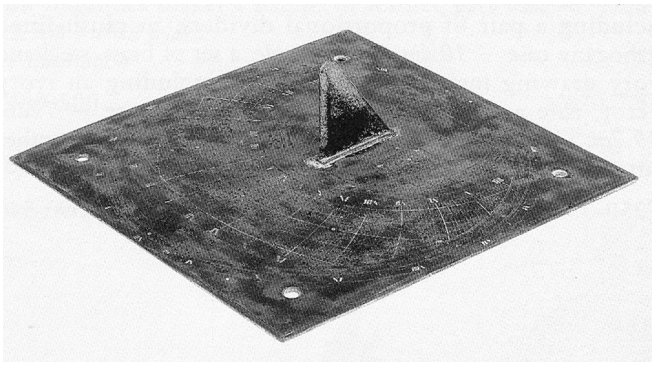




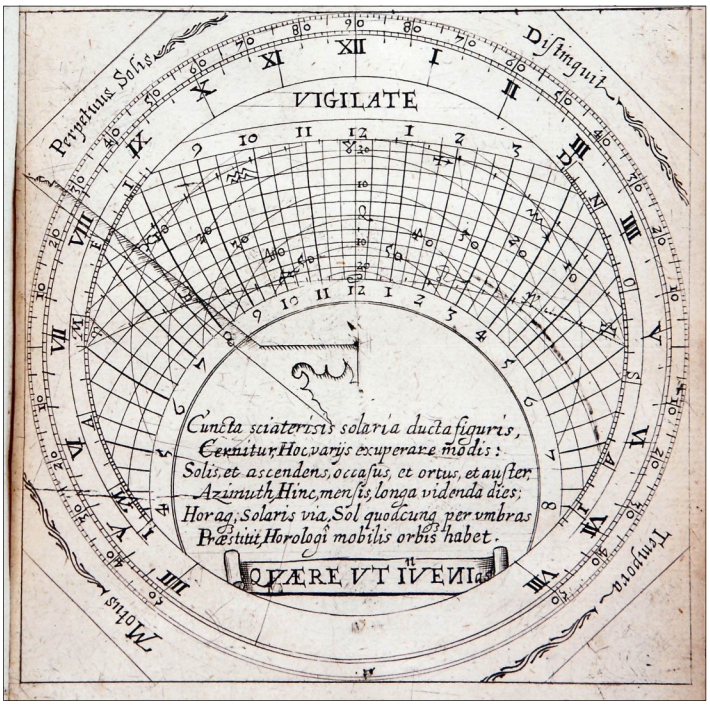
Record no.	**DH-27**
Signature	Jon Seller excud[it] Londini
Date	[1630s ?]
Dimensions	216 mm (8½ ins) a/f octagon. c.2 mm thick.
Material	Brass (see p.104).
Condition	Good. Dial plate polished and repaired around gnomon. Gnomon is an old replacement.
Latitude	[51.5° N]
Features	Polar dial: IIII-XII-VIII, divided 5 min, 15, 30 & 45s extended, 30s crossed. Stereo grid: 4-12-8, divided 15 min. Dec arcs: 2° intervals, 10s thicker. Ecliptic arcs: March equinox at E side. Date scale: on ecliptic, months, single days, numbered 10, 20, 28/30/31, 5 and 10s crossed. Azimuth scale: 45E to 45W, numbered 40-(0)-90-(0)-40, zeroes at E and W unnumbered. Altitude scale: to SW, single deg to 62, 10s numbered.
Location	Private collection, England.
Provenance	Sold at Sotheby's 'Sussex Garden Statuary & Architectural items' 30/31 May 1990. Sold again at Charles Miller Auction, 26 Oct 2011, lot 169 to Daniel Crouch Rare Books (£9,000) and then sold on,
References	Davis & Daniel, *SIS Bull* (2009) reprinted p.69. C. Daniel, *Clocks*, February 1993. BSS SRN 3121.
Notes	Elias Allen format with erased signature. Centres of dec arcs visible. Latitude is slightly uncertain, 51.5° is average of values from north (50.6°) and south (52.4°) arcs of stereo grid at horizon.



Record no.	**DH-28**
Signature	H: Sutton fecit 1660
Date	1660
Dimensions	205 mm (8 ins) square.
Material	Brass
Condition	Good.
Latitude	"56°30"
Features	Polar dial: IIII-XII-VIII, inward-facing, divided 5 min, 15, 30 & 45s extended. Stereo grid: inner ends of hour lines IIII-XII-VIII, outer X-XII-II, divided 15 min. Dec arcs: 2 deg intervals, 10s thicker, numbered in two places. March Equinox at E side, zodiacal sigils, single deg of longitude dotted, 5 and 10s crossed. Date scale: at ends of dec arcs, months (abbrev), two-day intervals, 10s extended. Azimuth scale: 0-90-0-90-0, single deg, 10s numbered, zeroes at N and S. Altitude scale: single deg 0-90, 10s numbered, running E-W to S of gnomon.
Location	National Museums of Scotland, Edinburgh.
Provenance	Bought from Sotheby's, Oct 1993, Lot 787.
Reference	A.J. Turner no. B.1 (?).
Notes	Unusual position for altitude scale.

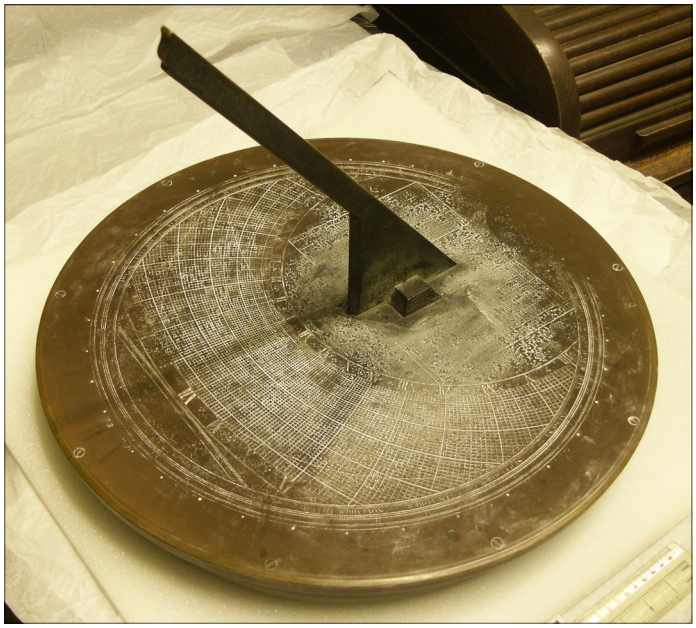


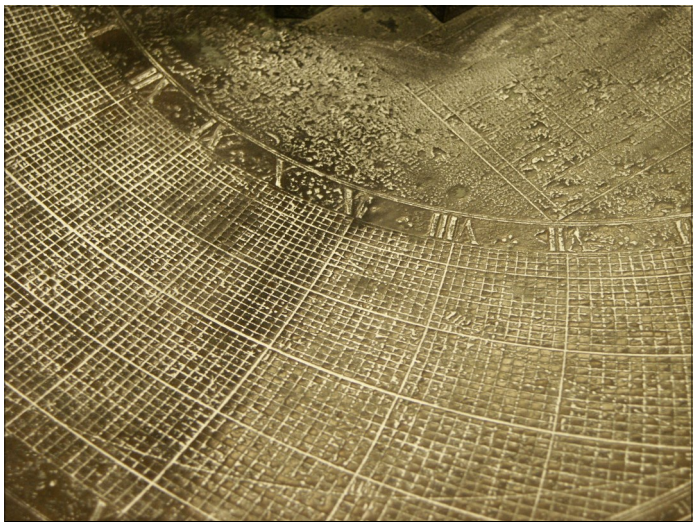
Record no.	**DH-29**
Signature	Henricus Sutton fecit 1659
Date	1659
Dimensions	254 mm (10 ins) square.
Material	Brass? Auctioneer's description says copper.
Condition	Fair. Tail of gnomon broken off.
Latitude	Unknown
Features	Polar dial: IIII-XII-VIII, inward-facing. Stereo grid: IIII-XII-VIII at inner ends of hour lines, IX-XII-III outer, divided 5 min. Dec arcs: single deg. Ecliptic arcs:
Location	Unknown.
Provenance	Sold by Christies, 2000 Dec. 9, lot no 128.
Reference	*BSS Bull* 12(i); *Bull SIS* 39 p.19 (1993)
Notes	Details have been taken from Christies catalogue half-tone illustration.

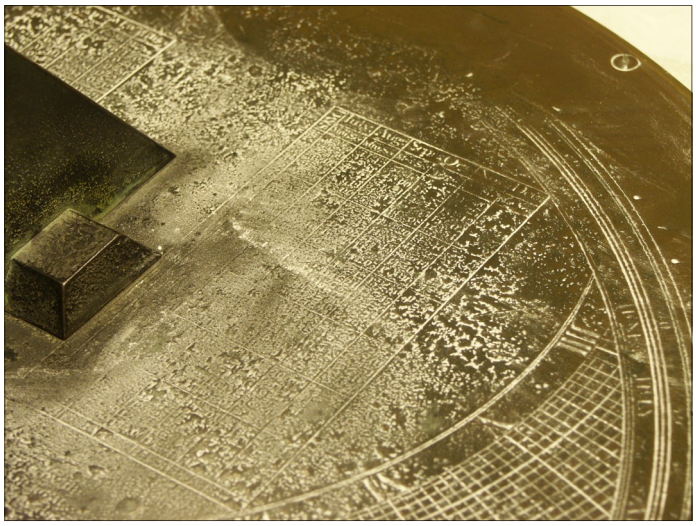


Record no.	**DH-30**
Signature	Unsigned, attrib. John Allen.
Date	c.1632
Dimensions	105 mm (4 ins) square, Horizon circle 41.7 mm radius.
Material	Paper.
Condition	Good.
Latitude	[51.5° N, uncertain]
Features	Polar dial: IIII-XII-VIII, inward-facing, divided 5 min, 20 & 40s extended. Stereo grid: 4-12-8 at inner ends of hour lines, 9-12-3 outer, divided 20 min. Dec arcs: 5 deg intervals, numbered 10, 20 on noon line. Ecliptic arcs: March equinox at W side, zodiacal sigils, divided 10 deg of longitude. Date scale: at ends of dec arcs, months (initials only) running anti-clockwise to agree with W position of March equinox, 2 day intervals: every month shown with 30 days, 10 and 20 extended. Azimuth scale: outside polar dial chapter ring (unusual), 50-(0)-90-(0)-50, single deg, 5s extended, 10s numbered, unnumbered zeroes at E and W. Altitude arcs: centred on base of vertical style, 10 deg intervals, 10s numbered.
Location	Science Museum, London.
Provenance	1934-122/38 (Colvin 386).
Reference	
Notes	Same as DH-60. Includes several mottoes (one in a different hand) and a drawn gnomon of unusual profile. Motto around perimeter (a hexameter in Allen's hand) reads "Perpetuus Solis Distinguit Tempora Motus" (The continuous motion of the Sun marks out times). Emended text (in hand of Delamain's book engraver) reads: "Cuncta sciatheri solaria ducta siguris, Cernitur, Hoc, varijs expuerare modus: Solis et ascendens, occasus, et ortus, et auster, Azimuth. Hinc, mensis, longa videnda dies: Horaque, solaris via Sol, quodcunque per umbras Praestitit, Horologi mobilis orbis habet" ([Seek in order that you may find] all the solar lines drawn with diagrams in the plane of the shadow-dial. This is perceived to excel in various methods: there are the climbing of the sun and his sinking and rising and the meridian to the south and the Azimuth. Hence the long[est] day of the month is to be seen. The hour and the path of the Sun ensures through the shadows, all these the sphere of the moving sundial includes.) In banner (Allen's hand) "QUAERA UT IVENIAS" Note several characters (e.g. '4' and 'N') are reversed.

Record no.	**DH-31**
Signature	Thos Tompion Londini
Date	1702
Dimensions	523 mm (20½ ins) diam. Dial plate 3 mm thick on a 65 mm deep cast/turned brass ring. Gnomon 11 mm thick. Radius of horizon circle 195.5 mm. Offset of polar style from centre 116.5 mm.
Material	Brass.
Condition	Very poor – eroded and badly worn. Periphery completely smooth.
Latitude	[51.7° N]
Features	Polar dial: IIII-XII-VIII, inward-facing. Two minute scales, outer unreadable, inner divided 7½ min? Stereo grid: IIII-XII-VIII at inner ends of hour lines, IX-XII-III outer, divided 5 min, 15, 30, 45s dotted, 30s with symbol at each end. Dec arcs: single deg, 10s thicker, 5s dotted. Ecliptic arcs: March equinox at E side, zodiacal sigils, single deg of longitude dotted. Date scale: at ends of dec arcs, months, single days. Azimuth scale: 40?-0-90-0-40?, 10s numbered, zeroes to E and W. Altitude scale: Running E-W to north of stereo grid, deg and ½-deg. Equation of time table: values for every day, Jan-Jun at E side of gnomon, Jul-Dec W side, details mostly unreadable. Text between vertical style and stereo grid, unreadable.
Location	Hampton Court Palace (in store).
Provenance	
Reference	BSS SRN 2119. C. Daniel '*Clocks*' Sept 1995.
Notes	One of a pair of Tompion dials – the other is an 'Equation and azimuth' dial. An unfinished replica, M-14, is on public display on the original pedestal in the Palace Gardens.

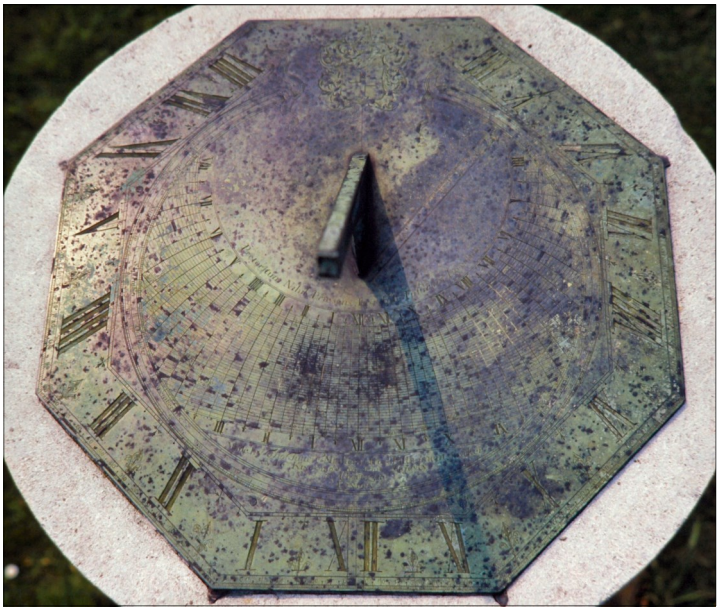


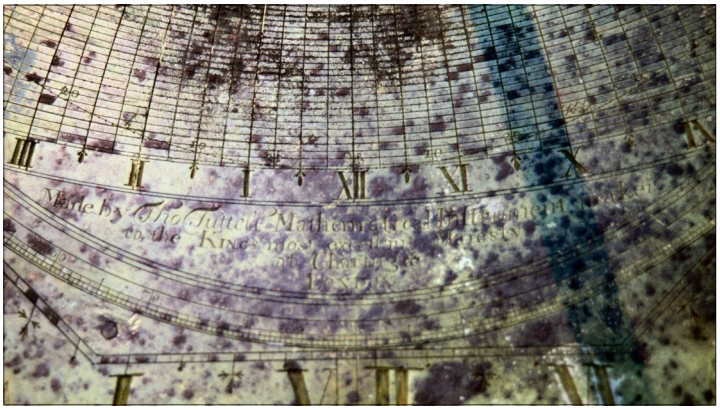






Record no. **DH-32**
Signature "Made by Tho Tuttell, Mathematical Instrument Maker to the KINGS most excellant [sic] Majesty at Charing □ London."
Date c.1700
Dimensions 380 mm (15 ins) a/f octagonal.
Material Brass?
Condition Fair.
Latitude [51.7° N—probably London]
Features Polar dial: IIII-XII-VIII outward-facing. Two time scales, outer divided 1 min, 10 numbered, fleur-de-lys at 30: inner 7½ min, 15, 30, 45s extended, 30s with triple inward-facing arrows.
Stereo grid: IIII-XII-VIII at inner ends of hour lines, IX-XII-II outer, divided to 15 min, symbols at each end of 30s.
Dec arcs: single degrees, 10s thicker lines, 5s dotted.
Ecliptic arcs: March equinox at W side.
Date scale: months running anti clockwise, single days, 5s and 10s extended.
Azimuth scales: ½ degrees 40-0-90-0-40, zeroes at E and W.
Altitude scale: to SW, single deg 0-60, 10s numbered.
Coat of arms *azure, a cross flory* (or *patonce?*) *or/argent*, for Sir John Ward(e).
Motto: "Preteritum Nihil, Praesens Instabile, Futurium Incertum." (*The past is gone, the present transient, the future uncertain*) also on DH-48.
Location Private garden, Kent (now in store).
Provenance Probably made for Sir John Warde to mark his inheritance from his uncle Sir Patience in 1696. Warde became Lord Mayor of London in 1719 and purchased Squerryes Court in 1731, taking the dial with him.
Reference BSS SRN 3539
Notes A smaller paper dialplate in the National Maritime Museum (DH-48) is a close copy of this dial with detail differences (including a different coat of arms). The W placing of the March equinox is unusual.
The pedestal is probably original.







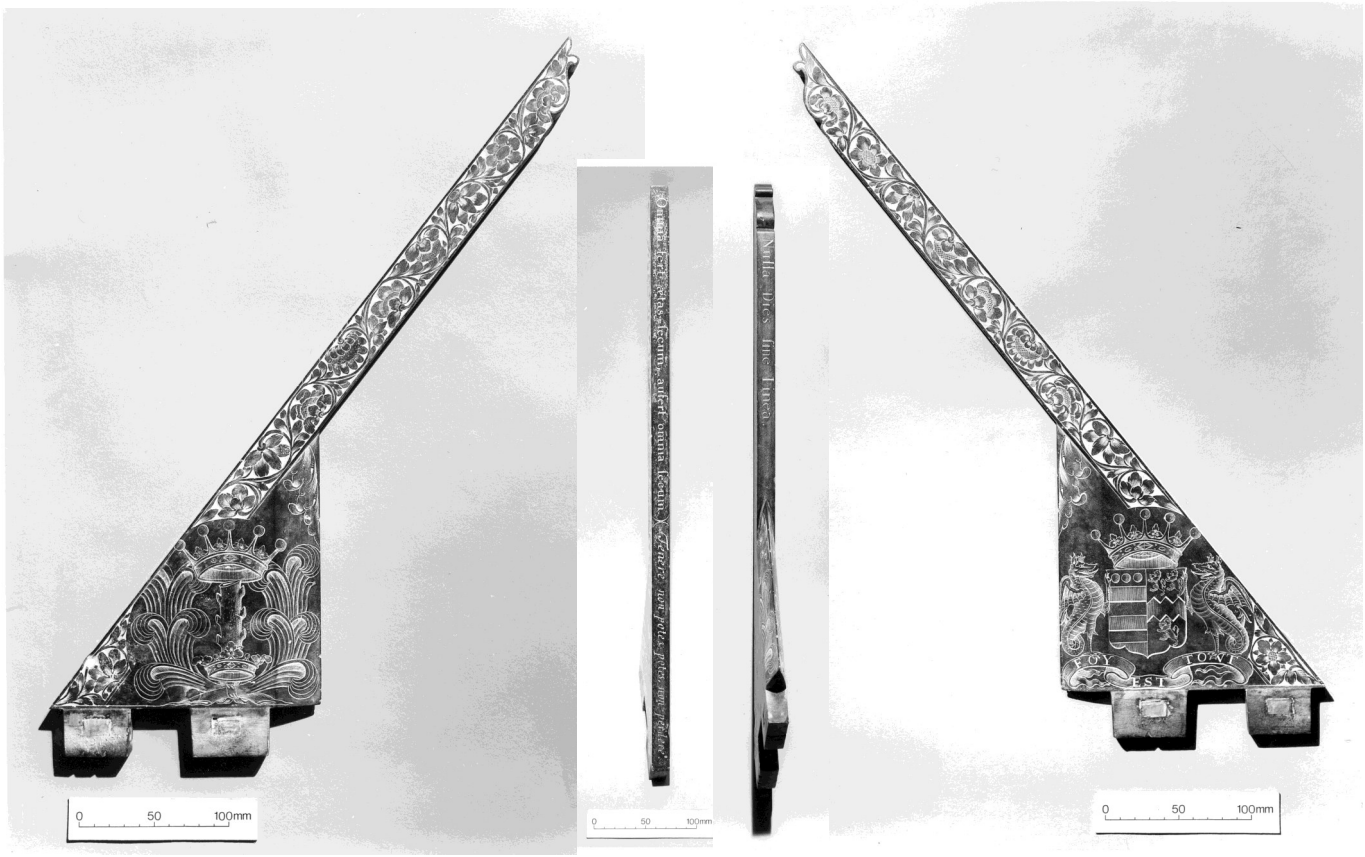


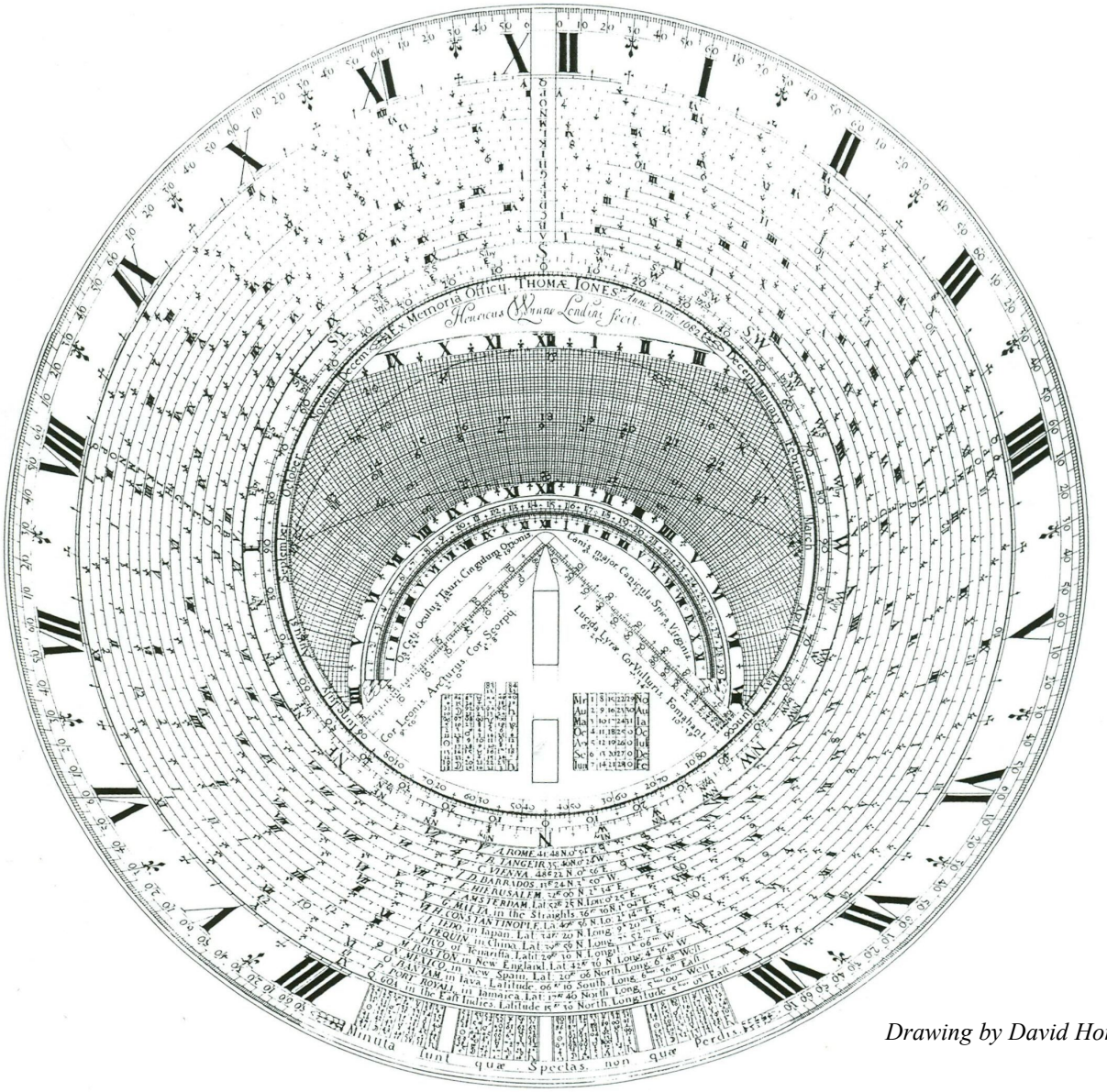
Record no. **DH-33** (No dial)

Record no.	**DH-34**
Signature	Henricus Wynne Londini fecit
Date	c.1682/3
Dimensions	775 mm (30.5 ins) circular.
Material	Brass.
Condition	Good.
Latitude	[51.6° N]
Features	Polar dial: IIII-XII-VIII, inward-facing. Two scales of minutes, outer divided 1 min, 5 and 10s extended, 10s numbered, fleur-de-lys at 30: inner 7½ min, 15 and 45 with arrow-heads, 30 with triple arrows. Stereo grid: IIII-XII-VIII at inner ends of hour lines, IX-XII-III outer, divided 5 min, 30 with fleur-de-lys at each end. Dec arcs: single deg, 10 numbered, RA of sun (Arabic numerals) on equatorial line. Ecliptic arcs: March equinox at E side, zodiacal sigils, single deg, 10s crossed. Date scale: at ends of dec arcs, months, single days, 5s extended. Azimuth circle: complete, 0-90-0-90-0, single deg, 10s numbered, zeroes at N and S. Compass: 32 labelled points, oriented to relate to shadow of vertical style. Each point divided into eighths. Trig. scales: to SW, altitude scale single deg 0-90, 10s numbered: outward-reading tangent scale 0-45, single deg, 10 and 45s numbered. To SE: two scales of sines, outer 0-90, single deg, 10 numbered, inner scale of sines of half-angles, single deg 0-180, 10 numbered. Concentric circular time dials for 16 named places, with latitudes and longitudes, showing the local times for each, Roman hour figures, divided 15 min.



Dials for each place identified by letter A-Q (no J), repeated at N, E and W.
Moon time correction arc, 29½ day lunation divided to days and one-eighth days, correction 2×12 hours, Roman numerals, 5 min intervals.
Names of 12 stars and their RAs.
Perpetual calendar.
Table of years 1623-1723, symbols for days of the week of March 1 in leap years, incorrect epacts.
Continuation of year table 1724-1835.
Text under this table: “Minuta sunt qua Spectas, non quæ Perdis”.





Drawing by David Honour

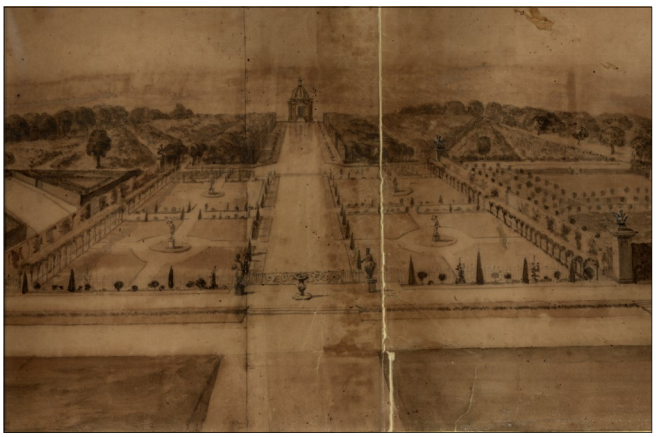
Dedication: "Ex Memoria Officy THOMÆ IONES, *Anno dom 1682"* .
Gnomon: E side: decoration, wheatsheaf design. W side: decoration, Coat of Arms.
Mottoes on upper surface: "Omnia sert ætas secum, ausert omnia secum, *Tenere non potes; potes, non perdure"*. Motto on lower surface: "Nulla Dies sine Linea".

Location — Wrest Park originally, now in English Heritage store.

Provenance — Made for Henry de Grey, Duke of Kent.

References — Inv. No. 794486. BSS SRN 2125

Notes — Most details for this dial have been obtained from an electrotype replica (M-6) now in position at Wrest Park.

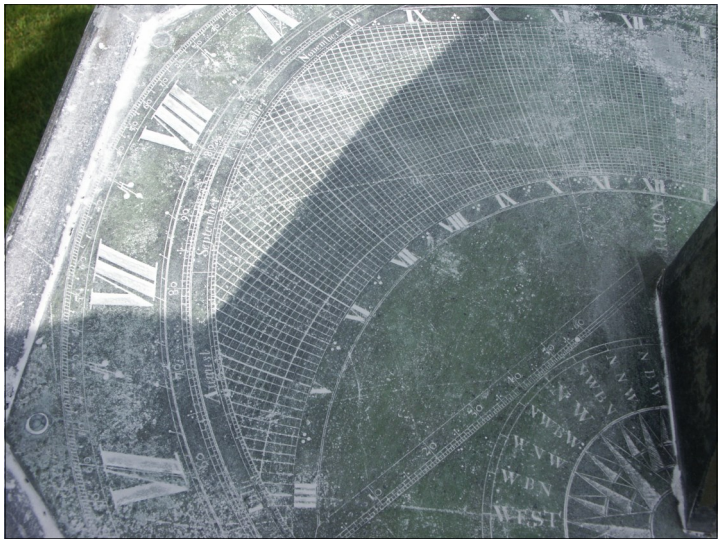




Record no.	**DH-35**
Signature	Henricus Wynne Londini fecit
Date	c.1680
Dimensions	c.430 mm (17 ins) a/f octagonal.
Material	Brass.
Condition	Fair/good. Tail of gnomon bent down.
Latitude	"Cherbury Lat 52 37 "
Features	Polar dial: IIII-XII-VIII, inward-facing. Two minute scales, outer divided 1 min, 10s extended, fleur-de-lys at 30: inner 7½ min, 30s dotted. Stereo grid: IIII-XII-VIII inner ends of hour lines, IX-XII-III outer, divided 5 min, 15, 45s crossed, 30s dotted with fleur-de-lys at each end. Ecliptic arcs: March equinox at E side, zodiacal sigils, single deg of longitude dotted. Date scale: at ends of dec arcs, months, single days, 10, 20, 28/30/31 extended. Azimuth scale: 0-90-0-90-0, deg and ½-deg, 5s triple dotted, zeroes to N and S. Altitude scale: to SW, deg and ½-deg 0-61, 10s labelled, 5s triple-dotted. Compass scale: around point of polar style, 32 labelled points, "NORTH" written between vertical style and XII of stereo grid, correctly oriented.
Location	Powis Castle, Welshpool. National Trust property. Not in publicly accessible area.
Provenance	Believed to have been made for Lord Herbert of Chirbury, owner of Powis Castle.
Reference	BSS SRN 3416. *BSS Bull* (see p.54)
Notes	Mounted on a cube dial which is probably earlier.



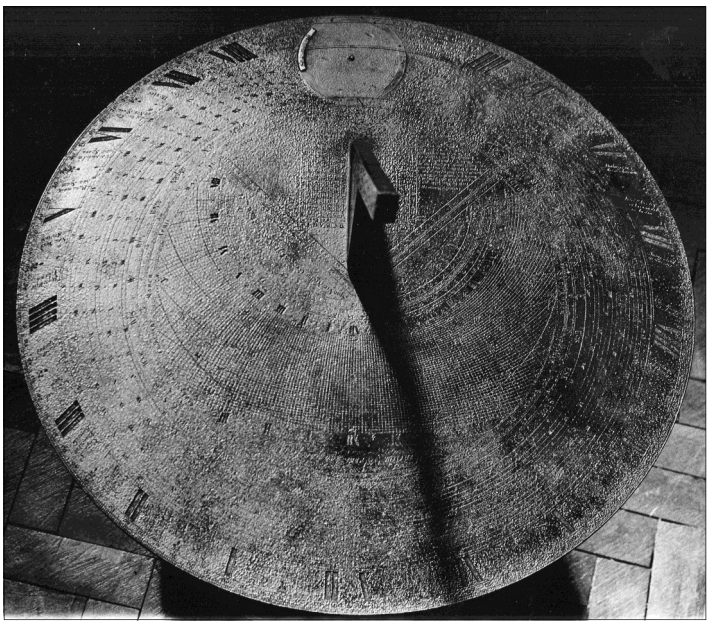




(Dusted with talc)



Record no.	**DH-36**
Signature	Henricus Wynne Londini fecit
Date	c.1685
Dimensions	770 mm (30¼ ins) diam. circular.
Material	Bronze.
Condition	Eroded, some detail indecipherable.
Latitude	[52.8° N] (for original location).
Features	Polar dial: IIII-XII-VIII, inward –facing. Two scales of minutes, outer divided 1 min, 10s numbered: inner divided 7½ min. Stereo grid: IIII-XII-VIII at inner ends of hour lines, IX-XII-III outer, divided 5 min, 15, 30, 45s dotted. Sun's RA, Arabic figures 0-(12) and 13-(24) on equator. Dec arcs: single deg, 5s dotted, 10s numbered in several places. Ecliptic arcs: March equinox at E side, zodiacal sigils, single deg of longitude. Date scale: at ends of dec arcs, months, single days. Azimuth scale: 0-90-0-90-0, deg and ½-deg, 10s numbered, zeroes at E and W. Between SE and SW, scale of deg and ½-deg, 10s numbered 0-90 in each direction. Trig. scales: to SW, altitudes 0-90, 10s numbered, scale of tangents of angles 0-45 running outward. To SE, scale of sines of angles 0-90, scale of sines of half-angles, both numbered in 10s running outward. Compass: 32 points labelled, divided to quarter-points, oriented to relate to shadow of vertical style. Place names: about 34 place names (some indecipherable). See p.51. Two moondials: 1) direct-reading, 15 concentric circles for moon ages 1-15 and 16-30, hours (Roman numerals) divided to ⅛ hours. 2) moon-time conversion table, 29½ day lunation, time correction scale 2×12 hours, divided half- and quarter-hours. Instructions for the use of this table. Table of epacts and dominical letters starting 1685. Instructions for finding age of moon from the epact. Perpetual calendar. Nocturnal, now lost. Instructions for use. Names and RAs of 24 prominent stars (see p.48). On gnomon: E side, table of epacts and dominical letters to derive dates of Easter and associated festivals. W side, epacts and dominical letters, dates of Whit-Sunday, start and end of Easter and Trinity terms. On top edge: linear equation of time table, on lower edge motto 'Nulla Dies sine Linea'
Location	Originally Staunton Harold, now in store at Ditchingham Hall.
Provenance	Known to have been installed at Staunton Harold when new.
References	BSS SRN 4680. Davis & Lowne, *BSS Bull*, 15(ii), (2003), reprinted p.41; Davis & Lowne, *BSS Bull*, 18(i) (2006), reprinted p.53.
Notes	The cited articles contain additional details.

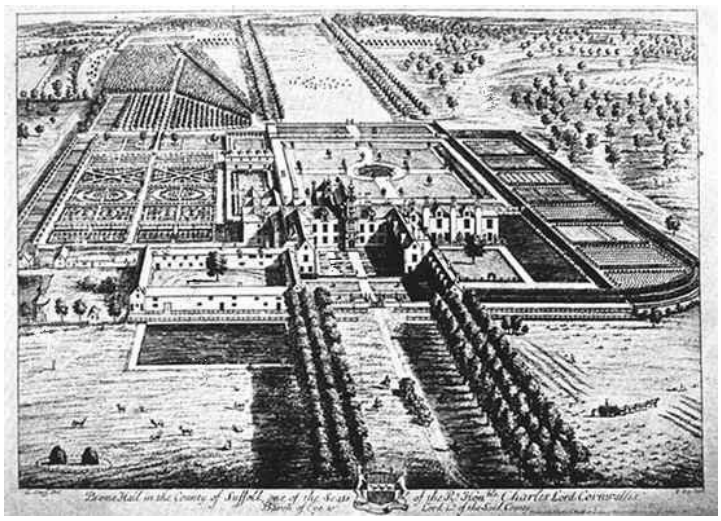


The dial in raking light

Record no.	**DH-37**
Signature	Henricus Wynne Londini fecit
Date	1667/8?
Dimensions	686 mm dia (27 ins).
Material	Brass (laminated).
Condition	Some patina, eroded, finer details lost.
Latitude	"52° 24' " [Brome is actually 52° 21'; calc. design lat 52.4° N]
Features	Polar dial: IIII-XII-VIII, inward-facing. Two scales of minutes, outer divided 1 min, 10s numbered, symbols at 30s: inner divided 7½ min, 30 triple-dotted. Stereo grid: IIII-XII-VIII at inner ends of hour lines, IX-XII-III outer, divided 3 min, 15, 30, 45s dotted, 30s triple-dotted at each end. Dec arcs: single deg, 10s thicker, 5s dotted. Ecliptic arcs: March equinox at E side, zodiacal sigils, single deg of longitude dotted. Date scale: at ends of dec arcs, months, single days. Azimuth scale: 0-90-0-90-0, deg and ½-deg, zeroes N and S. Between SE and SW, deg, 10s numbered 0-90 in each direction. Trig. scales: to SW altitude scale 0-90 deg, tangents of angles 0-45 running outward: to SE, scale of sines 0-90, sines of ½ angle 0-180. Moon time conversion scale: 29½ day lunation, time correction scale 2×12 hours. 12 stars and their RAs. Table of epacts, for 1668-1707 (7 cols by 7 rows). Perpetual calendar. Coat of arms for Charles, 2nd Baron Cornwallis of Eye (1632-73). These are quartered with earlier families from which the family descended.
Location	Originally Brome Hall, Suffolk. Current location unknown.
Provenance	Sold at Sothebys, complete with pedestal, 1991, (£11,500).
Reference	
Notes	Details from text and photographs in Sotheby's catalogue. Pedestal has unusual 3-ball adjustable mounting for dial.







Brome Hall, demolished in the 1960s





Cornwallis arms in Brome church

Record no.	**DH-38**
Signature	Henry Wynne
Date	Anno Domini 1692
Dimensions	850 mm (33½ ins) diam.
Material	Brass.
Condition	Very good for age.
Latitude	[55.9° N]
Features	Polar dial: inward-facing, III-XII-IX divided 1 min, 5 and 10s extended. Stereo grid: III-XII-IX at inner ends of hour lines, IX-XII-III outer ends, divided 5 min, 30s triple-dotted at each end. Dec arcs: single deg. Ecliptic arcs; Azimuth scale: Compass scale: 32 labelled points, oriented to relate to shadow of vertical style. Moondial: direct-reading, 15 concentric rings between main chapter ring and compass, hours (Roman numerals). Equation of time table labelled "A Table of the Equation of Days shewing ?? which a good Pendulum watch…moves.. faster or slower than a sundial every day of the year". Columns are "watch too fast/slow" and give values in mins:secs from the Tompion 1683 table. Place names in two rings with XII for local noon. Perpetual calendar (divided by gnomon) labelled "A table whereby to find … … Easter for ever" Star data: Lucida Pleida, Bull's Eye, Great Dog?? Lyon's Heart" etc.
Location	Drumlanrig Castle, Dumfriesshire, Scotland (completed 1691). On balcony.
Provenance	Commissioned by William Douglas, 1st Duke of Buccleuch. Still owned by the Duke of Buccleuch and Queensberry.
References	A.J.Turner no. B.10. BSS SRN 0897.
Notes	East side of gnomon engraved with the Douglas Heart; the west side with the arms of the Queensbury family; all surrounded by elaborate vine-leaf scrolls.

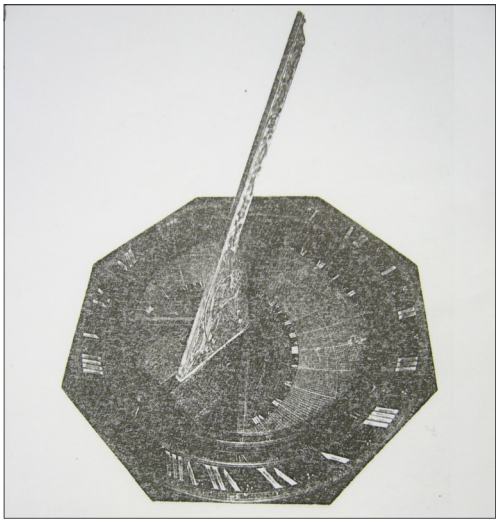
OUTER RING	INNER RING
Meaco	Nangosaqui?
Peking	Canton
Bantain	Siam
Bengale	Balasore
Agra	Fort St George
Surral	Ispahan
Babilon	Mecca
Aleppo	Jerusalem
Gran Cairo	Constantinople
Oran	Naples
Stockholm	Paris
Vienna	Edinbro
Rome	Dublin
Amsterdam	Madera
London	St Michaels Hand[?]
Madrid	Cape Augustine Brazil
Lizbon	Surrinam
Tenerif	Rio de la pla.
Coruo & Flores	Boston
Cape Raze nr. Newfoundland	Port Royal
Barbados	Havana
Bermuda	St Iago Cantimale
New York	Guadalaiara
Jamestown	Port St Francis Drake
Charlestown	
Mexico	
New Mexico	







Record no.	**DH-39**
Signature	[Henry Wynne]
Date	1695
Dimensions	Unknown. Octagonal.
Material	Brass.
Condition	Fair.
Latitude	[Berwickshire?]
Features	Standard Wynne design (as e.g. DH-37) with twin 'sector' scales, epact tables, stars, etc. Decorated gnomon.
Location	Not known.
Provenance	Made for Richard Maitland, 4th Earl of Lauderdale.
Reference	A.J. Turner no. B.4, Details only from catalogue of the Scottish Antique Dealers Fair, Edinburgh, 1966, p.31.



Record no.	**DH-40**
Signature	[Henry Wynne]
Date	1677/8(?)
Dimensions	661 mm dia. Thickness c.12 mm recessed into pedestal by c.4 mm. Gnomon 13 mm thick, 494 mm along style, vertical style 160 mm, offset of origins 155 mm.
Material	Brass (laminated and rivetted).
Condition	Very badly eroded. Hardly any details now visible, apart from traces of a coat of arms for Knight of the Garter on the gnomon.
Latitude	[gnomon 51.5° N]
Features	Details now unclear but appears to be very similar to 'Cornwallis' dial DH-37 with finely-divided stereo grid and including sector-like trig scales, moon time conversion arc, full circle azimuth scale, etc. Remains of a presumed nocturnal, 56 mm diam, to SE of gnomon.
Location	Clarence House, London.
Provenance	The Royal Collection Trust. Presumed to be the dial originally installed on the South Terrace of Windsor Castle at a cost of £25. Moved to present position from elsewhere in the St James' Palace Gardens in 1968.
References	BSS SRN 5756. J. Walker, *BSS Bull* 98 (2). Declared Accounts of the Exchequer & Adit Dept AO 1/2478/271, PRO, Kew.
Notes	Pedestal is not thought to be the original which is described as "with carved eagles", by John Vanderstraine.





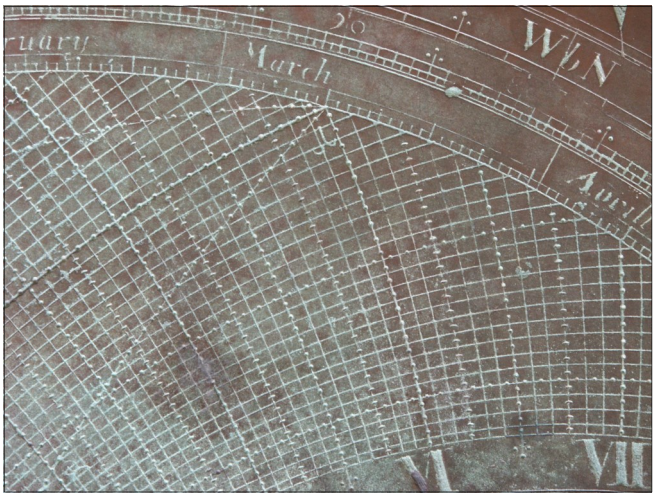


The dial in 1968

Record no.	**DH-41**
Signature	Henricus Wynne Londini fecit
Date	[1660s?]
Dimensions	412 mm (16¼ ins) a/f octagonal.
Material	Brass.
Condition	Fair, some patina. Gnomon missing.
Latitude	[51.7° N]
Features	Polar dial: IIII-XII-VIII, inward-facing. Two scales of minutes, outer divided 1 min, 5s extended and dotted, 10s numbered, 30s triple-dotted: inner scale 7½ min, 15, 45s extended, 30s triple-dotted. Stereo grid: IIII-XII-VIII at inner ends of hour lines, IX-XII-III outer, divided 5 min, 15, 45s dotted, 30s crossed with triple dots at each end. Dec arcs: single deg, 0 heavier, 5s crossed, 10s dotted. Ecliptic arcs: March equinox at E side, zodiacal sigils, single deg of longitude dotted. Date scale: at ends of dec arcs, months, single days, 5 and 10s extended. Azimuth scale: 0-90-0-90-0, single deg, 5s triple-dotted, 10s numbered, zeroes at N and S. Altitude scale: to SW, single deg 0-62, 10s numbered. Compass: 32 labelled points, divided ¼, ½ (triple-dotted) points, oriented to relate to shadow of vertical style.
Location	Hotham Park, West Sussex (kept in store).
Provenance	
Reference	SRN 4531.
Notes	



Temporary gnomon



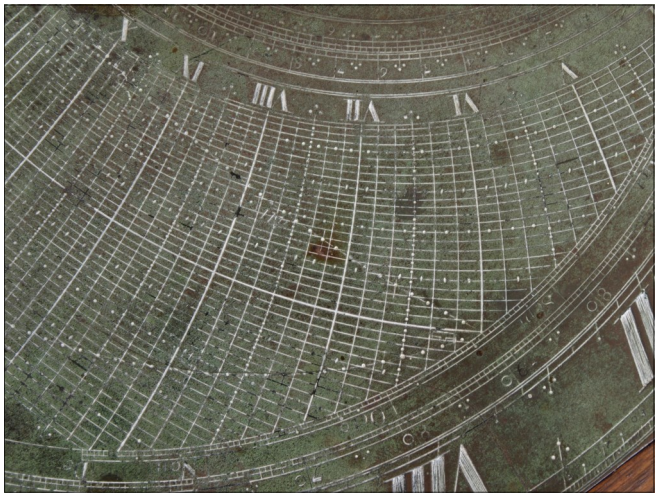


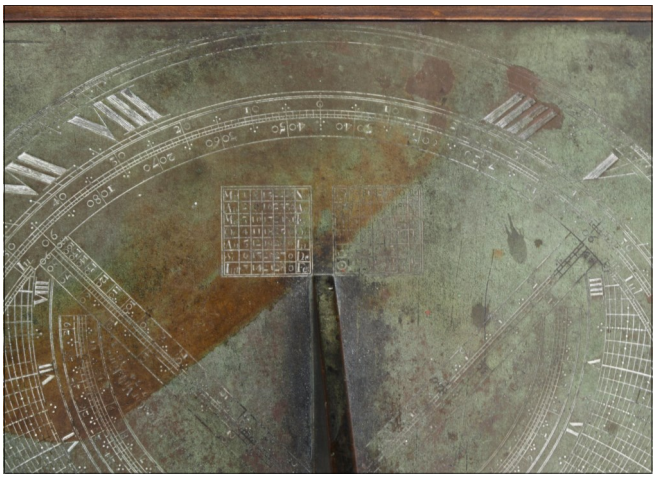


Temporarily in position on original (?) pedestal

Record no.	**DH-42**
Signature	unsigned
Date	[1680] based on epact table.
Dimensions	311 mm (12¼ ins) a/f octagon. 2.8 mm thick. Gnomon 6.5 mm thick. Horizon circle 118 mm radius. Offset of style from centre 73.5 mm.
Material	Brass. Mounted in a wooden frame.
Condition	Good. Generally blue/green patina with one section brown.
Latitude	[52.5° N] based on polar dial time range. (52.0º gnomon angle)
Features	Polar dial: IIII-XII-VIII (actually 3:42 to 8:18). Two scales of minutes, outer scale divided 1 min, 5s extended, 10s extended with single dots, numbered, 30 striple dotted: inner scale ⅛ hours, 15s extended with single dots, 30 sextended with triple dots. Stereo grid: IIII-XII-VIII at inner ends of hour lines, IX-XII-III outer, divided 10s min, 30s dotted with triple dots at ends. Dec arcs: single deg, thicker line at equator, 5s dotted, 10s crossed. Ecliptic arcs: March equinox at E side, zodiacal sigils, 2 deg intervals of longitude dotted. Date scale: at ends of dec arcs, months (abbrev.), single days, 5s extended with dots, 10s extended. Azimuth scale: 0-90-0-90-0, deg and ½-deg, 5s triple dotted, zeroes at N and S. Between SE and SW, numbered (0)-90 in each direction. Moon time conversion scale: 29½ day lunation divided ¼ days, ½ triple dotted, time correction 2×12 hours to ⅛ hour, ¼ extended, ½ triple dotted. Names and RAs of prominent stars. Trig. scales, to SW altitude scale single deg, 10s numbered, 5s triple dotted, tangent scale 0-45 single deg running outward, 5 triple dotted: to SE sines 0-90 single deg numbered in 10s, sines of ½ angles 0-180, 2 deg intervals numbered in 10s. Table of epacts 1680-1712. Perpetual calendar. Gnomon has small foot along base of knife-edge, fixed with two tenons and iron (rusted) pins.
Location	Private collection, England.
Provenance	Bought from a dealer (Stuart Talbot) in 2006.
Notes	Follows Sutton/Marke pattern but calendrical tables rotated 180° (read from the N of dial). Small numerals 0, 6, 8 & 9 based on punched circles (several sizes). Origins of polar dial and stereo grid drilled through from back.









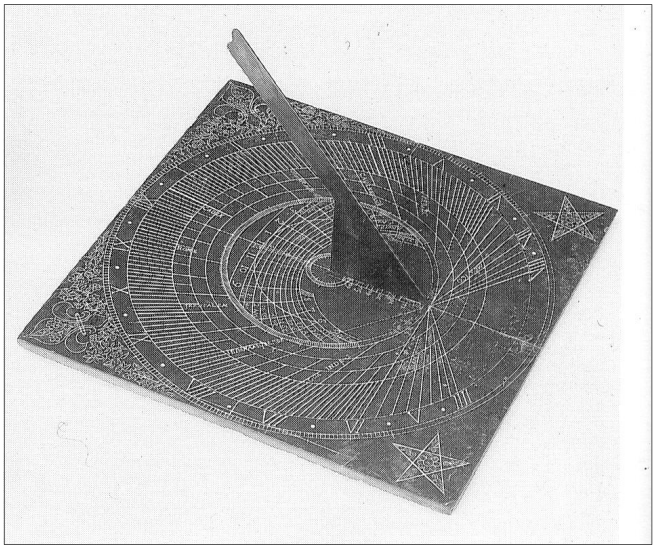
Record no. **DH-43** No dial

Record no. **DH-44**
Signature Erased
Date 3Q 17C ??
Dimensions 311 mm (12¼ ins) a/f octagon. Gnomon 10 mm thick (est.)
Material Brass.
Condition Good (polished). Modern replacement gnomon.
Latitude [51.7° N]
Features Polar dial: IIII-XII-VIII, inward-facing.
Two minute scales, outer divided 1(?) min, 5, 10s extended, 10s numbered, 30s triple-dotted: inner 7½ min, 15, 30, 45s extended, 30s dotted.
Stereo grid: IIII-XII-VIII inner ends of hour lines, IX-XII-iii outer, divided 7½ min, 30s triple dotted at each end.
Dec arcs: single deg, 5 and 10s dotted.
Ecliptic arcs: March equinox at E side, zodiacal sigils, 2 deg (?) intervals dotted.
Date scale: at ends of dec arcs, months, single days (?).
Azimuth scale: 0-90-0-90-0, deg and ½ deg, 10s extended and numbered, 5s dotted, zeroes to N and S.
Altitude scale: to SE, deg, 5, 10s extended, 10 numbered.
Two inscriptions: 'From the rising of the Sun THE LORDS NAME IS TO BE PRAISED unto the going down of the same.' (quotation from Psalm 133) 'The Gift of Eliza Hayton from Bledlow House Bucks'
Location Now unknown.
Provenance Was Time Museum Inventory 1614. Sold Sotheby's NY, 14 Oct 2004 Lot 766,



$5400 including buyer's premium.
References A.J. Turner no B.2. *Time Museum – Time Measuring Instruments, Astrolabes & Astrolabe-related instruments*, pp.198-9, (1985).
Notes Details taken from auction catalogue photograph: some details obscure.

Record no. **DH-45**
Signature None
Date 19 C
Dimensions 565 mm (22¼ ins) square.
Material Slate, metal gnomon.
Condition Good.
Latitude [50° gnomon angle?]
Features Polar dial: IIII-XII-VIII, Two minute scales, narrow outer divided 3 min: broad inner divided 15 min IIII-VI and VI-VIII, 5 min VI-VI, 15, 30, 45s extended. No noon gap.
Stereo grid: 4-8, 4-8 at inner ends of hour lines, 9-12-3 outer ends, hours only.
Dec arcs: 11 arcs, presumably for entry of sun into signs and their mid-points, indecipherable labels. No date scale.
Azimuth scale: single deg, 10s extended, unnumbered. Small scale close to vertical style, divided 5 deg, 10s extended, unnumbered.
Altitude scale along base of gnomon, divided 5 deg, 10s numbered.
Circular arc running over the dec arcs, meeting arc for +23.5° at 6 and 6, that for -23.5° at 12.
Names of 10 places within the extended time lines of the polar dial (Mexico, Kebec, Cayenneame, Olinde Au Bresi, Cadix, Rome, Jerusalem, Ispahamperse,



Goa Inde-s, Siam).
Location Unknown.
Provenance Offered for sale by Christies, April 1988, lot 2828, estimate £300-500.

Reference
Notes Spandrels: fleur-de-lys, floral decoration, 5 -pointed stars.

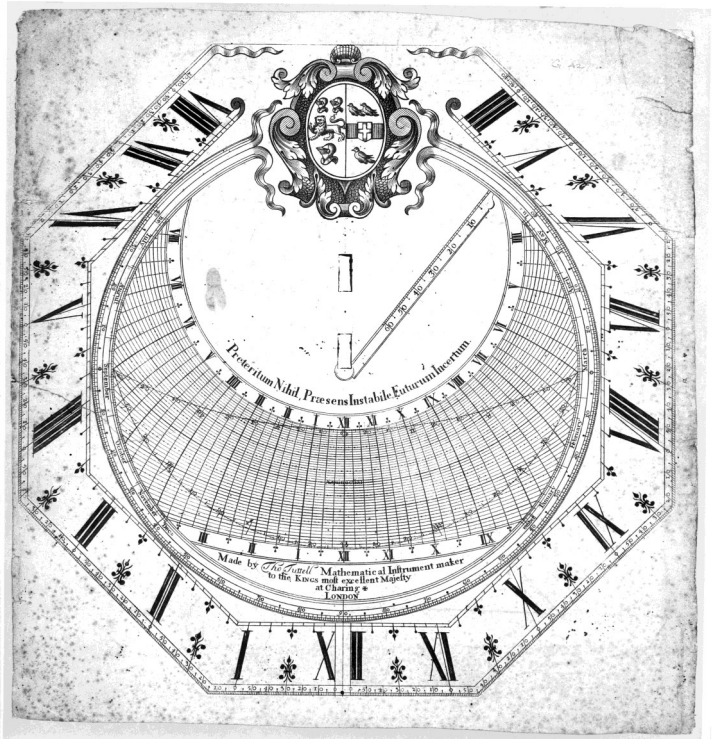
Record no.	**DH-46**
Signature	(Henry Sutton)
Date	1660
Dimensions	305 mm (12 ins) diam.
Material	Paper.
Condition	
Latitude	
Features	Inscription “RC 1660”.
Location	
Provenance	
Reference	A.J. Turner no. B.3: Bryden *SIS Bull* 55 p9: Eagleton and Jardine (2005) ref 40.
Notes	Probably similar to DH-61 & 62.

No picture available.

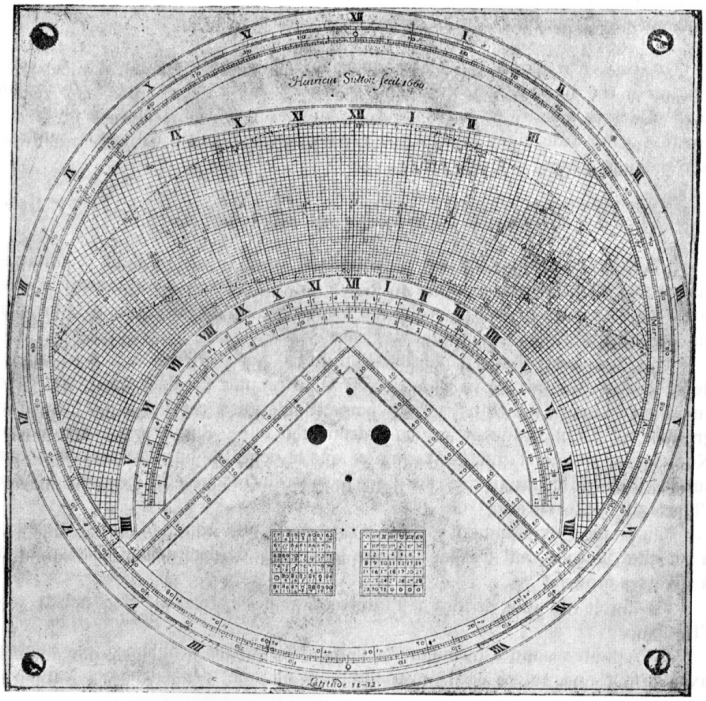
Record no.	**DH-47**
Signature	
Date	c. 1694?
Dimensions	
Material	Paper.
Condition	
Latitude	
Features	Hour lines extended outside tropics. Inscription on the back: “A Sun diall to be pasted on a board given me by Mr Mol* 1694”
Location	Private collection, France.
Provenance	From library of John Evelyn, sold with rest of Evelyn Library in 1977-8 by Christie, Manson & Wood.
References	A.J. Turner no. B.*. Bryden *SIS Bull* 55 p.9. Eagleton and Jardine (2005) ref 40.
Notes	Engraver of plate unknown.

No picture available.

Record no.	**DH-48**
Signature	Made by Tho Tuttell, Mathematical Instrument maker to the Kings most excellent Majesty at Charing □ LONDON
Date	c.1700
Dimensions	254 mm (10 ins) a/f octagonal.
Material	Paper.
Condition	Good.
Latitude	[52.3° N]
Features	Polar dial: IIII-XII-VIII outward-facing. Two minute scales, outer divided 1 min, 5 and 10s extended, 10s numbered, symbols at 30: inner 7½ min, 15, 30, 45s extended, symbols at 30s. Stereo grid: IIII-XII-VIII inner ends of hour lines, IX-XII-III outer, divided to 15 min. Dec arcs: single deg, 10 thicker lines, 5s dotted, 0° labelled “Æquinoctial”. Ecliptic arcs: March equinox at W side, zodiacal sigils, single deg of longitude, numbered 10, 20. Date scale: months running anti-clockwise, single days, 5 and 10s extended. Azimuth scales: deg and ½-deg 40-0-90-0-40, 10s numbered, zeroes at E and W. Altitude scale:to SW, single deg 0-60, 10s numbered. Coat of arms, poss. for George Compton, 4th Earl of Northampton and wife. Motto: Preteritum Nihil, Præsens Instabile, Futurum Incertum (*The past is gone, the present transient, the future uncertain*), also on a Tuttell portable analemmatic dial in the Lewis Evans collection, ref: Gatty.
Location	National Maritime Museum, Greenwich.
Provenance	
Reference	A.J. Turner no. B.11.
Notes	Compare with Tuttell dial DH-32 and also anonymous dial DH-66.



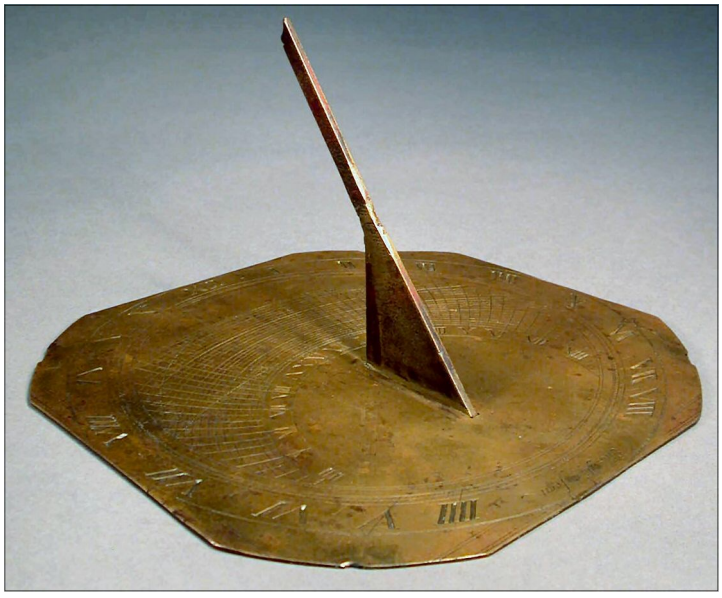
Record no.	**DH-49**
Signature	Henricus Sutton fecit 1660
Date	1660
Dimensions	205 mm (8 ins) square.
Material	Brass.
Condition	Good (clean brass). Gnomon missing.
Latitude	"Latitude 51 32."
Features	Polar dial: IIII-XII-IIII inward-facing, divided 1 min, 15s extended, 30s triple-dotted. Stereo grid: IIII-XII-IIII at inner ends of hour lines, IX-XII-III outer, divided 5 min. Sun's RA (Arabic figures) on equatorial line. Dec arcs: single deg, 10s thicker and numbered in two places. Ecliptic arcs: March equinox at E side, zodiacal sigils, single deg of longitude, 5s crossed. Date scale: at ends of dec arcs, months (abbreviated), single days. Azimuth scale: deg and ½-deg, 0-90-0-90-0, 10s numbered, zeroes at N and S. Between SE and SW, scale of deg and ½-deg numbered 0-90 in each direction. Moon time conversion table: 29½ day lunation, in ¼-days, correction 2×12 hours in 7½ min intervals. Trig. scales: to SW, altitude scale 0-90 reading inwards, tangents of angles 0-45 reading outwards. To SE: sines of angles 0-90 reading outwards, sines of half-angles 0-180 reading outwards. Table of epacts 1657-1690. Perpetual calendar.

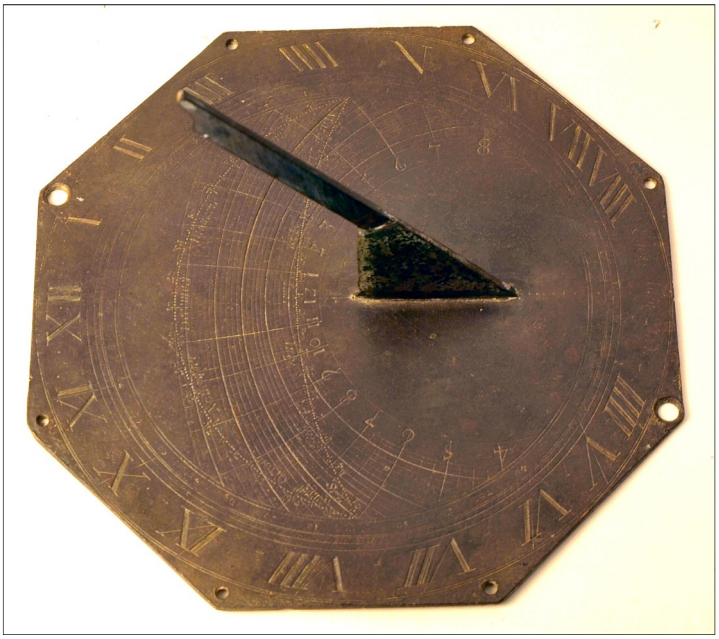


Reproduced from H Michel 'Traité de l'Astroblabe'

Location	Unknown.
Provenance	
Reference	H. Michel (1947).
Notes	The chapter ring is narrow in proportion to the rest of the dial. May be related to DH -46.

Record no.	**DH-50**
Signature	Elias Allen fecit
Date	c. 1630
Dimensions	250 mm (9⅞ ins) a/f. Originally square but corners now rounded which has cut into the fixing holes. 2 mm thick.
Material	Brass.
Condition	Fair – has been cleaned. Broken gnomon re-attached.
Latitude	[51.5° N]
Features	Polar dial: IIII-XII-VIII, inward-facing, divided 5 min, 15s extended, 30s crossed. Stereo grid: IIII-XII-VIII, divided 15 min. Dec arcs: 2 deg intervals, 10s thicker Ecliptic arcs: March equinox at E side. Date scale: on ecliptic, months, single days dotted, 5 and 10s crossed, numbered 10, 20, 28/30/31. Azimuth scale: 40-(0)-90-(0)-40, 10s numbered, omitting zeroes at E and W. Altitude scale: to SW, single deg, 10s numbered.
Location	Musée d'Histoire des Sciences, Ville de Genève.
Provenance	Bought in a London antiques shop in 1992.
Reference	MHS-2098.
Notes	Centres of dec arcs and hour lines visible.



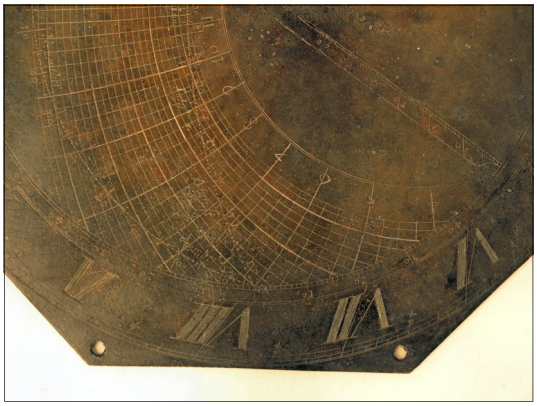


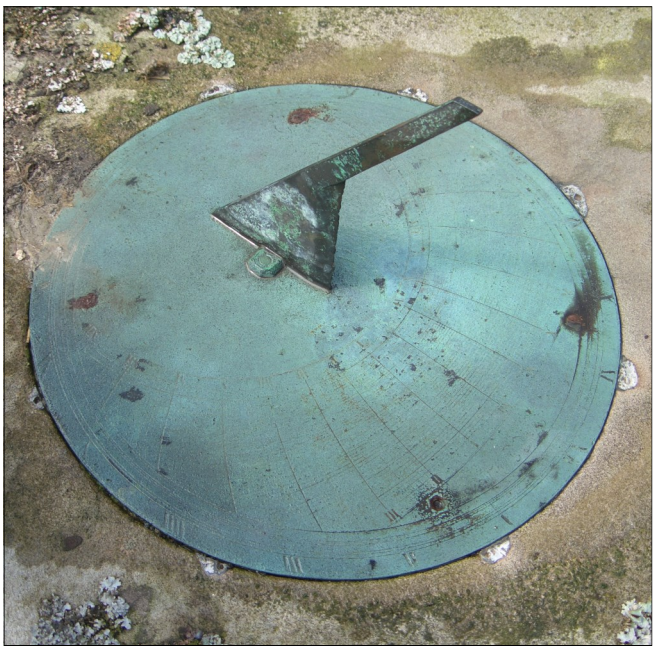
Record no.	**DH-51**
Signature	Elias Allen fecit
Date	c. 1630
Dimensions	199 mm (7¾ ins) a/f octagon.
Material	Brass.
Condition	Fair. Gnomon tail is a replacement.
Latitude	[51.5° N]
Features	Polar dial: IIII-XII-VIII, divided 5 min inside numerals, 15, 30, 45 extended, 'T-bar' half-hour marker. Stereo grid: 4-12-8, divided 15 min. Dec arcs: 2 deg intervals, 10s thicker. Ecliptic arcs: March equinox at E side. Date scale: on ecliptic, months in full, oriented to be read from inside ecliptic, single days dotted, 5 and 10s crossed, numbered 10, 20, 28/30/31. Azimuth scale: 40-(0)-90-(0)-40, 10s numbered, omitting zeroes at E and W. Altitude scale: to SW, single deg, 10s numbered, eroded.
Location	Private collection, England
Provenance	
Reference	H. Dawes: *Instruments of the Imagination*, (2009).
Notes	Centres of dec arcs and hour lines visible.



Record no.	**DH-52**
Signature	Unsigned, possibly Elias Allen workshop.
Date	C17 ?
Dimensions	245 mm (9½ ins) a/f octagonal.
Material	Brass.
Condition	Good. Tail of gnomon is a replacement.
Latitude	[51.4° N]
Features	Polar dial: IIII-XII-VIII, inward-facing, divided 5 min outside the numerals, 15, 30, 45s extended, 'rosebud' marker at 30. Stereo grid: 4-12-8, divided 15 min. Dec arcs: 2 deg intervals, 10s thicker. Ecliptic arcs: March equinox at E side. Date scale: on ecliptic, single days dotted, 5 and 10s crossed, numbered 10, 20, 28/30/31. Months in full (note "Febᶠuary"), oriented to be read from N. Azimuth scale: 45-0-90-0-45, 10 numbered, zeroes to E and W. Altitude scale: to SW, 0-62, single deg, 10s numbered. Divisions drawn E-W, oblique to scale edge.
Location	Private collection, England.
Provenance	
Reference	
Notes	Similar to Greatorex DH-20 but small differences in engraving hand.



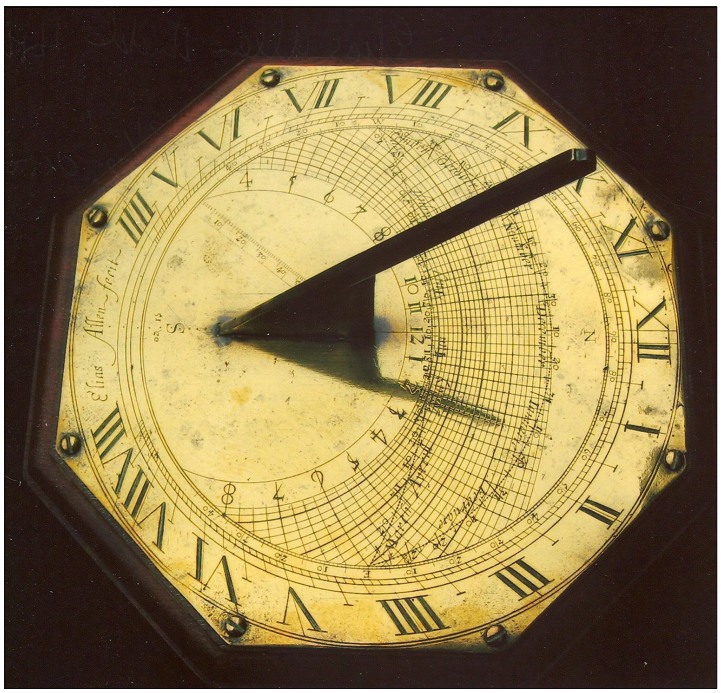








Record no.	**DH-53**
Signature	Johannes Marke Londini fecit / [illegible]
Date	c.1680
Dimensions	302 mm (12 ins) circular, c.2 mm thick. Horizon circle 262 mm dia. Gnomon style length 302 mm, base 78 mm, thickness 3.8 mm. Vertical style height 87 mm.
Material	Brass.
Condition	Heavy blue-green patina. Fine detail obscured. Original gnomon.
Latitude	
Features	Polar dial: IIII-XII-VIII, inward-facing Stereo grid: IIII-XII-VIII at inner ends of hour lines, IX-XII-III outer. Divided to 5 mins, 15s dotted, hours heavier. Dec arcs: single deg, 10s heavier Date scale: at ends of dec arcs. Small circular scale around centre of grid may be compass rose: outer circle has numbered azimuths from S. Sides of gnomon carry engravings, almost lost, e.g. a globe on the E side.
Location	Private garden, Wales.
Provenance	May be in original location.
References	BSS SRN 6408. *BSS Bull* 20(iii) pp.116-7 (Sept 2008).
Notes	Cast feet to gnomon. Narrow chapter ring.



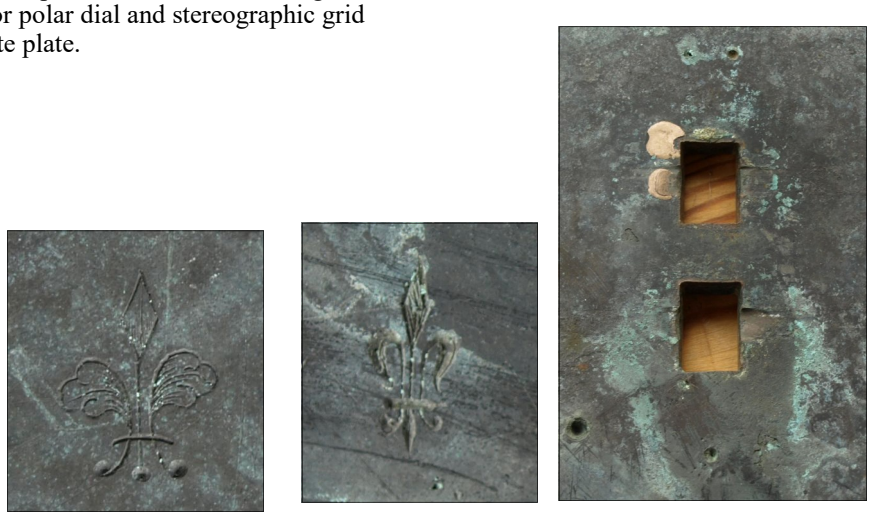
Record no.	**DH-54**
Signature	Elias Allen fecit
Date	c. 1630
Dimensions	194 mm (7⅝ ins) a/f octagon. c.1.6 mm thick.
Material	Brass.
Condition	Good (polished). Gnomon is an old replacement but correct profile.
Latitude	"51 20"
Features	Polar dial: IIII-XII-VIII, inward-facing, divided 5 min. Stereo grid: 4-12-8, divided 15 min. Dec arcs: 2 deg intervals, 10s thicker. Ecliptic arcs: March equinox at east side. Date scale: months, single days, numbered 10, 20, 28/30/31. Azimuth circle: 45-E-90-W-45, single degrees, 10s numbered. Positions of zeroes marked E and W. Altitude scale to SW; single degrees, 10s numbered. N and S marked.
Location	Private collection, England.
Provenance	Was at Hazlemere Park nr. High Wycombe, given to owner's father in 1930s by Ledbetter family as payment for a debt. Was in a garden until 1970s then brought inside, polished and mounted.
Notes	Centres for dec arcs and hour lines visible. There may at some time have been a hooped gnomon supporter fitted as re-filled holes are visible in the dial plate near the N edge.

Record no.	**DH-55**
Signature	(Adam Ordway)
Date	1662
Dimensions	
Material	Paper.
Condition	
Latitude	
Features	
Location	
Provenance	
Reference	Advertisement in Ordway's *The description and use of the double horizontal dial*: "The Print of this Dial and Almanack pasted on a Board and fitted with a Cock, is to be sold by *Adam Ordway*.....". See transcription on page 14.
Notes	No known examples.

No image known.

Record no.	**DH-56**
Signature	R GLYNNE [fecit?]
Date	Q1 18C
Dimensions	544 mm (21½ ins) diam. 6 mm (¼ in) thick, profiled edge. Gnomon thickness 12.3 mm (½ ins), offset of style from centre 101.4 mm (4 ins).
Material	Brass.
Condition	Terrible. Surface eroded and abraded; very little still readable. Gnomon mislaid.
Latitude	[around 52° N]
Features	Polar dial: inward-facing numerals. Moon time scale, direct reading, 15 concentric chapter rings. Coat of arms (not deciphered).
Location	St Hugh's College, Oxford.
Provenance	Given to St Hugh's College, Oxford, in 1938.
Reference	*BSS Bull* 21(ii), p.11 (June 2009).
Notes	Early photograph shows dial with its gnomon on pedestal. Was coated in silver paint (now stripped) and scratched by students. Two trial fleur-de-lys on back. Basis for replacement dial M-23. Origin holes for polar dial and stereographic grid penetrate plate.





Back of dial plate

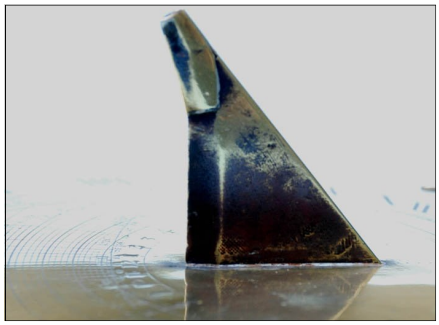
Record no.	**DH-57**
Signature	Elias Allen fecit
Date	c. 1630
Dimensions	199 mm (7¾ ins) a/f octagon. Thickness 1.5 to 1.8 mm. Horizon circle diameter 145.5 mm (5¾ ins). Offset of polar style from origin 51.5 mm (2 ins).
Material	Brass.
Condition	Fair, dark brown patina. Inappropriate 'art -noveau' gnomon unsoldered and proper replacement fitted in 2007.
Latitude	[51.5° N]
Features	Polar dial: IIII-XII-VIII, inward-facing, divided 5 min, 15, 30, 45s extended, 30s crossed. Stereo grid: 4-12-8, divided 15 min. Dec arcs: 2 deg intervals, 10s thicker. Ecliptic arcs: March equinox at east side. Date scale: on ecliptic, months, single days dotted, 5 and 10s crossed, numbered 10, 20, 28/30/31. Azimuth scale: single deg, 40-(0)-90-(0)-40, 10s numbered omitting zeroes at E & W. Altitude scale: to SW: single deg, 10s numbered.
Location	Private collection, England.
Provenance	Bonhams sale 15617 lot 127, 28 Nov 2007. £1799.
Reference	
Notes	

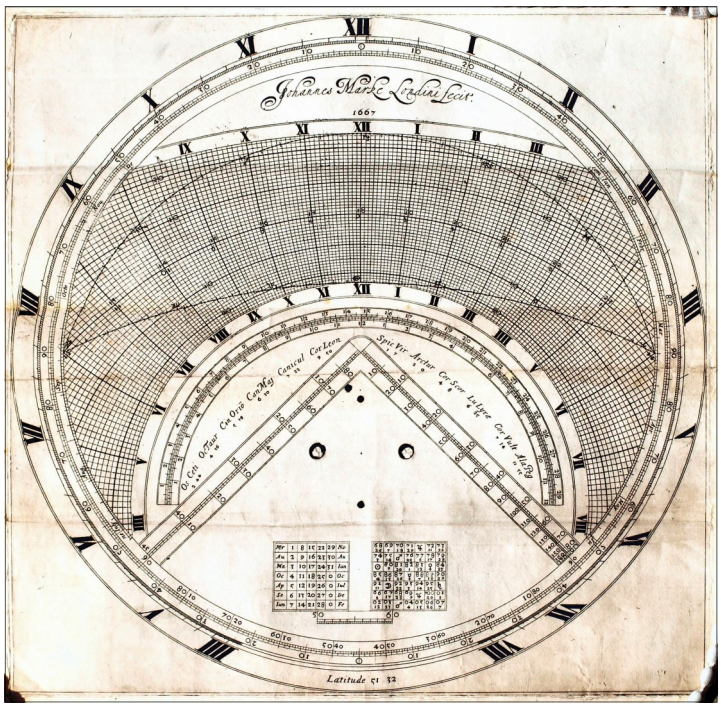




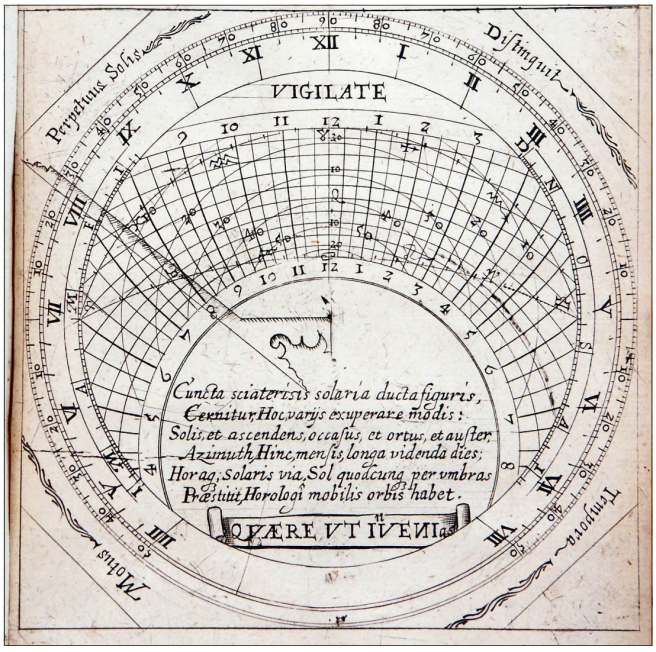
Record no.	**DH-58**
Signature	Elias Allen fecit
Date	c. 1630
Dimensions	229 mm (9 ins) square. Horizon circle 161 mm (6½ ins) diam. Offset of polar style from origin 55.5 mm (2⅛ ins).
Material	Brass
Condition	Fair/poor. Over-polished and worn. Upper section of gnomon broken off.
Latitude	[51.4° N]
Features	Polar dial: IIII-XII-VIII, inward-facing, divided 5 min, 15, 30, 45s extended, 30s crossed. Stereo grid: 4-12-8, divided 15 min. Dec arcs: 2 deg intervals, 10s thicker. Ecliptic arcs: March equinox at east side. Date scale: on ecliptic, months, single days dotted, 5, 10s crossed, labelled 10, 20, 28/30/31. Azimuth scale: single deg, 40-(0)-90-(0)-40, 10s numbered, omitting zeroes at E & W. Altitude scale: to SW, too worn to discern details. Compass: NE-S-NW only, 25 labelled points.
Location	Private collection, Wales.
Provenance	
Reference	
Notes	Centres for dec. arcs and hour lines visible.





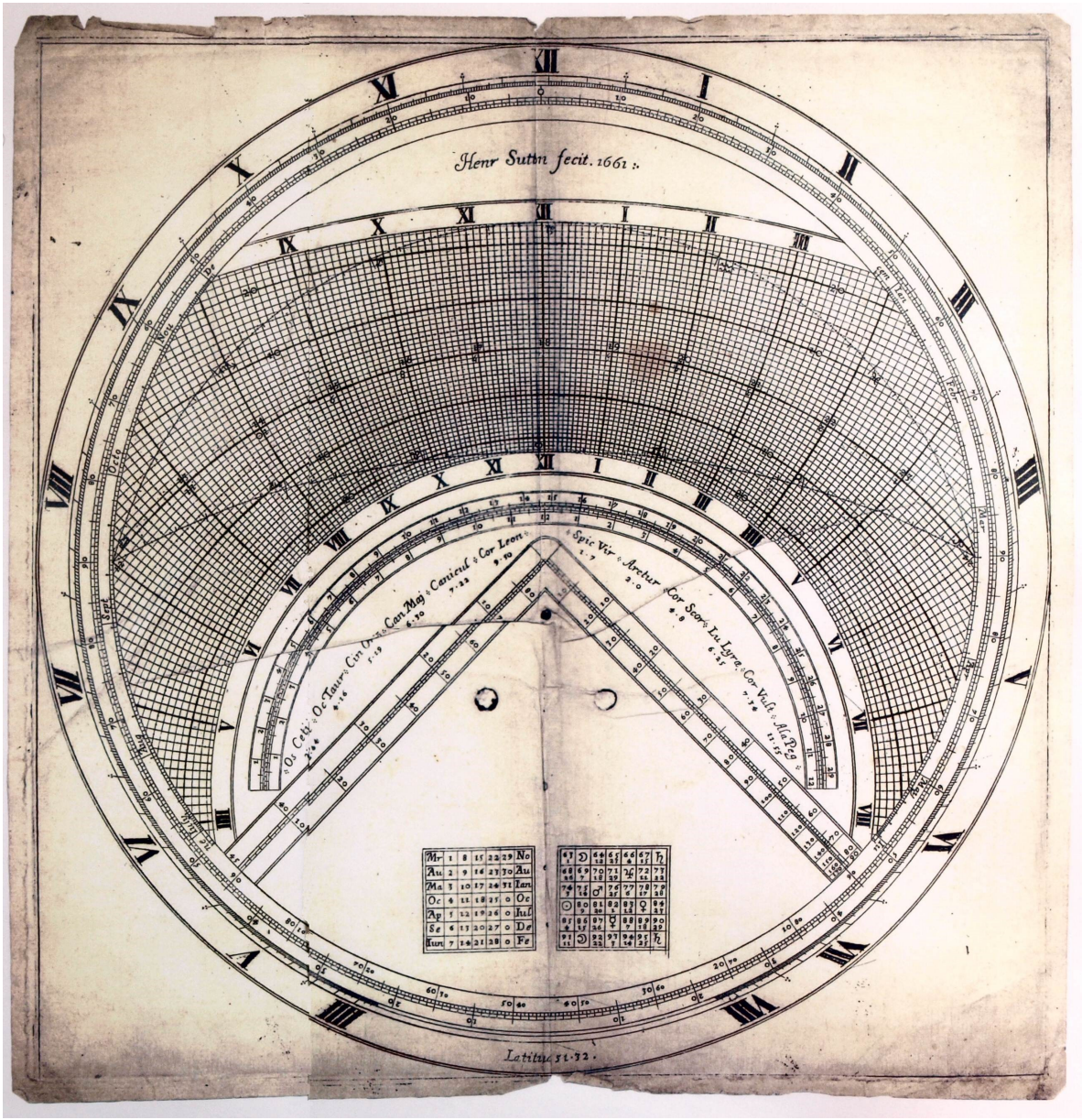


Record no.	**DH-59**
Signature	Johannes Marke Londini Fecit / 1667
Date	1667
Dimensions	299 mm (11¼ ins) diam.
Material	Paper (3 off engravings).
Condition	Good.
Latitude	"Latitude 51 32"
Features	Polar dial: IIII-XII-IIII, inward-facing, divided 1 min, 15, 30, 45s extended. Stereo grid: IIII-XII-IIII inner ends of hour lines, IX-XII-III outer, divided 5 min, 15, 30 & 45s dotted. Dec arcs: single deg, 10s thicker and numbered, 5 dotted. Ecliptic arcs: March equinox at E side, zodiacal sigils, single deg of longitude, 5 crossed. Date scale: at ends of dec arcs, months (abbrev.), single days, 5 and 10s extended. Azimuth scale: 0-90-0-90-0, deg and ½ deg, 10s numbered, zeroes at N and S. Also numbered 0-90 each way between SE and SW. Trig. scales: to SW 0-90 reading inward, single deg, 10s numbered (altitude scale): tangents 0-45, deg and ½ deg reading outward. To SE: sines of angles 0-90 reading outward, sines of half-angles 0-180 reading outward. Moon time correction scale: 29½ day lunation, days and ¼-days, time corrections hours, quarters and eighths. 12 star names and RAs. Epact table 1668-1707. Perpetual calendar. Small linear scale underneath calendar, 50 -60, uniformly divided units and quarters, purpose unknown.
Location	Royal Society, London.
Provenance	In Robert Boyle archives, vol 35 folios 201 & 209.
References	Michael Hunter: *The Boyle Papers – understanding the manuscripts of Robert Boyle,* Ashgate (2007). Davis (2008).
Notes	Proof (reversed) and counterproof pulled from a real dial plate. Compare with Sutton's DH-61 & 62.

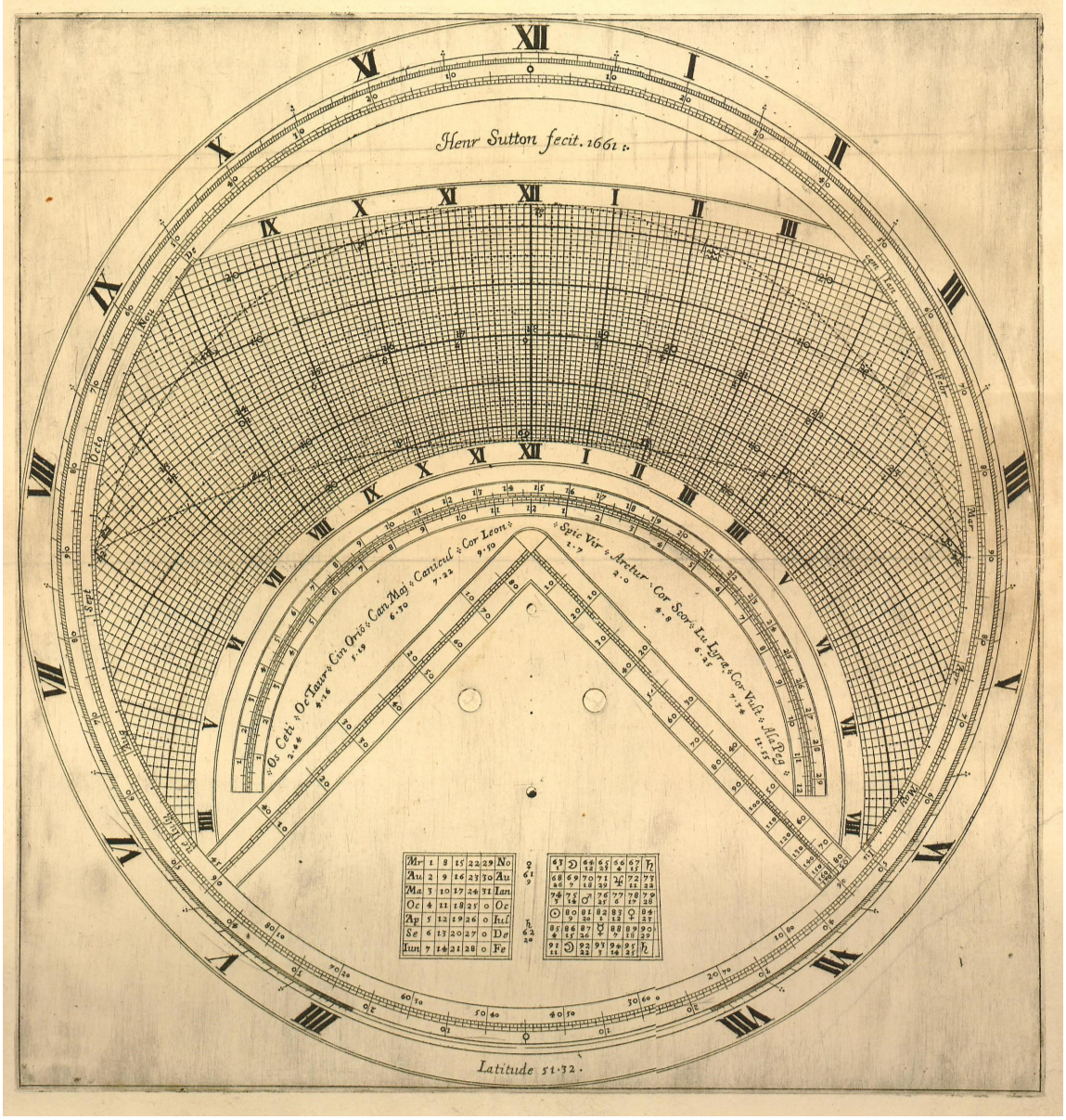


Record no.	**DH-60**
Signature	Unsigned, attrib. John Allen.
Date	c.1632
Dimensions	105 mm (4⅛ ins) square, horizon circle 41.7 mm (1⅝ ins) radius.
Material	Paper.
Condition	Good.
Latitude	[51.5° N]
Location	
Provenance	Printed at end of Delamain's *Horizontal Quadrant…* (1632 edition).
Reference	
Notes	Same as DH-30. See that entry for further details. A revised edition of this engraving, not in John Allen's hand, appears in a later edition of Delamain's book. The edition is undated but the new figure is engraved "Anno Doñi 1637". The wording remains the same but, for example, the flourishes after the words in the spandrels are absent and the reversed numerals on the grid have been corrected. It appears that Allen has recalled his plate and Delamain has had a replacement cut, closely following the original.

Record no.	**DH-61**
Signature	Henr Sutton fecit 1661
Date	1661
Dimensions	296 mm (11⅝ ins) square, horizon circle radius 126 mm (5 ins), offset of polar style from origin 82 mm (3¼ ins).
Material	Paper.
Condition	Good.
Latitude	"Latitude 51 32"
Features	Polar dial: IIII-XII-VIII inward-facing, divided 1 min, 15, 30 & 45s extended. Stereo grid: IIII-XII-VIII inner ends of hour lines, IX-XII-III outer Dec arcs: single deg, 10s thicker and numbered. Sun's RA (Arabic figures) on equatorial line. Ecliptic arcs: March equinox at E side, zodiacal sigils, single deg of longitude, 5s crossed. Date scale: at ends of dec arcs, months (abbrev) single days, 10 & 20s extended. Azimuth scale: 0-90-0-90-0, deg and ½-deg, zeroes at N and S. Moon-time correction table: 29½ day lunation, correction time 2×12 hours divided ⅛ hours. 12 star names and RAs. Table of epacts 1663-1695. Perpetual calendar. Trig scales: to SW 0-90 single deg inward (sun's altitude), tangents 0-45 outward. To SE sines of angles 0-90 outward, sines of half-angles 0-180 outward. Scale of single deg and half-deg 0-90 between SE and SW, numbered in 10s in each direction.
Location	The Byrom Collection.
Provenance	
Reference	Joy Hancox: *The Byrom Collection*, pp.188-191, Jonathan Cape, (1992).
Notes	Almost the same as brass dial DH-49 but has star RAs added. Counterproof very similar to proof of DH -62 but this version has v. minor engraving slips.

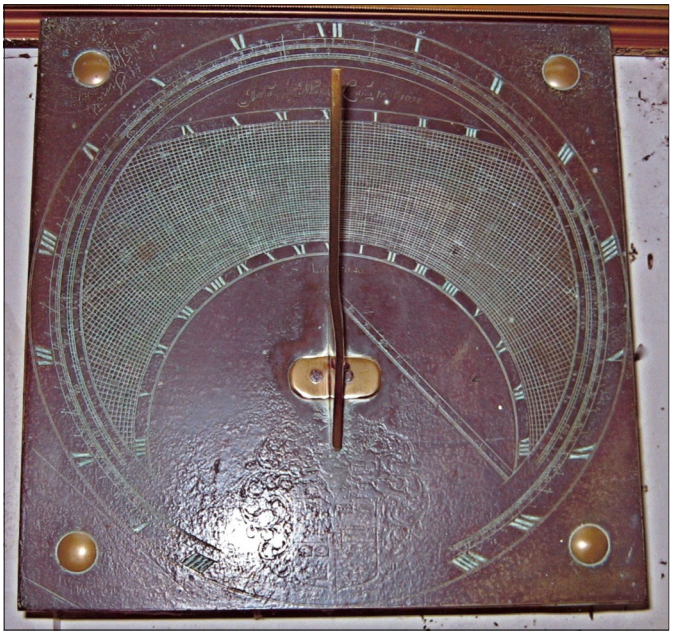


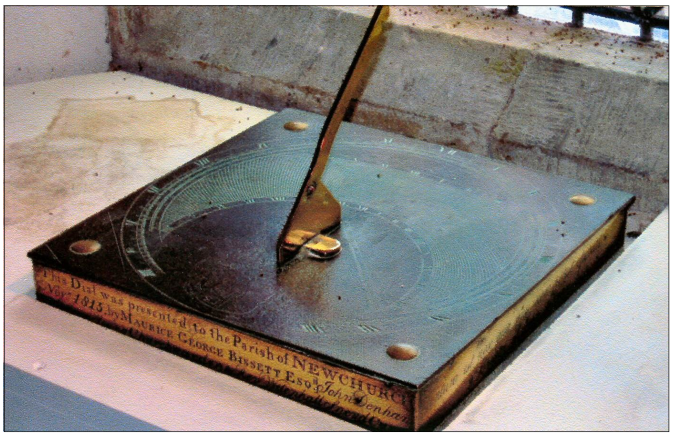
Record no.	**DH-62**
Signature	Henr Sutton fecit 1661
Date	1661
Dimensions	296 mm (11¾ ins) diam on square plate.
Material	Paper (proof engravings).
Condition	Good.
Latitude	"Latitude 51 32"
Features	Polar dial: IIII-XII-VIII, inward-facing, divided 1 min, 15, 30 & 45s extended, 30s triple-dotted. Stereo grid: IIII-XII-VIII at inner ends of hour lines, IX-XII-III outer, divided 5 min, 15, 30 & 45s dotted. Dec arcs: single deg, 10s thicker, 5s dotted, 10s labelled in two places, sun's RA (0 -24^{h}) on equatorial line. Ecliptic arcs: March equinox at E side, zodiacal sigils, single deg of longitude dotted, 5s crossed. Date scale: at ends of dec arcs, months (abbrev.), single days, 10s extended with dots. Azimuth scale: 0-90-0-90-0, zeroes at N and S, deg and ½ deg. Between SE and SW, same scale numbered 0-90 in each direction. Trig. scales: to SW altitude scale 0-90, single deg, 10s numbered, tangents of angle 0-45 running outwards, 10 and 45 numbered. To SE, sines of angles 0-90 and half-angles 0-180 running outward, 10s numbered. Moon time correction dial: 29½ day lunation in quarter days, time correction hours and ⅛ hours. Names of 12 stars and their RAs. Table of epacts 1661-1695. Values for 1661 and 62 are entered outside the body of the table, on the N-S line. Perpetual calendar.
Location	British Library Add MS 4473 f.10, 'Birch Collection'.
Provenance	Possibly collected by John Pell.
Reference	
Notes	The print is reversed l-r and is a proof from a dialplate. Plate is corrected from DH-61.



This image has been photo-graphically mirrored. It also contains some scanning defects.

Record no.	**DH-63**
Signature	Johannes Marke Londini 1678
Date	1678
Dimensions	310 mm (12 ins) square.
Material	Brass.
Condition	Dialplate good, patinated and slightly eroded but readable. Gnomon is incorrect with only a very short vertical style.
Latitude	"Lat 50 40"
Features	Polar dial: IIII-XII-IIII, divided 5 min, 10s numbered, 15, 30 (with symbol), 45s extended. Stereo grid: IIII-XII-IIII inner ends of hour lines, IX-XII-III outer, divided 5 min. Dec arcs: single deg, 10s thicker lines. Ecliptic arcs: March equinox at E side, zodiacal sigils. Date scale: at ends of dec arcs, months, single days, 10, 20 28/30/31 numbered. Azimuth scale: 50-90-0-90-50, 10s numbered, zero at N. Altitude scale: to SE, single deg, 10s numbered.
Location	All Saints church, Newchurch Isle of Wight.
Provenance	Originally for Sir Robert Dillington of Knighton Manor (nearby). Given to Newchurch in 1815 by Squire Bissett. Initially in churchyard but now indoors.
References	Frank Coe *BSS Bull*. 20(iii) Sept 2008. BSS SRN 2721.
Notes	Coat of arms does not seem to match the Dillingtons'. Standard Marke/Sutton pattern but without the moon's age scale, stars or sector scales.





Record no.	**DH-64**
Signature	HENRY SEPHTON FECIT 1722. Also signed "H Sephton West Derby" underneath.
Date	1722
Dimensions	455 mm (18 inches) dia. Bevelled edge.
Material	Brass.
Condition	Good/fair. Restored in C20, significant fine pitting to surface and fine detail may have been lost. Brown patina.
Latitude	[53° 22' N for Woolton Hall]
Features	Polar dial: IIII-XII-VIII (inward facing) divided to 7½ mins and 5 mins with transversals reading to 1 min, fleur-de-lys half-hours. 10s numbered (Arabic) Stereo grid: IIII-XII-VIII inner end, IX-XII -III outer end with "Tropick Capricorn" labelled. Divided to quarter hours, hours heavier. Dec lines: for 2° intervals, unlabelled. 0 deg heavier. No ecliptic. Date scale: Not visible—band around horizon circle contains floral decoration. "Horizon" labelled at N. Azimuth scale: 0-90 ×4, zeroes at E/W, divisions not visible. No altitude scale. EoT scale in centre, Watch Faster/Slower (values not legible).



Coat of Arms (for Molyneux family): *azure, a cross moline, or*; quartered with arms for wife, Mary Brudenell (of Cardigan) with motto *Vivere sat vincere* (to conquer is to live enough). Lion supporters and coronet crest.
On gnomon: west, "RICH LORD MOLYNEUX " with coronet; east, foliate pattern with coronet.

Continues over

	Gnomon knife-edge blends in with tail.
Location	Croxteth Park, Liverpool City Council (in store).
Provenance	Originally for Richard, 5th Viscount Molyneux at Woolton Hall (sold by Molyneux family 1772). Dial purchased back by family in 1903 for residence at Croxteth Hall. Was restored by R.D. Oliver, 38 Soho Square, London. Bequeathed with Hall to Liverpool Council.
References	Illustrated in-situ at Croxteth Park in *The Gardens of England in the Northern Counties*, Charles Holme (ed.), The Studio, London (1910). BSS SRN 6925.
Notes	Complete with original (prob.) pedestal by same maker(?). See also M-30 for a modern facsimile. The stereographic portion of the dial is unusable because of the absence of a date scale and ecliptic. The use of transversals on sundials is rare (thought to have been introduced by John Rowley) and only found on two DH dials (both by Sephton).





Record no.	**DH-65**
Signature	[Henry Sephton] attrib.
Date	c.1720
Dimensions	625 mm dia. Cast rim 33 mm deep. Gnomon 9 mm thick, 230 mm base, 460 mm style edge.
Material	Brass.
Condition	Heavily patinated, wrong gnomon, but basically sound.
Latitude	[53° 26' for location]
Features	Polar dial: IIII-XII-VIII (inwards facing) divided to 7½ mins and 5 mins with transversals reading to 1 min, fleur-de-lys half-hours. 10s numbered (Arabic) Stereo grid: IIII-XII-VIII inner end, IX-XII -III outer end Divided to quarter hours, hours heavier. Dec lines: for 2° intervals, unlabelled. 0 deg heavier. No ecliptic. Date scale: EoT scale in centre, Watch Faster/Slower (values not legible but reference to "FLAMSTEED …").
Location	Knowsley Hall, Merseyside.
Provenance	Probably made for Earl of Derby at present location.
Reference	BSS SRN 6926.
Notes	Very similar to DH-64. Pedestal (1260 mm tall) is v. similar to the Hawksmoor designs for the John Rowley dials at Blenheim Palace.





Record no.	**DH-66**
Signature	Unsigned, but probably a Wynne apprentice, most likely Thomas Tuttell.
Date	c.1695 ±10 years (from EoT table)
Dimensions	540 mm (21¼ ins) dia, 2.5 mm thick on a cast rim 27 mm high. Attached by ring of 15 unequally-spaced rivets around periphery. Horizon circle radius 410 mm. Offset of polar origin 120 mm. Knife edge height 115 mm. Overall gnomon height 320 mm. Gnomon thickness 11.7 mm, underside of tail chamfered.
Material	Brass.
Condition	Fair. Light blue-green patina. Plate beginning to separate from rim.
Latitude	"Lati: $52^{d} = 14^{m}$ "
Features	Polar dial: IIII-XII-VIII, (3:43am to 8:17pm) inward-facing, outer scale divided 1 min, 10 numbered, "H-form" fleur-de-lys at 30, inner scale 7½ min, 15, 30 (with 'H' fleur-de-lis) & 45s longer with 'spear-heads'. Stereo grid: IIII-XII-VIII inner ends of hour lines (extended through numerals), IX -XII-III outer, divided 5 min, 15, 45 crossed, 30, dotted with triple dots at ends, hours thicker. Dec lines: single deg, 10s thicker, 5s dotted. 10, 20 numbered in several places. Ecliptic arcs: zodiacal sigils, single deg of solar longitude. RAs along equatorial line [0]-12 and back 13-[24]. Date scale: at ends of dec. lines, single days, 5s extended. Azimuth scale: 60-0-90-0-60, deg and ½ deg, zeroes to E and W. Pennant ends. Altitude scale: none. Large EoT table in two halves, either side of gnomon, gives values in mi:secs for each day of the year using data from Tompion (1683); max value 16^{m} 05^{s} on 24 October. Coat of arms of Compton family: *sable, a lion, passant, guardant, or, between three esquires helmets, ar*. Supporters: *Two dragons, with wings expanded, erm. ducally gorged and chained, or.* Crest: *Earl's coronet.* Motto "IE NE SERCH NE QUE UNG" – 'Je ne cherche que ung', 'I seek but one'.
Location	Central England.
Provenance	Probably made for current location.
Reference	BSS SRN 6924.
Notes	Columnar pedestal with cast bronze (?) sunflowers probably original. Probably made for George Compton, 4^{th} Earl of Northampton. Compare with Thomas Tuttell's DH-48 which has same coat of arms on male side.

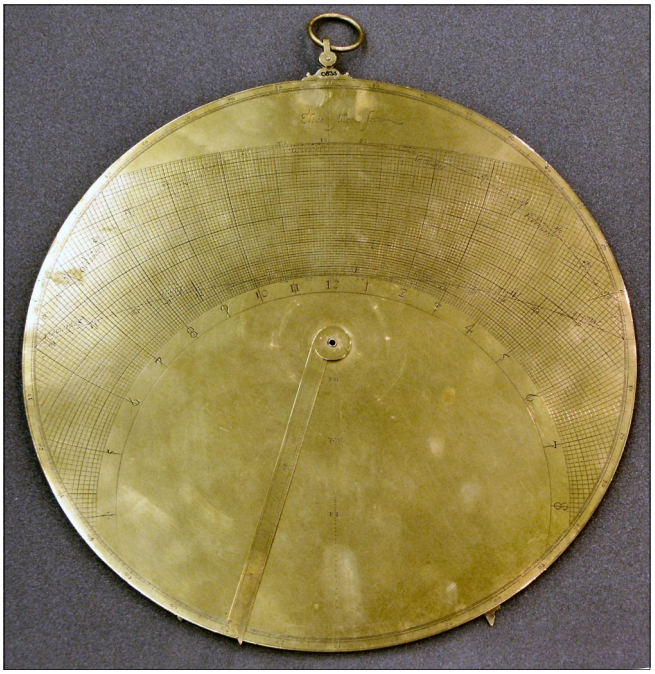


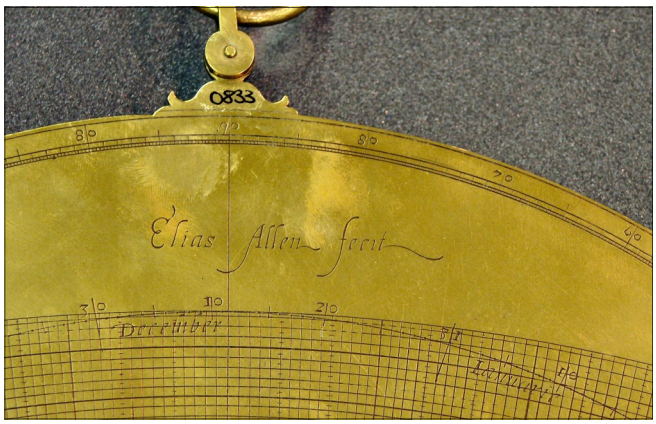




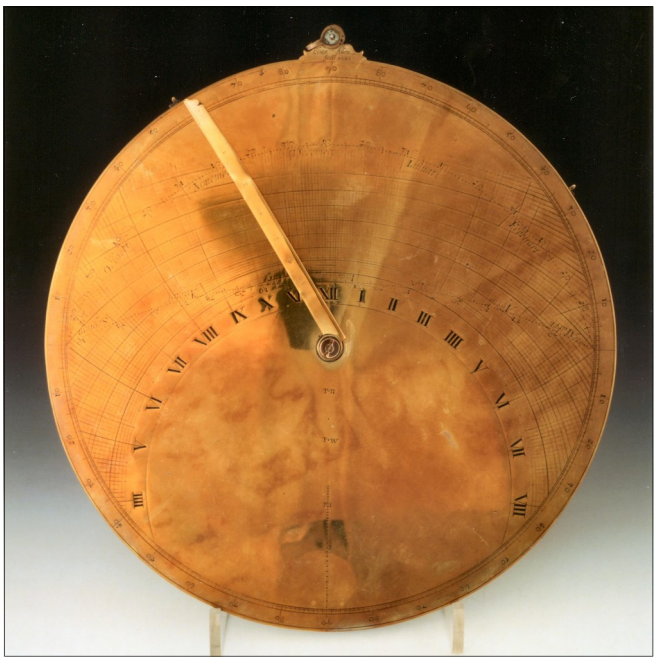
HORIZONTAL INSTRUMENTS

Record no.	**HI-1**
Signature	Elias Allen fecit
Date	Q2 C17
Dimensions	314 mm dia.
Material	Brass.
Condition	Good.
Latitude	[52° N]
Location	Whipple Museum, Cambridge
Provenance	W.H. Wollaston Collection, transferred from Cavendish Laboratory (CU Reporter May 20 1876, p.498)
References	Wh: 833. Gunther (1937) pp.35 & 183. Bryden (1988). A.J. Turner no. A.3.
Notes	Circles of proportion on the reverse.





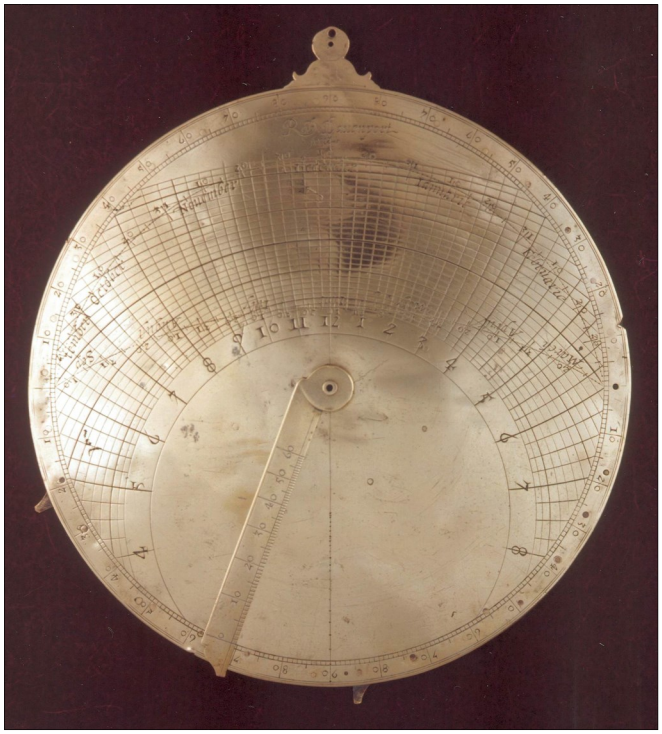
Record no.	**HI-2**
Signature	Elias Allen fecit 1648
Date	1648
Dimensions	270 mm dia, 2 mm thick.
Material	Brass.
Condition	Good.
Latitude	[51.5° N]
Features	Circumference calibrated 90-0-90 twice, divided to ½°. Radial index arm 0-60°, numbered in 10s. Stereo grid: dec lines to 1°, hours lines to 4 mins. Ecliptic by months and days (10s numbered).
Location	National Museums of Scotland, Edinburgh.
Provenance	Believed belonged to Sir James Reid (1805 -76), Ionian judge. Donated by family in 2004.
References	NMS T.2004.723. *Bull SIS* 85 pp.20-21 (2005).
Notes	Circles of proportion on the reverse.

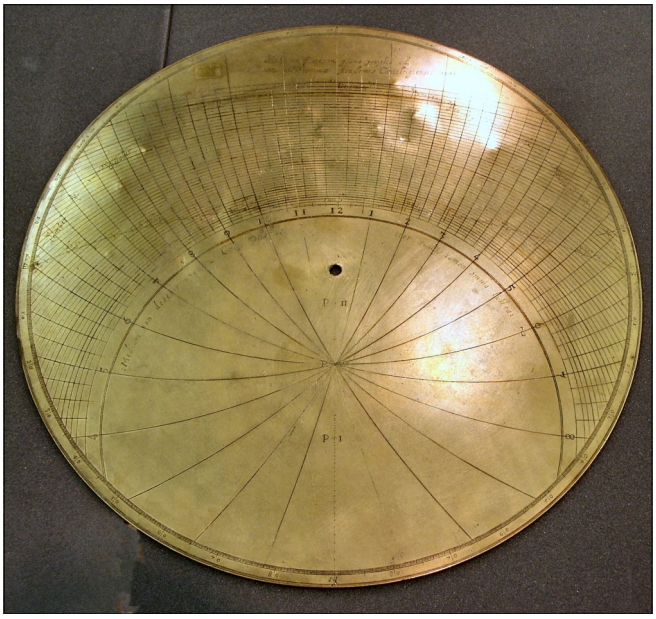


Record no.	**HI-3**
Signature	Elias Allen …..
Date	Before 1635
Dimensions	c. 450 mm dia.
Material	Brass.
Condition	Good.
Latitude	
Location	Museum of the History of Science, Oxford.
Provenance	Given to St. John's College by George Barkham, 1635. Lent to Oxford MHS by St John's College.
References	Inventory 40847; Aquisition 1924-32. A.J. Turner no. A.2. *Bull SIS* 85, 20-2 (2005). Illustrated in Gunther v.II f.p.140
Notes	Added inscription in Allen's hand: GEORIVS BARKHAM; / FILIVS D. IOHANNIS / COMMENSALIS; BARKHAM S.T.P / DONO DEDIT A^{O} 1635. Circles of proportion on the reverse.



Record no.	**HI-4**
Signature	Rob. Dauenport fecit [Robert Davenport]
Date	c.1647
Dimensions	150 mm dia., 3 mm thick (laminated from two pieces).
Material	Brass.
Condition	Good.
Latitude	[56° N - latitude for Edinburgh]
Features	Circumference divided 90-0-90 twice, divided to 1°. Radial index arm calibrated 0-60° divided to 1°. Stereographic grid: declination lines 2° intervals, unnumbered. Hour arcs to quarter-hours. Ecliptic arcs calibrated by months and days, 10s numbered.
Location	National Museums of Scotland, Edinburgh.
Provenance	Bought from Christies, Dec 1972, lot 66. Previously owned by William J Shaw of Sheffield.
References	A.J. Turner no.A.5. Illustrated in Wynter & Turner (1975). *Bull SIS* 85 pp.20-21 (2005).
Notes	Circles of proportion on the reverse.





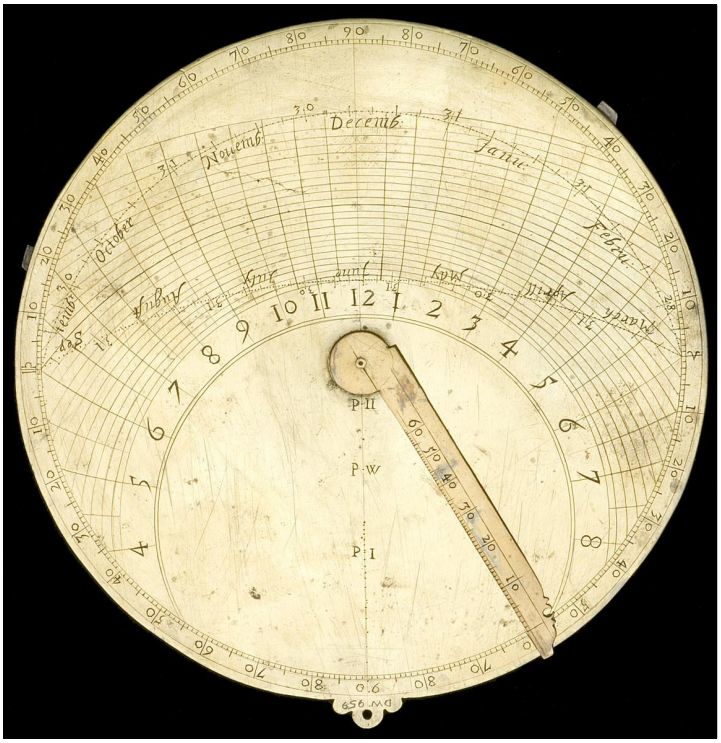


Record no.	**HI-5**
Signature	Johannes Holland fecit, et donauit Anno Dom 1650 (on verso)
Date	1650
Dimensions	368 mm dia. (14½ ins)
Material	Brass.
Condition	Good.
Latitude	"52° 15' "
Location	Whipple Museum, Cambridge.
Provenance	Presented to Trinity College Collection by Holland on election to a Fellowship. Currently on long term loan.
References	Wh: 1029. A.J. Turner no. A.4. Price (1952). Bryden (1988).
Notes	Inscription at top: "Calorum Facies in plano projecta ad latitudinem celeberrima Acadamiæ Cantabrigiensis 52 15". Inside projection: " = Medium non desrie unquam Calj Phoebus iter radijs iamen omnia lustrat ∞". Thomas Brown's circular slide rule on reverse. Hour arcs extend beyond tropics.



Record no.	**HI-6**
Signature	Anon
Date	c.1660?
Dimensions	775 mm (30½ ins) 12-sided a/f.
Material	Brass.
Condition	Good.
Latitude	[52.25° N]
Location	Whipple Museum, Cambridge.
Provenance	On loan from Trinity College, Cambs.
Reference	Wh: 349. A.J. Turner no. A.6. Price (1952). Bryden (1988).
Notes	Unfinished, numerous mistakes.

Record no. **HI-7**
Signature Anon
Date Q2 C17 ?
Dimensions 133 mm (5¼ ins) dia.
Material Brass.
Condition Good.
Latitude [52.5° N]
Location Univ Harvard Dept History of Science
Provenance Purchased by David Wheatland in 1949
References DW0959. www.fas.harvard.edu/~hsdept/chsi.html. *Bull SIS* 85 pp.20-22 (2005).
Notes Circles of proportion on verso. Follows diagram in *Circles of Proportion…* very closely. Slightly uncertain hand. Copy (contemporary?) of Elias Allen's instruments.



Record no. **HI-8 - No instrument**

Record no. **HI-9**
Signature Anon. Possible Allen workshops.
Date C17 ?
Dimensions 205mm (8 ins) dia. Approx 2 mm thick.
Material Brass.
Condition Good.
Latitude [54.5° N]
Location Centro de História das Ciências Universidade de Lisboa (CHC-UL) (History of Science Museum, Lisbon University).
Provenance
Reference Inv No. 00501
Notes Circles of proportion on verso. Zodiac sigils on the circumference. Counterpoised alidade with sights.

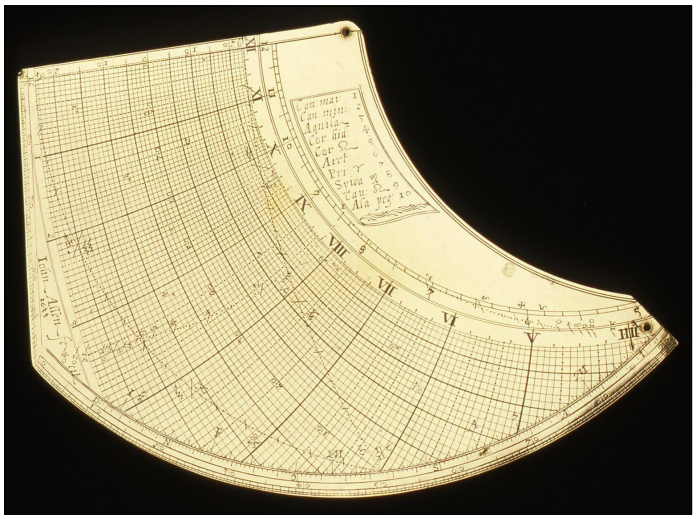


Record no.	**HI-10**
Signature	Anon.
Date	C18?
Dimensions	143 mm radius.
Material	Brass.
Condition	Good.
Latitude	[51.5° N]
Location	National Maritime Museum, Greenwich
Provenance	
Reference	Inv No. NAV1045
Notes	Version of *panorganum* on verso. May simply be a horizontal stereographic projection drawn as an aid to dial delineation or solving trigonometrical problems. Scale 0-90 with 45 at centre of projection, along meridian for reading tan(45- θ). Probably an amateur piece.



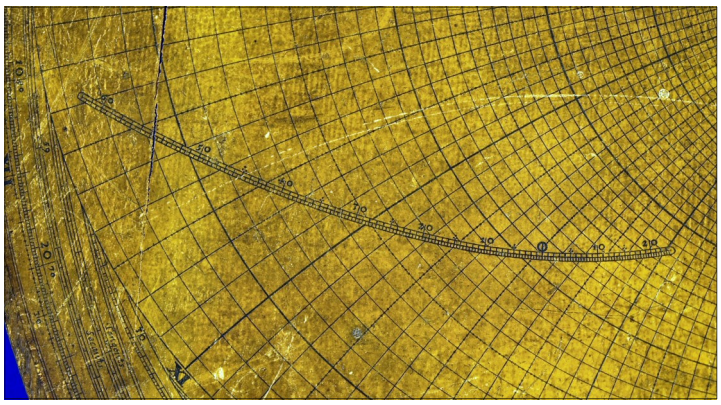
HORIZONTAL QUADRANTS

Record no.	**HQ-1**
Signature	Iohn Allen fecit 1633
Date	1633
Dimensions	100 × 158 mm (4 × 5½ ins)
Material	Brass.
Condition	Good (but sights and index missing).
Latitude	[51.5º N]
Features	Includes stars.
Location	Musees Royaux d'Art et d'Histoire, Brussels.
Provenance	Inventaire No. 5846.
References	A.J. Turner no. C.1. H. Michel *Traite..* (1947).
Notes	Reported as a DH in J. Brown (1979) and in museum catalogue entry. Very similar to diagram in Delamain's book. Verso is blank.

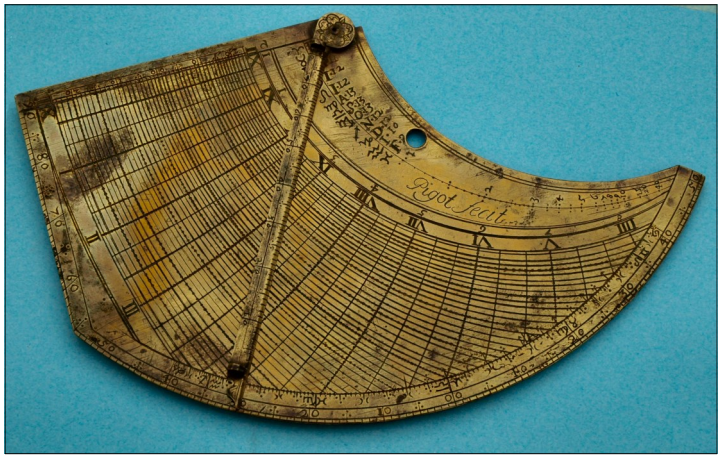


Record no.	**HQ-2**
Signature	Henricus Sutton fecit 1658
Date	1658
Dimensions	280 mm (11 ins) radius.
Material	Wood and paper.
Condition	Fair. One sight and plumb-bob missing, paper varnish) discoloured. Wood has shrunk 3 mm and split paper along panel joins.
Latitude	"51º 32' "
Features	Hour arcs [XII]-VII and 7-[0] divided to 5 min, 15, 30, 45 dotted. Declination arcs for single degrees, 10, heavier, 5 dotted. Scale of altitudes 30-0-[62], 10s numbered, divided to ¼ deg.
Location	Oxford Museum of the History of Science.
Provenance	Lewis Evans Collection
References	Inventory no. 32551. A.J. Turner no. C.2 (assumed). Lowne & Davis: 'The Horizontal Quadrant' (t.b.p. 2010)
Notes	An example of John Collins' 1658 *General quadrant with the horizontal projection upon it inverted.* The arc for the horizon (see p.90) is not shown but it does include 'Mr Dary's line'. Trigonometrical and calendrical tables are printed on the back.





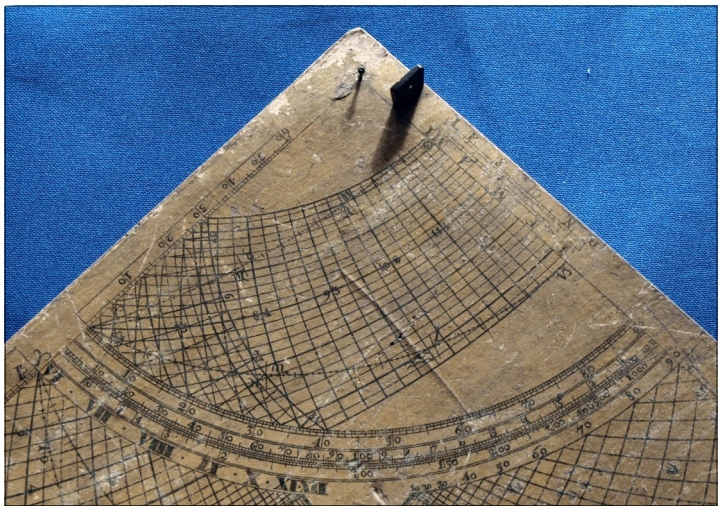
Record no.	**HQ-3**
Signature	[Francis] Pigot fecit
Date	c.1655
Dimensions	108 mm × 190 mm (4¼ × 7½ ins). Horizon circle radius 111.5 mm. Thickness 0.8 to 1 mm.
Material	Brass.
Condition	Good.
Latitude	[52.4º N] - Ludlow?
Features	Hour arcs for 20 min intervals (hours dotted), labelled Roman and Arabic (pm) numerals. Declination lines for 1º, (5s dotted), labelled with zodiac signs and degrees around horizon circle (no ecliptic arcs). Altitude/azimuth scale around perimeter. Swinging rule with altitude scale [0]-90º, fitted with pair of pinhole sights. No sights on main quadrant. List of dates for sun's entry into the signs: ♈ M 12; ♉ A 10; ♊ M 11; ♋ I 12; ♌ I 12; ♍ A 13; ♎ S 13; ♏ O 13; ♐ N 12; ♑ D 12; ♒ I 10; ♓ F ? Curved scale (1-40) for shadow length.
Location	Arbury Hall, Warwickshire.
Provenance	Newdigate collection: was on loan to the Oxford MHS 1926-1993.
References	Accn No (at OHMS) 1926-90/7. Inventory 29345. A.J. Turner no. C.3.

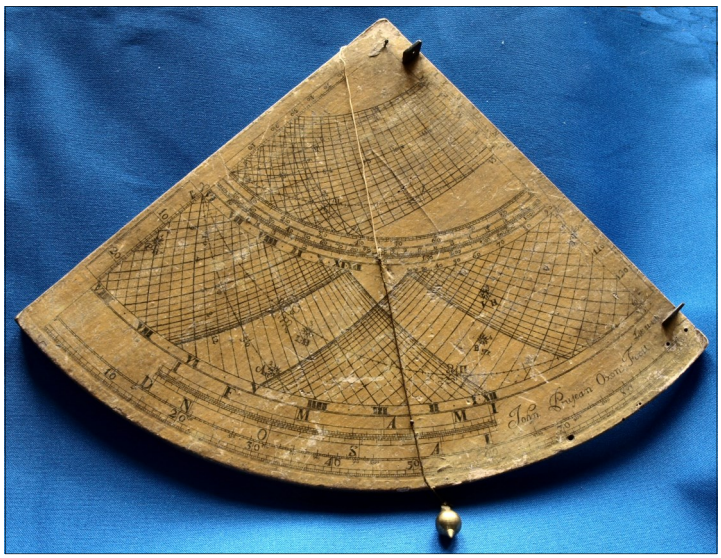




Notes	Possibly a student piece—arcs not uniformly drawn. Follows Delamain's description quite closely.

Record no.	**HQ-4**
Signature	John Prujean Oxon: Fecit
Date	c. 1670
Dimensions	Overall radius 220 mm. Radius of horizon circle 94 mm.
Material	Oak and paper.
Condition	Fair.
Latitude	"51° 45' " [Oxford]
Features	Meridian along righthand edge. Hour arcs for quarter hours (halves dotted, hours heavier) numbered along equatorial line, Arabic, both ways. Declination lines 2°, folded for hours after 6pm. Date scale on meridian. Ecliptic arcs with zodiac sigils and divided to 1°. Altitude/azimuth scale [0]-90°, divided to ½°. Sights along meridian edge. Plumb-bob present.
Location	Arbury Hall, Warwickshire.
Provenance	Newdigate collection: was on loan to the Oxford MHS from 1926 to 1993.
Reference	OHMS Inventory No 26017. A.J. Turner no. C.4.
Notes	Horizontal quadrant as described by Christopher Brookes with a 'reverted tail' (i.e. reflected). Sometimes called an 'Allen quadrant'. Only a minor part of the overall instrument: Gunter's quadrant outside it and Collins' (Sutton's) quadrant on verso.



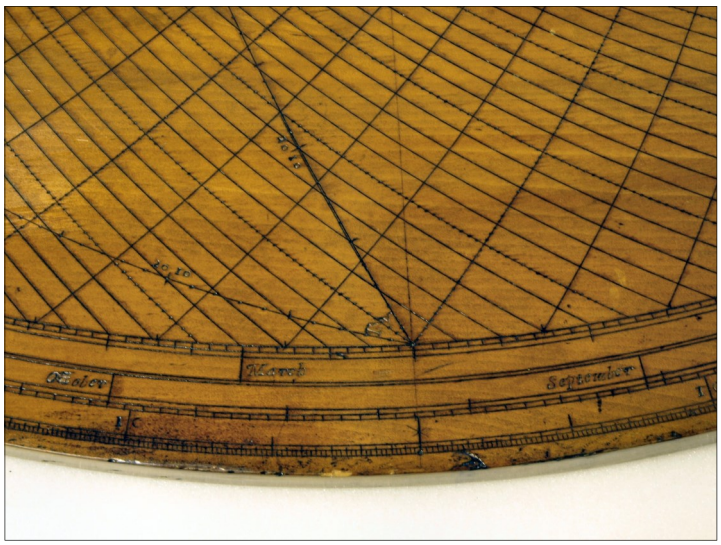


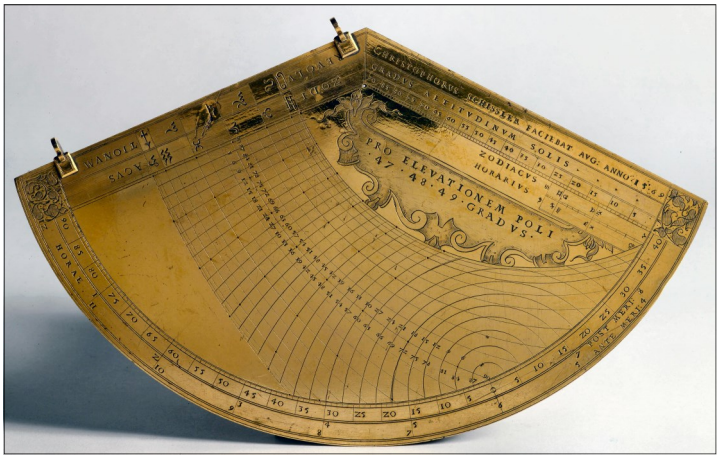
Record no.	**HQ-5**
Signature	Anon
Date	c. 1635 ?
Dimensions	
Material	Silver.
Condition	
Latitude	
Location	
Provenance	Given to Duke of York by the King
Reference	H. Higton, *Dictionary of National Biography* entry for Richard Delamain
Notes	Speculative entry only.

Record no.	**HQ-6**
Signature	Anon
Date	1689/99
Dimensions	
Material	Paper.
Condition	
Latitude	
Location	No known examples.
Provenance	
Reference	Advert in Lea quoted by Bryden *SIS Bull*, 55 p.9 (1997).
Notes	

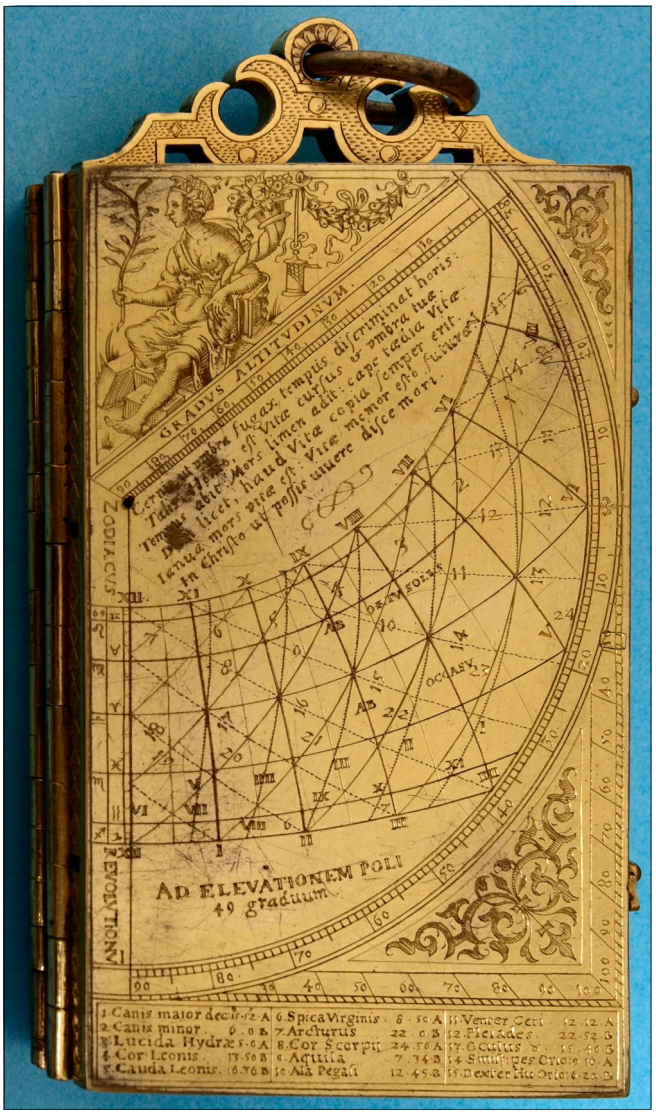
Record no.	**HQ-7**
Signature	Anon, attrib John Brown
Date	mid C17
Dimensions	L 555 mm, W 345 mm, T 12 mm (22, 13½, ½ ins.).
Material	Boxwood.
Condition	Good.
Latitude	[51.5° N?]
Location	Science Museum, London.
Provenance	George III Collection, Inv. no. 1927-2065/29
Reference	A.Q. Morton and Jane Wess: *Public and Private Science: the King George III Collection*, OUP, (1993), pp.538-9.
Notes	Similar to Delamain's design. With circular and tabular calendrical scales on back, plus star data. Unusually large instrument with hour arcs extending beyond the tropics.







Record no.	**HQ-8**
Signature	CHRISTOPHORVS SCHISSLER FACIEBAT AUG: ANNO 1569 [Christopher Schissler]
Date	1569
Dimensions	256 × 160 mm.
Material	Gilt brass.
Condition	Good.
Latitude	"PRO ELEVATIONEM POLI . 47.48.49 GRADVS"
Features	Triens.
Location	Germanisches Nationalmuseum, Nuremburg.
Provenance	
References	WI-137. Zinner (1956) p.511
Notes	Another quadrant and an engraving of an astronomer on verso. See description p.126.



Record no.	**HQ-9**
Signature	[Johann Anton Linden, Heilbronn]
Date	1596
Dimensions	126 mm × 80 mm.
Material	Silver & gilt.
Condition	Excellent, but lacking string and bead.
Latitude	"49 graduum"
Features	Declination arcs for zodiac; sigils along meridian. Hour lines for whole and half hours (equal hours), also lines for temporary hours, Italian hours and Babylonian hours. Altitude scale [0]-90, azimuth scale 90-[0]-38 (would also serve as scale for measuring altitude if there were sights along the hinge edge. Shadow square around outside. Star table underneath with declinations.
Location	British Museum, London.
Provenance	Purchased, 1857.
References	57 11-161. FAB Ward (1981) p.123, no. 357.
Notes	On the outside of a complicated compendium consisting of many astronomical instruments, including an astrolabe. Effectively a triens but described by Ward as a calculator diagram. Much decorative engraving including a seated female figure with cornucopia and pillar dial. Inscription reads: "Cernis ut umbra fugax tempus discriminat horis: Talis, Homo, est Vitæ cursus & umbra tuæ. Tempus abit: Mors limen adit: cape tædia Vitæ Dum licet, haud Vitæ copia semper erit. Ianua mors vitæ est: Vitæ memor esto futuræ. In Christo ut possis vivere disce mori" which may be translated as: "See that the fleeting shadow apportions time by hours: such, Man, is the course and shadow of your life. Time passes away; death approaches the threshold. Take hold of the weariness of life while you can, lest its moments of opportunity always elude you. Janus' door is the death of life, but I will be mindful of the afterlife. May you live to learn to die in Christ".

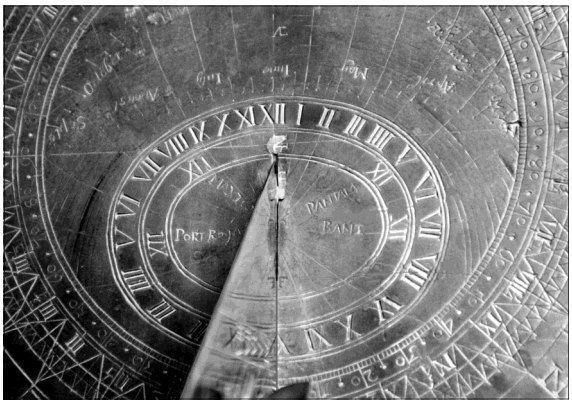
ASSOCIATED DIALS

Record no.	**AD-1**
Signature	Anon
Date	Unknown 17C?
Dimensions	540 mm a/f octagon, c. 4 mm thick.
Material	Brass.
Condition	Good (dark patina).
Latitude	
Features	Reverse Oughtred projection.
Location	Private garden, southern England.
Provenance	
References	BSS SRN 0001. See description on p.116.
Notes	



Record no.	**AD-4**

Record no.	**AD-2**
Signature	Anon
Date	Unknown
Dimensions	
Material	
Condition	
Latitude	
Features	Reverse Oughtred projection
Location	Westcountry, England
Provenance	"Property of a Lady".
References	BSS SRN 5753. See description on p.119.
Notes	



Record no.	**AD-3**
Signature	[attrib. Charles Whitwell]
Date	"An Azumoth dyall for the latitude of 52 deg. inuented by Sr. Ro: Duddeley Ano 1598"
Dimensions	145 mm dia, 3 mm thick.
Material	Gilt brass.
Condition	Good.
Latitude	"52° "
Features	
Location	British Museum, London
Provenance	Purchased from Henry Heilbronner in 1894
References	1894, 0615.2. A.J. Turner no. A.1. Gerard Turner (2000)
Notes	Blagrave's Mathematical Jewel on reverse.



Signature	GEORGIVS HARTMANN NOBENBERGE [Georg Hartmann]
Date	FACIEBAT ANNO M D XXVII (1527)
Dimensions	77 mm dia.
Material	Brass, gilt.
Condition	Good but lacks compass needle.
Latitude	[49° N]
Features	Azimuth dial 'compast' Stereographic grid: Dec lines for zodiac, labelled by signs on circumference. Hour arcs IIII-XII-VIII (no sub-divisions) numbered counter-clockwise. Babylonian hour lines 1-15. No ecliptic. Pierced hole at centre. Centreline for magnetic north 8½° E.
Location	Germanishes National Museum, Nuremburg
Provenance	
References	WI-1623. Zinner (1956) p.362 & plate 15. Hartmann's *Practika* (1527/8). Andreas Schöner's *Gnomonice* (1562).
Notes	See page 78. Separate lid.

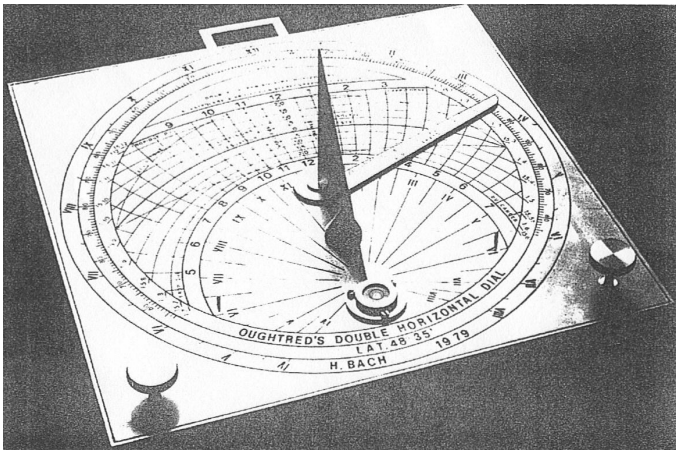


Record no.	**AD-5**
Signature	Joshua Habermel (attrib)
Date	
Dimensions	
Material	
Condition	
Latitude	
Features	
Location	Private collection, France
Provenance	
Reference	A.J. Turner (1981), footnote 5, p.101.
Notes	

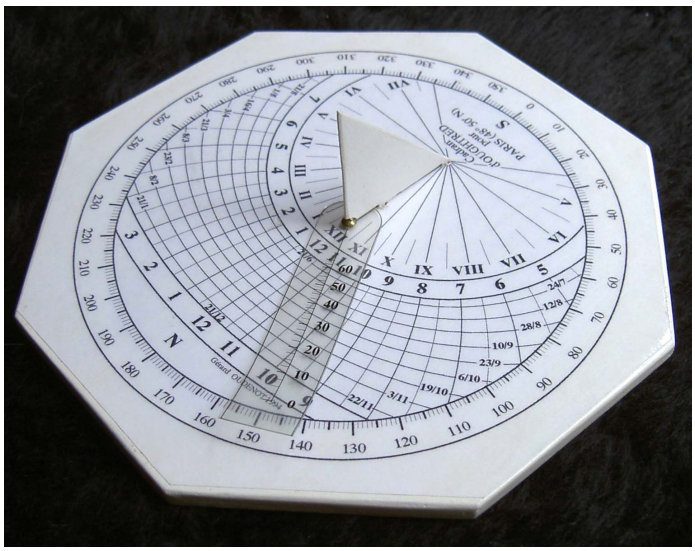
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MODERN DIALS

Record no. **M-1**
Signature H. BACH
Date 1979
Dimensions Square plate.
Material
Condition
Latitude "LAT 38° 35' "
Features Two levelling screws and bubble level. Right-angled triangular gnomon. Rotating altitude rule.
Stereographic projection: 5° declination lines, half-hour time arcs. Some numerical dates on horizon circle. Ecliptic arcs.
Azimuth scale, 0° at N, 90° at E & W.
Polar-style dial in centre and around projection, divided to half-hours.
"OUGHTRED'S DOUBLE HORIZONTAL DIAL" and other text not readable.
Location Paris?
Provenance
Reference Photograph shown in R. Rohr: *Les Cadrans Solaires*, Edition Oberlin, p.128 (1986).
Notes Earliest 20th century example? Appears to be in the 'French tradition' originated by Ozanam. Same basic design as M-20.

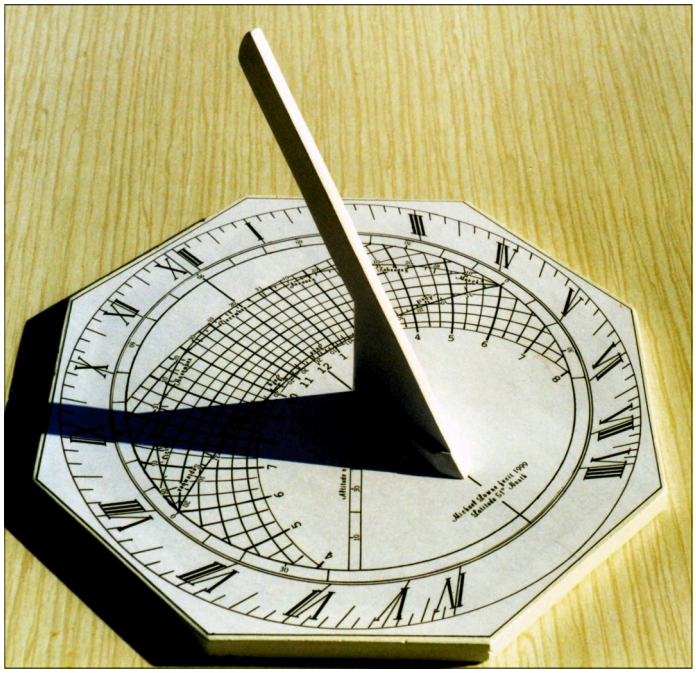


Record no. **M-2**
Signature Gérard Oudenot
Date 1994
Dimensions Octagonal plate.
Material Paper/wood/plastic.
Condition Good.
Latitude "48° 50' PARIS"
Features Right-angled triangular gnomon in plastic.
Transparent rotating altitude rule (0-62°)
Stereographic projection: 5° declination arcs, labelled with dates e.g. 3/11. Hour arcs divided to half-hours. No ecliptic arcs.
Azimuth scale: 0°, 180° at N.
Polar-style dial entirely within the projection.
"Cadran d'OUGHTRED"
Location Paris.
Provenance Made by owner for personal use.
Reference
Notes Based on published design in Rohr (M-1). Calculated in Basic and drawn with Mac Draw II.



Record no. **M-3**
Signature Michael Lowne
Date 1999
Dimensions Octagonal, 10.5 ins a/f, 0.5 ins thick.

Material	Paper, hand-drawn, on chipboard base, painted wood gnomon. Paper surface protected with self adhesive transparent plastic film.
Condition	Excellent.
Latitude	"Latitude 51° North".
Features	Polar dial: IV-XII-VIII, inward-facing, divided to 10 minutes. Stereo dial: 4-2-8, divided to 20 min. Dec lines at 5° interval, 10s thicker than 5s. Ecliptic arcs: March equinox at east side. Date scale: on ecliptic, Gregorian calendar, 5-day intervals, labelled 10, 20 and last day of month. Azimuth scale: 40-0-90-0-40 in 10-degree intervals, zeroes at E and W, labelled every 30°. Altitude scale: 0-70 in 10° intervals, labelled 10, 30, 50, 70.
Location	Hailsham, East Sussex.
Provenance	Owned by maker.
Reference	Michael Lowne, *BSS Bull* 13(iv), pp.138-146, (December 2001) and p.25 of this monograph.
Notes	This dial was made in the early days of the modern revival of interest in DH dials, to investigate methods of dial delineation and to illustrate the *BSS Bulletin* article. It is based on the Elias Allen pattern of dial but simplified in several respects.

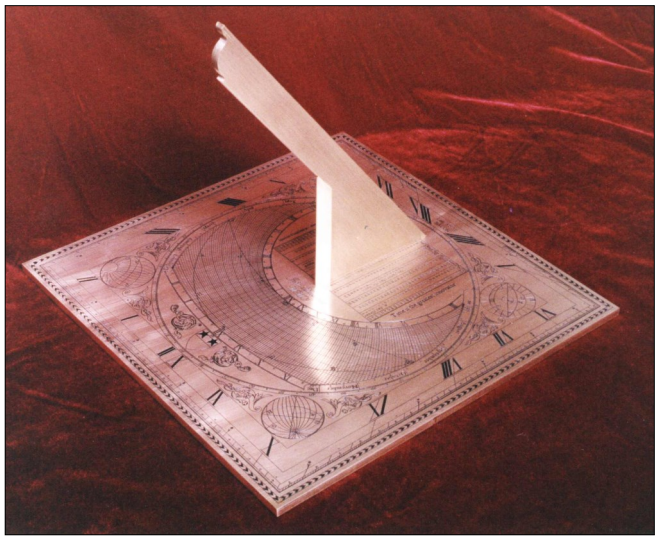


Record no.	**M-4**
Signature	John Davis fecit
Date	2000
Dimensions	310 mm a/f octagon, 6 mm thick, profiled edge. 6.4 mm gnomon. Vertical style 67 mm. Offset of polar origin from centre: 85 mm.
Material	Brass, photo-etched.
Condition	New.
Latitude	"Lat: 52° 4' 52" N Lon: 1° 2' 37" E "
Features	Stereo projection: 2° declination lines (10s heavier). 10 min hour arcs (hours heavier). Ecliptic arcs as 365 days (5 heavier, month divisions). Date scale anticlockwise around horizon circle, 5-day divisions. 1st point of Aries to E. Azimuth scale, -138-0-138°, 0° at N. Equation of time scale (Dial Slow/Fast) inside projection (modern values). Polar-style dial: divided to 5 min intervals. Rotating altitude rule (two inter-changeable mirror-image versions) 0-67°, also engraved SE & SW on dial; also serves for azimuth scale. "Greenwich time = Flowton time - 4 mins 10 secs" Motto: "Our Science is from the watching of shadows" (Ezra Pound, Canto 85). Wheatsheaf and plough logos for Flowton village. Colour-coded engraving: blue – vertical style; black – polar style; green – other data.
Location	Flowton, Suffolk.
Provenance	Made by owner.
Reference	BSS SRN 4547.
Notes	Loosely based on the Benjamin Scott dial DH-26.



Record no.	**M-5**
Signature	J Davis fecit MMI
Date	2001
Dimensions	330 mm square, 5 mm thick.
Material	Brass, photo-etched.
Condition	New.
Latitude	"52° 31' "
Features	For full list of features, see ref.
Location	Raveningham Hall, Norfolk.

Provenance	Made by Flowton Dials for Sir Nicholas Bacon.
References	BSS SRN 5109. Davis & Lowne (2001), reprinted p.34.
Notes	Near-replica of DH-9.
Record no.	**M-6**
Signature	Henry Wynne (facsimile).
Date	1960s
Dimensions	762 mm dia (30 ins).
Material	Electrotype (from a silicone mould).
Condition	Fair, but beginning to delaminate.
Latitude	
Features	See DH-34.
Location	Wrest Park, Silsoe.
Provenance	Made by English Heritage to display on original pedestal.



References	BSS SRN 5169. Inv. No. 88094585. Davis & Lowne (2003) reprinted p.41.
Notes	Accurate replica of DH-34. See also M-22. Made by Colin Slack
Record no.	**M-7**
Signature	Henry Wynne (facsimile).
Date	1960s
Dimensions	762 mm (30 ins) dia.
Material	Resin from a silicone mould.
Condition	Poor – beginning to delaminate and may have been scrapped.
Latitude	
Features	See DH-36
Location	Ditchingham Hall, Norfolk.
Provenance	Commissioned by Earl Ferrers to display on original pedestal.



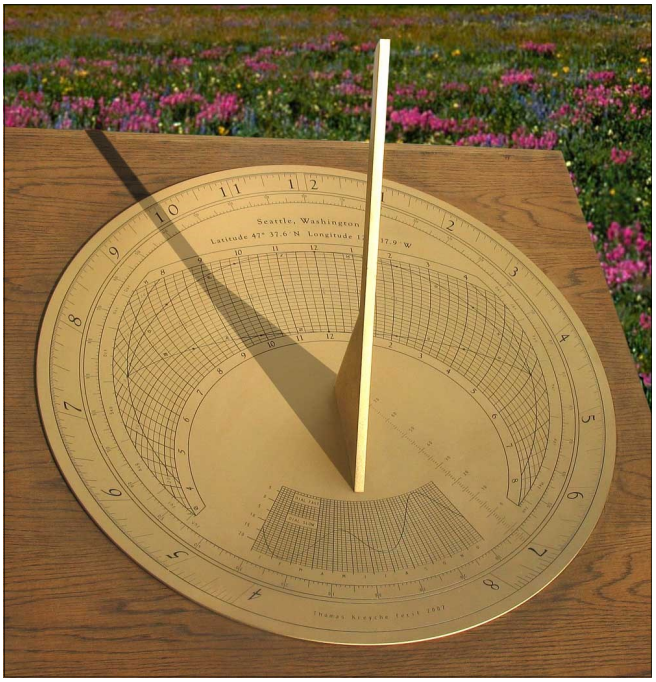
September 2008

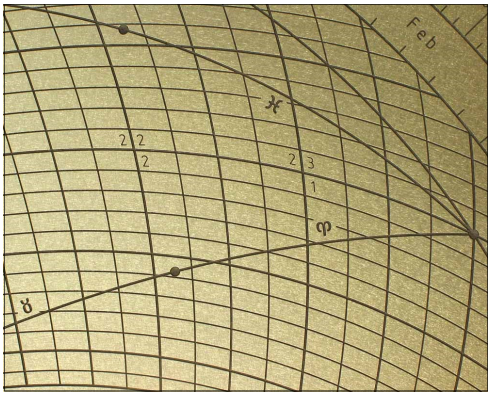
References	BSS SRN 6798. Davis & Lowne (2003) reprinted p.41.
Notes	Made by Plowden & Smith. Subsequently replaced by M-12.
Record no.	**M-8**
Signature	Thomas Kreyche fecit 2002
Date	2002
Dimensions	23¼ in diameter, ⅛ inch thick brass, mounted on ¾ inch thick hardwood, 27 in square. Polar gnomon offset 5½ inches from centre.
Material	High Leaded Brass (C35600 Alloy).
Condition	New.
Latitude	"Latitude 47º 37.6' N, Longitude 122º 17.9' W"
Features	Uses azimuthal-equidistant projection. Incorporates equation of time adjusted for



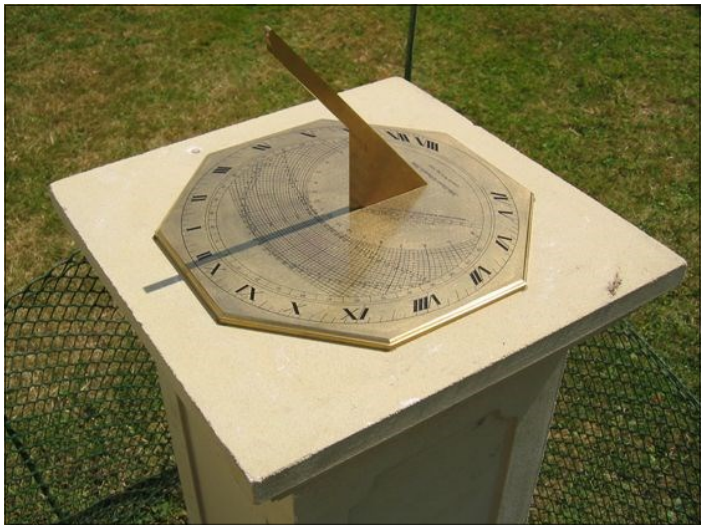
July 2002

	120° West standard meridian. Hour lines are also used to indicate RA.
Location	Seattle, USA.
Provenance	
Reference	Exhibited at NASS and BSS (Exeter) conferences 2002 (see conference reports).
Notes	Unorthodox projection with twilight altitudes included outside horizon circle. The dial was built as a proof of concept, and designed to be quasi-portable for the purposes of demonstrating at sundial conferences. It was therefore engraved on ⅛ inch brass plate. Thicker plate would have been prohibitively heavy, considering the diameter. The entire dial (including gnomon), was designed using automated software drawing techniques on Adobe Illustrator and Rhino 3D. All components were machined on a CNC router using Mastercam software. The dial is not permanently mounted outdoors.
Record no.	**M-9**
Signature	John Hayes
Date	2005
Dimensions	300 mm a/f octagon.
Material	Brass.
Condition	New.
Latitude	"50.85° N"
Features	Stereographic grid: dec lines for 2°; time line for 10 mins; ecliptic labelled months, days numbered 5s. Azimuth scale around horizon circle Polar dial Roman numerals inwards, divided to 3 mins.
Location	Private location, Chichester.
Provenance	Made as a learning exercise.
Reference	Hayes (2005).





Notes	Delineation by John Hayes, dial plate by John Davis, gnomon by Tony Moss.
Record no.	**M-10**
Signature	Tony Moss Lindisfarne Sundials
Date	2005
Dimensions	356 mm (14 ins) a/f octagon. 5.8 mm thick, profiled edges.
Material	CZ120 Brass (patinated). Photo-etched
Condition	New.
Latitude	"55° 07' 47" N, 1° 35' 47" W"
Features	Polar dial Roman numerals inwards, divided to 3 mins. Stereographic grid: dec lines for 2°; time line for 10 mins; ecliptic labelled months, days numbered 5. Azimuth scale around horizon circle. Motto: VERITATE – SCIENTIA - LABORE
Location	Private residence, Northumberland.
Provenance	Made by owner.

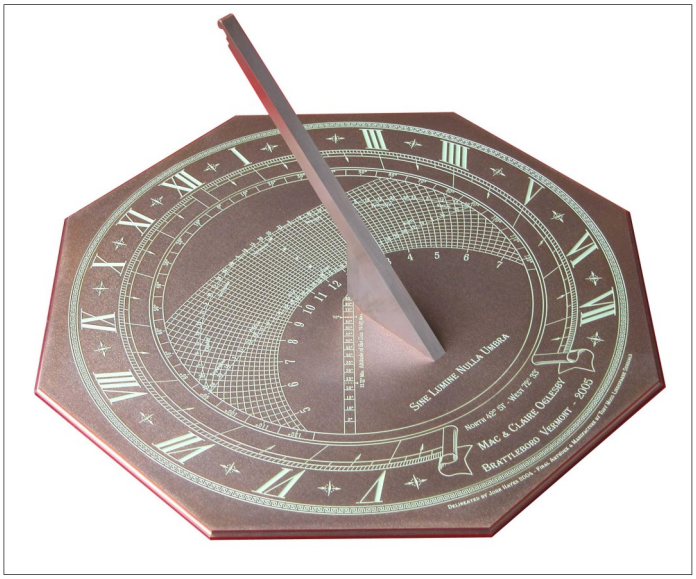


Reference
Notes Delineation by John Hayes. Final artwork by Tony Moss.

Record no. **M-11**
Signature Claire & Mac Oglesby
Date 2005
Dimensions 356 mm (14 ins) a/f octagon. 5.8 mm thick, profiled edges.
Material CZ120, chemically patinated brass, photo-etched.
Condition New.
Latitude "42° 51' N, 72° 33' W"
Features
Location Brattleboro, Vermont, USA
Provenance Made by Tony Moss as a 'twin' to M-10. Reference
Notes Motto "Sine Lumine Nulla Umbra". Delineation by John Hayes. Final artwork by Tony Moss.



Record no. **M-12**
Signature Henry Wynne (facsimile).
Date 2005
Dimensions 775 mm dia (30½ ins).
Material Gunmetal.
Condition New.
Latitude
Features As DH-36 (interpreted/transcribed) Additional signature: "Hoc horologii antiqui simularcum delineavit Iohannes Davis Ipswichianus, fecit Antionius Moss Bedlingtoniensis, numeris investigavit Carolus Lowne Hailshamicum, Anno Domini MMIII"
Location Ditchingham Hall, Norfolk.
Provenance Commissioned by Earl Ferrers to replace M-7. Viscount Tamworth is now the custodian.
Reference BSS SRN 6749. Davis & Lowne (2003), reprinted p.41. Moss (2006), reprinted p.55.
Notes Made by Tony Moss, delineated and designed by Davis & Lowne.



Record no. **M-13**
Signature John Davis Flowton Fecit
Date 2003 (completed 2006).
Dimensions 686 mm (27 ins) dia; 8.3 mm thick.
Material Phosphor bronze PB102.
Condition New.
Latitude "39° 19' 8.7" N; 129° 42' 54.9" W"
Features See ref for full description.
Location Redwood Valley, California.
Provenance Designed and made for Dr Rudy Light.
Reference Davis (2008) reprinted p.60.
Notes Triple horizontal dial partially based on Henry Wynne dial DH-36.

Record no. **M-14**
Signature Unsigned
Date 2003
Dimensions (20.5 ins).
Material Brass/bronze casting by Harling Foundries Ltd, Hastings.
Condition New, chemically patinated (unengraved).
Latitude
Features Physical features as per DH-31.
Location Hampton Court Palace.
Provenance Commissioned by the Royal Palaces



September 2007

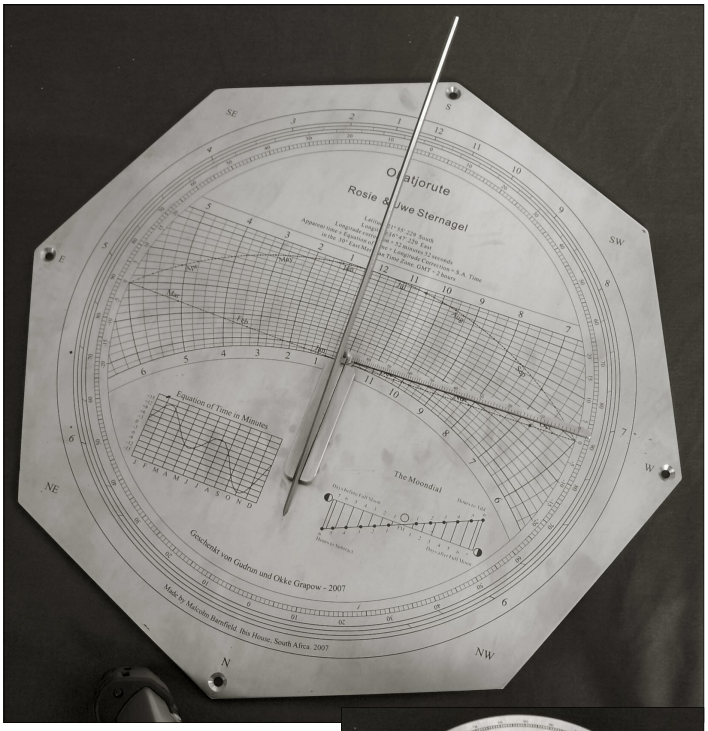
	Collection.
Reference	BSS SRN 6505
Notes	A partially-finished (due to lack of funds) replica of the Tompion DH-31. A fully-completed replica of the matching Equation/Azimuth dial was engraved by Charles Scarr.
Record no.	**M-15**
Signature	Malcolm Barnfield, Ibis House, South Africa
Date	2007
Dimensions	390 mm a/f octagon.
Material	Stainless steel, photo-etched.
Condition	New.

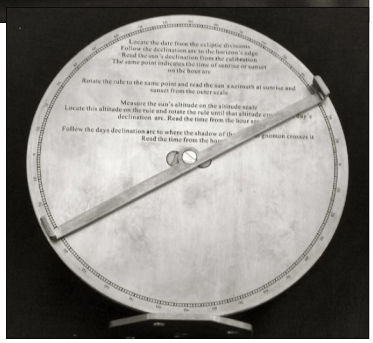


Latitude	"21° 55' S; 16° 47' E"
Features	Gnomon is an open lattice with a knife-edge polar style and wire vertical style. Stereo grid: declination lines for 2° intervals labelled in 5s around horizon circle; hour arcs for quarter-hours. Ecliptic arcs as 365 dots (1st of months heavier), labelled with months. Rotating altitude rule divided 0-90°, 1° divisions. Azimuth scale 0-90° ×4, 0s at N & S. Polar-style dial, 6-12-6 hours ,divided to half-hours. Equation of Time graph. Moondial correction for full moon ±7.5 days
Location	Okatjuruti Farm, Namibia.
Provenance	Commissioned by Gudrun und Okke Grapow for Rosie & Uwe Sternagel
Reference	*BSS Bull* 19(iv), 'New Dials' (Dec 2007).
Notes	Believed to be the first DH dial for the



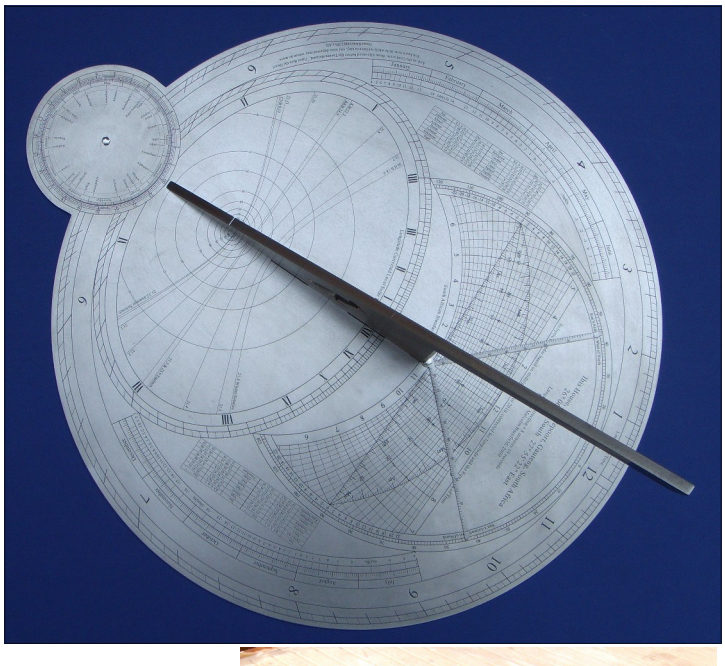
Tropics and the southern hemisphere. Dial is accompanied by a revolving vertical disc altitude instrument with rotating alidade and sights. Design input from James E Morrison.

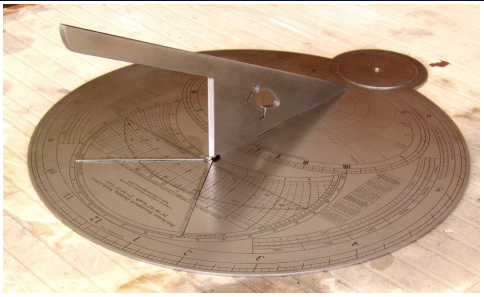




Record no. **M-16**
Signature Made by Malcolm Barnfield, 2009
Date 2009
Dimensions 520 mm dia. Gnomon base (offset of origins) 268.5 mm; length 500 mm, knife-edge height 108 mm. Horizon circle radius 144 mm.
Material Stainless steel (316L) 3 mm thick. Gnomon 8 mm thick. Nocturnal 140 mm dia (110 mm × 1.2 mm star disc)
Condition New
Latitude "26° 06' 02" South, Long. 27° 55' 22" East"
Features Stereo grid: Hour arcs to ¼-hours; dec arcs to 2°, labelled around horizon circle 22 -0-(-22). Reads South African Standard Time by means of Ecliptic calculated to account for EoT & longitude. Two rotating altitude indexes 0-90°.
Azimuth scale 120-90-0-90-120
Elliptical dial reading longitude-corrected solar time; declination lines for family anniversaries.
Motto: "And, as the cock crew, those who stood before the Tavern shouted, 'Open then the door! You know how little while we have to stay, and, once departed may return no more'. Rubáiyát of Omar Khayyám, 12th C AD."
Outer polar dial LAT to 5 mins.

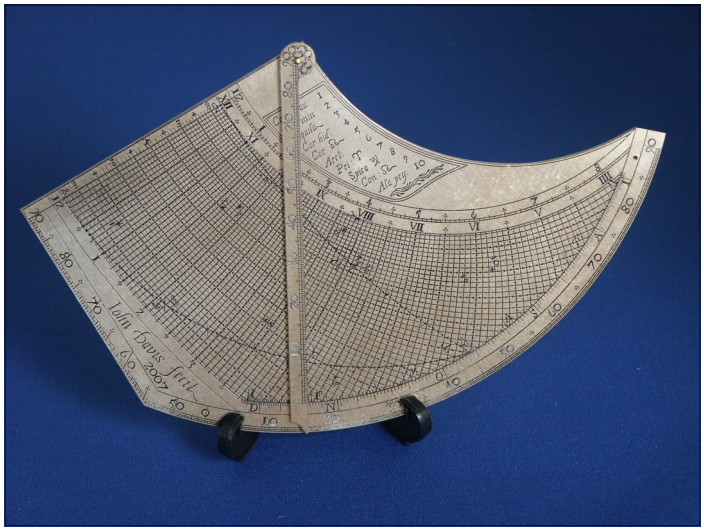
EoT for J2050 (split Jan-Jun and Jul-Dec).
Nocturnal with 28 stars inc. Southern Cross. Star data in 2 tables.
Gnomon pierced with ibis *Bostrychia Hagedash* and with notch nodus.
Location Ibis House, Roodepoort, Gauteng, South Africa.
Notes Triple horizontal modelled on M-13, made for maker's home. Drawn in CorelDraw v12. Input from J. Morrison, J. Davis, M. Lowne.



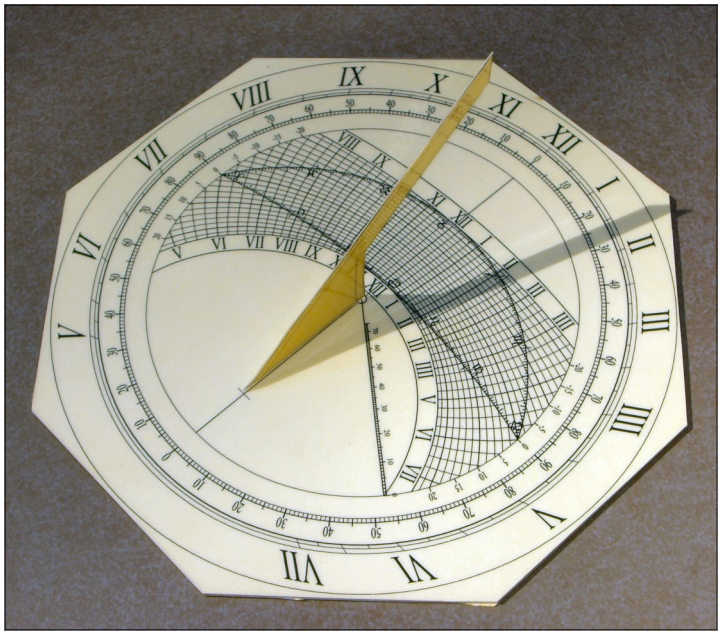


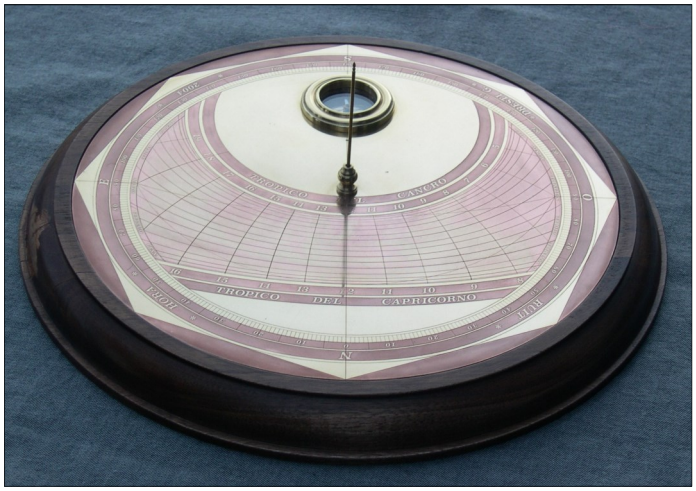
Record no. **M-17**
Signature Iohn Davis fecit
Date 2007
Dimensions 100 mm radius (horizon circle) quadrant. 50 mm version also made. 1.6 mm thick.
Material Versions in bronze, brass and nickel silver, photo-etched.
Condition New.
Latitude [51.5° N]
Features Delamain's quadrant.
Stereographic grid: declination arcs for 1° (5s dotted); hour arcs for 5 min intervals, labelled IIII-XII am and 12-8 pm. Date scale inside/outside horizon circle. Ecliptic arcs with 180 added dots for solar longitude (labelled with zodiac sigils in pairs).
10 numbered stars (RA & dec) with key.
Altitude scale (corrected for centre of gravity of plummet) around curved edge; partial azimuth scale along N straight side.

	Pair of sights and hanging plummet also acts as altitude scale 0-90°.
Location	Various.
Provenance	Made as a limited edition production run.
Reference	
Notes	Based on the John Allen quadrant HQ-1. Modern calendar and star positions corrected.
Record no.	**M-18**
Signature	James E Morrison
Date	2009
Dimensions	8 inches a/f octagon.
Material	Laminated card (gnomon double laminated with 5 mil pouches).
Condition	New.
Latitude	[38° 42' N]
Features	
Location	
Provenance	
Reference	
Notes	One of a number of paper instruments made during the writing of *Astrolabes* (Morrison (2008)).

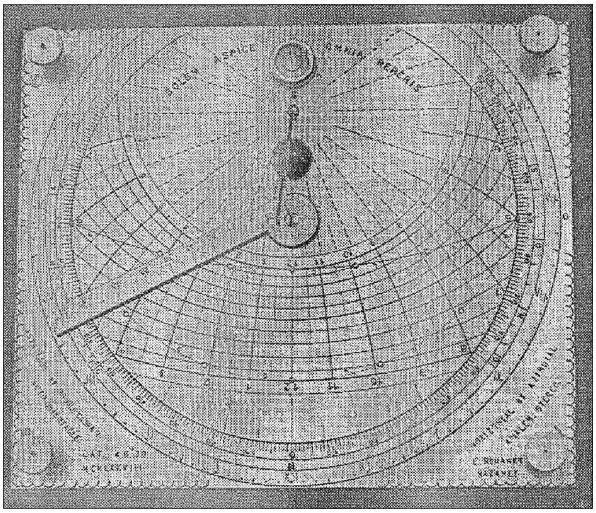


Record no.	**M-19**
Signature	G[uido] Dresti
Date	2004
Dimensions	318 mm diameter (across corners of octagon). 2 mm brass.
Material	Brass (photo-etched) on walnut base.
Condition	New.
Latitude	[46° N]
Features	Vertical pin gnomon (90 mm) only. Magnetic compass inset. Stereographic projection: declination arcs 5° intervals, hour arcs only. Date scale around horizon circle. No polar-style dial.
Location	Craveggia, Valle Vigazzo, Piemonte, Italy.
Provenance	Made by owner for his private collection.
Reference	G. Dresti & R Mosello, *Orologi solari portatili fra storia, sceinza e artigianato*, Centro Internationale di Documentazonie Alpina.
Notes	
Record no.	**M-20**
Signature	E Rouanet
Date	c.1979
Dimensions	
Material	Card?
Condition	
Latitude	
Features	Separate wire gnomons. Levelling screws and bubble.
Location	
Provenance	
Reference	Illustrated in Janin (1979)
Notes	Same basic design as M-1—probably made as a pair.
Record no.	**M-21**

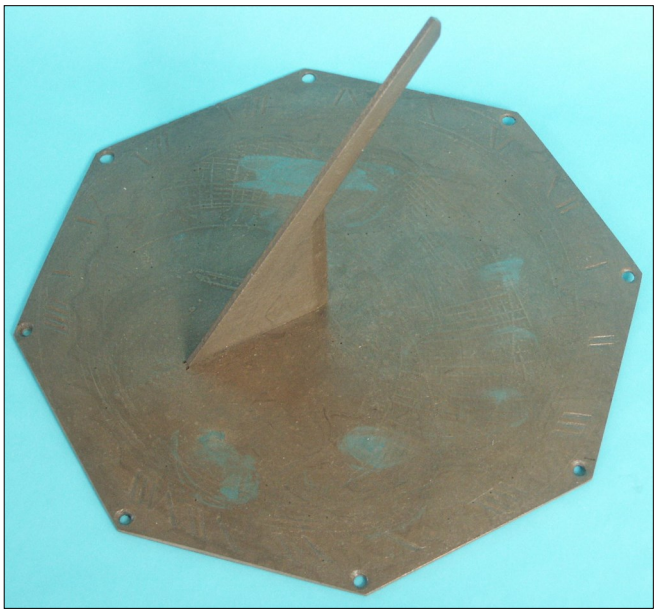




Signature	Elias Allen fecit (facsimile).
Date	2005
Dimensions	
Material	Resin from a silicone mould, integral gnomon.
Condition	
Latitude	
Features	As per DH-4.
Location	Flowton, England.
Provenance	
Reference	
Notes	Exact facsimile of DH-4, made by J. Davis for study purposes.
Record no.	**M-22**
Signature	Henry Wynne (facsimile).
Date	1960s
Dimensions	762 mm dia (30 ins).
Material	Electrotype (from a silicone mould).
Condition	Unknown.
Latitude	
Features	See DH-34.
Location	At one time in the reception area of Fort Cumberland (English ~~Heritage),~~ Portsmouth, now in store.
Provenance	Made by English Heritage as trial for M-6
Reference	Davis & Lowne (2003) reprinted p.41.
Notes	Accurate replica of DH-34. See also M-6. Made by Colin Slack.
Record no.	**M-23**
Signature	MADE BY JOANNA A MIGDAL AFTER RICHARD GLYNNE
Date	2008/9
Dimensions	540 mm dia. 8 mm thick. Horizon circle 324 mm dia. Gnomon 15 mm thick, 407 mm along style edge, offset of style from origin (base of gnomon) 136 mm, vertical style 136 mm tall.
Material	Naval brass, patinated.



After Janin (1979)



Condition	Excellent (new).
Latitude	"51° 46' 01" N; Longitude 1° 15' 49" W"
Features	Polar dial: VI-XII-VI, inwards facing numerals, divided to quarter hours (half-hours with fleur-de-lys. Transversals reading to 1 min. Stereo grid: IIII-XII-VIII (inner) and IX-XII-III (outer), divided to ¼ hours. Declination lines 5° (equatorial with additional dots and labelled (0)-12-(24) for right ascension), numbered 10s. Date scale around horizon circle, JAN – DEC, divided to days. Ecliptics shown dotted, labelled zodiac signs (Aries at E).

	Correction graph for EoT + longitude, -10,0,10,20 mins, radial layout, individual days. Compass rose 16 point, labelled e.g. SW. Coat of arms for St Hugh's College at S with motto "FIDELITAS". Initials "JD" (J Davis, projection delineation) and "G.S.J.W" (Sir George White, engineering support). Gnomon: engraved along style edge with musical stave and notes. Glynne-style fleur -de-lys at tip. Sides engraved with moondial offset table, (48 mins per day). "FAST" on E and "SLOW" on W.
Location	St Hugh's College, Oxford.
Provenance	Made for location and funded by a College benefactor.
Reference	*BSS Bull,* 21(ii), p.11, (June 2009).
Notes	Commissioned to replace Richard Glynne dial DH-56. The music on the gnomon is the St Hugh's College song "Good and Clever"– an original poem by Elizabeth Wordsworth , the first Principal, later set to music by Gary Bachlund…"so friends let it be our endeavour to make each by each understood…" Wordsworth wished for the College to be a place where the good and the clever understood each other and lived harmoniously. First hand-engraved brass DH dial for nearly three centuries.

No picture available—refer to similar replica M-6



Record no.	**M-24**
Signature	E Vilaplana, P Gagnaire
Date	1989
Dimensions	1250 mm dia, on a 750 mm high pedestal.
Material	Ceramic tiles, polychrome details.
Condition	Excellent.
Latitude	"Lat 45° 46' N, Long 4° 56' E"
Location	Route de Corbas 69200, France.
Provenance	Made for the "Foire de Lyon", centenary 1789-1989.
Reference	
Notes	Delineated by Paul Gagnaire and made by Émile Vilaplana (d. 2006). It consists of 31 ceramic ("carreaux de lave Volvic") tiles painted with polychromic glaze and fired at 800°C. Hour arcs for V-XII-VII. Declination arcs labelled with dates of entry and zodiac signs. Coat of arms for Lyon (lion rampant under three fleur-de-lys) and dates 1789-1989 to S of thin brass triangular gnomon. Azimuth scale 0-360° (S at 180°). Names of 70 towns in France and 100 towns worldwide, with their orthodromic directions and distances in kilometres from Lyon. NSEW geographic directions.

Record no.	**M-25**
Signature	Jean-Michel Ansel
Date	2000
Dimensions	195 mm dia, 5 mm thick.
Material	Brass.
Condition	Good.
Latitude	
Features	Rotatable demonstration instrument. Vertical style is semi-cylindrical and projection features a noon gap so not a true stereographic projection. Declination arcs for zodiac signs, dated e.g. 21/1; intermediate lines for 10°s of solar longitude. Hourlines for whole hours only, inside projection. "CADRANS DOUBLE D'OUGHTRED"
Location	In the grounds of the Observatory & Planetarium 'Ludiver', 1700, rue de la Libération, Tonneville in the departement

of Manche (Cotentin), France.

Provenance Made for current location.

Reference

Notes Designed using the *Solarium* software by Pierre Dallet. Part of an interactive sundial display on a hexagonal stone table. Dial can be rotated to obtain meridian alignment. Stereographic projection has a noon gap (rounded vertical edge to gnomon). ‘French style’ layout.

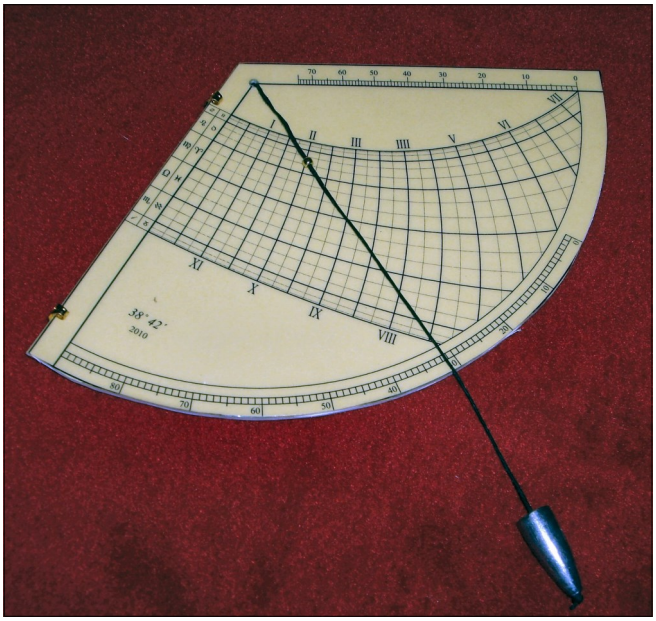




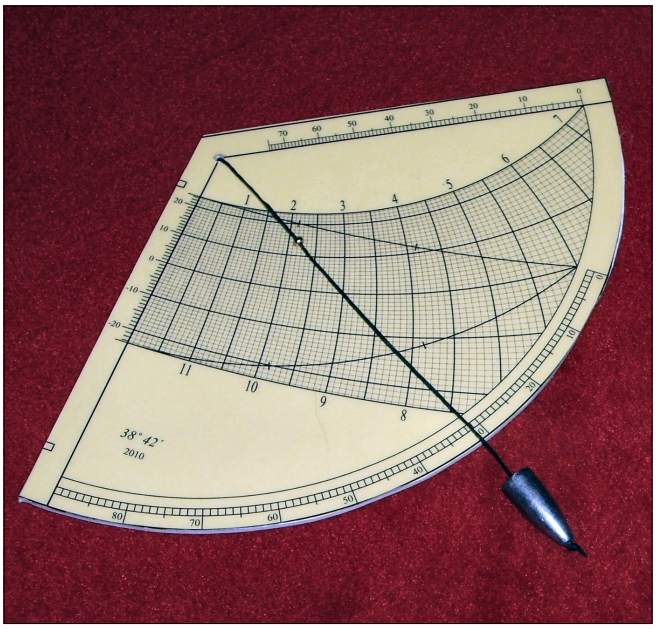




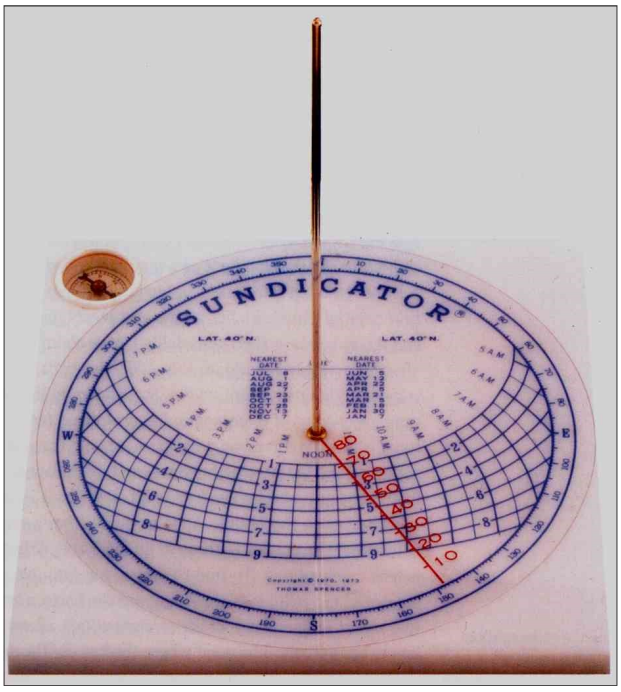
Record no.	**M-26**
Signature	
Date	2009 (but dated 2010)
Dimensions	4 inch (102 mm) radius.
Material	Laminated card. Sights from jewellery findings.
Condition	New
Latitude	"38°42' "
Features	Apian-style triens.
Location	
Provenance	
Reference	
Notes	One of a number of paper instruments made by James E Morrison during the writing of *Astrolabes,* Morrison (2007).



Record no.	**M-27**
Signature	
Date	2009 (but dated 2010).
Dimensions	4 inch (102 mm) radius.
Material	Laminated card. Sights from jewellery findings.
Condition	New.
Latitude	"38° 42' "
Features	Delamain-style quadrant
Location	
Provenance	
Reference	
Notes	One of a number of paper instruments made by James E Morrison during the writing of *Astrolabes,* Morrison (2007).



Record no.	**M-28**
Signature	Copyright 1970 Thomas Spencer
Date	1970 - c.1980
Dimensions	7 inch (180 mm) diameter.
Material	Plexiglass and brass.
Condition	
Latitude	Various, e.g. example for 40° N.
Features	Hour lines for hours and half-hours, am and pm. 9 declination lines for pairs of dates at approx 6° intervals, max/min ±22.5°. Rotating clear plastic altitude index, [0]-80° (not subdivided). Removable brass pin gnomon. Inset magnetic compass on some models.
Location	
Provenance	
Reference	
Notes	Copyright design "Sundicator®" by Thomas Spencer, sold in USA.



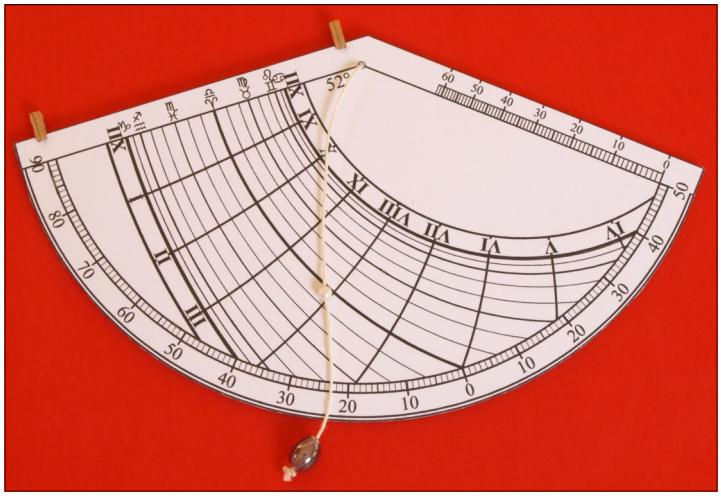
Record no.	**M-29**
Signature	"David M Brown delineavit fecitque MMX" in banner at S.
Date	2010
Dimensions	Octagonal, 520 mm a/f. 28 mm thick.
Material	Welsh slate, brass style edges to gnomon.
Condition	New.
Latitude	"51° 03' N, 2° 44' W"
Features	Polar dial: IIII-□-VIII, divided 15 mins. Azimuth scale, divided to 1 deg, numbered (Arabic) in 10s. Stereo grid: Divided to 15 mins, hours heavier. Dec arcs: 2 deg intervals, 10s heavier, numbered (Arabic) in 5s. Ecliptic arcs: Marked daily, months in capitals, zodiac divisions marked with diamonds. EoT scale (circular) for minutes correction. Altitude scale: rotating stainless steel index. Maker's mark to N.
Location	Somerton, Somerset.
Provenance	Made by owner.
Reference	
Notes	Hand-cut, grey-filled lettering.

Record no.	**M-30**
Signature	Henry Sephton fecit 1722 (facsimile)
Date	1960s
Dimensions	455 mm dia.
Material	Resin?
Condition	
Latitude	
Features	See DH-64
Location	Croxteth Hall, Liverpool (in store).
Provenance	
Reference	
Notes	Replica of DH-64. Made by Liverpool City Council for display (internally) when the original was vandalised and removed from Croxteth Park.

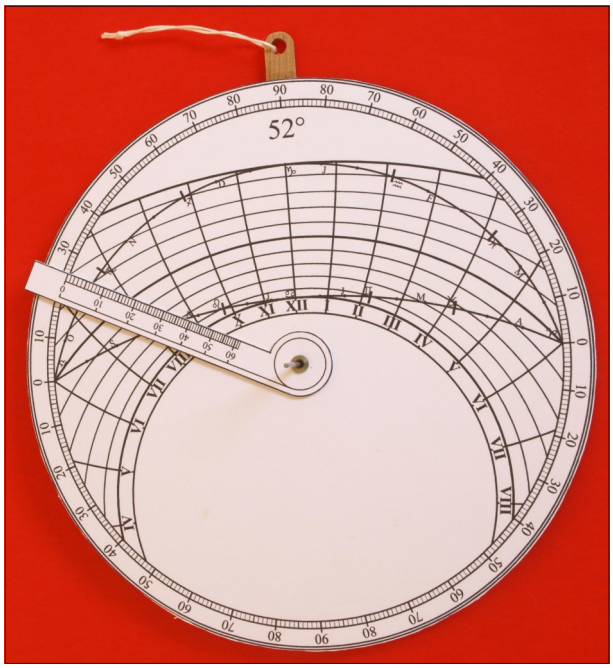
Record no.	**M-31**
Signature	John Davis fecit Flowton, England.
Date	2010
Dimensions	15 ins nonagon.
Material	Brass.
Condition	New.
Latitude	"41° 30' 31″ N; 87° 3' 40″ W"
Features	Gnomon, with logos for NASS and Flowton Dials, has mottoes "Our Science is from the Watching of Shadows" and "NULLA DIES SINE LINEA". Dial has motto "I mark my hours by shadow; Mayest thou mark thine By sunshine" (Carol Brevoort Hilton-Turvey) with portrait.
Location	Purdue University, USA.
Provenance	Presented by maker.
Reference	
Notes	Funded with assistance from the 2009 NASS Sawyer Dialing Prize.



Record no.	**M-32**
Signature	[Mike Cowham]
Date	2008
Dimensions	Horizon circle radius 90 mm.
Material	Paper/card.
Condition	New.
Latitude	"52° "
Features	IV-XII inner, III-XII outer, whole hours only. Dec arcs for zodiacal signs (along meridian). Altitude scale 90-0-50 around circumference, linear 0-62 along radius. Wooden sights, plumb-bob with sliding bead.
Location	Cambridge.
Notes	Triens made to illustrate *A Study of Altitude Dials*, BSS monograph no. 4.



Record no.	**M-33**
Signature	[Mike Cowham]
Date	2008
Dimensions	Horizon circle radius 90 mm.
Material	Paper/card.
Condition	New.
Latitude	"52° "
Features	Stereo grid: IV-XII-VIII on summer side (hours only). Dec lines for 5° (0 heavier). Ecliptic with both zodiacal signs and initials of months. Azimuth/altitude scale 0 -90° ×4 with 0 at E/W. Altitude index 0-62 in single degrees. Central pin gnomon 25 mm high. Wooden suspension point.
Location	Cambridge.
Notes	Horizontal instrument made to illustrate *A Study of Altitude Dials*, BSS monograph no. 4.



2. BSS Register

Some double horizontal dials (mainly those in gardens) are recorded in the British Sundial Society's Register of Fixed Dials (2005 edition). The list below shows the Register Serial Numbers (SRNs) for the dials so listed. Note that some of the dials have their locations recorded as "In confidence—refer to Registrar".

This monograph	Maker	BSS Fixed Dial Register SRN
DH-4	E. Allen	5291
DH-6	J...P...	0846
DH-7	J. Allen	6035
DH-11	H. Bedford	6793
DH-15	W. Croft	3949
DH-16	E. Culpepper	5343
DH-17	D. Delander	3607
DH-18	J. England	5306
DH-22	S. Gray	4123
DH-24	J. Rowley	5352
DH-27	J. Seller	3121
DH-31	T. Tompion	2119
DH-32	T. Tuttell	3539
DH-34	H. Wynne	2125
DH-35	H. Wynne	3416
DH-36	H. Wynne	4680
DH-38	H. Wynne	0897
DH-40	H. Wynne	5756
DH-41	H. Wynne	4531
DH-53	J. Marke	6408
DH-63	J. Marke	2721
DH-64	H. Sephton	6925
DH-65	H. Sephton	6926
DH-66	Anon	6924
AD-1	Anon	0001
AD-2	Anon	5753
M-4	J. Davis	4547
M-5	J. Davis	5109
M-6	English Heritage	5169
M-7	Plowden & Smith	6798
M-12	Moss/Davis/Lowne	6749
M-14	Royal Palaces	6505
M-22	English Heritage	?

APPENDIX 2

COMMISSIONERS OF DOUBLE HORIZONTAL DIALS

The original owners of some double horizontal dials can be deduced from the coat of arms engraved on them or, occasionally, by documentary evidence. This means that generally only the dials made for 'conspicuous consumption' can be associated with an owner. As a result, none of the Elias Allen dials, which are generally quite small and are 'working' instruments, have had their owners' identified (although the horizontal instrument HI-3 was made for presentation to St John's College, Oxford).

Dial	Owner	Maker
DH-10	James Gregory / Univ of St Andrews	Hilkiah Bedford
DH-16	Richard Hill of Hawkstone Hall, Salop	Edmund Culpepper
DH-17	CoA not identified	Daniel Delander
DH-21	Bolles of Scampton	Ralph Greatorex
DH-22	Sayer of Pett Place, Kent	Stephen Gray
DH-23	Middle Temple	Edward Hatton
DH-24	1st Duke of Marlborough	John Rowley
DH-31	William III & Mary	Thomas Tompion
DH-32	Sir John Warde	Thomas Tuttell
DH-34	Henry de Grey, Duke of Kent	Henry Wynne
DH-35	Lord Herbert of Chirbury	Henry Wynne
DH-36	1st Earl Ferrers	Henry Wynne
DH-37	Charles, 2nd Baron Cornwallis	Henry Wynne
DH-38	William Douglas, 1st Duke Buccleuch	Henry Wynne
DH-39	Richard Maitland, 4th Earl Lauderdale	Henry Wynne
DH-40	Charles II	Henry Wynne
DH-47	John Evelyn	Unknown
DH-48	Compton family	Thomas Tuttell
DH-53	Lord Mostyn	John Marke
DH-59	Robert Boyle	John Marke
DH-64	Richard, 5th Viscount Molyneux	Henry Sephton
DH-65	Earl of Derby	Henry Sephton
DH-66	George Compton, 4th Earl Northampton	Anon
-	Samuel Pepys	Unknown

APPENDIX 3

GLOSSARY OF ASTRONOMICAL TERMS

Altitude. The vertical angular elevation of a celestial body above the horizon.

Azimuth. The angular distance from the *meridian* of the vertical arc through a celestial body. In astronomical usage, it is generally measured from the north as zero through east, south, west for the full 360º, but most 17th century dialmakers chose east and west as the zero points, with azimuths 0-90º either side of these. Altitude and azimuth define the position of a body relative to the horizon and *meridian* local to the observer.

Celestial sphere. The imaginary sphere situated at a large distance, on which the stars appear to be fixed and the motions of the sun, moon and planets take place. The observer is at the centre of the sphere, and angles and angular distances of the various bodies are related by the rules of spherical trigonometry.

Declination. The angular distance of a body north (positive) or south (negative) from the *equator.* Circles of equal declination are parallels of declination. Together with *right ascension* it defines the position of a body (sun, moon, planets and stars) on the *celestial sphere*.

Ecliptic. The *great circle* on the *celestial sphere* which marks the path of the sun around the sky in the course of a year. It is the projection on the sky of the earth's orbit around the sun.

Equation of time. The difference between *apparent solar time* (shown by a sundial) and *local mean solar time* (given by a clock). Modern almanacs and ephemerides provide it in the sense (apparent time *minus* mean time), the correction which is to be applied to mean time to obtain apparent time. It is due to a combination of the non-uniform motion of the sun in the *ecliptic* and the *obliquity*, causing a variation in the intervals between the sun's daily return to the meridian at midday. The greatest daily change in the difference between apparent and mean time is about half a minute, and the maximum values of the equation of time occur in early February (dial 14 minutes slow) and early November (dial 16 minutes fast).

Equator. The *great circle* on the *celestial sphere* which is the projection of the earth's geographical equator. It is also known as the equinoctial as the *equinoxes* occur when the sun is in the equatorial plane.

Equinox. The times when and the places where on the *celestial sphere* the sun in the *ecliptic* crosses the *equator* at the first points of Aries (northbound) and Libra (southbound). The sun's *declination* changes most rapidly at these points, about 23 arc-minutes per day.

First point of Aries. One of the two intersections of the *great circles* of the *ecliptic* and *equator,* the other is the first point of Libra. It is the position of the sun at the northern hemisphere spring *equinox* and is the zero point of the system of *right ascensions*. Due to *precession* it is no longer in the constellation of Aries but in Pisces.

Great circle. On a sphere, a circle whose plane passes through the centre of the sphere and bisects it. In sundial terms, the observer can be considered to be at the centre so that great circles are seen projected on the sky as straight lines. Small circles are those whose planes do not pass through the centre, for example parallels of declination.

Hour angle. The angle between an *hour circle* and the observer's *meridian.* It is measured east (negative) or west (positive) of the meridian. Sometimes it is expressed continually in the direction of the diurnal motion, from 0º to 360º.

Hour circle. A *great circle* on the sky which passes through the north and south poles. It meets the *equator* and parallels of declination at right angles.

Meridian. The special case of an *hour circle* which passes through the observer's zenith and meets the horizon at the north and south points.

Obliquity of the ecliptic. The inclination of the plane of the *ecliptic* to that of the *equator.* In the 17th century it was 23º29' but due, to the small centennial decrease of 47 arc-seconds, is now 23º 26'.

Precession (of the equinoxes). A slow rotation of the earth's axis about the pole of the *ecliptic*, at a distance equal to the *obliquity* and period about 26,000 years. It is due to the gravitational attraction of the sun, moon and planets on the equatorial bulge of the earth and causes the *equinoxes* to move around the *ecliptic* in the opposite di-

rection to that of the sun's annual motion at 50·3 arc-seconds per year. The *right ascension* and *declination* of a celestial body such as a star are thus subject to slow variation.

Prime vertical. The *great circle* passing through the observer's zenith and the east and west points of the horizon. It meets the *meridian* in the zenith at a right angle.

Right ascension (RA). The angle between the *hour circle* of the *first point of Aries* and any other hour circle. It is measured from Aries in the direction of the sun's annual motion, generally in time (0-24 hours) but for special purposes is used expressed in arc. With declination, it defines the position of a body on the *celestial sphere*.

Time, apparent solar. Time as measured by the return of the true sun (moving in the *ecliptic*) to the local *meridian* at midday.

Time, local mean solar. Time as derived from the fictitious mean sun which moves in the *equator* at a uniform rate. Found by application of the *equation of time* to the time shown by a sundial and would require further correction, for longitude and daylight saving if in force, to obtain civil time.

Time, sidereal. 'Star time', whose zero point (0^h ST) is the *transit* of the *first point of Aries* and at any moment is the *right ascension* which is on the *meridian*. It is therefore the *hour angle* of the first point of Aries and gains 3 min 56 sec on *mean solar time* per day.

Transit. The passage of a celestial body across the *meridian*. There are two transits in a period of 24 hours, upper transit (or upper culmination) when the body is highest in the sky and lower transit (or lower culmination) when lowest. In the case of the sun, the lower transit will generally occur when the sun is below the horizon.

Year. Tropical year (the basis of the calendar): 365·2422 days from equinox to equinox.
Julian year: 365·25 days
Gregorian year: 365·2425 days averaged over the 400-year cycle. The Gregorian year is longer than the tropical year by 0·0003 days, an error of one day in about 3500 years.

Zenith distance. The angle of the vertical arc between a body and the zenith, 90º minus the *altitude*.

Zodiacal signs. The twelve equal divisions of the *ecliptic*, marking the progression of the sun's annual path. Starting with Aries at the March equinox and continuing through Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricorn, Aquarius and Pisces, the sun spends approximately 30 days in each sign. Due to precession the signs no longer correspond to the constellations of those names.

BIBLIOGRAPHY

New Oxford Dictionary of National Biography
The New ODNB is not shown in the list below. However, it is a valuable resource as it has entries for many of the makers or designers of the instruments described in this monograph. The list includes:

Elias Allen
Hilkiah Bedford (his father's entry)
Edmund Culpepper
Richard Delamain
Stephen Gray
Walter Hayes
Michael Honywood
Samuel Morland
Joseph Moxon
William Oughtred
John Prujean
John Seller
Henry Sutton
Thomas Tuttell

W.O. Alexander: 'A Brief Review of the Development of the Copper, Zinc and Brass Industries in Great Britain from AD 1500 to 1900', *Murex Review* Vol. 1 No 15, pp 389-427 (1955).

R.G.W. Anderson, J.A. Bennett & W.F. Ryan (Eds): *Making Instruments Count*, Variorum (1993).

Philippe Apian: *De utilitate trientis, instrumenti astronomici novi libellus*. Tübingen (1586).

J.H. Appleby: 'A new perspective on John Rowley, vituoso master of mechanics and hydraulic engineer', Annals of Science, 53, pp.1-27 (1996).

T. Belk: 'The stereographic projection as a graphical method for designing sundials. Pt. 1: Horizontal and south facing vertical sundials' and 'Pt. 2: Declining and reclining vertical and double horizontal sundials', *BSS Bulletin* 13(ii), pp.85-88 and 13(iii), pp.123-7, (June & September 2001).

I. Brightmer: 'Over Three Hundred Years in the Sun: Thoughts of an Old Double Horizontal Dial', *BSS Bulletin,* 20(iii), p.116 (September 2008).

C.B. [Christopher Brookes]: *A New Quadrant of more Naturall, Easie, and Manifold Performance, than any heretofore Extant, Framed according to the Horizontall Projection of the Sphere, with the Uses thereof, By C. B. Maker of Mathematical Instruments in METALL.*, London (1649).

John Brown: *The Description and Use of the Triangular Quadrant, being a particular general instrument useful at land or sea: both for observation and operation etc.*. Includes *Part 2, Horologriographia: or, The art of dyalling, being the second book of the use of one trianguler-quadrant etc*. John Darby & John Wingfield, London (1671).

John Brown (& Henry Sutton): *The Triangular Quadrant; or the quadrant on a Sector, Being a general instrument for land or sea observations etc*. London (1662).

J. Brown: 'Mathematical Instrument-Makers in the Grocers' Company 1688-1800'. Science Museum, London, (1979).

R. Brownsword: 'Medieval metalwork: an analytical study of copper-alloy objects', *Historical Metallurgy* 38 pt 2 , 84-105, (2004).

Thomas Brush: Stereographic projection. British Library Sloane Ms 3881 folio 127v (c.1653).

D.J. Bryden: 'A Patchery and Confusion of Disjointed Stuffe: Richard Delamain's Grammelogia of 1631/33', *Trans Cambridge Bibliographical Soc*, 6, pp.158-166 (1974).

D.J. Bryden: *Sundials and Related Instruments (catalogue 6),* The Whipple Museum of the History of Science (1988).

D.J. Bryden: 'Made in Oxford : John Prujean's 1701 catalogue of mathematical instruments', *Oxoniensia*, 58, 263-85 (1993)

D.J. Bryden: 'Mr Clerk the graver'; a Biographical Study in the Cultural Infra-Structure of Early Modern Scotland', *Review of Scottish Culture, 11* pp.13-31 (1998-9).

D.J. Bryden: 'The Instrument-Maker and the Printer: paper instruments made in seventeenth century London', *Bull. SIS*, 55, pp.3-15 (December 1997).

Florian Cajori: *William Oughtred – a great seventeenth-century teacher of mathematicks*, Open Court Publishing Company, London, (1916).

H.K. Cameron: 'Technical Aspects of Medieval Monumental Brasses', *The Archaeological Journal*, vol. 131, pp. 215-237 (1974).

François Charette: *Mathematical Instrumentation in Fourteenth-Century Egypt and Syria: The Illustrated Treatise of Najm al-Dīn al-Mīsṛī,* Brill Academic Publishers (2003).

G. Clifton: *Directory of British Scientific Instrument Makers 1550 – 1851*, pub. Zwemmer, London, 1995.

F. Coe: 'The Dillington Double-Horizontal Dial and John Marke', *BSS Bulletin* 20(iii), p.119 (September 2008).

John Collins: *The Description and Uses of a General Quadrant, with the Horizontal Projection, upon it inverted*. together with John Lyon: *An Appendix touching Reflective Dialling*, J. Maycock, London, 1st edition (1658).

John Collins: *The Sector on a Quadrant – or a treatise containing the description and use of four several quadrants, two small ones and two great ones, each rendered many wayes, both general and particular. Each of them accommodated for dialling: for the resolving of all proportions instrumentally: and for the ready finding of the hour and azimuth universally in the equal limbe. Of great use to seamen and practitioners in the mathematics*, Printed for George Hurlock, London (1659).

C. Daniel: 'Best Seller', *Clocks*, The Sundial Page, p.38 (February 1993).

C. Daniel: 'On Kew', *Clocks*, The Sundial Page, 18(4) (September 1995).

C. Daniel: 'An electrical connection', *Clocks*, The Sundial Page, p.30 (December 2000).

C. Daniel: 'A strange sundial', *Clocks*, The Sundial Page, p.34 (December 2002).

J. Davis: 'The Equation of Time as Represented on Sundials', *BSS Bulletin*, 15(iv), pp.135-144 (2003).

J. Davis: 'Sundials at Trinity College Cambridge', *BSS Bulletin*, 16(i), pp 7-14 (2004).

J. Davis: 'John Marke's Double Horizontal Dials', *BSS Bulletin* 20(iii), p.117 (September 2008).

J. Davis: 'More on the Equation of Time on Sundials', *BSS Bulletin*, 17(ii), pp. 66-75 (June 2005).

J. Davis & C.M. Lowne: 'The "Bacon" Double Horizontal Sundials', *BSS Bulletin*, 13(iv), pp 160-165 (2001).

J. Davis & C.M. Lowne: 'Henry Wynne's Double Horizontal Dial at Staunton Harold', *BSS Bulletin*, 15(ii), pp 46-58 (2003).

J. Davis & C.M. Lowne: 'Henry Wynne's Double Horizontal dials – Update', *BSS Bulletin,* 18(i), pp.33-34 (March 2006).

J. Davis & C. Daniel: 'John Seller – Instrument maker and plagiarist', *Bull. Scientific Instrument Society*, 102, pp.6 -10 (Sept 2009).

H. Dawes: *Instruments of the Imagination: A history of drawing instruments in Britain 1600-1850*, The Dawes Trust (2009).

Richard Delamain: *The making, description and use of a small portable instrument…called a Horizontal Quadrant*. Printed for Richard Hawkins, London (1632).

Raymond D'Hollander: *L'Astrolabe, Histoire, Théorie et Pratique*, Institut Océanographique, France, (1999).

Robert Dudley: *Dell 'Arcano del Mare*, F. Onfi, Florence, Vol.3, Book V; p.4, fig 4 and p.13,(1647).

C. Eagleton and B. Jardine: 'Collections and Projections: Henry Sutton's paper instruments', *J. Hist Collections*, 17(1), pp.1-13 (2005).

Lazarus Ercker: *Beschriebung allefürnemsten mineralischen Ertzt- und Bergwercksarten* (1580), Trans. A.G. Sisco & C.S. Smith as *Treatise on Ores and Assaying*, U of Chicago Press (1951).

Henry van Etten: *Mathematical Recreations. Or, a Collection of sundrie Problemes extracted out of the Ancient and Modern Philosophies…. Whereunto is added the Description and Use of the General Horologicall ring and the Double Horizontal Diall. Invented and written by William Oughtred.* Imprinted by William Leake, London (1653).

J. Evans: *Thomas Tompion at the Dial and Three Crowns*, The Antiquarian Horological Society, Ticehurst (2006).

James Ferguson: *Lectures on selected subjects: Of Dialing*, Fifth edition, London (1776).

Oronce Finé: *Protomathesis: opus uarium, acscitu non minus*, Paris (1532). See vol. 4 book 3.

William Forster: *The Circles of Proportion and the Horizontal Instrument &c. Both invented, and the uses of both Written in Latine by W.Oughtred Ætonens. Translated into English and set forth for the publique benefit by W.F.*, R. Davis, Oxford (second edition, 1660, first published 1632).

Samuel Foster: Miscellanies or Mathematical Lucubrations, translated from Latin to English and edited by John Twysden, London, (1659).

A. Gatty and H.K.F. Eden & E. Lloyd (Eds): *The Book of Sun-Dials,* 4th edition, Bell & Sons, London (1900).

Edmund Gunter: *The Description and use of the Sector. The Crosse-staffe and other instruments*. Printed by William Jones, sold by Edmund Weaver, London (1624).

Edmund Gunter: *The Works of the famous mathematician Mr Edmund Gunter, sometimes Professor of Astronomy at Gresham Colledge London*, edited and augmented by William Leybourn, Fifth edition, London (1673)

R.T. Gunther: *Early Science in Oxford.* Oxford University Press, Vol. II p. 140 (1922).

Aboul Hassan Ali al Marrakchi: Trans by L. Sédillot as *Mémoire sur les instruments astronomiques des Arabes*, Paris, p.515 (1841).

Joy Hancox: *The Byrom Collection*, pp.188-191, Jonathan Cape (1992).

John Harris: *Lexicon Technicum: or, an Universal English Dictionary of Arts and Sciences, explaining not only the terms of Art but the Artes Themselves,* London (1704).

Georgius Hartmann: *Collectanea mathematica praeprimis gnomonicam spectania*. MS Vienna Österreichisch Nationalbibliothek 12768 (1518-28).

William Hawney: *The Doctrine of Plain and Spherical Trigonometry*, London (1725).

Bibliography

J. Hayes: 'Double Horizontal Sundial: Design, Construction and Use', *NASS Compendium,* 12(4), Digital Bonus, p.36 (Dec 2005).

H. Higton: *Sundials at Greenwich*, OUP, Oxford (2002).

Katherine Hill: 'Juglers or Schollers ? : negotiating the role of a mathematical practitioner', *British Journal for the History of Science,* xxxi, 253-74 (1998).

R. D' Hollander: *L'Astrolabe, Histoire, Théorie et Practique*, Institut Océanographique, France, (1999).

Michael Hunter: *The Boyle Papers – understanding the manuscripts of Robert Boyle,* Ashgate (2007).

Michael Hunter and Edward B Davis *(Eds): The Works of Robert Boyle*, Vol. 11, pp.89-90, *The Christian Virtuoso and other publications 1687-91*, Pickering & Chatto (1999).

Charles Hutton: *A Philosophical and Mathematical Dictionary Containing ... Memoirs of the lives and writings of the most Eminent Authors* (1815).

Louis Janin: 'L'astrolabe et cadran solaires en projection stéréographique horizontale', *Centaurus: International Magazine of the History of Mathematics, Science and Technology*, 22, pp.298-314 (1979).

J. Lamprey: *Hartmann's Practika – a manual for making sundials and astrolabes with the compass and rule*, Privately published, Bellvue, USA (2002).

R. Latham & W. Matthews (eds.): *The Diaries of Samuel Pepys* (1970-83).

Philip Lea: *Advertisement of Globes, Books, Maps &c Sold by Philip lea, Globe Maker at the Atlas and Hercules in Cheapside, near the corner of Friday-street; and at his shop in Westminster Hall, near the Court of Common Please.* London. (Broadsheet) (1689-95).

Philip Lea: *A Catalogue of Globes, Spheres, Maps Mathematical Projections, Books and Instruments*, London. (1699)

William Leybourn: *The Works of Edmund Gunter,* Fifth edition (1673).

B. Loomes: *The Early Clockmakers of Great Britain.* NAG Press, London (1981).

C.M. Lowne: 'The design and characteristics of the double-horizontal sundial', *BSS Bull,* 13(iv), pp 138-146 (2001).

C.M. Lowne: 'Moondials and the moon', *BSS Bull,* 17(i), pp.3-12, (March 2005).

C.M. Lowne & J. Davis: 'A Universal Altitude Dial by John Marke', *BSS Bulletin,* 21(iii), pp.2-8 (September 2009).

H. Michel: *Traité de l'Astroblabe,* Ch. XVIII, Astrolabe d'Oughtred et Quadrant d'Allen, Gauthier-Villars, Paris (1947).

J.E. Morrison: *The Astrolabe*, Janus, Rehoboth Beach (2007).

A.D. Morrison-Low: 'Recent acquisition by the National Museums of Scotland: William Oughtred's horizontal instrument and 'Circles of Proportion' by Elias Allen, London, 1648', *SIS Bulletin*, 85, pp.20-22, (June 2005).

T. Moss: 'Double Trouble – the realization in bronze of the Henry Wynne replica dial', *BSS Bulletin,* 18(i), pp.35-39 (March 2006).

Joseph Moxon: *Mathematicks made Easie – or a mathematical dictionary*, 3rd edition, printed for J Moxon and T Tuttell, London (1700).

A. Neri: *L'arte vetraria distinta in libri sette*, Florence (1612). English translation, greatly extended by C. Merret, London (1662).

O. Neugebauer: *A history of ancient mathematical astronomy*, Sepinger-Verlag, Berlin (1975).

Adam Ordway: *The Description and Use of the Double Horizontal Diall*, London (1662). (Includes paper instrument.)

William Oughtred: *The Description and Use of the double horizontall dyall*. Printed by M Flesher, London (1632).

William Oughtred: *The Description and Use of the double horizontall dyall*. 2nd edition. Includes *The description of the General Horologicall Ring*. Printed by William Leake, London, (1652).

William Oughtred: *Clavis Mathematicæ*, Printed by Leon. Lichfield, Oxford, 5th Edition (1693).

Jacques Ozanam: *Cursus Mathematicus of, a complete course of mathematics*. Part V, Geography and Dialling. Translated from French (Paris, 1693) to English by J.T. Desaguliers, Oxford & London (1712).

Jacques Ozanam: *Récréations mathématiques et physiques* (2 vols, revised by *Montucla* in 1778, 4 vols) (1694).

John Page-Phillips: *Palimpsests: The Backs of Monumental Brasses*, The Monumental Brass Society, London (1980).

D.J. Price: 'The Early Observatory Instruments of Trinity College Cambridge', *Annals of Science,* 8(1), pp.1-11 (1952).

John Prujean: *A short description of a Quadrant of the particular Astrolabe inverted. These notes with all Mathematical Instruments are Made and Sold by John Prujean in Oxon*. with *Oughtred's Quadrant*. (Broadsheet), Wing P.3384. Christ Church Library, Oxford (c.1701).

H. Robinson & W. Adams (Eds): *The Diary of Robert Hooke 1672-1680*, Taylor & Francis (1935)

R.R.J. Rohr: *Les Cadrans Solaires – histoire, théorie, practique. Traité de gnomonique, Edition revue et augmentée.* Editions Oberlin, Strasbourg (1986).

D. Savoie: *Gnomonique Moderne*, Société Astronomique de France (1997)

F.W. Sawyer: 'William Oughtred's Double Horizontal Dial', *NASS Compendium*, 4(1), pp.1-6 (March 1997).

F.W. Sawyer: 'Ptolemaic Coordinate Sundials', *NASS Compendium*, 5(3), pp.17-24 (September 1998).

F.W. Sawyer, J. Schilke & N. Severino: 'Andreas Schöner's Stereographic Sundial Design', *NASS Compendium*, 16(4), pp.15-18 (December 2009).

Andeas Schöner: *Gnomonice, hoc est De descriptionibus horologiorum sociotericorum omnis generis, proiectionibus circulorum sphaericorum ad superficie,.....Gnomonices mechanices, ... De inuentione lineae meridianae, ... De compositione astrolabji plani & columnaris, omnia recens nata & edita.* Norimbergae. apud Iaonnem Montanum, (1562).

Benjamin Scott treatise on the Double Horizontal dial. British Library Sloane Ms 2040 (c.1720?).

L. Sédillot (trans.) (Aboul Hassan Ali al Marrakchi) *Mémoire sur les instruments astronomiques des Arabes*, Paris, p.515 , (1841).

A.V. Simcock: 'An Equatorial Ring Dial by Ralph Greatorex', pp.201-15 in R.G.W. Anderson, J.A. Bennett & W.F. Ryan (Eds): *Making Instruments Count*, Variorum (1993).

C. Singer, E.J. Holmyard, A.R. Hall and T.I. Williams (eds.): *History of Technology*, 8 volumes, especially vol. 3. Oxford, (1954-84).

E.G.R. Taylor: *The Mathematical Practitioners of Tudor & Stuart England*, Cambridge University Press (1954).

E.G.R. Taylor: *The Mathematical Practitioners of Hanovarian England 1714-1840*, Cambridge University Press (1966).

Gordon E. Taylor: *J. Brit Astr. Ass.* **84**, 3 (1974).

A.J. Turner: 'William Oughtred, Richard Delamain and the Horizontal Instrument in Seventeenth Century England', *Annali dell Instituto e Museo di Storia della Scienza di Firenze*, Anno VI, Fasc 2 (1981). Reprinted with minor changes in A.J. Turner: *Of Time and Measurement – studies in the history of horology and fine technology*, pp. 99-125, Variorum, Aldershot (1993).

A.J. Turner: 'Le cadran solaire de Benjamin Scott', *La Revue*, Musée des arts et Métiers, Paris, pp.55-57, (Sept 1998).

A.J. Turner: *Time Museum Catalogue of Instruments, Vol. 1, Time Measuring Instruments, Pt. 1 Astrolabes & Astrolabe-related instruments*, pp.191-201, The Time Museum, Illinois (1985).

A.J. Turner: *Early Scientific Instruments, Europe 1400-1800*, pp.161-163, London (1987).

Tho. Tuttell: *The Description and Uses of a New Contriv'd Eliptical Double Dial……*, Printed by W. Redmayne, London (1698).

G.L'E. Turner: *Elizabethan Instrument Makers – the origins of the London trade in precision instrument making*, OUP, Oxford (2000).

F.J. de Vries: 'The Other Oughtred Sundial', *De Zonnewijzerkring*, 72(1) (Jan 2000).

R.V. & P.J. Wallis: *Index of British Mathematicians Part III 1701-1800*, PHIBB, Newcastle (1993).

R.V. & P.J. Wallis: *Biobibliography of British Mathematics and its applications, Part II, 1760-1800*, PHIBB/ Epsilon Press, Newcastle (1986).

F.A.B. Ward: *A catalogue of European Scientific Instruments in the Dept of Medieval and Later Antiquities of the British Museum,* British Museum Publications, London,(1981).

Christopher Wilkins: *The Horizontal Instrument*, Transworld publishers, London (1999) (fiction).

Frances Willmoth: *Sir Jonas Moore: Practical Mathematics and Restoration Science*, Boydell Press, Woodbridge (1993).

A.E. Waugh: *Sundials – their theory and construction*, Dover Publications, New York (1973).

R.S. Whipple: 'Some Scientific Instrument Makers of the Eighteenth Century', *J Sci Inst,* VI(8), pp.241-253 (Aug 1930).

J. Wilson: *Biographical Index of British Sundial Makers from the Seventh Century to 1920*, BSS Publications (2003).

H. Wynter & A. Turner: *Scientific Instruments*, Studio Vista, (1975).

E. Zinner: *Deutsche und Niederländische astronomische instrumente des 11-8 jahrhunderts*, Beck'sche Verlagbuchhandlung, Munich (1956).

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