BSS Bulletin 21(ii)

The British Sundial Society

BULLETIN

June 2009

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GUIDELINES FOR CONTRIBUTORS

1. The editor welcomes contributions to the *Bulletin* on the subject of sundials and gnomonics; and, by extension, of sun calendars, sun compasses and sun cannons. Contributions may be articles, photographs, drawings, designs, poems, stories, comments, notes, reports, reviews. Material which has already been published elsewhere in the English language, or which has been submitted for publication, will not normally be accepted. Articles may vary in length, but text should not usually exceed 4500 words.

2. Format: The preferred format for text is MS Word or text files sent by email to john.davis51@btopenworld.com. Material can also be sent on CD or as a single-sided typescript, single- or double-spaced, A4 paper.

3. Figures: For photographs, colour or black-and-white prints as large as possible (up to A4). Slides and transparencies are also acceptable. Pictures can be sent electronically as separate jpg (do not over-compress) or tif files—do not embed them in Word files. For email attachments, do not exceed 10 Mbytes per message. Tables should be treated as figures and numbered as part of the same sequence. Drawings and diagrams should be in clear, strong black lines (not pencil) on a white background. Each figure illustrating an article should carry on the back the author's name and a number indicating its relative position in the text (Fig. 1, Fig. 2 etc…). Label the top of the figure if it is not obvious. Captions for the figures should be written on a separate sheet in numerical order. They should be sufficiently informative to allow the reader to understand the figure without reference to the text.

4. Mathematics: symbols used for the common dialling parameters should follow the conventions given in the Symbols section of the *BSS Glossary* (available online on the Society's website). Consult the editor if in doubt or for help in laying out equations.

5. The *Bulletin* does not use footnotes. Where additional information is required, notes should be numbered as a Reference with a superscript number. For very long notes, use an appendix.

6. References: Sources are referred to in the text by a superscript number. They are listed in numerical order under the heading 'References' (or 'References and Notes') at the end of the article. The *Bulletin*'s convention is as follows:

   For books: Author's name; Title of book, in italics; Name of publisher, Place and date of publication.
   For papers and articles: Author's name; Title of article in single quote-marks; Name of journal, in italics (this may be abbreviated); volume number, underlined in Arabic numerals; first and last page numbers; date, in brackets.

   Examples:

   A.E. Waugh: *Sundials, their theory and construction,* Dover, New York, (1973).
   D. Colchester: 'A Polarized Light Sundial', *Bull BSS,* **96.2**, 13-15 (1996)
   A.A. Mills: 'Seasonal Hour Sundials', *Antiquarian Horol.* 19, 142-170 (1990)
   W.S. Maddux: 'The Meridian on the Shortest Day', *NASS Compendium,* 4, 23-27 (1997).

   If you simply wish to give a short list of books associated with the subject of the article, this may be given at the end of the article under the heading 'Bibliography', using the convention as given for 'Books' above.

7. Acknowledgements: These should be as brief as is compatible with courtesy.

8. The address of the author will normally be printed at the end of the article unless the author, when submitting the article, expresses a wish that this should not be done.

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Front cover: *The magnificent armillary sphere in the Royal Botanic Gardens, Sydney, installed in 1993 by Sundials Australia. See story on page 5. Photo: David Isaacs.*

Back cover: *The Barrington (or Highworth) stained glass dial, long thought to be lost but discovered safe with a private owner. See page 12 for further details. Photo: John Davis.*

Designed by J. Davis. Printed by Henry Ling Ltd., Dorchester, 01305 251066

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CONTENTS

EDITORIAL

The mini-theme for this issue is sundials within the Tropics; articles by Malcolm Barnfield and Mike Cowham deal with a topic which we rarely think about but which is a good test for how well we really understand the apparent movement of the sun across the globe's surface.

The very observant of you may have noticed that this second issue of volume 21 starts with page 1, rather than page 49. In previous years, the page numbering was sequential across the four issues of the volume. Logical, perhaps, but a real nuisance for the Editor when compiling the layout and producing partial printouts. I hope readers aren't upset by this change.

Erratum: In Allan Mills' article 'An electronic polarization sundial and photometer' in the March *Bulletin,* the caption to Fig. 1 on p.14 should refer to a selenium photocell not a silicon one. I apologise for letting this slip through—the error was only discovered when 500 copies had been printed.

Accounts 2008

The later-than-usual date for the Conference this year has meant that a signed-off copy of the 2008 Accounts was not available at the time this issue was finalised. They will be printed with the September issue.

THE 67 SUNDIALS OF CAIUS COURT, CAMBRIDGE

MICK LE MOIGNAN

[The author is the Deputy Director of Development for Gonville & Caius College, Cambridge. This article is based on one which originally appeared in the house magazine *Once A Caian…* in September 2008.]

Fresh eyes can sometimes help us to see the familiar in a new light. This was certainly the case when Dr Richard Gibbens, Fellow of Caius College and College Lecturer in Mathematics and Computer Science, invited Dr Frank King of Churchill College, the University Bellringer and a well-known authority on sundials, to visit the College.

The six sundials around the tower surmounting the Gate of Honour (fig. 1) are a regular attraction on Dr King's Guided Walks around the sundials of Cambridge, so they naturally provided the first focus of attention. Magnificent they are, and possibly even useful in terms of telling the time, at least to a passer-by in Senate House Passage, shortly before or after midday, on one of those increasingly rare days when the sun shines. To the inhabitants of Caius Court, on the north side of the Gate, they have been mainly decorative for over four hundred years.

The Gate of Honour was completed in 1575, two years after the death of Dr John Caius (b. 1510) but according to Professor Christopher Brooke in his *History of Gonville & Caius College*:[1] "There is no doubt that the Gate of Honour represents in almost every detail his (Caius') conception, even if the relative shares of the founder and the architect can never be precisely determined." The architect was Theodore Haveus of Cleves, (fig. 2) who oversaw the construction of Caius' tomb in the Chapel and probably most of Caius Court as well.

Indeed, Haveus himself became a benefactor to the College in 1576, when he presented an extraordinary stone monument, set just off-centre in Caius Court, which more than compensated for the rather uninformative north-facing sundials atop the Gate of Honour on the Caius Court side. It was, according to Professor Brooke an "elaborate, fantastical column with 60 sundials", with a weathervane in the shape of Pegasus on the top. No excuse, then, for the students of the day not arriving punctually for their supervisions!

As far as we know, no image survives of the 60 sundials, which were arranged with mathematical precision as a hexecontahedron (sixty-faced solid) but there is a clue in the portrait of Haveus in figure 2. There you see a dodecahedron which, of course, has 12 faces. If you place a pyramid on each pentagonal face (each pyramid having five faces excluding its base) you get 60 faces altogether. That's a hexecontahedron. Pegasus and the sundials survived until at least 1625, since there is an entry in the Bursar's Book for that year for gilding and repairing them, but by 1690 they were gone: the celebrated etching of the College by David Loggan, dated 1690, (fig. 3) shows clearly just the central column and the base on which the great globe of the

Yao Liang

Fig. 1. The sundial on the east face of the Gate of Honour at 07:49 GMT.

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Fig. 2. Theodore Haveus of Cleves, Dr Caius' architect and a College benefactor in his own right.

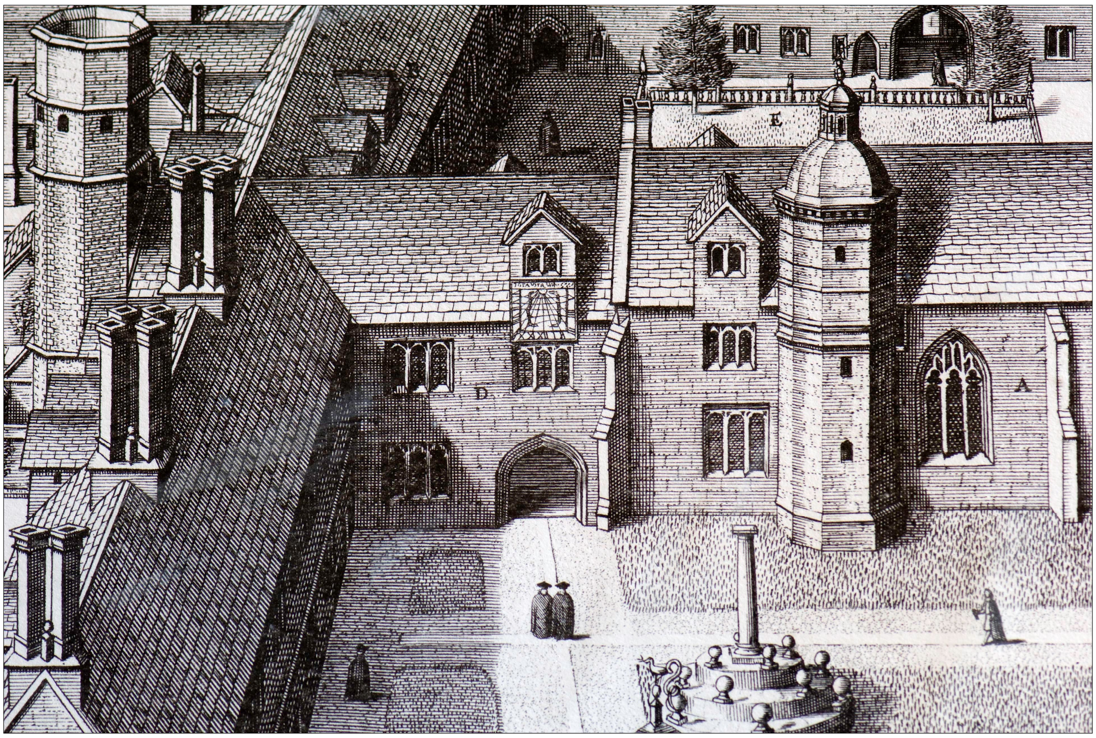

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Fig. 3. The Loggan engraving of 1690 shows both the great sundial over Chapel Arch and, in the foreground, remnants of the Pegasus-topped sundial given to the College by Haveus.

hexecontahedron must have stood. With luck, the many historians and mathematicians of the College will hypothesise further about this spectacular structure in the future!

I must admit that I failed to grasp why 60 sundials should be preferable to one, but Dr King seemed delighted to have discovered the site of such a monument to sundial excess. He was, however, still not satisfied and argued that there must have been another sundial, a much bigger one, somewhere on the side of the Chapel. We inspected the ivy-clad walls (fig. 4), noted the comparatively modern clock and belltower, shook our heads regretfully and went in to lunch.

Professor Anthony Edwards, an old friend of Frank King's, decided to do a little research of his own and returned beaming triumphantly. He had enlarged a small portion of the Loggan print, (which each of us must have looked at hundreds of times) and had made a discovery: there, on the wall over Chapel Arch, was a sundial which quite outshone those on the tower of the Gate of Honour (see fig. 5). Moreover, it enjoyed the distinct advantage, for a sundial, of facing south and therefore had a sporting chance of registering the time of day, if the sun should happen to be shining on it.

Christopher Brooke's *History* was consulted at once, but no mention was found of the Chapel sundial. We dared to

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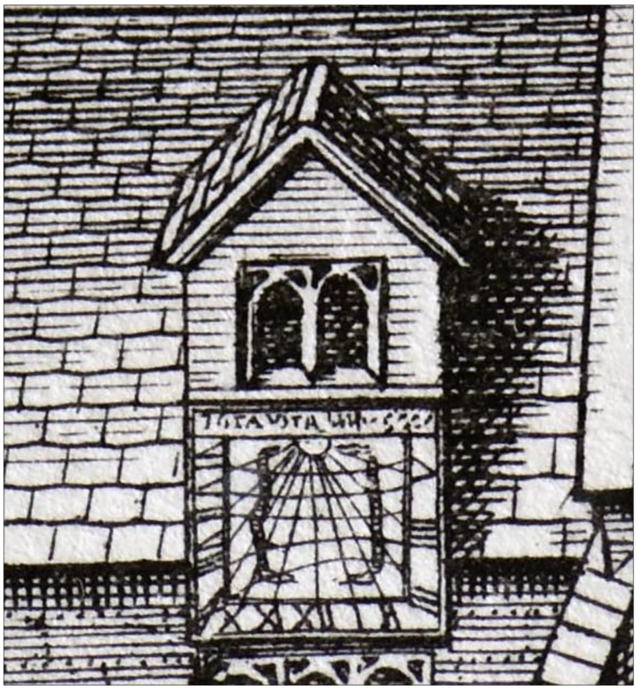
Fig. 4 (left). Chapel Arch today, with the nineteenth century belltower and clock.

Fig. 5 (right). Anthony Edwards' magnifying glass revealed an important (but often overlooked) detail in Loggan's 1690 engraving.



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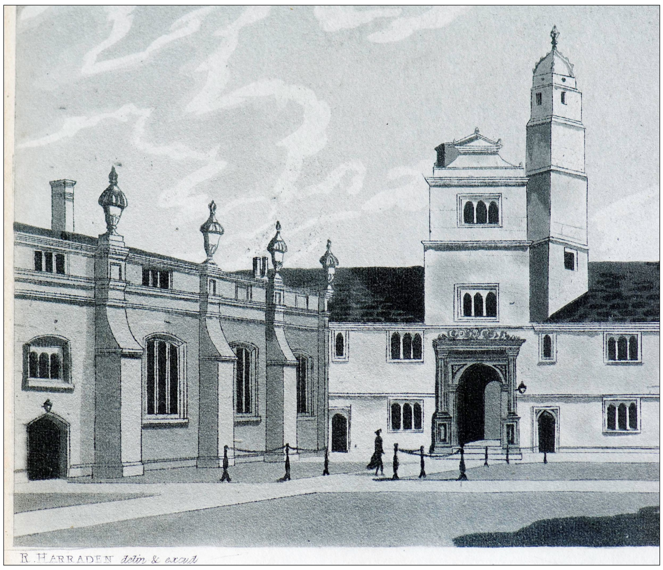

Yao Liang

Fig. 6. Harraden's print shows the eighteenth century alterations to the Chapel. No sign of any sundials!

wonder if it might have passed beyond the ken of any living Fellow. Dr King was not surprised: it had seemed to him inconceivable that two sundial devotees like Caius and Haveus should miss the opportunity to place the greatest of their sundials on Caius Court's south-facing wall.

He later discovered a reference to it in Willis and Clark's *The Architectural History of the University of Cambridge and of the Colleges of Cambridge and Eton*[2] taken from the Bursar's Book and also quoted in *The Caian Vol. LVI no. 2 1960*:

> "In 1625 Russel, the painter, was paid 'for gilding and working ye great mural dial £4; for gilding and working the six dialls over Hon. Gate £3."

Dr King observes: "I assume ye great mural dial is the one over the Chapel Arch. Given that Russel was paid more for attending to this dial than to all the six dialls over Hon. Gate together we may guess that it was either a really substantial dial or that it was in much worse condition!" The entry in the Bursar's Book continues:

> "... for gilding and working ye globe dialls £3; for gilding ye pegasus, gilding and working the concave diall, and colouring all the rest, with the roundles there, 20s".

The "concave diall" seems to be a reference to a scaphe dial, yet to be discovered. On examining Loggan's drawing of the Chapel Arch sundial, he noted: "The asymmetry in the hour-lines suggest a dial that faces about 8° east of due south. I think the wall flanking Senate House Passage faces a degree or two east of due south and the Chapel inclines a little more than that wall so Loggan has the gist of it correct."

The first half of the inscription on the sundial reads "IOTA VITA" (or possibly "TOTA VITA") but the second half is not legible. Dr King was at first puzzled by the 'squiggles' on the face, but any Caian will recognize them at once as the snakes on Dr Caius' coat of arms.

The Chapel itself has been renovated and altered in every century of the College's existence. One of Dr Caius' favourite 'pepperpot towers' caps the medieval (1430) turret rising from the second buttress from the right in Loggan. In a print by J Harraden, dated c.1800 (fig. 6), the tower has disappeared, as have the great sundial and the dormer windows, the shape of the main windows has changed and an apparent top storey has been added (but with two false or blocked windows on the right). Today, probably since the alterations of c.1870, a less elegant tower surmounts the third buttress and carries a large bell to summon the faithful (or recalcitrant!) It is a matter of taste, but many will prefer the simplicity of the earlier design.

As Christopher Brooke pointed out,[1] the only one of Dr Caius' statutes that has been wholly and consistently obeyed is the one that prohibits the construction of any building on the south side of Caius Court "lest the air, being prevented from free movement, should be corrupted, and so do harm to us… and bring on us sickness and death."

And, Caius might have added, lest it should prevent the sunlight from striking the magnificent sundial on the Chapel Wall, which surely awaits a latter-day Theodore Haveus to restore it to its former glory!

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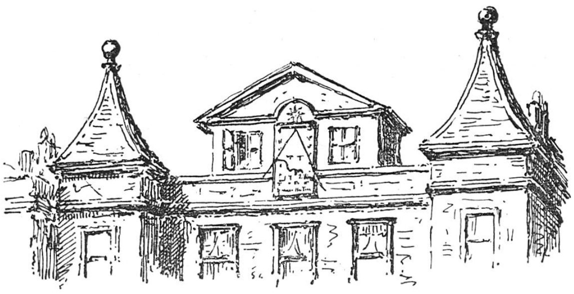


This drawing from *Gatty* shows Dial House, Twickenham, where the dial has the motto 'Redeeming the Time' (Eph. v.16). The dial was erected by Thomas Twining (d.1741), the founder of a well-known tea warehouse in the Strand. The dial itself was dated to 1725 and is believed to have been inspired by the one on nearby Clement Danes church.

Folkard and Ward, Sundials Australia

a visit report by Douglas Bateman

This is the fourth of my personal 'encounters' with well known sundial makers and came about by a series of coincidences. In September 2008 I was planning a visit to New Zealand and Australia and when the editor heard that I would be in Adelaide, he said "I didn't know our roving reporter was travelling that far, but whilst I was there, could I write a report on Sundials Australia?".

Dates were arranged, but first some homework was required by re-reading their excellent publication.[1] The spiral bound book gives a comprehensive review of the historical background to sundials and their theory, and is very well illustrated together with 51 references. The 113 page book shows the wide range of their work and has a section on practical measurements of the optical geometry of sun, gnomon thickness and sharpness, or otherwise, of the shadow. But what caught my eye is a short section on the electromagnetic spectrum and the range of wavelengths covering the visible and two of the main infrared atmospheric 'windows'. This is somewhat unusual for any book on sundials and gave a clear hint to me that they have worked, rather like me, in the fields of infrared optics in government research. So it proved and gave extra depth to our lively discussions.

The story started in 1976 when Dr Margaret Folkard consulted her colleagues about a present for friends and John Ward suggested a sundial. The dial would obviously have to be made for the southern hemisphere and their background drove them to a thorough research on the topic consulting many of the traditional textbooks. They found these, by their standards, quite disappointing and naturally based on the northern hemisphere. (Such disappointment lingered, ultimately leading to their own book on the subject.)

Not having access to good workshop facilities, their very first dial was an etched horizontal which

Sundials Australia

became the forerunner of an all-consuming hobby. More commissions were accepted, still using etching in brass as the main method. By coincidence they met Andrew and Anne Somerville when they were visiting Anne's home town of Adelaide in 1982. John recalls having a discussion with Andrew about Andrew's idea for the formation of a British sundial society! It will be recalled that Andrew went on to become one of our founder members to form the Society in 1989.

A major change took place in 1984 when John prepared an application for a Churchill Fellowship grant to study the history and development of sundials. (The Churchill Trust is an Australian Trust established in 1965, the year in which Sir Winston Churchill died. The principal object of the Trust is to perpetuate and honour his memory by the award of Travelling Fellowships known as Churchill Fellowships. The awards can be substantial and between 50 and 120 awards are made each year.)

The grant enabled both to spend 5 months wandering around the USA; Eastern Europe (as it then was) – East Germany, Poland, Czechoslovakia, Hungary; Western Europe (Austria, Switzerland, Italy, France, West Germany, Holland) then England and Scotland. They met most of the significant sundial people in those countries including the Mayalls and Rene Rohr. During the 1984 tour John and Margaret visited the Somervilles and returned again in 1985 for a three week sundial study tour of Scottish-type sundials and their possible origins in Holland and parts of Germany, then to a sundial conference at Oberperfuss near Innsbruck with the German sundial group, then to *another* conference at Brugine (50 km west of Venice). There they met Christopher Daniel and Doreen Bowyer, and many other luminaries from the world of historical scientific and navigation instruments.

They had already decided to concentrate on dials with the hour markers and detail cast in relief despite having to learn the art of pattern making. Such a practice is contrary to European 18th century and later traditions of engraving, and their judgement is based on the poor long-term legibility of engraved dials. To 'prove' the point, they produced from an odds and ends box in their workshop an extreme example of a badly corroded 'British' sundial to compare with their legible and highly raised numerals. Inevitably such numerals and hour markers prevent very fine detail, or more pedantically, the fine resolution of engraving. On the other hand, a thicker hour line can still achieve the necessary *precision*, indeed Margaret assured me that, as designers, they are fanatical about accuracy.

The hobby grew rapidly in scale and a large workshop was gradually built up (since 1977) with a range of milling machines and adapted machine tools. Both Margaret and John have become skilled machinists and Margaret also specialises in the computer generated graphics. If we

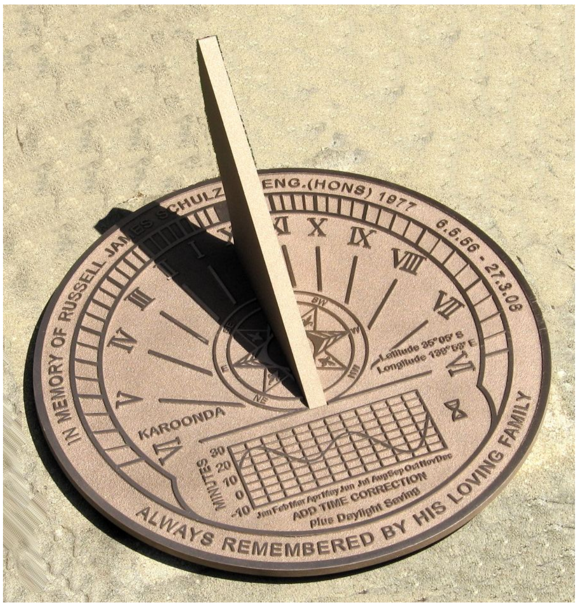


Fig. 1. *A horizontal dial from their basic range, in this example the finished dial straight from the workshop.*

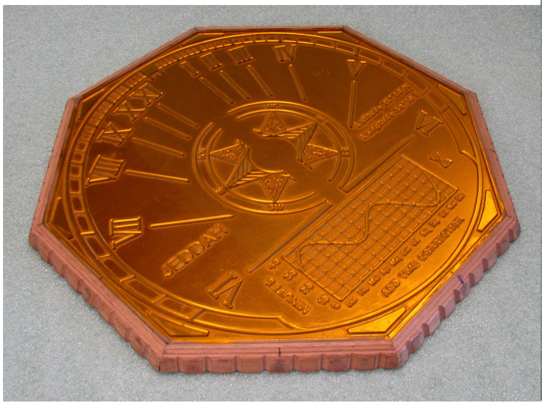
Fig. 3. The magnificent armillary sphere in the Royal Botanic Gardens, Sydney, installed in 1993.

Fig. 4.(below) A detail of the horizon ring showing 3 of the 38 herbs sculpted by South Australian Karin Rumpf.

imagine a customer seeking a horizontal dial, the first steps are either by visits to the workshop, or sending photographs of examples from their 'standard' range (Fig. 1). Typically these are mainly octagonal 310 mm or 400 mm wide, circular or square. After the basic design is decided upon, dedications, mottoes, coats of arms or other artwork, latitude and longitude can be added very quickly with computer graphics. The hour lines are computed to suit the latitude. The design was printed in a dense black on paper then a litho film negative was produced and sent to the foundry. (Current methods use pdf files and the internet to send an electronic master from which the foundry produces the negative.) The negative is placed in contact with a shallow bath of a liquid *photopolymer* which is exposed to an ultraviolet light for a few minutes. The liquid is drained off and resultant hardened polymer gives a precise 3D replica of the desired dial to act as the pattern for a mould. The arrangement of the ultraviolet light is such that the details all have a slight chamfer or *draw*, thus enabling the pattern to be released from the sand. The resultant mould in the sand is claimed to give a precision of ¼ mm. Fig. 2 shows a typical pattern after mounting and returned for inspection.

Casting is carried out in a specialist foundry in Melbourne that casts, on a daily basis, a large number of similar flat memorial, dedication and explanatory panels, with the sundials a small percentage of their work. The preferred material is gunmetal bronze, an alloy of copper, tin and a small percentage of zinc. On return, the casting is fettled (casting marks and sprue removed); sand blasted to give the matt texture between the numerals, etc.; and the top surface fine-ground with a linisher. (A linisher is commonly a motor-driven belt sander ranging in size from a belt 25 mm wide with a 300 mm working belt length, to a large improvised version in their workshop with a belt 15 cm wide and 2 m long.) Any final touching up is done with a small dental burr.

Plain gnomons are machined from slab bronze, filigree gnomons are cut by water-jet from slab bronze, while 'sunflame' gnomons are cast from patterns made using photopolymer on both sides. In



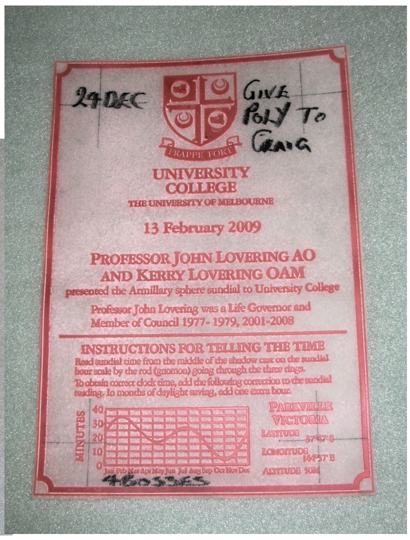


Fig. 2. Far left: a photopolymer master mounted on a stiff board ready for impressing in the sand to create the moulded cavity for casting. The rectangular master (left) is in a different polymer and is a flexible sheet prior to mounting. The hand written notes will not be reproduced in the casting!

Fig. 5. An earlier design of armillary that has a uniform equatorial ring. Attractive features are the banner on the top and signs of the zodiac on the horizon ring. Sadly the tip and fletching of the gnomon 'arrow' have recently been cut off for safety reasons, but is must be said that the lawns are used for many social functions.

Fig. 8. An hour ring after rolling into shape.

Fig. 9. Margaret with a 500 mm armillary ready for fitting the gnomon.

addition, certain gnomons with ornate designs on both sides may be machined using a pantograph. With a thickness of 12 mm or 14 mm, depending on the dial plate size, the gnomon is securely bolted in place. Together with the bold numerals and hour markers, the longevity of the whole dial is assured.

Despite the apparent complexity of the process, all the manufacturing stages are quite rapid enabling the prices—in my estimation—to be relatively low, ranging from A$500 to A$650 in basic form (approximately £250 to £325).

Whilst horizontal dials may be in the majority, and within reach of the private purchaser, their armillary spheres are perhaps the most striking and well known of their sundials. Their best known is the wonderful sculptural dial in the herb garden of the Royal Botanic Gardens in Sydney. It is very large with a height of 2.4 m and a mass of 1.5 tonnes, see Figs. 3 & 4. On a personal note, I like the fact that it is not on a raised stone pedestal but is free-standing on its own sturdy base, aligned and marked with the directions of the compass. From a sundial designer's point of view, the hour ring is tapered to ensure that it does not eclipse the opposite side when the sun is in line with the ring at each equinox. Apart from the overall scale, the other purely sculptural detail is the casting of no less than 38 well known herbs in the horizon ring. Credit is given to Marion Westmacott of the Royal Botanic Gardens who selected and prepared the herbs, and to Karin Rumpf who sculpted the herbs in clay for each quarter of the ring, before they were transformed to bronze using a modern variant of the ancient 'lost wax' process.

An earlier armillary of 1991 is in the grounds of Government House, Adelaide, Fig. 5. The dial is the gift of a very popular former Governor, Dame Roma Mitchell, and Fig. 6 is good example of an associated plaque.

Given the success of the Sydney dial it is not surprising that armillary spheres feature as one of the standard products. The design evolved into cast flat rings to give dials in two sizes, 500 mm high and 800 mm high. Quite a lot of machining is required, needing some decent equipment (Fig. 7).

Having machined all three rings, the next step is the apparently drastic action of chopping the equatorial ring in half. The polar ring is cut in one place, sprung apart to fit over the uncut meridian ring and then squeezed back to correct size and shape. The cuts, of course, are made with a precise space and angle to suit the latitude

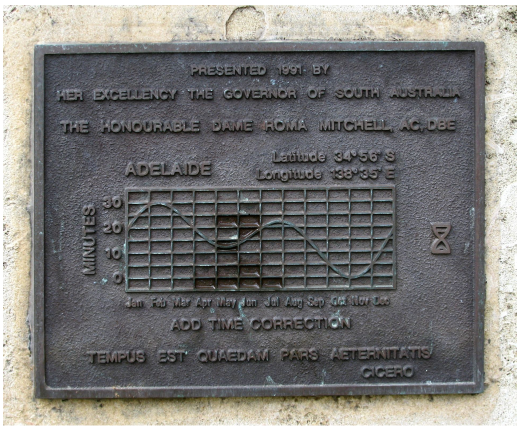


Fig. 6. A typical dedication plaque with equation of time. Note the high relief and the 'signature' sand timer logo of Sundials Australia.

Fig. 7. Machining the one of the flat surfaces of the meridian ring. Further work follows for the displaced circular outlines of the ring.

Sundials Australia

Fig. 10. An analemmatic dial at Mount Annan Botanic Gardens, near Campbelltown, Sydney. A distinguishing feature is the basalt date plate marked with an analemma.

Sundials Australia

Fig. 12. An example of dial-making versatility in stained glass.

angle for the gnomon. The component parts are jigged in place and bronze welding is contracted out to a local specialist. The completed joints are dressed to give an attractive smooth joint before fitting the hour ring (Fig. 8) and gnomon (Fig. 9).

As their reputation has grown, Sundials Australia has tackled a wide variety of designs in different materials and style to suit many different locations. The analemmatic

Sundials Australia

Fig. 11. Bishops Court - a dramatic dial in private grounds.

or 'sundial of human involvement' is popular, with the example in Fig. 10 being fairly typical.

Stainless steel has been used for a number of vertical dials, with a particularly striking example on the wall of Bishops Court, the Archbishop's residence, Adelaide (Fig. 11). The surfaces of the steel have been lightly etched to prevent them being too shiny.

Even stained glass has not escaped their technical capability, with a fine direct south facing dial for a college in Melbourne (Fig. 12). With such skills and experience, it is not surprising they are called upon to make a variety of plaques, dedication and other information panels.

Commissions for sundials have come from many different locations (widely scattered in the continent of Australia) and around the world, such as the Palace of the Dalai Lama, India; Carlisle and Yorkshire, England; Austin, Texas, USA; Sao Paulo, Brazil; Jeddah, Saudi Arabia; Suita, Japan; and several locations in New Zealand.

Although sundials cast in relief predominate, etching is still used where appropriate and, like all good businesses, Sundials Australia has diversified into instruments such as sun compasses, astrolabes, replicas of navigation instruments and a repair service. A current major project that is dependent on sunshine is a water purification system with cascading sheets of 'solar' panels that support evaporation and condensation to give distilled water.

The company does not have accurate records of how many sundials they have made and in answer to the question, the reply was "probably more than a thousand". I would not challenge this number as it is quite consistent with a busy workshop producing about a dial a week. This makes them certainly the most prolific maker of quality dials in the Southern Hemisphere. All credit to their robust designs, combining an honesty of form and function.

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READER'S LETTER

Poet Identified

In his article on memorial sundials in the March *Bulletin* (21(i)), John Wall asks for information about the inscription on the dial-bearing headstone at Mawnan Smith which reads:

"Say not Good-night, but in some brighter clime
Bid me Good-morning."

These are the last lines of 'Ode to Life' by Anna Laetitia Barbauld (1743-1825). The poem, which was admired by Wordsworth, can be found in *The Oxford Book of English Verse.* The *Dictionary of National Biography* contains an account of the poet's life and her enormous industry in the field of literature.

John Lester, Walsall.

TWO NEWLY DISCOVERED SUNDIALS ON THE ISLE OF WIGHT

ELIZABETH HUTCHINGS

This 7-inch diameter brass dial (right) was found in a box of old tools that was purchased cheaply some twenty-five years ago on the Isle of Wight. It is inscribed "Benjamin Cole No. 136 Fleet Street London". Benjamin Cole and his son, also Benjamin, ran their business from The Orrery adjoining The Globe Tavern in Fleet Street from 1751 to 1766.[1] This became 136 Fleet Street in about 1760 when the father would have been 65. It is perhaps possible that this dial was the work of his son who was then 35. There is no clue as to why it was found on the Island but maybe someone knows of a small pedestal in need of its missing dial. It is a pity that it is far too small to be the missing one at Tennyson's home, Farringford.[2]

The Isle of Wight resident who owns the previous dial bought the dial below in 1985. It was in the grounds of Swainston Manor at Calbourne not far from the famous Water Mill. The Simeon family had already sold the manor and moved to Canada in 1956. They were descended from Alfred, Lord Tennyson's friend Sir John Simeon about whom he wrote his famous poem *In the Garden at Swainston.* Part of the grounds had been a market garden run by Cyril Hawes. On his retirement he sold all his tools and equipment including a 1965 Ferguson tractor at an auction conducted by the Island auctioneers Way, Riddett. The County Press reported that the highlight of the sale was a Georgian sundial that raised £500. The present owner remembers that a dealer was bidding against him but he was determined that it should not leave the Island. He asked his friend John Polding to restore it and take photographs and they erected it in his garden in a paved sunken garden. Unfortunately the inscription is now largely worn away although the date 1735 can still be read around the four corners from an old photograph.

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ERRORS IN DIALS AT THE WRONG LATITUDE

TONY BELK

If a horizontal dial designed for one latitude is to be used at another latitude it can be set on a slightly inclined plane so that the style still points to the celestial pole. This is less convenient than setting the dial plate horizontal and I was recently asked for advice on what errors would occur if a horizontal dial was set with its dial plate horizontal at a latitude other than that for which it was designed. I could see a way of solving the problem based on a previous analysis.[1] I calculated some results and did some experimental verification to ensure that the calculated errors were of the right sign and value, allowing for experimental error. There are two aspects to the problem, firstly the style is not polar and secondly the hour line positions are not correct.

I then found a paper where Sawyer had discussed this problem for a particular dial and produced a general formula for any non-declining dial used at the wrong latitude.[2] The table of errors he gave matched my independent calculation to six significant figures, giving me confidence that they were both correct.

Lauroesch and Edinger[3] produced a series of articles analysing errors in manufacture, assembly and mounting of horizontal sundials. They studied gnomon angle, hour line angle and various assembly and mounting errors but they did not look specifically at a correctly designed and manufactured horizontal dial mounted with a horizontal dial plate at the wrong latitude.

There are a number of general points that emerge from these analyses.

1. For a given latitude difference, the maximum errors occur at about 6:00 hours and 18:00 hours but the error is not linear with time.

2. A two degree difference in latitude only causes a three minute maximum error in time reading, and a five degree difference a maximum error of nine minutes.

3. The errors depend only on the difference between the design latitude and the site latitude and not on the absolute value of either.

4. A change in the sign of the difference in latitudes gives exactly the same table of errors if the sign of the sun's declination is also reversed.

5. A vertical non-declining dial set at the wrong latitude has exactly the same errors as the equivalent horizontal dial.

I define the difference as the design latitude of the dial minus the latitude of the site at which it is used.

I tabulate below, as an illustration of the above points, a set of time readings for differences of latitude of -5°. The column at the left is LAT and the other columns are times read from the dial face. This table is an expanded version of the one published by Sawyer, covering more values of sun's declination.

Hour	Sun's Declination, degrees										
	-23.43	-20	-15	-10	-5	0	5	10	15	20	23.43
05:00	4 :52	4 :53	4 :55	4 :57	4 :59	5 :00	5 :02	5 :04	5 :05	5 :07	5 :09
06:00	5 :51	5 :53	5 :55	5 :56	5 :58	6 :00	6 :02	6 :04	6 :05	6 :07	6 :09
07:00	6 :51	6 :53	6 :55	6 :56	6 :58	7 :00	7 :01	7 :03	7 :05	7 :07	7 :08
08:00	7 :52	7 :53	7 :55	7 :57	7 :58	8 :00	8 :01	8 :03	8 :04	8 :06	8 :07
09:00	8 :53	8 :54	8 :56	8 :57	8 :58	9 :00	9 :01	9 :02	9 :03	9 :05	9 :06
10:00	9 :55	9 :56	9 :57	9 :58	9 :59	10 :00	10 :00	10 :01	10 :02	10 :03	10 :04
11:00	10 :57	10 :58	10 :58	10 :59	10 :59	11 :00	11 :00	11 :01	11 :01	11 :02	11 :02
12:00	12 :00	12 :00	12 :00	12 :00	12 :00	12 :00	12 :00	12 :00	12 :00	12 :00	12 :00
13:00	13 :03	13 :02	13 :02	13 :01	13 :01	13 :00	13 :00	12 :59	12 :59	12 :58	12 :58
14:00	14 :05	14 :04	14 :03	14 :02	14 :01	14 :00	14 :00	13 :59	13 :58	13 :57	13 :56
15:00	15 :07	15 :06	15 :04	15 :03	15 :02	15 :00	14 :59	14 :58	14 :57	14 :55	14 :54
16:00	16 :08	16 :07	16 :05	16 :03	16 :02	16 :00	15 :59	15 :57	15 :56	15 :54	15 :53
17:00	17 :09	17 :07	17 :05	17 :04	17 :02	17 :00	16 :59	16 :57	16 :55	16 :53	16 :52
18:00	18 :09	18 :07	18 :05	18 :04	18 :02	18 :00	17 :58	17 :56	17 :55	17 :53	17 :51
19:00	19 :08	19 :07	19 :05	19 :03	19 :01	19 :00	18 :58	18 :56	18 :55	18 :53	18 :51

Table 1. Time readings for a horizontal dial positioned 5° further north than its design latitude.

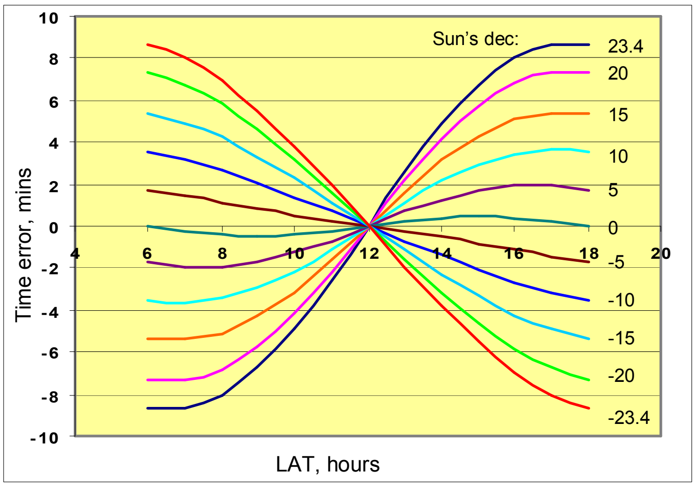

Fig. 1. Time errors for a dial with a -5° latitude error as a function of the sun's declination.

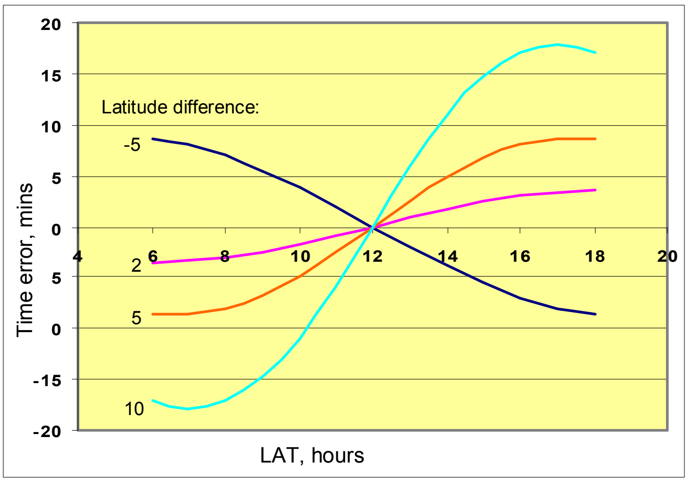

Fig. 2. Time errors for a dial as a function of the latitude error for a sun's declination of 23.4°.

I also include two graphs. Fig. 1 shows the error versus time for a latitude difference of -5° for a range of values of the sun's declination. Fig. 2 shows error versus time at the summer solstice for latitude differences of -5, 2, 5, and 10 degrees. In both cases the error is to be added to the dial reading to give LAT.

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3. T.J. Lauroesch & J.R. Edinger Jr.: 'Error Analysis of the Horizontal Sundial – I', *NASS Compendium*, 2 (3), 18-22 (1995).

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The Double Horizontal Dial – Then and Now

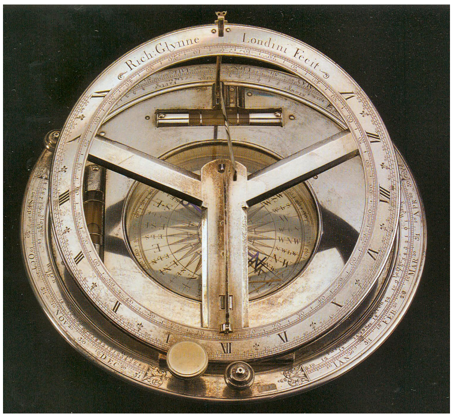
at the Oxford Museum of the History of Science

A mini exhibition with the above title was held at the Oxford MHS in February and March 2009. It was timed to co-incide with the completion of what is believed to be the first hand-engraved double horizontal dial for nearly three centuries, designed and made by Joanna Migdal. It was commissioned by St Hugh's College, Oxford, to replace a badly corroded double horizontal by the early 18th century maker Richard Glynne which had been given to the College in 1938 but had suffered badly since. The culmination of the exhibition was a private viewing on 19 February when the new dial was formally presented to St Hugh's and the story told to the assembled guests by Jim Bennett of the Museum, Joanna, and the Master of St Hugh's.

The exhibition also included the dialplate of the Richard Glynne double horizontal dial (the gnomon had been mislaid in the 1960s) and another by Elias Allen. Allen was also represented by a large horizontal instrument, the forerunner of the DH dial. Instruments by Richard Glynne are rare but we were treated to a close-up view of a superb universal inclining dial in silver by him. This instrument, in its original shagreen case, was once in the now defunct Rockwell Time Museum but was flown over to England by private plane for this exhibition.

Joanna Migdal with her new dial on display

A series of contemporary books describing the use of the dials was in another display case. These included William Oughtred's (the inventor of the dial) personal copy of his *Circles of Proportion and the Horizontal Instrument*, complete with his manuscript annotations for the next edition.



Richard Glynne's silver inclining dial

The new dial will shortly be installed at St Hugh's. An article describing its genesis and construction is promised for a future edition of the *Bulletin* so I will refrain from giving its full details here.

John Davis

THE 'LOST' BARRINGTON STAINED GLASS DIAL REDISCOVERED

JOHN DAVIS

The history of the Barrington (or Highworth) stained glass sundial was described in Geoffrey Lane's groundbreaking *Bulletin* article in 2006.[1] At that time the fate of the dial was unknown and the only known illustration was a b&w photograph from 1945. Now, as a result of diligent work by Jo Clark, a local historian, following up on an initiative by John Carmichael, the dial has been located and photographed in detail (Fig. 1 and rear cover).

The dial was made in 1641 by Baptist Sutton for the Puritan Essex MP Sir Thomas Barrington. It was made for his London house in Great Queen Street and is said to have cost 6s 8d.[1] The house was later pulled down but the dial survived at Warneford Place near Highworth, Wilts., the home of Lord Banbury. Warneford Place was sold to Ian Fleming (of James Bond fame) in the 1960s but he then extensively remodelled it and the dial diasppeared from the premises and from sight of the dialling community. Now, the dial remains in private hands near London and is kept safely indoors.

Fig. 1. The Barrington dial

The actual dial is just 278 × 173 mm though the overall panel is 460 × 288 mm. It features the coat of arms for Sir Thomas and his second wife Judith, neé Lytton. It also has both a spider and a fly, with the fly painted on both sides of the glass in order to give it a three-dimensional effect (Fig. 2). The body and legs are on the outside and the wings are on the inside – the same arrangement as on Sutton's *Non Sine Lumine* dial. The gnomon is unsurprisingly missing but its mounting holes are clearly visible: the origin is in the lower left border of the shield and there are three other holes (two now filled) carefully positioned in the black horizontal strip above the lower numerals. Generally, the dial is in very good condition.

Fig. 2. The spider and fly viewed from the inside.

One unusual feature is the number '42' scratched into the glass on the back (outside) of the dial, behind the decoration above the shield and hence only visible on close examination (Fig. 3). This, it seems, is not a serial number for the dial but its design declination. Reverse engineering of the dial gave a declination of around 41° E, about right for the a house along the northern side of Great Queen Street. A similar scratched number exists on the back of at least one other stained glass dial, that at The Merchant's House, Marlborough, Wilts (in that case the number is '45').[2] The Marlborough dial is attributed to John Oliver so either the practice of labelling dials with their declinations was quite general to mid-17th century London diallists or the attribution is wrong. If you have the opportunity to view the outside of a stained glass dial closely, please look for such numbers.

ACKNOWLEDGEMENTS

It is a pleasure to thank the owners of the dial for permission to photograph it and also John Carmichael and Jo Clark for locating it.

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1. G. Lane: 'Glass Sundial Makers of 17th Century London', *BSS Bulletin*, 18(i), 41-47 (March 2006).
2. Thanks to David Brown for pointing this out to me.

Fig. 3. The scratched number '42' on the outside of the dial.

EARLY EAST-FACING DIALS

TONY WOOD

These are what the French call 'cadrans orientales' which makes them sound like Chinese dials. A recent expedition to a remote part of Northamptonshire resulted in the discovery of a direct east-facing dial, high up on the end of a house in Eydon (Fig. 1). The house also has a straightforward direct south vertical (Fig. 2) and a mass dial by the door (Fig. 3); riches indeed (in sundial terms anyway).

Fig. 1. A direct East dial in Eydon.

The east-facing dial's hour lines are angled to be almost parallel to the roof line and initial thoughts of the edging providing a gnomon were dispelled by the two holes on the 'six' line. They tell us that there was a 'goalpost' type gnomon and imply that the dial is comparatively old as later direct-east or direct-west dials had 'wedge' type gnomons. Roman numerals mark the hour lines and go up to 10am with a mistake in that the 6am line is marked with VII.

The presence of a direct-east dial on a relatively modest secular building is most unusual and direct carving into the stonework implies an early date; is this one of the earliest direct-east dials ever? Maybe, maybe not, but another east-

Fig. 4. The direct East dial at Great Washbourne.

facing dial, this time in Gloucestershire, has certain similarities and may be claimed to be the earliest direct-east church dial (Fig. 4). It is at Great Washbourne and is carved at the lower left corner of the east window. The church has one or two mass dials but this direct-east is unexpected and is low down, carved across two or three stones. Again, two holes on the 'six' line indicate a 'goalpost' gnomon and the numerals are in clear Arabic form this time, the '11am' almost detached on a spare bit of stonework. The dial is at chest height following mass dial tradition and one imagines the gnomon may not have lasted long as iron was a valuable commodity. It was soon learnt to put your dials high up – so high indeed that one wonders if they could be read by anyone – the slightly later *west*-facing dial at Ilmington in Warwickshire (Fig. 5) illustrates the point nicely in spite of being described as 'Saxon' in the church booklet.

So, do we have two 'earliest' east-facing dials as described here – any other offers?

Many thanks to Alison Parsons and Kevin Lodge from Eydon Historical Society for their help.

Fig. 2. Direct South (left) and Fig. 3 (right) mass dials in Eydon.

Fig. 5. Direct West dial in Ilmington.

THE ADJUSTMENT OF WALL MOUNTED VERTICAL SUNDIALS

ORTWIN FEUSTEL

The Problem

An engraved, metal, vertical sundial had been calculated for the geographical latitude ϕ and a wall declination $d_{wall} = 0$ or $d_{wall} \neq 0$. The sundial plate was fastened using a level and with the help of threaded rods, hexagon nuts, washers and hexagon domed nuts on the wall, see Fig. 1. The holes on the plate's corners are elongated. After installation, the indicated time, LAT_{dial}, is not in accordance with the actual time LAT_{act}. This resulted from an inaccurate declination d_{dial} – see Fig. 2 – of the sundial plate causing $LAT_{dial} \neq LAT_{act}$. Thus we require the angle of rotation $\Delta d = d_{wall} - d_{dial}$ in order to turn the plate through Δd degrees towards the correct position so that $LAT_{dial} = LAT_{act}$. The axis of rotation is the vertical through the base of the polar-pointing gnomon.

Geometric Arrangement

For convenience, we take a rectangular triangle for shadow casting as a basis for solving the problem, see Fig. 3: the

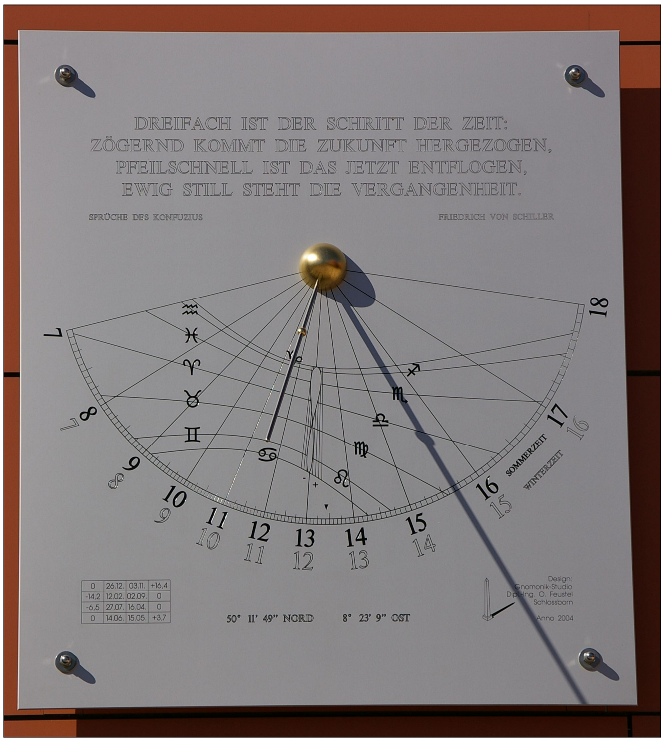

Fig. 1. The vertical declining sundial in operation. The engraved dial plate is of matt, silver-coloured electrolytically oxidized aluminium; the engraving is filled black. The hemisphere at the base of the stainless steel polar-pointing gnomon and the small spherical nodus are gold coated. The wall fastening of the dial plate is equipped with a fine adjustment.

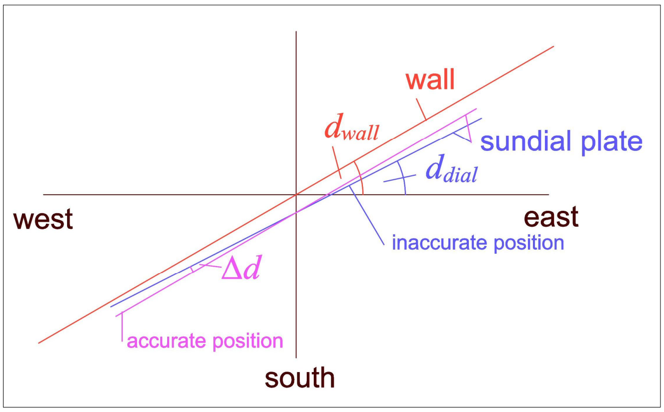

Fig. 2. Looking from the zenith on the declining dial plate with its true as well as inaccurate position; after turning the dial plate according to angle Δd will result in $d_{wall} = d_{dial}$ and hence $LAT_{dial} = LAT_{act}$.

hypotenuse OH embodies a style with the footpoint at the origin of coordinates O, perpendicular GH (perpendicular to the dial face) fulfils the function of a pin gnomon (typically a thin metal rod) with footpoint G and the perpendicular OG (runing parallel to the dial face) is same as the substyle. The trigonometrical details of the the shadow triangle OSG are shown Fig. 4. The pin gnomon casts the

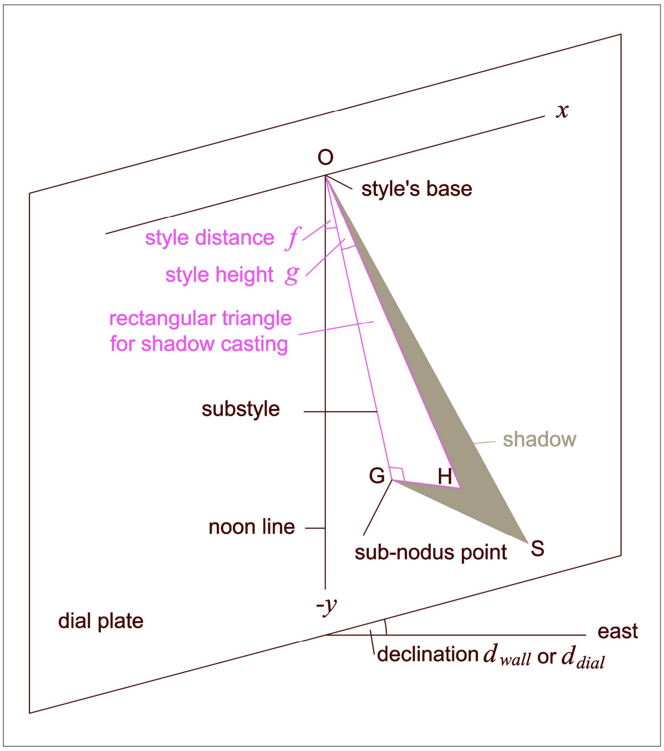

Fig. 3. Schematic representation of a declining dial plate showing the rectangular triangle OHG for casting the shadow OSG.

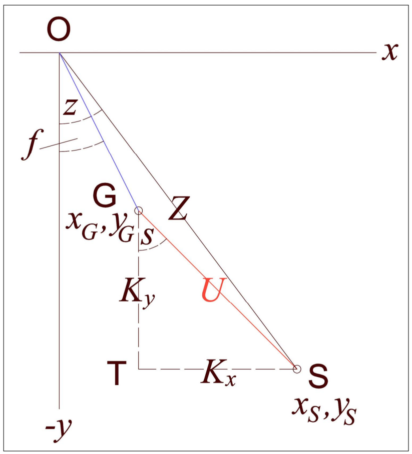

Fig. 4. A rectangular triangle produces, on the face of a declining south sundial, the shadow triangle OSG. Point O has the coordinates 0, 0 and fulfils the base of an adequate style, point G with the coordinates x_G , y_G functions as the corresponding pin gnomon base and the coordinates x_S , y_S belongs to the shadow tip S. U embodies the pin gnomon's shadow length and Z is synonymous with the style's shadow. Further symbols and their meanings are: f substyle distance, z time line angle and s shadow angle.

shadow line *U* making the shadow angle *s* with the vertical. The hypotenuse generates the time line *Z* making the angle *z* with meridian line (the ordinate, *y*). The substyle OG makes the angle style distance *f* with meridian line.

The properties of the shadow angle measuring instrument[3] (equipped with a pin gnomon, i.e. a thin metal rod perpendicular to the instrument face) shown in Fig. 5 on p.19, are helpful for calculating the required dial plate declination d_{dial}, i.e. the sun's coordinates – declination δ, azimuth a and altitude h at the moment of adjustment LAT_{act} (hour angle τ_{act}) – are needed. Furthermore, the coordinates of the pin gnomon origin (expressed by the style characteristics *f* and *g*) will be taken into consideration.

Symbols and Sign Conventions

	positive values	negative values
wall declination d_{wall}; sundial declination d_{dial}	looking from the zenith: turning the wall w.r.t. the dial plate clockwise, away from the east-west direction	looking from the zenith: turning the wall w.r.t. the dial plate counterclockwise, away from the east-west direction
hour angle τ	western of the local meridian	eastern of the local meridian; ($\tau = 0$ at midday)
time line angle z	westward between an hour line and the vertical through the style's base	eastward between an hour line and the vertical through the style's base; ($z = 0$ at midday)
shadow angle s	eastward between a shadow line and the vertical through the pin gnomon origin	westward between a shadow line and the vertical through the pin gnomon origin
geographical latitude ϕ	northern hemisphere	southern hemisphere
geographical longitude λ	eastwards of the Prime meridian	westwards of the Prime meridian
sun azimuth a	westward of the local meridian	eastward of the local meridian; ($a = 0$ at midday)
sun altitude h	above the horizon	below the horizon

Fundamental Calculations

Sun coordinates

The relationships between the coordinates of the equator system and the horizon system are

$$a = \arctan\left(\frac{\sin\tau_{act}}{\sin\phi\cos\tau_{act} - \cos\phi\tan\delta}\right) \qquad (1)$$

$$h = \arcsin(\sin\phi\sin\delta + \cos\phi\cos\delta\cos\tau_{act}) \qquad (2)$$

Style characteristics[2]

The style height is given by

$$g = \arcsin(\cos\phi\cos d_{wall}) \qquad (3)$$

and the style distance reads

$$f = \arctan\frac{-\sin d_{wall}}{\tan\phi} \qquad (4)$$

Both angles are drawn in Fig. 3.

At the substyle hour angle

$$\tau_{sub} = \arctan\frac{\tan d_{wall}}{\sin\phi} \qquad (5)$$

the directions of the style's shadow, the pin gnomon's shadow and the substyle coincide. Furthermore, the style's shadow has its shortest length.

Pin gnomon coordinates[1]

The dial plate coordinates of a pin gnomon's base (the subnodus point) can be expressed by its length *G*, the style height *g* and the style distance *f* :

$$x_G = -G\frac{\sin f}{\tan g} \qquad y_G = -G\frac{\cos f}{\tan g} \qquad (6, 7)$$

From (3) we get

$$1 + \frac{1}{\tan^2 g} = \frac{1}{\sin^2 g} = \frac{1}{\cos^2\phi\cos^2 d_{wall}} \qquad (8)$$

$$\frac{1}{\tan g} = \sqrt{\frac{1}{\cos^2\phi\cos^2 d_{wall}} - 1} \qquad (9)$$

and from (4) it follows

$$1 + \frac{1}{\tan^2 f} = \frac{1}{\sin^2 f} = 1 + \frac{\tan^2\phi}{\sin^2 d_{wall}} \qquad (10)$$

$$\sin f = \frac{\sin d_{wall}}{\sqrt{\tan^2\phi + \sin^2 d_{wall}}} \qquad (11)$$

producing, respectively

$$1 + \tan^2 f = \frac{1}{\cos^2 f} = 1 + \frac{\sin^2 d_{wall}}{\tan^2\phi} \qquad (12)$$

$$\cos f = \frac{\tan\phi}{\sqrt{\tan^2\phi + \sin^2 d_{wall}}} \quad (13)$$

Inserting relations (9) and (11) in (6) yields

$$x_G = G\frac{\tan d_{wall}}{\cos\phi}\sqrt{\frac{1-\cos^2\phi\cos^2 d_{wall}}{\tan^2\phi + \sin^2 d_{wall}}} \quad (14)$$

and inserting (9) and (13) in (7) produces

$$y_G = -G\frac{\tan\phi}{\cos\phi\cos d_{wall}}\sqrt{\frac{1-\cos^2\phi\cos^2 d_{wall}}{\tan^2\phi + \sin^2 d_{wall}}} \quad (15)$$

Pin gnomon's shadow casting[3]

The shadow angle s – depending on azimuth a, altitude h and dial declination d_{dial} – is defined by

$$s = \arctan(\frac{\sin(a - d_{dial})}{\tan h}) \quad (16)$$

or reordered

$$\sin s = \frac{\sin(a - d_{dial})}{\tan h}\cos s \quad (17)$$

The shadow length U (the distance between the sub-nodus point G and the style's tip S in Fig. 4) amounts to

$$U = G\frac{\tan h}{\cos(a - d_{dial})\cos s} \quad (18)$$

Using shadow length and shadow angle we obtain the perpendiculars of the triangle GST in Fig. 4,

$$K_x = U\sin s \qquad K_y = U\cos s \quad (19, 20)$$

In consideration of (17) and (18), formula (19) becomes

$$K_x = G\tan(a - d_{dial}) \quad (21)$$

and the insertion of (18) in (20) leads to

$$K_y = G\frac{\tan h}{\cos(a - d_{dial})} \quad (22)$$

Time line angle[1]

$$z = \arctan\frac{-\cos\phi\tan\tau_{dial}}{\cos d_{wall} + \sin d_{wall}\sin\phi\tan\tau_{dial}} \quad (23)$$

Zone time, local apparent time, hour angle[3]

$$CET = CEST - 1h \quad (24)$$

$$LAT = CET - (1 - \frac{\lambda}{15}) + ET \quad (25)$$

$$\tau = (LAT - 12)15 \quad (26)$$

The date dependent values of the equation of time ET, which are required for calculating the local apparent time LAT, can be obtained either from an astronomical yearbook or by using the formulae given in reference 3.

General solution

We require the effective sundial declination d_{dial} if, at a certain moment τ_{act}, the shadow point S – casting from the triangle tip H (= style's tip = pin gnomon's tip) – meets the time line Z which makes the angle z with noon. The Cartesian coordinates of the shadow tip S are composed of the pin gnomon coordinates (14) and (15) as well as the perpendiculars (21) and (22), see Fig. 4:

$$x_S = x_G + K_x = x_G + G\tan(a - d_{dial}) \quad (27)$$

$$y_S = y_G - K_y = y_G - G\frac{\tan h}{\cos(a - d_{dial})} \quad (28)$$

It follows from this directly

$$z = \arctan\frac{x_S}{y_S} = \arctan\frac{x_G + G\tan(a - d_{dial})}{y_G - G\frac{\tan h}{\cos(a - d_{dial})}} \quad (29)$$

(23) corresponds to (29), i.e. it is valid

$$\frac{-\cos\phi\tan\tau_{dial}}{\cos d_{wall} + \sin d_{wall}\sin\phi\tan\tau_{dial}} = \tan z = \frac{x_G + G\tan(a - d_{dial})}{y_G - G\frac{\tan h}{\cos(a - d_{dial})}} \quad (30)$$

and consequently we obtain

$$\tan z = \frac{x_G\cos(a - d_{dial}) + G\sin(a - d_{dial})}{y_G\cos(a - d_{dial}) - G\tan h} \quad (31)$$

the equation of condition for d_{dial}.

Using in (31), the well known addition theorems instead of the functions with the argument a - d_{SU} and furthermore the relation $\sin^2 d_{SU} + \cos^2 d_{SU} = 1$ we obtain two quadratic equations for the variables $\sin d_{SU}$ and $\cos d_{SU}$. Finally the relations required are

$$d_{dial\,s\pm} = \arcsin(\frac{CD}{1+D^2} \pm \sqrt{(\frac{CD}{1+D^2})^2 + \frac{1-C^2}{1+D^2}}) \quad (32)$$

and

$$d_{dial\,c\pm} = \arccos(\frac{C}{1+D^2} \pm \sqrt{(\frac{C}{1+D^2})^2 + \frac{D^2-C^2}{1+D^2}}) \quad (33)$$

with the terms

$$C = \frac{B}{A\cos a - \sin a} \qquad D = \frac{A\tan a + 1}{A - \tan a} \quad (34, 35)$$

$$A = \frac{y_G\tan z - x_G}{G} \quad (36)$$

where

$$B = \tan z\tan h \quad (37)$$

Two of the angle values $d_{dial\,s+}$, $d_{dial\,s-}$, $d_{dial\,c+}$, $d_{dial\,c-}$, obtained from (32) and (33) have the same magnitude but different signs. The dial plate angle d_{dial} whose sign equals to the sign of the wall declination d_{wall} is the correct one. This value has to be used for the required change of the dial

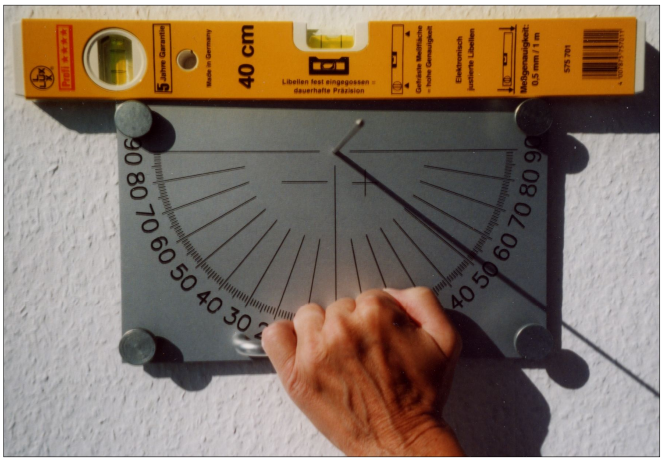

Fig. 5. The pin gnomon of this shadow angle measuring instrument is perpendicular to the instrument face. It has a length of 200 mm and its diameter is 3 mm. The calculation of a wall declination is based on the angle which the pin gnomon's shadow makes with the vertical through its base at a certain time.

plate direction

$$\Delta d = d_{wall} - d_{dial} \qquad (38)$$

Example

The following quantities will be given: location parameters $\phi = 50°$, $\lambda = 7.5°$, $d_{wall} = 25°$; design parameter $G = 20$; date of adjustment 1st May, $\delta = 15°$, $ET = 3$ min; moment of adjustment $CEST = 16{:}28$, $LAT_{dial} = 15{:}00$. We require d_{dial} and hence Δd.

formula	symbol	dependent on	value
(24)	CET	$CEST$	15:28
(25)	LAT_{act}	CET, λ, ET	14:55
(26)	τ_{act}	LAT_{act}	43.75°
(26)	τ_{dial}	LAT_{dial}	45°
(1)	a	τ_{act}, δ, ϕ	61.14°
(2)	h	τ_{act}, δ, ϕ	40.30°
(14)	x_G	ϕ, d_{wall}, G	-9.33
(15)	y_G	ϕ, d_{wall}, G	-26.30
(23)	z	$\tau_{act}, d_{wall}, \phi$	-47.81°
(36)	A	y_G, z, x_G, G	1.92
(37)	B	z, h	-0.94
(34)	C	A, B, a	-18.85
(35)	D	A, a	43.56
(32)	$d_{dial\ s+}$	C, D	-24.32°
(32)	$d_{dial\ s-}$	C, D	**-26.96°**
(33)	$d_{dial\ c+}$	C, D	26.96°
(33)	$d_{dial\ c-}$	C, D	155.67°
(38)	Δd	d_{wall}, d_{dial}	**1.96°**

Plausibility test: The sum of the relevant angle values equals to 0°, the difference of the non-relevant angle values yields 180°.

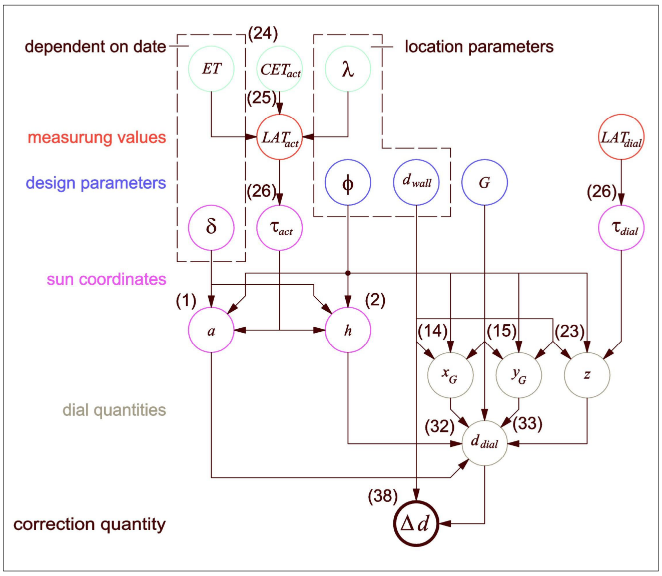

Fig. 6. Flow diagram for the calculation of the correction angle Δd. The numbers in brackets refer to the relevant formulae.

Fig. 6 represents the above mentioned calculation procedure as a logical flow diagram.

Final Remarks

For a direct south sundial, the insertion of $d_{wall} = 0°$ in (27), (28) and (29) yields finally formulae which are less complicated than the relations (32) and (33). Using them for the above example makes clear that the appropriate formulae of a vertical sundial also can be used basically for the calculation of a vertical declining sundial's correction angle Δd. This results from the fact that the pin gnomon's shadow casting depends on the relevant sun coordinates at the moment of adjustment (according to the functional principle of a shadow angle measuring instrument[3]).

Furthermore, it is very interesting to consider the shadow casting in connection with the substyle. At the time τ_{sub} when the style's shadow coincides with the substyle, i.e. the style distance f equals to the shadow angle s and the points O, G and S in Fig. 4 form a straight line. Linking (4) with (16) results in a clear relation for this special case.

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SUNDIALS WITHIN THE TROPICS

MALCOLM BARNFIELD

By definition, 'The Tropics' refer to a torrid zone surrounding the Earth's equator. This zone is bounded by the Tropic of Cancer in the north and the Tropic of Capricorn in the south.

The ecliptic is the name given to the apparent path which the sun follows around the earth in one solar year and its extremes define the sun's maximum declination, from a geocentric perspective, north or south of the celestial equator. These extremes define the lines of the tropics 23.44° north and south of the terrestrial equator. This angle is also referred to as the 'obliquity of the ecliptic'. Of course, it is the earth moving and not the sun and the phenomenon causes the seasons because the earth's axis is tilted away from the perpendicular by 23.5° and so different zones are facing the sun at different times of the solar year. It is these ecliptic extremities that mark the limits of the points where the sun will be directly overhead at the summer solstices: the solar altitude at local solar noon on that day, in that place, is 90°. Further north of Cancer or south of Capricorn, the maximum solar altitude reduces with increasing latitude and, as you continue into the temperate zones, there is less sunlight in winter and the colder it becomes. Eventually, in the frigid zones, the Arctic/Antarctic zones get no sun at all for many months of each year and 24 hours of sunlight at other times. All the while, the exact opposite is happening in the other hemisphere.

Inside the tropics, day length is much less variable compared to that of the poles. At the tropic boundaries, maximum day length is roughly 13.5 hours and the minimum is 10.5 hours. At the equator, day length is constant with exactly 12 hours of day and 12 hours of night. Perhaps this makes the region an ideal sundial territory.

The word twilight refers to pre-dawn or post-dusk light. The words crepuscular and gloaming have similar meanings. Inside the tropics, it almost seems that there is no twilight or at best only a few minutes of it. It is day and then it is night with no intervening period. The reverse occurs at dawn. Twilight is due to the scattering by the atmosphere of light from the sun when it is below the horizon. Within the tropics, the sun crosses the horizon at a very steep angle and so it rapidly becomes too far below the horizon to allow significant scattering.

The northern Tropic, Cancer, was named after the constellation of the Crab (in Latin) by Hipparchus in the 2nd century BC as the ecliptic at that time ran through this constellation at the solstice. Similarly, in the south, the same applied to the constellation of Capricorn (Latin for *goat's horn*). Precession of the Equinoxes renders that naming invalid now because 2200 years on we are in the Age of Aquarius and not the Age of Pisces as we were then. Old habits die hard so we retain the original names.

Approximately a quarter of the world's landmass is contained within the tropics and these areas are highly populated so, logically, a quarter of the world's sundials might be expected to be inter-tropical too. This is clearly not so and the heaviest concentrations of dials are within the temperate zones of the northern hemisphere. The United Kingdom, for instance, has a very high concentration of sundials but the least sunny days, unlike the tropics: strange but true.

It may then be thought that there are problems in the making of dials for tropical latitudes. Again, this is not so and whilst there are limitations to such dials the very same formulae used for calculating temperately-located dials apply equally to tropical dials.

As a southern hemisphere diallist who lives close to Capricorn (Johannesburg, 26° south) I have made dials for South Africa, Zambia, Namibia, Botswana and Australia, all within the southern tropic, and experienced no problems with any of them.

I personally only know one other diallist who has made such a dial: Henk van der Ham, a South African dial-making colleague with whom I have often worked jointly. It seems that inter-tropical sundials are a fairly rare breed.

Horizontal Sundials

Horizontal sundials are probably the best-known and most frequently made of all sundial formats. Their simplicity, practicality and beauty have appealed for more than 600 years. The very fancy and beautiful filigree work so often seen on the gnomons of European dials is just not possible on inter-tropical dials. This is for space reasons and is clearly illustrated in Fig. 1, a dial made by Henk van der Ham for Rundu, at 18° South, in Namibia. Here the very flat gnomon simply does not allow cutouts but it works perfectly and that dial is exceedingly accurate.

A horizontal dial actually on the equator is a teaser. Not only does its gnomon look very different, being completely flat and parallel to the dial plate, but how should it be calibrated? Does that resident consider himself a citizen of the

Fig. 1. Horizontal sundial at 18° south. Dial and photo by Henk van der Ham.

northern hemisphere, in which case the dial would be calibrated clockwise, the wrong way, from 6am to 6pm only, or, a member of our southern tribe when the dial would be calibrated anticlockwise, the right way? Humour aside and besides its strange appearance, the dial would work whichever way the numbering went. It is actually a polar dial and need not be dual calibrated to work after the sun's transition of the equator provided the observer uses the same observational orientation for all seasons. So, after the sun's apparent transition of the equator, the same dial would be unaffected.

The very flat gnomon inclination angle at Rundu and the direction to the equator seem normal to me and the highest angle we could get in South Africa is about 33° in the southern Cape. To an English diallist, 'normal' would be a minimum of 50° at Land's End. Some European diallists have commented on strange-looking gnomons after seeing my web site and some of my local work. It is what you have become accustomed to I suppose.

A point raised by all of those canvassed for opinion about inter-tropical dials was the crowding of hour lines around the noon mark on an inter-tropical horizontal sundial. Indeed, calibration to less than 15 minutes is almost impossible on a small dial and 5-minute calibration on a dial of 400 mm diameter is the closest practical spacing possible. Again, Fig. 1 illustrates this.

Fig. 2 is taken from the PowerPoint™ presentation 'Dancing Hour Lines' by Tony Moss.[1] It shows the phenomenon of noon line crowding as the latitude decreases. This then raises the point that the space for the insertion of the noon figure XII on a dial inside the tropic is small. However, this is easily overcome and here size does count. Simply increase the gnomon thickness. This still works when the dial is longitude-corrected like that in Fig. 1. Alternatively, it is just a slight design change to bring the numbering inside the hour calibration. Unconventional yes, but it works when a client insists on a horizontal dial at Rundu. Yet another method is to place odd numbers in an arc above the even numbers as stonemasons have done on sundials.

Horizontal dials in the tropics are not new. There is an example of an 18th century London-made dial from Joseph Jackson at Codrington College in Barbados, at 13° 10' N, with another by Henry Pyefinch nearby.[2]

Analemmatic Sundials

Theoretically, horizontal-format analemmatic dials work equally well at most latitudes. Within the tropics, the minor axis of the ellipse becomes smaller until the ellipse degenerates to a simple E-W line at the equator, so the engineering of the dial becomes a problem. I have made two analemmatic dials for Johannesburg at 26° south: in one case the proximity of the sliding gnomon to the midday mark caused headaches during construction as did the person standing on the declination plate of the other dial. The situation only gets worse upon entering the tropic as the noon mark is obliterated by the date scale for the gnomon. It is not a format I would recommend for the tropics or even close to them.

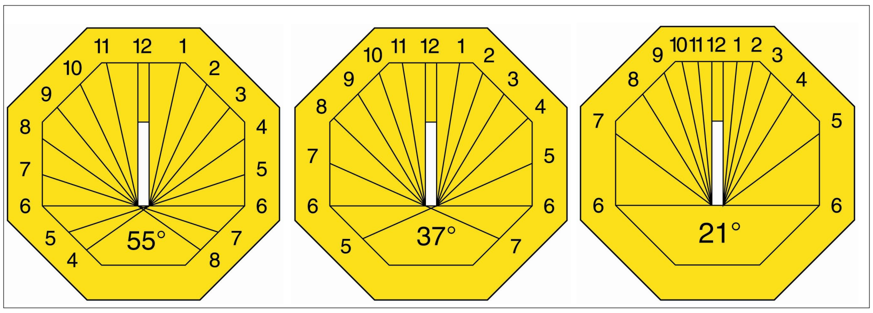

Fig. 2. Horizontal sundial plates for latitudes 55°, 37° & 21° N. Courtesy of Tony Moss.

Fig. 3. Local Meridian cutout on an armillary sphere. Photo by Richard Barnfield.

Two dials in the Botanic Gardens, Singapore, at 1° 22′ N. Fig. 4 (left) an armillary sphere, and Fig. 5 (above) an armillary dial. Photos by David Isaacs.

Armillary Spheres

The armillary sphere has always allowed the maker great artistic licence during construction. On some, there is so much symbolism such as tortoises, the Zodiac, statuettes, unneeded rings, stars and so on that the time-telling function is virtually lost in all the clutter. Even at higher latitudes, the armillary sphere always produces the problem of the local meridian ring shadowing the equatorial ring near midday. Fig 3 illustrates a partially successful attempt to overcome this problem with a cutout from the local meridian. Inside the tropics, the problems become two-fold because, in addition to that above, the top of the equatorial ring also begins to shadow its lower section of hour lines on the inside bottom of the ring. Fig. 4 shows an armillary sphere in Singapore at just over 1° north and, whilst the engineering of this dial is excellent and the dial is attractive, I doubt it reads at all for at least five months of the year. Thus the installation of an armillary sphere at such low latitudes is a compromise between artistry/symbolism and practicality which leads on to the variant known as an armillary sundial.

Armillary Sundials

This type of sundial is half of an armillary sphere. It has in the past been called it a solar chronometer by some French diallists. It is eminently suitable for every latitude as Fig. 5 shows. This dial is in the same Singapore Botanic Garden as Fig. 4 and comparing the two vividly highlights the practical value of the armillary sundial as opposed to that of the armillary sphere. Sundials on public display are always subjected to rough handling and the clever and rugged design of this one makes it not only robust and attractive but also readable during all sunlit hours. Of note is its longitude correction (which the armillary sphere can also have) but in terms of usage and delivery the armillary sundial has to be the winner every time. Such dials are easy to make and contain no trigonometry to scare off the novice. For a dial within the tropics, this style gets my vote and for the beginner it is an ideal starting point. Still, if it is 'pretty' you want, go with the sphere.

Polar Sundials

Polar sundials are a very good choice of sundial for the tropics. Less well-known than horizontal sundials and perhaps a little odd looking with their upturned 'ears' for the earliest/latest hours, they remove any perceived problems the horizontal dial may present. The 'ears' are upturned because the light striking the dial at very low angles would project towards infinity, never touching the dial plate. If the dial has provision to adjust the inclination of the face to an angle equal to its latitude, it is a universal (and portable) dial. Of course, the numbering needs to be reversed for northern and southern hemisperes which prevents the longitude correction being easily applied. These dials are relatively easy to draw and calculate and are simple to construct. The choice of gnomon size also then allows filigree and fancy work that other formats inside the tropics do not. The usefulness of this dial within the tropics is probably belied by its relative obscurity. Fig. 6 shows an example of a commercial brass polar dial from Spot-On Sundials.[3] It is adjustable for the northern hemisphere and shows both LAT in Roman numerals and British Summer Time (approx.) in Arabic numerals. Namibia now also uses daylight saving time in winter so again the polar dial shows its versatility and value within the tropics.

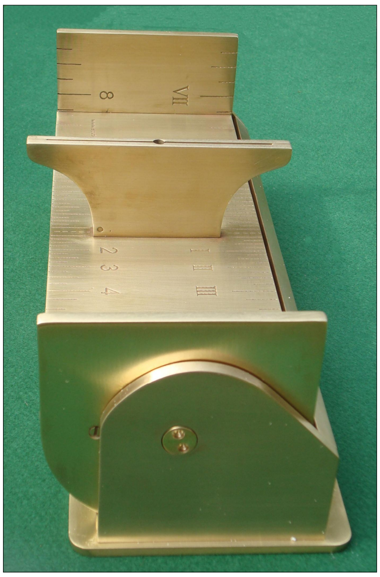

Fig. 6. A univeral polar sundial, set with its dial plate horizontal for the equator. Photo by Piers Nicholson.

Vertical Sundials

The single direct north or south facing vertical sundial is largely useless inside the tropics and such a dial at the equator would only read for six months of the year. To clarify, a vertical direct north or south sundial at less than 23.5° north or south respectively would happily read all day during most of the appropriate winter. In summer, however, readability rapidly declines the further north from the southern hemisphere tropic or south from the northern hemisphere tropic that the dial is situated. This because of the sun's azimuth angle of well over 90° from north at dawn and dusk and the problem increases as the summer solstice is approached. A vertical dial at 25° south will only read for about 5½ hours a day in midsummer. Direct east and west vertical sundials have limited readability anyway, and a combination of all three dials on a single square pillar or plinth would not solve the problem, especially on the equator. Similarly a cubic plinth containing direct north, south, east and west vertical sundials still has limited readability and surely the east and west dials would have to be dual calibrated. Suffice to say that the vertical sundial is not a good choice of sundial format for the tropics.

A further difficulty with vertical dials within the tropics is positioning them. A southern hemisphere house usually has its living rooms facing north and bedrooms to the south so it is unlikely that a direct north facing wall is available for a vertical dial. Further to this, the pitch of a roof is said to closely follow the latitude of the place where it stands. I live at 26° south and my roof pitch is 26° with a 1 m overhang at the eaves. This design ensures that the sun does not penetrate my glass doors even at floor level from September to March. It then follows that a vertical dial two metres up my north facing wall would not be lit for half of the year. Many inter-tropical houses have large eaves all around the house to help cool the place and since the sun is mostly right overhead no house wall is available for the dial. So for the vertical dial inside the tropic it is a plinth or nothing and to me that takes away from the very beauty of the dial format often so attractively attached to the front of a building in temperate regions.

I have lived in Africa within or close to the tropics for most of my life and the only vertical sundial I have ever seen is at Cape Town Castle, 33° 56' south. There must be a good reason for this.

Thus the direct vertical sundial and its family of vertical declining sundials, within the tropics, cannot be considered successful. However, there are several most interesting and ancient examples in Ecuador on the Quito Sundial Trail,[4] only 0° 14' south, some dating from the 18th century as shown in Figs. 7 and 8.

François Blateyron, author of the Shadows sundial drawing program,[5] suggests Fig. 9 as a possible solution for a vertical dial on the equator. He adds that this dial is a direct East sundial but its drawing appears almost vertical, following the path of the Sun from East to West and passing close to the zenith. As the location is 2° 53' S, the equinoctial line is slightly tilted. Even this still can not deliver a midday reading since the tip of the shadow at midday does not touch the dial plate, much like the 6am and 6pm shadow of the polar dial. The gnomon of this dial would be a horizontal pin from the centre of the equinoctial line at A with a T piece on top between points B and C.

Jaime Gaviria, from Medellin, Colombia, approaches the problem in a different way with this lovely composite pyramid dial (Fig. 10). The dial stands at 6° 15' N. Here the very clever use of four reclining dials solves some of the problems of direct vertical dials inside the tropics and delivers a beautiful and practical solution which must be a big talking point to all those who are lucky

P. Nicholson

Fig. 7. A vertical dial at the 17th century church of Guapolo, near Quito, Ecuador. The horizontal gnomon, now missing, would have rested in the channel across the top of the dial.

Fig. 8. Another vertical dial in Ecuador, this one outside the main entrance of the Universidad Central de Quito. It is double-sided and also has markings on the edges but unfortunately the gnomons are badly bent.

Fig. 9. A design for a direct east dial using ShadowsPro, by François Blateyron.

enough to see it. However, readings from the dials after 3pm are restricted, irrespective of season. But a reading from one or other dial, for the other hours, will always be available wherever the sun may be in its annual journey.

Elevation or Altitude Sundials

The elevation (altitude) sundial in its various guises, including the cylindrical shepherd's dial and perforated ring sundials, works on the sun's altitude casting a shadow from a pin gnomon or from a sunray through a hole, the dial having been turned to face the sun. Thus it is not fixed north/ south for the sun's azimuth to cast a shadow from a gnomon. Many types are designed for a specific latitude. They are not usually quite as accurate as azimuth dials, partly because portable types are rather small.[6] The big difference between summer and winter daylight hours in the higher latitudes, where they were initially popular as portable

Fig. 10. Pyramid dial in Medellin, Columbia. Dial and photo by Jaime Gaviria.

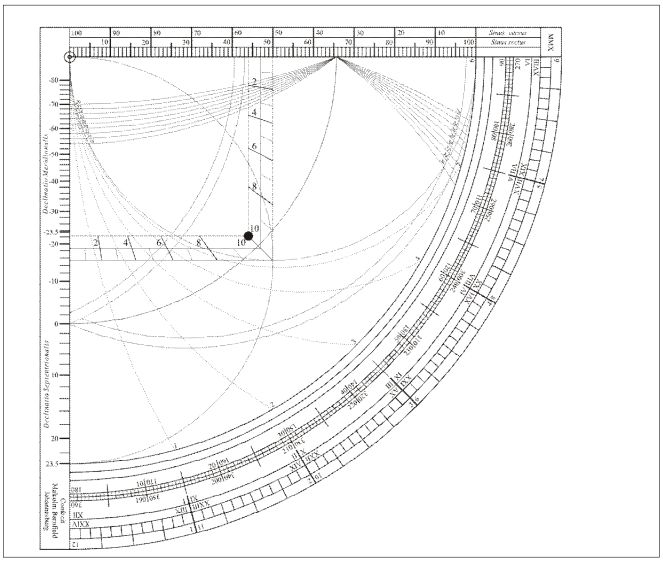

Fig. 11. Astrolabe quadrant. Drawing by the author.

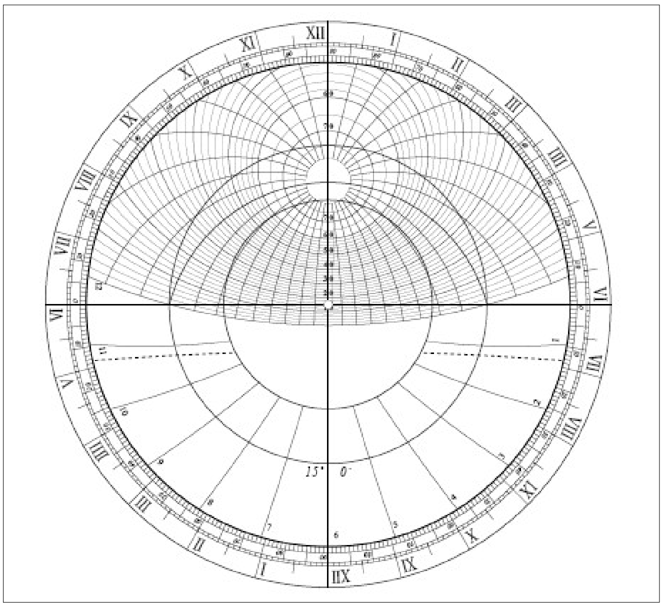

Fig. 12. Planispheric astrolabe plate for 15° north. Drawing by James E. Morrison.

dials, can make their calibration rather cramped for some seasons. This should be less of a problem for tropical latitudes so they most certainly deserve further investigation and development as an inter-tropical instrument. [See article by M. Cowham elsewhere in this issue. Ed.]

Astrolabes and Quadrants

These instruments are both in part sundials and, like the elevation dials above, find the time from the sun's altitude. In a planispheric astrolabe, provided it is calibrated for a particular latitude, even if that is inside the tropic, it remains an accurate time teller. Other formats of universal astrolabes, like the *saphea arzachelis,* also work well at low latitudes but become increasingly inaccurate towards the poles. The *quadrans vetus* or 'old quadrant' was specifically designed to find the time in equal hours from the temporal hour, measured using the sun's noon altitude and its current altitude. More advanced quadrants like the astrolabe quadrant or *quadrans novus* use the same principal as the

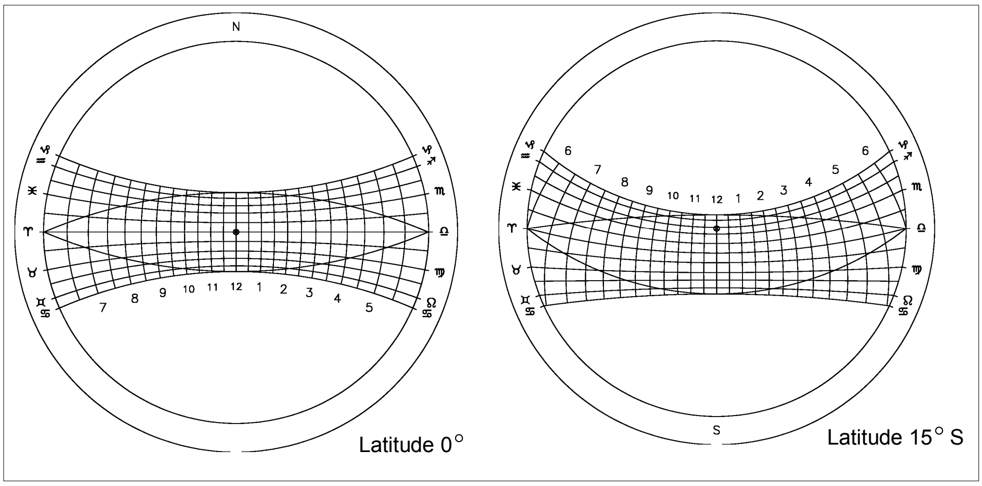

Fig. 13. Stereographic projections for the Equator and 15° south. Drawings by Fred Sawyer.

astrolabe but instead of almucantars it contains several horizons which give additional portability and allows accurate usage at many latitudes. Fig. 11 is an incomplete drawing of such an instrument that can be used from Musina at 20° south to Aghulas at almost 35° south. These are the northern and southern extremities of South Africa. Musina is well within the tropic and Aghulas well outside it. However, finding the time quickly is far more difficult than on a planispheric astrolabe or quadrans vetus.

Fig. 12 is a planispheric astrolabe plate for the latitude of 15° north. It shows the nearly constant day length over a year and the unequal hour arcs are almost straight lines. The -18° crepuscular arc curves in the opposite direction to that of a plate for outside the tropics and the zenith is between the tropics which shows how the sun goes both north and south of the zenith. Thus it illustrates the full range of solar motion rather compactly and demonstrates the usefulness of the instrument, irrespective of season.

The Double Horizontal Sundial

Also known as Oughtred's double dial, this sundial is part sundial and part astrolabe. A conventional horizontal sundial is around its outer edge and this reads in the normal way. Inside is a horizontal stereographic projection for the site latitude. I have only made one such dial and it stands within the tropic in Namibia.[7] The crowding problems around noon were overcome as outlined in the section on horizontal dials above. The vertical gnomon for the shadow reading of the stereographic portion presented its own problems. Not only was its base within the stereographic grid, obliterating readings around noon, but also its portion to the north had to be hollow to allow readings of the stereographic projection after the sun's apparent transit of the location to the south during December and January. Thus instead of the normal knife-edge for the vertical gnomon this was replaced by a thin rod. So, because readings around noon during the transition period would be difficult anyway, a second accompanying instrument was supplied. This instrument was an altitude scale with a sighted alidade. The whole instrument rotated about a vertical axis to allow it to follow the sun's azimuth and provide a reading of the sun's altitude which could be transferred to a suitably calibrated rule on the main instrument. Thus the dial is similar in operation to Oughtred's original 'horizontal instrument'. Building this dial was a worthwhile project producing an instrument which delivers full solar data and much more.

Fig. 13 reproduces two stereographic grids from Sawyer[8] for 15° south and the equator, showing what happens to the grid at varying latitudes inside the tropics. Interestingly, the double dial at the equator would only have a single vertical pin gnomon with a 'T' piece top to deliver readings on the horizontal sundial. This rather flimsy construction renders it impractical for daily use. The hour lines on the horizontal dial would be straight lines and it would look very much like a polar dial. The beautiful symmetry of the grid on the equator for the two halves of the year is notable.

Of course, there are many other sundial formats that I have not dealt with here. Both sides of an equatorial sundial can be made to work inside the tropic for instance, as can an astronomical ring. More exotic sundial forms, such as the helical, bi-filar and other formats using different projections, can be adapted to inter-tropical use but, in my opinion, the only really suitable formats are the armillary and polar sundials or an astrolabe.

ACKNOWLEDGEMENTS

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AN EQUATORIAL SUNDIAL WITH EOT ADJUSTMENT

ROGER BUNCE

[The author was Technical Editor of *Model Engineer* magazine. This article was originally published as R.A. Bunce: 'Equatorial Sundial', *Model Engineer,* Issues 4347, 4348, 320- & 386- respectively, (2009). Ed.]

I am interested in the design of clocks.[1] But, as we all know, clocks evolved from sundials. In fact, sundials were more reliable than early mechanical clocks and were used by some authorities to set clocks to time as late as the mid 1920s. So, for those of you who like clocks but dislike cutting wheels and pinions, here is a sundial that indicates 'clock time'.

BACKGROUND

In order to understand the design of this sundial it is important to distinguish the difference between 'Greenwich Mean Time' (GMT), which is the time shown on accurate clocks and watches in England, and 'Local Apparent Time' (LAT), which is the time shown by 'ordinary' sundials. The difference between these two time-defining systems is significant. For example, in early November an ordinary sundial, located at Greenwich, would be about 16.5 minutes fast, and in mid February about 14 minutes slow, relative to a clock set to GMT. This difference varies in a quite a complex manner throughout the year. In addition, the difference between GMT and LAT also varies as the ordinary sundial is moved in any direction away from Greenwich. The reason for this is outside the scope of this article but for more information on this and many other aspects of sundials see references 2 and 3.

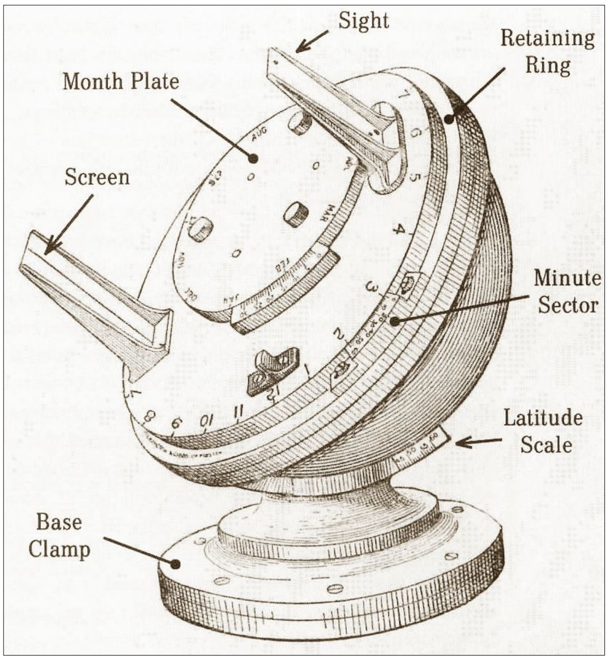


Fig. 1. The Pilkington & Gibbs Heliochronometer from an illustration in their original catalogue.

In fact, it was the spread of railways across England, in the mid nineteenth century, which bought about the introduction of GMT. Incidentally, GMT has been replaced by 'Coordinated Universal Time' (UTC). GMT is based on astronomical observation and UTC on atomic clocks. GMT and UTC are virtually identical, the difference being no more than a second.

Before the introduction of the BBC time signal in 1924, some railways still set their clocks using a sundial. However, for the reason mentioned earlier, common sundials were somewhat difficult to use because they did not indicate GMT directly. The solution came with the invention of a special sundial called the Pilkington & Gibbs Heliochronometer[4,5] (Fig. 1). The P&G heliochronometer indicated GMT directly and was reputed to be capable of being read to about one minute of GMT during the year (provided the sun was out!). Unlike 'ordinary' clocks and watches of the time, once it was set up properly, it was never slow or fast and, in fact, it was always as good as the earth's motion about the sun which, as the basis of a time standard, was good enough in those days.

The working of the P&G heliochronometer depended upon, amongst other things, an understanding of the relationship between GMT and LAT – this is expressed by the equation of time (EoT). The EoT normally takes one of three forms: a table of numbers, a graph, or a mathematical expression. Confusingly, any of these forms is normally referred to as the EoT. In fact, the P&G used a polar graph arranged to act as a cam. The cam was fitted to a dial called the month plate. Before reading the time from the instrument, the operator had to turn the cam to the correct date. In addition, the P&G would also have to be set up according to its location relative to Greenwich but, provided this location was not changed, the setup procedure only had to be done once. Since the invention of the P&G heliochronometer, many other ingenious sundials have appeared commercially and in the patent literature.[6]

The P&G was no doubt an accurate sundial. However, the price paid for accuracy was that, for 'a quick look at the time', it was not so easy to use as an ordinary sundial or a clock. One had to ensure that the month plate was set correctly and then, to read the time, physically rotate another dial so that the sun shone through the pinhole sight to project a spot of light centrally onto an engraved line on the screen (Fig 1). Both the sight and screen are fixed to that dial and the time read from a scale fitted to the dial. I wanted to make a sundial which indicated UTC but which could be read more easily – rather like a clock.

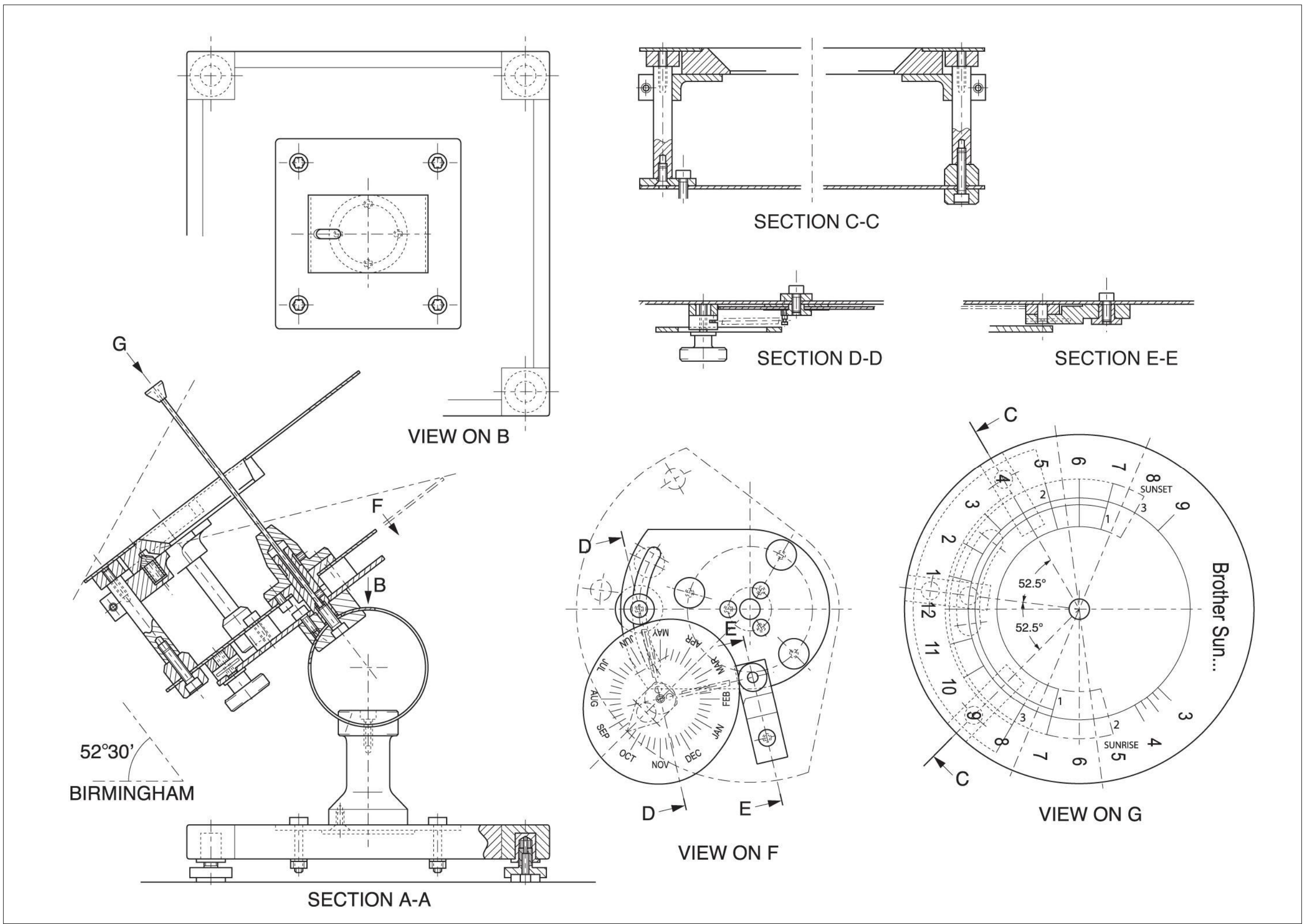


Fig. 2. General arrangement drawing of the sundial.

Fig. 3 (left). Front view of sundial.

Fig. 4. (right) Rear view of sundial.

EQUATORIAL SUNDIAL

My design is based on an equatorial sundial. The important features of this type of sundial are:

1) The gnomon (the axial rod which casts the shadow) is parallel to the earth’s rotational axis.

2) The hour dial is set at 90° to the gnomon.

3) The hour dial is divided into equal radial divisions whereas, in an ordinary sundial, the dial plate is horizontal and the divisions are unequally spaced.

The equatorial arrangement has a number of important advantages over the common sundial:

1) It does not have to be individually designed for a particular location relative to Greenwich.

2) It can easily be arranged to display UTC directly rather than LAT.

3) It can easily be adjusted to display either UTC or British Summer Time.

4) The hour dial looks rather like a 24-hour clock dial – which was part of my design criteria.

GENERAL DESCRIPTION

Figure 2 shows the general arrangement drawing of the sundial and Figs. 3 & 4 show front and rear views respectively. The hour dial measures 220 mm in diameter. This sundial was very much a concept model designed to explore new ideas.

The base is made of mahogany with beech lipping. There are four levelling feet with cork protective discs. The wooden base is merely for development purposes and is not weatherproof. Most of the other parts are made from brass.

The sundial mechanism is supported on a column via a short horizontal tube. The tube is fixed to the column and the sundial mechanism by large washers; each washer has a cylindrical face. The tube is provided with slots, rather than holes, so that the sundial mechanism can be set at a particular angle to the horizontal.

The mechanism assembly includes three main plates (Fig. 2, Section AA and View on F). The lower plate has a curved slot and is fixed to the tube via the special washers. The intermediate plate is sector-shaped and pivots about the central axis of the sundial. The intermediate plate has three bearing pads which slide on the lower plate. Projecting from the intermediate plate are three columns which support the third plate – the hour dial.

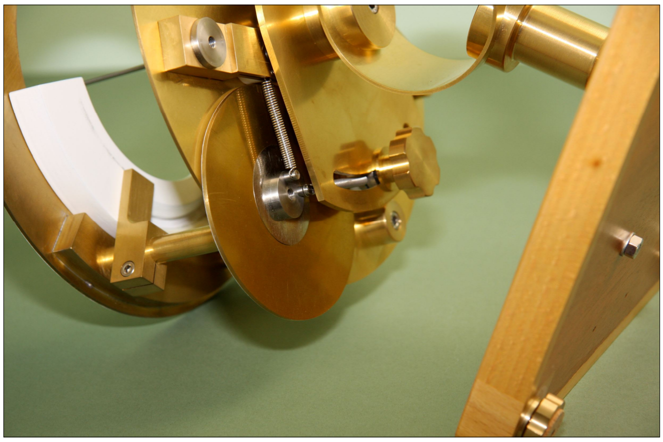


Fig. 5. Underside view showing the EoT cam and the thumbscrew for longitude adjustment.

Screwed to the intermediate plate is the EoT cam (Fig. 5). This has a months dial glued to the upper side. A pointer fixed to the intermediate plate indicates the setting of the EoT cam. The EoT cam is spring-loaded against a follower which is pivotally mounted in the curved slot of the lower plate. Hence, by turning the EoT cam the intermediate plate and therefore the hour dial pivot about the axis. The

Fig. 6. Spring loaded follower to provide balancing action for the EoT cam.

position of the cam follower can be moved and locked along the slot – this also has the effect of turning the hour dial.

A second spring-loaded follower acts on the EoT cam at 90° to the first follower (Fig. 6). This is merely to provide a balancing action and avoids the need to physically lock the EoT cam after changing the month. However, the balancing action is not perfect due to the asymmetric shape of the cam and a shim-steel 'curved' friction washer is used under the EoT cam.

Located under the hour dial is an auxiliary dial. This is held in place by three 'fingers', each one being clamped to a column. The centre finger incorporates a spring-loaded plunger to bias the auxiliary dial against the bore of the hour dial and keep it in position. Hence, the auxiliary dial can be pivoted about the main axis of the sundial.

MATERIALS

Most of the parts are made from brass. This was purely for convenience at this stage of development. If ever I were to design and make the 'new improved model', I would use mainly stainless steel. Various pivots and the springs are already in stainless steel.

The three bearing pads, supporting the intermediate plate, are made from white polyacetal (Delrin), and the cam followers are PTFE.

The hour dial is brass on which is glued a paper dial made using CAD. The paper dial is covered with 'sticky-backed' plastic for protection. This is obviously not suitable of continuous outside use but is fine for development. If I were to make another dial, particularly one in stainless steel, I would consider using laser or water jet methods to cut and engrave the dial.

The auxiliary dial is made from plywood and painted gloss white – again, not suitable for outside use. In future, I would consider using opaque white Corian. This is an acrylic polymer filled with alumina trihydrate, made by DuPont.

The gnomon is made from NiTinol super elastic metal.[7] This is a nickel/titanium alloy discovered by the Naval Ordinance Laboratory, US, in 1962. NiTinol is difficult to machine – I could not cut it with a hacksaw and had to resort to grinding. The problem with the gnomon used in this type of sundial is that it is 'free-standing' and, if bent, will ruin the accuracy of the sundial. Figure 1, Section AA, shows that the maximum the gnomon can be deflected is about 90°; even this amount of deflection is within the elastic limit of NiTinol and, if bent, it springs back 'good as new'. A remarkable material!

ADJUSTMENTS

As indicated earlier, in order for any sundial to function properly it has to be adjusted according to the latitude and longitude of its location. This, together with other adjustments and features, are as follows.

Orientation: As with any equatorial sundial, the gnomon is aligned parallel to the earth's rotational axis and the plane of the hour dial is parallel to the equatorial plane. So, in the northern hemisphere, the person reading the time would be facing south. An easy way to set the orientation is, assuming the hour dial and gnomon are mounted accurately on the base, use a compass to set the LH or RH side of the base to true north (not magnetic north).

Latitude adjustment: To make this adjustment, the two screws within the large supporting tube are slackened and the dial mechanism turned about the axis of the tube to set the plane of the hour dial relative to the horizontal (Fig. 4). This is only necessary when first installing the sundial or if it is moved to a different location. In Birmingham, UK, the latitude is about 52° 30', the angle the gnomon makes with the horizontal is also 52° 30' (Fig. 2, Section AA). However, it is generally more convenient to measure the angle the hour dial makes with the horizontal; this is called the colatitude which equals (90° – latitude), so, in Birmingham, this is 37° 30'.

Longitude adjustment: This is made by slackening the thumbscrew under the lower plate and rotating the dial assembly about the gnomon axis (Fig. 4). An easy way to set this is: first set the month dial to the correct date then, using an accurate clock, turn the dial so that the sun's shadow indicates that time, then lock the thumbscrew.

UTC and British Summer Time: This is also done by slackening the thumbscrew under the lower plate and turning the hour dial forward or backwards an hour.

EoT correction: This is done simply by turning the month dial so that the correct month and week are adjacent to the pointer (Fig. 7). The month dial incorporates the EoT cam which turns the hour dial via the sector-shaped plate and so effectively converts LAT to UTC. Several people have asked me how to design and make an EoT cam so that is given in the appendix.

Summer and winter months: Like many other equatorial sundials, in the summer the sun shines on top of the hour dial and in winter below the dial (according to the dates of the spring and autumn equinoxes, which, for 2009, are March 20 and September 22. For ease of reading during the winter, I wanted the shadow cast by the gnomon to be

Fig. 7. Month dial fitted to the EoT cam.

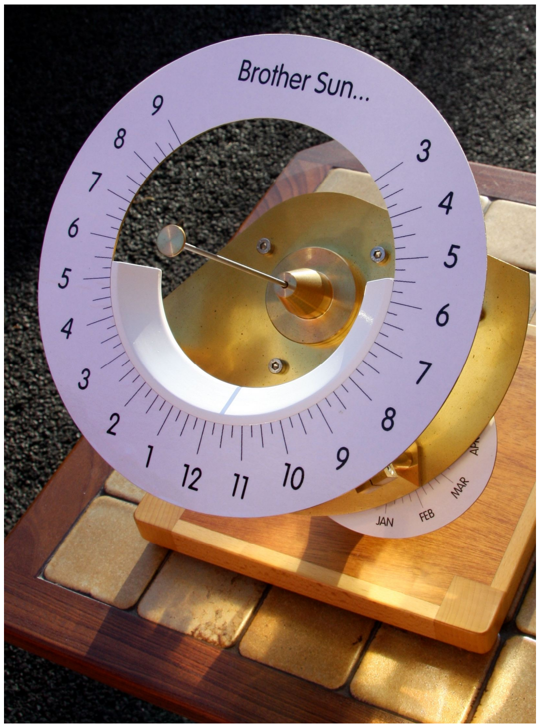
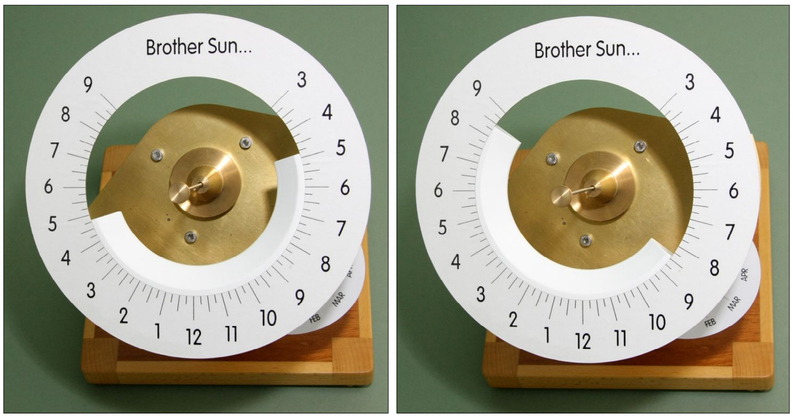


Fig. 8. Photograph taken at the end of the first week in February 2009. The time shown is about 11:35.



Figs. 9 & 10. Ancillary dial turned to 'catch' (far left) the morning sun and (left) the evening sun.

visible from above. To allow this, the main dial is provided with the auxiliary dial with a non-graduated inclined surface (painted white). Fig. 8 was taken at the end of the first week in February 2009 and the month dial is set accordingly. The sun is shining on the underside of the dial and so the shadow is cast on the auxiliary dial and not on the upper surface of the hour dial. The time shown is about 11:35.

During the winter months, the difference between the earliest sunrise and latest sunset in Birmingham (and other places) is greater than 12 hours. This means that the auxiliary dial would need to encompass a span of greater than 180°. However, this would mean that on some days, in the early morning or late evening, one end or other of the auxiliary dial would obscure the sun's rays from casting a shadow on the opposite side of the dial. To avoid this problem, the auxiliary dial can be turned axially relative to the hour dial (Figs. 9 & 10). This allows the time to be read during all winter sunshine hours.

Accuracy: The dial is graduated in hours and quarters and can be read (estimated) to within about 2 minutes of UTC. This may be unimpressive by modern standards but, on the other hand, it never gains, never loses, doesn't go wrong and doesn't need batteries!

MOTTO

All sundials should have a motto! The motto on my dial reads: *Brother Sun…* from Saint Francis of Assisi, *Canticle of the Sun*, c.1225: "Be praised, my Lord, with all Thy creatures, above all Brother Sun who gives the day and lightens us therewith."

APPENDIX

Equation Of Time Cam

The equation of time cam is not difficult design providing a computer is used for the sums and a CAD package is used to draw the artwork. It is certainly possible to do this without a computer - as we saw with the Pilkington & Gibbs Heliochronometer in 1906. However, I haven't the time or patience to do it without using a computer.

The EoT cam is designed using the following equations[8]

$$E = 9.87\sin 2B - 7.53\cos B - 1.5\sin B$$

$$B = \frac{360(N - 81)}{365}$$

where:

E is the number of minutes an ordinary sundial is either fast or slow.
N is the number of days from the beginning of the year.
B is a function within the main equation to give sin and cos in degrees.

There are other EoT equations, including at least one based on a Fourier transform approximation.[9] The one I have shown here is perhaps a little simpler but both are approximations.

CHECKING EQUATIONS

Before proceeding, it is a good idea to confirm that the basic equations are correct by plotting the EoT graph. However, to give reasonable resolution can involve several thousand calculations. As I mentioned earlier, I would not do that 'manually'. I have used a software package called Mathcad for many years and find it excellent.[10] The name is slightly ambiguous – it is a mathematics package and not a drawing package like, for example, AutoCad. The equations are entered in much the same way as one would write them on paper – so no clever programming is needed and Mathcad documents are very easy to understand. Figure 11 shows the Mathcad plot of the EoT graph plotted at one-day intervals. It is exactly as expected. The curves above zero are the minutes an ordinary sundial is fast and, below zero, the minutes it is slow, throughout the days of the year. Incidentally, the computation time for the whole design of the sundial using Mathcad take less than a second – I dread to think how long this would take manually. The huge advantage of using Mathcad is that the effects of making design changes can be seen in seconds.

Comparing the results from the above equation with a 'more accurate' EoT table,[11] the error appears to be no

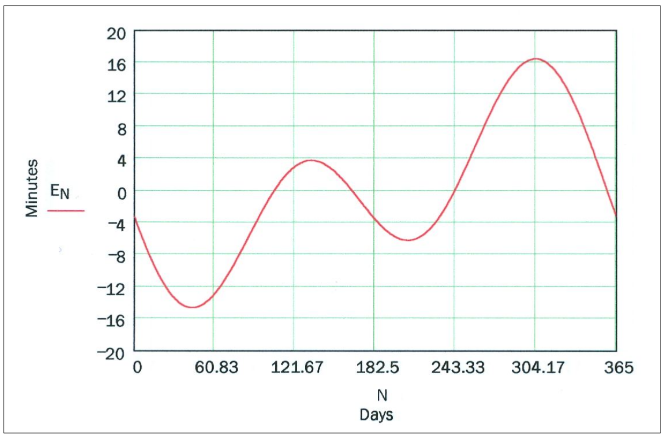


Fig. 11. A 'normal' EoT graph.

more than about 15 seconds at any time during the year. This is good enough for this sundial, which can only be read to, at best, an accuracy of two minutes.

PRACTICAL DESIGN

When designing this type of sundial, the cam radius needs to be as large as possible to ensure timing accuracy. In the case of my dial it is 50 mm radius at the base circle (the radius at zero time correction or UTC).

Next, the maximum 'dip' in the cam needs to be found. From a graph of the EoT or an EoT table, the maximum time correction needed occurs on about 3 November (308 days into the year), when an ordinary sundial is about 16m 23s fast relative to UTC. At this date, the EoT cam will need to have turned the hour dial clockwise, relative to zero correction, so the shadow of the gnomon indicates 16m 23s earlier than LAT. This establishes the maximum dip of the cam from its base circle (50 mm radius), and is found from the general arrangement drawing. To do this, imagine the cam follower is touching the 50 mm base radius of the cam. Then the hour dial is turned 16m 23s clockwise and the distance the cam follower overlaps the 50 mm radius of the cam is measured, or calculated, from the drawing. In the case of my sundial it is 4.6 mm.

Knowing that a maximum dip of 4.6 mm corresponds to a maximum correction of 16m 23s, and knowing all the time corrections needed thoughout the year from the EoT, the profile of the cam can be computed. In order to do this a scaling factor between cam lift and time correction needs to be found:

This is simply

$$S = \frac{CR}{E} = 0.282$$

where: S = scaling factor, CR = 4.6 mm dip in the cam, E = 16m 23s fast.

MIRROR IMAGE

Returning to the EoT graph Fig. 11, the maximum number of minutes the ordinary sundial is fast occurs at about day 308 and is shown as a rise on the graph. However, looking at Fig 2, View on F, a rise on the cam surface would turn the hour dial anticlockwise, whereas we have already seen that it needs to be turned clockwise and so, at that point, the cam needs to dip. In other words, the graph on which the cam needs to be based has to be the mirror image of the normal EoT graph. This is very simple to do: the RHS of the main EoT expression is multiplied throughout by minus one:

$$E = -9.87 \sin 2B + 7.53 \cos B + 1.5 \sin B$$

Fig. 12 shows a Mathcad plot of this equation, which is the mirror image of Fig 11.

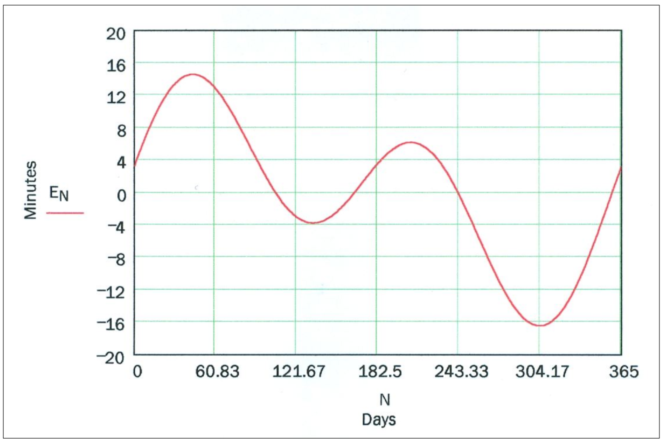


Fig. 12. Mirror image of the normal EoT graph.

POLAR PLOT

It is now simply a matter of using this equation to plot a polar graph to form the EoT cam. One turn of the EoT cam (360°) represents the 365 days of the year. However, Mathcad needs the angular coordinate A in radians:

$$A = 2\frac{\pi}{365}N$$

The radial coordinate R at any place on the cam surface corresponding to A is

$$R = RZ + (E \times S)$$

where: RZ = radius of the cam at zero time correction (50 mm in this case).

Fig. 13 shows the polar plot of the EoT of time cam as a continuous red line and the radius of the cam at zero time correction as a blue broken line.

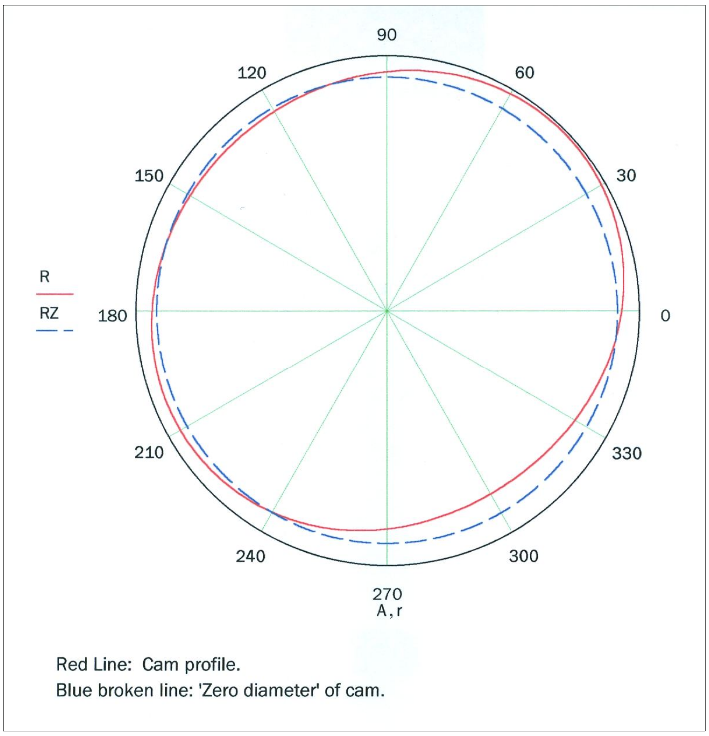


Fig. 13. Polar plot of the EoT graph.

COMPLETING THE DESIGN

There are two more things needed to finish the design of the cam: make a phase shift and add the months of the year dial. This cannot be done in Mathcad and a CAD program is needed: I used AutoSketch. The polar graph was 'copied' from Mathcad and 'pasted' into AutoSketch. However, the file format (probably a 'bit map'), cannot be scaled directly in AutoSketch and so the graph was traced onto another drawing layer using a 'fitted' Bezier curve. The Bezier curve can then be scaled to match the dimensions specified in Mathcad.

The artwork for the month dial was also drawn in AutoSketch. Regarding the phase change: Fig 2, View on F, shows that the position of the month pointer, fitted to the middle plate, does not correspond to the position of the cam follower; in fact, there is a difference of 123.25° between them. To give this phase shift, the artwork was simply superimposed onto the cam profile and rotated 123.25°. Fig. 14 shows the artwork for making the cam. The continuous solid line is the cam, the broken line is the 'blank' diameter.

MAKING THE CAM

I would imagine that those of you with a CNC miller would make light work of machining the cam. I do not have CNC equipment so had to do it the 'old fashioned way'. I simply stuck the artwork on to a sheet of 16swg brass, covered it with clear 'sticky backed plastic' and linished it to shape – looking through my binocular magnifier to 'split the line'. Then I draw-filed the edge and finished with fine wet-or-dry paper.

TESTING THE CAM

All that is needed to test the cam is set the month dial to the middle of April (the 16th to be precise – which is one of the zero correction times) then set a scribing block to point to, say, 12:00 o'clock on the hour dial and turn the month dial. The hour dial should turn backwards and forwards corresponding the EoT correction minutes for the month set on the month dial. If you want to be 'Mr Meticulous' you could make any small corrections to the cam by 'filing a bit off'. I didn't do that, after all, it's just a sundial that 'thinks' it's a clock!

ACKNOWLEDGEMENT

The BSS gratefully acknowledges the permission of *Model Engineer* magazine to republish this article (the copyright of the design remains with the author).

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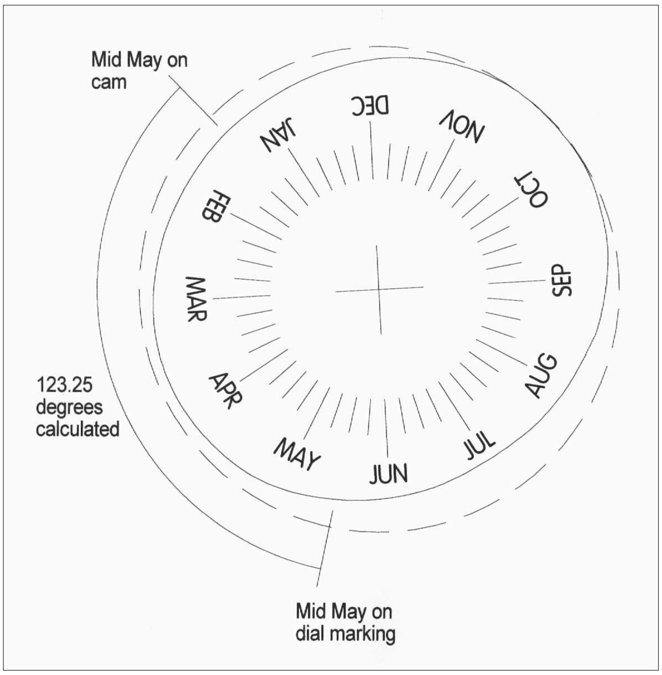

Fig. 14. Finished artwork for making the EoT cam.

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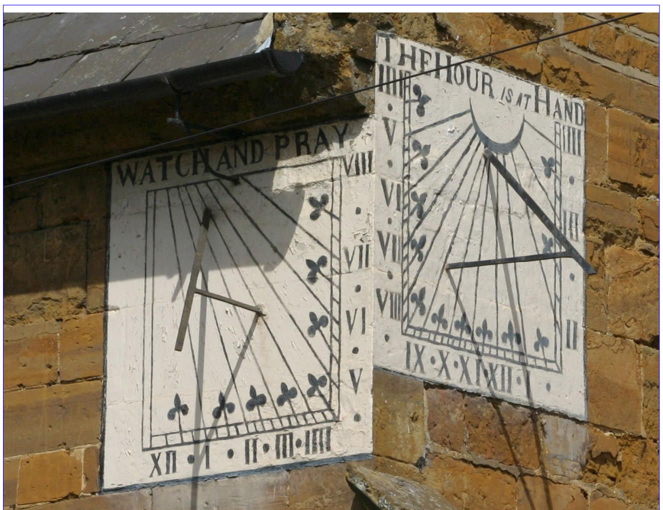


M. Cowham

Harlestone, Northants

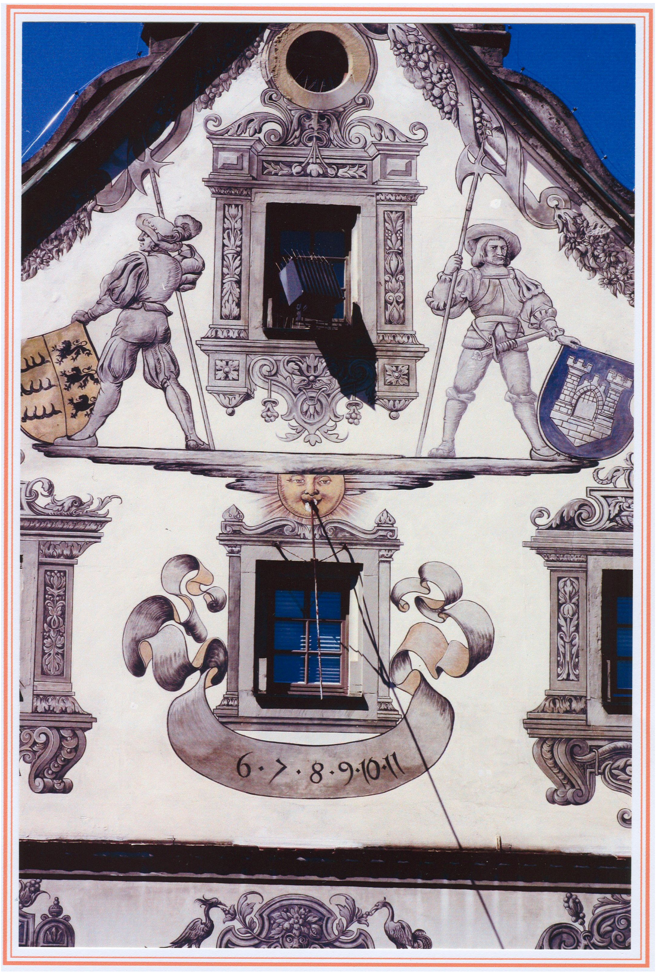
Redacted

First Place

Sundial Thief - Caught in the Act!
Mike Cowham

Second Place

Crystals mark the even hours
David Hawker

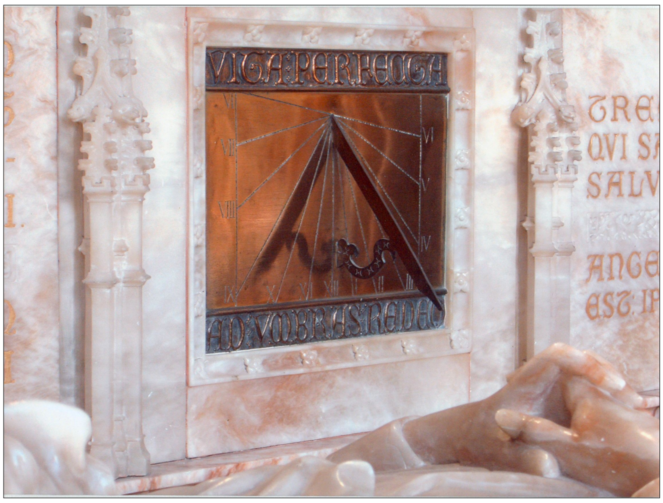


Third Equal

Ooooh! Get off my head
Mike Cowham

Third Equal

Polar Pointing
John Davis



Top Ten
Indoor Tomb Dial 1918
Irene Brightmer

Top Ten
No! I haven't any more food for you
Mike Cowham

There will be more entries in the September issue.

A LEAD DOMESTIC 'WINDOWSILL' DIAL

PETER BAXANDALL

I am surprised by how few contemporary accounts I have seen of the domestic use of sundials before they became unnecessary in everyday life. I am tempted to make plausible assumptions unsupported by evidence, no doubt exaggerating their importance in the household scene. BSS member John Baxandall has found the following in a letter from Jane Austen to her sister Cassandra during a passing visit to Godmersham Park, Kent, on 26th October 1813.[1]

> "Owing to a difference of Clocks, the Coachman did not bring the carriage so soon as he ought by half an hour; – anything like a breach of punctuality was a great offence – & Mr Moore was very angry – which I was rather glad of – I wanted to see him angry – & though he spoke to his Servant in a very loud voice & with a good deal of heat I was happy to perceive that he did not scold Harriot at all."

Harriot was Revd George Moore's second wife (they had been married for seven years), the coachman and coaches would I suppose have been housed in the stables with a clock or in what might have now become 'The Old Coach House', the 'Servant' presumably one whose job included the (daily?) synchronisation of the house and estate clocks.

But… where would the time be taken from? Perhaps all that was important was that the clocks should agree both upstairs and down so that when JA in the same letter tells her sister that "we do not dine till ½ past 6" it was the time by one of the house clocks that was followed to avoid a "breach of punctuality" rather than the local Solar or Mean Time.

In finding the time directly (as opposed to relying perhaps on church bells or a clock displayed in a shop window) it might not have been necessary to consult a pedestal or wall sundial in the garden; the household might sensibly have had a horizontal dial small enough to fit indoors next to a window, designed for *use* rather than *show*. The size and lack of elegance should not be held against such a 'domestic' dial, after all a matchstick stuck into a lump of BluTac on a windowsill provides a satisfactory noon mark if that is all one needs.

The domestic dials I have in mind were small (perhaps 4" or less across), simple, and were to be screwed down indoors near enough to a window to catch the sun. Despite their size they are not travelling 'Poke Dials' as described in Mike Cowham's book.[2] It is an easy assumption to make that their miniature style was introduced by clockmakers late in the 17th century as accessories to the increasingly available lantern and long cased domestic clocks: yet again I am in the comfortable arms of the plausible. On the other hand they might have been made for domestic use long before that.

Lee Borrett,[3] a specialist on early rural clocks, writes "However, I have never heard of records about these dials being sold with clocks … but it makes sense that they were!" Other 'clockies' I have talked to (Brian Loomes for example and Dorset's Polly and Michael Legg) are equally uncertain. Perhaps the two were not sold together, perhaps clockmakers and sellers feared that they would undermine a customer's confidence if they offered a sundial to compensate for their clock's inaccuracy?

Thomas Tompion's sundial,[4] currently displayed on a plinth outside a window in Bath across the Pump Room from his marvellous 1709 'watch' (which JA would certainly have known with its third 'sun slower, sun faster' EoT hand), is often quoted as an example of a sundial-clock association,

Fig. 1. Pewter domestic dial, 3.75", Photo: Paul Madden.

Fig. 2. Brass domestic dial, 3.4", Photo: Lee Borrett.

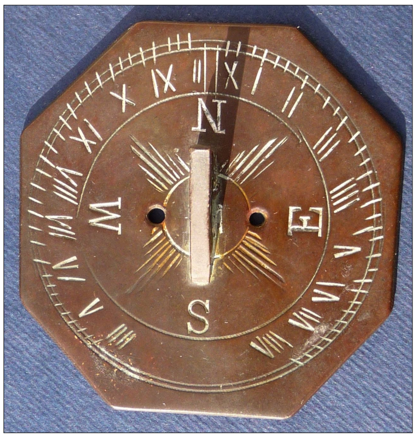


Fig. 3. Bronze domestic dial, 2".

but even that is in doubt as we read in a letter[5] to the *Bulletin* from Sir George White telling us that *that* Tompion dial was "found in some nettles just outside Bath, either at Corston or Corsham" in the 1960s. I myself prefer for family reasons the possibility suggested by Sir George that it was set up initially in the grounds of Corsham Court[6] (from 1946 to 1986 the home of the celebrated Bath Academy of Art). There are two later 18th century BSS Registered sundials in the Corsham grounds, one of them bought from Tho. Wright, perhaps as a replacement when the Tompian dial was stolen?!

Some Domestic Dials

This article is really about a sundial half of whose dial plate was found in 2007 by metal detecting enthusiast and horticulturalist David Green in a freshly ploughed field in the village of Child Okeford between Blandford Forum and Sturminster Newton in Dorset. It is made of lead, the recovered semi-circular shape being very close to the size of the school protractors nostalgically still found in tin boxes of 'Oxford Mathematical Instruments'. A fuller description comes later but before that I would like to show three complete domestic dials that I came across recently and one that is intriguingly damaged.

Figure 1 is from Paul Madden's website[7] where it is described as "18th Century pewter windowsill sundial, 3.75 inches diameter". It is a gem but unfortunately no longer for sale!

Figure 2 shows a brass dial owned by Lee Borrett. It is 3.5 inches AF (Across the Flats) with gnomon angle 48°, perhaps sold as an accessory for a clock.

Figure 3 shows a recent eBay purchase. It is 2 inches AF with a gnomon angle of 45°. Made of a bronze, it is small, light and delightful despite the mistakes in the chapter ring around 6:00pm!

Finally here is another (damaged) lead dial of the domestic type (Fig. 4) about which there has been some public discussion. Perhaps it is <u>very</u> old, perhaps not.

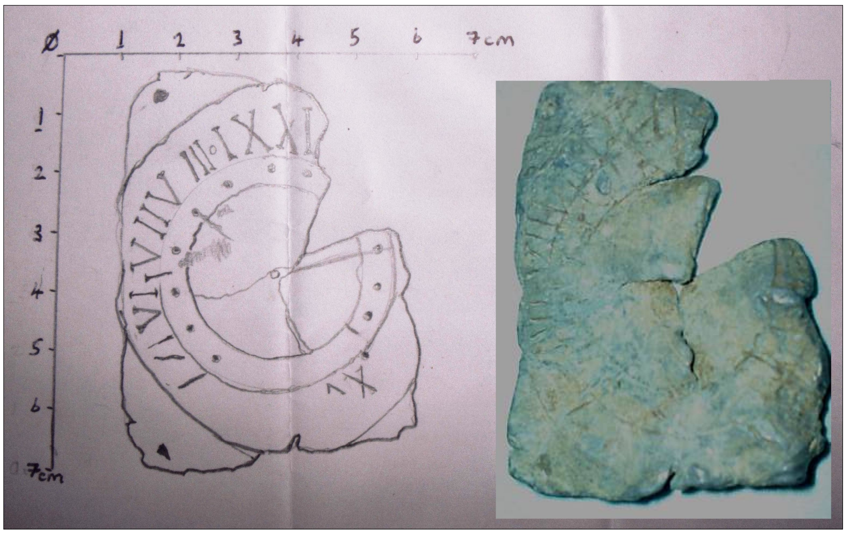


Fig. 4. A damaged lead dial. Photo: Albi Pinnion.

Fig. 5. The lead half-dial as it was found.

A Metal Detected Lead Half-dial

Figure 5 shows a photograph of what was found by the metal detector in Child Okeford. The surviving surface was smoothly curved and was not split. Risking expulsion from the Society I asked neighbour, friend and naturalist Nicky Butt to press the dial flat in a book press and to take the higher resolution photograph in Figure 6.

What remains of the original dial would just fit into a rectangle 5 cm by 10 cm. It is made of lead of thickness varying from 4 mm where the metal has not been corrupted, to 2 mm where it has. I found that a close-up photograph does distort things a bit but by fitting the dial into a semicircular hole cut in the middle of a 4 mm 'canvas board' to extend its surface plane I could line things up, draw circles, bisect chords and measure angles to 'school protractor' accuracy. I don't think it is reasonable to be more precise than that, inscribed marks in lead are inevitably more 'chunky' than in engraved brass.

Fig. 6. The flattened half-dial.

The two semi-circles forming half of the chapter ring are clear, as is a smaller semi-circle bordering some decoration. Hour lines are clearly drawn from 4:00am to noon and there are half-hour punched spots between 3:30am and 11:30am (some only visible after enlargement of the photograph and knowing where to look): there are no 'minute' marks. There is clear evidence of a noon gap and close to its inscribed western line there is the edge of a mortise where I assume a gnomon tenon fitted. There are two fixing holes, one complete and the other broken.

It was the work of someone who found it worthwhile to have punches made, although he was not too careful about the positioning of the Roman numerals. The 'I's and 'X's have been punched using perhaps just an I-punch, the 'V's appear to have at least the broader side punched with the same. There is also an intriguing upper case T close to the broken edge and to the south of the blue-grey stain. That might have been used to guide the construction or it might be part of a maker's mark – it was firmly punched in with what looks like its own punch.

The numerals are oriented to be read from *outside* the chapter ring, as they are on the bronze dial of Fig. 3 but not on the other domestic dials illustrated.

The Numerals

Eagle eyed readers will have noticed in Fig. 6 that some of the Roman numerals viewed from outside the ring look 'wrong' (although the 'V's are the right way up) and the temptation is to blame the maker's ignorance. However, John Lester has drawn attention[8] to a similar feature on a 17th century vertical dial in St Ive, Cornwall in which the numerals (read in that case from *inside* the ring) follow what he describes as an 'anti-clockwise convention'. The

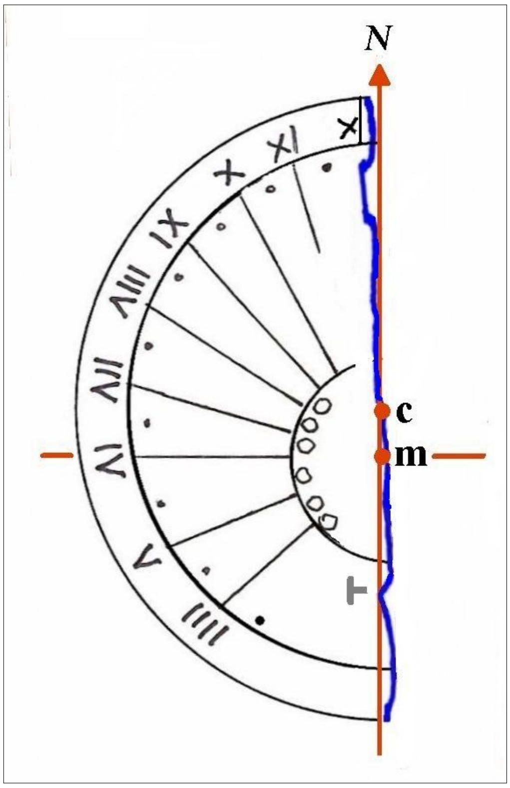


Fig. 7. The centreline.

shadow of the style passes over the vertical surface anticlockwise picking out as it does so the components of the numerals in the 'correct' order. Thus as it passes 8:00am (and pm) the shadow would pick out 'V' first then three 'I's. On the dial face that would appear from the inside as IIIV. John tells us that that feature is far from uncommon in Devon and Cornwall and elsewhere.

The lead dial I am discussing would be fixed horizontally, the gnomon shadow moving around the surface in a *clockwise* direction. Figure 6 shows that 7:00am viewed from outside the ring is written IIV. The shadow of the gnomon would pick out the components of the numerals in the 'correct' order, it would allow first 'V' into the sunlight and then the two 'I's. Similarly 11:00am appears from outside the ring as 'IX' which read in a clockwise sense would be first 'X' and then 'I'. I expect that the other side of the noon gap was marked by 'II' so that noon shows as 'II..X' to the outside eye. Matching John's phrase we have here a 'clockwise convention' for horizontal dials.

The Blue-Grey Stain

I was puzzled by the blue-grey corruption of the lead across a parallel strip and was concerned that it might have changed the geometry. I thought that perhaps the whitish surface acquired over the years had protected the lead while the dial was under the ground but that perhaps a stone in Child Okeford's flinty ground pushed by a passing ploughshear had struck across the surface exposing the bare lead leaving it open to chemical action. I am very grateful to Peter Northover,[9] an archaeo-metallurgist from Oxford University, who looked at some photographs and found the time to email his opinion.

> "Both parts of the surface are something I have seen on archaeological lead. The majority of the surface has the sort of stable lead patina you might expect on a sheet (probably mainly oxides and carbonates although some chlorides and chlorophosphates may also be there). The blue-grey strip is where that surface has been disrupted and bare metal has been to some extent exposed and has started corroding again. Microenvironments can vary quite rapidly over a short distance, but your guess of an agricultural chemical is a reasonable one, especially if ploughing has left that part of the dial close to the surface, say just under the bottom of a furrow."

Other chemist and geologist correspondents have agreed and also suggested that the intrusive chemical (it has changed the lead right through from front to back) having a blue effect might have contained copper or even chromium (what did they put in agricultural chemicals?).

The Centreline

Despite the blue-grey stain and the thinning of the lead along it, the halves of the chapter ring 'circles' and the half of the decorative 'circle' are remarkably 'circular' with centres at the points 'c' and 'm' respectively marked on Fig. 7. That the three semi-circles show very little distortion

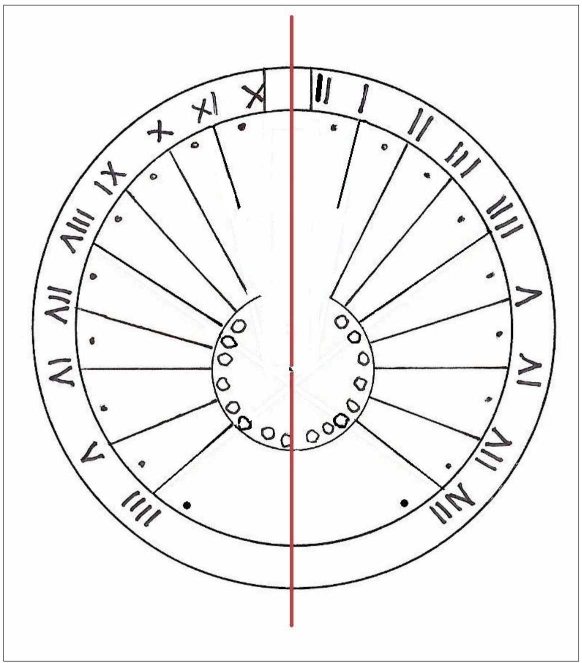


Fig. 8. What the full dial might have looked like.

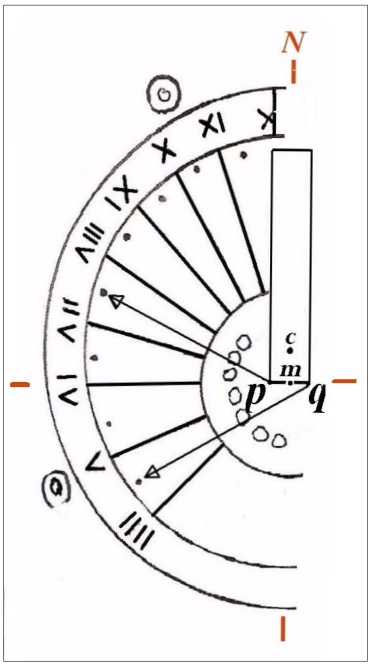


Fig. 9. The gnomon root.

suggests that there has been little distortion overall despite the breaking off from its fixed position on the windowsill, the knocking about and corruption in the ground and the flattening.

That belief is strengthened by noting that the hour lines inscribed in the surface (if there was doubt in drawing them, I was guided by the points where they meet the chapter ring and decorative circle) all pass through or very near (in the case of the 5:00am line) to the point m with the possible exception of the shortened 11:00am line. I regard m then as the 'centre' of the dial and the line through c and m as the 'centreline'. I was pleased to find that the centreline is parallel to the western edge of the noon gap (clearly marked in the fragment) and also to the western side of the gnomon mortise. It appears also to be parallel to the broad cross piece of the maker's T.

The 6:00am hour line passes through m and is at right angles to the centreline there so if the centreline was positioned north-south then the 6:00 hour line would lie west-east as it should. By reflecting the known semicircle in the centreline, I have (Fig. 8) my first sketch of what the dial face might have looked like. The outside of the chapter ring has a diameter of about 9 cm.

The Gnomon and its Root

Blandford Forum (50° 51' N, 02° 10' W) six miles south east of the village would be a significant trading centre for Child Okeford in the 17th century and afterwards. We know[10] that one of Blandford's leading instrument makers in the early 18th century had a copy of Thomas Stirrup's *Horometria: Or the Compleat Diallist* of 1652 published by Leybourn. Blandford was something of a centre of clock selling from the early 18th century, the earliest Blandford maker listed in Tom Tribe's *Dorset Clocks and Clockmakers*[11] is "Baker, Thos 1690-1720".

In exploring further how the dial might have looked when it was new, I assumed that it was made locally, that the maker knew what he was doing and that he either completed an accurate drawing himself or followed an accurate template for Blandford's latitude.

Having found the centreline the problem now was to find the root where the gnomon sits on the dial face. The southern edge of the root would lie along the 6-6 line, the point m being its mid-point as shown in Fig. 9. The end of the mortise (see Fig. 6) is a guide to where the northern edge lay so I just need to find the other two edges, the western and eastern sub-styles. They would be parallel to the centreline and symmetrically placed on either side through the (yet to be found) vertices p and q respectively of the southern edge.

The shadows of the western and eastern styles on the top of the gnomon would cross the dial plate in lines that for this account I shall call '*shadow lines*' to distinguish them from the inscribed hour lines. *It is the shadow lines that would show the time on the chapter ring.*

The hour lines inscribed in the surface of the dial (except for the 6-6 line) cannot be shadow lines. The shadow lines before 6:00am pass through the point q, and between 6:00am and noon through p. The switch of the origin from q to p so early in the morning (and back again in late afternoon) although well understood always (when remembered) comes as a pleasant surprise – it curiously is not allowed for in W Richardson's Appendix (Plate 1) to Mrs Gatty's famous book.[12]

The points p and q were found by drawing the correct shadow lines for Blandford's latitude on a sheet of (transparent) OHP acetate, fixing the half dial inside the canvas board and sliding the acetate over the extended dial plate to find remarkably (rather like breaking a code) that there are origins for which the shadow lines would cross the chapter ring at the correct Blandford local solar time on the hour and the half hour. Well, that is true except for 5:00am and 5:30am in the middle of the corruption where they are 1° behind. Perhaps this reverse engineering is too generous to the maker, he might have got it totally wrong but at least I believe now that there are origins which work, and in his favour after finding p and q experimentally I found that m *is* the mid-point of pq and that the line through p parallel to the centreline, effectively the shadow line just before noon, passes along the western edge of the noon gap marked in the lead.

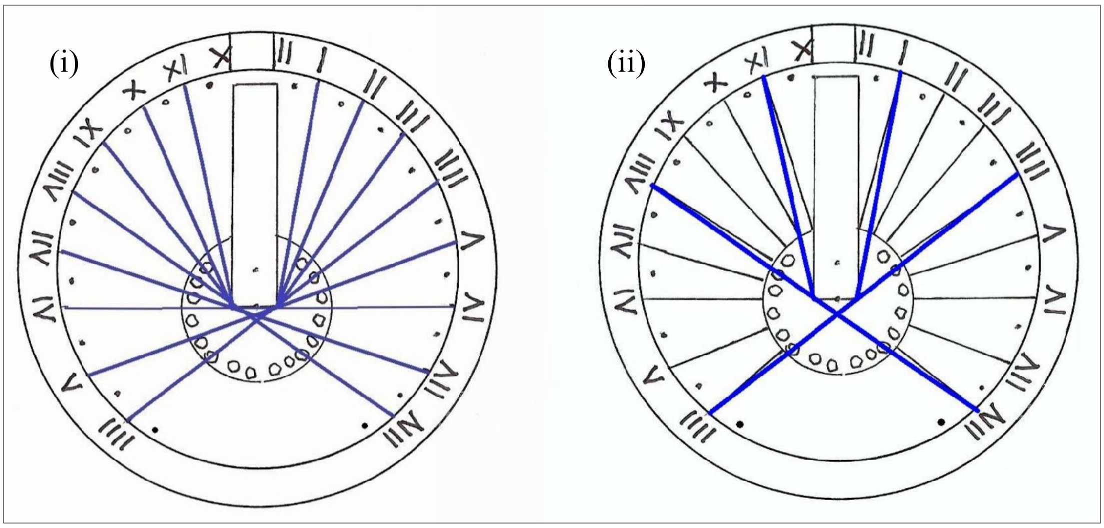


Fig. 10. (i) Shadow lines only (ii) hour lines and some shadow lines.

Figure 10(i) shows the shadow lines only on the full dial face and Fig. 10(ii) shows how those shadows lines would relate to the hour lines at 4:00 am and 4:00pm; 8:00am and 8:00pm; 11:00am and 1:00pm. The origin switches back from q to p at 6:00pm.

The distance between p and q gave a gnomon thickness 8 mm, double the thickness of the uncorrupted lead.

The Edge and the Back

Figure 11 shows the edge and the back of the half dial with the positions of c (the centre of the chapter ring circles) and m (the centre of the dial) and the upper case T marked.

The dial would have to lie flat on the windowsill. There is no sign of a mortise near c or m but there are indentations nearby which perhaps were cut to accommodate a flange that could then be screwed through into the gnomon. The northern end of the gnomon would be held in the mortise clearly shown in Fig. 11 where there are signs of perhaps a split tenon having been folded over. Perhaps a lead gnomon was held in that way or perhaps it was made of some other material?

The Regular Octagon

Accepting that the dial was originally the familiar regular octagonal shape, the question arises as to how the dial face fitted into it. It is common in octagonal dials (the dials shown in Figs. 2 & 3 for example) for the centre line to lie along a short diameter of the octagon, perpendicular to two opposite sides, where the AF measurement is taken. When that is done (Fig. 12) it looks alright but the screw holes and the worn edges seem randomly placed.

However, if the screw holes are placed more naturally within the vertices of the octagon (Fig. 13) then the worn edges fit well and the whole picture looks more comfortable.

For me that change was something of a revelation and begged the question as to why the arrangement is not the usual one. The centre (noon) line would be skewed 8.5° clockwise from its conventional position. It is important to remember that that angle is determined by the centres c and m only and does not depend on assumptions about the dial being made for Blandford's latitude nor on whether arguments about the gnomon's thickness are sound. Three possibility come to mind (the second one suggested to me by the Editor to balance my enthusiasm).

First, the dial might have looked something like it does in Fig. 12 and fixed in position using a compass.

Secondly, the dial might have been made for a *particular* windowsill and designed so that by placing one of the flat edges neatly adjacent to the window the centre line would be in true north-south orientation. If that is true I do not have anything exciting to say, and I have no more idea about the dial's date than I have about the dates of the dials illustrated earlier, particularly since I am uncertain about associating them with the sale of clocks. I do wonder whether a clockmaker would make a dial out of lead, and if he did whether anyone who could afford a clock would want such a down market accessory.

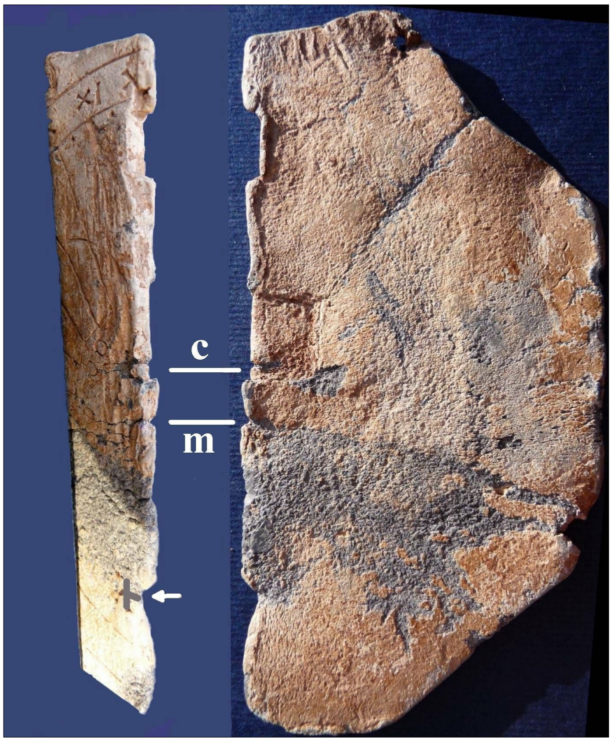


Fig. 11. The edge and the back of the lead half-dial.

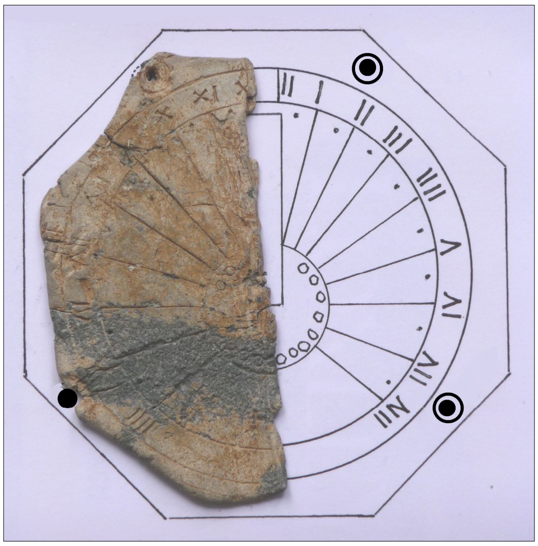
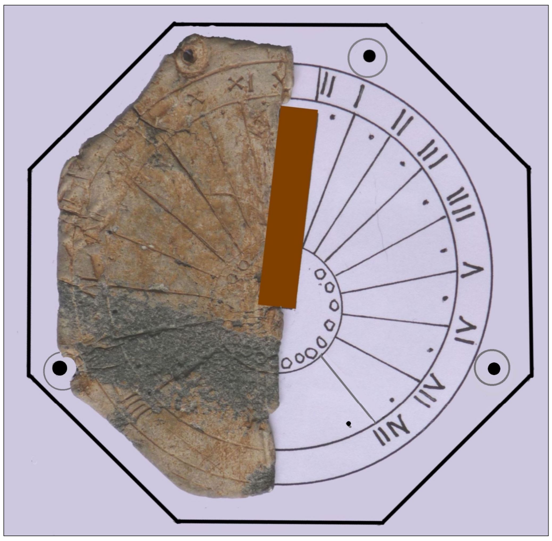


Fig. 12. Misfit?

Fig. 13. How the dial might have looked from above with the gnomon in place.



A third possibility is that the skewed centreline compensated for magnetic variation.[18] The customer (*any* Blandford customer) would be shown figure 13 and told to use a compass to fix the short diagonal of the octagon in the *magnetic* north-south direction (lead would not affect the compass needle). The gnomon would then be correctly positioned for a variation of 8.5º W. Fig. 13 is reminiscent of the design of some 17th and 18th century pocket sundials[2,13] which guide the user in that adjustment, but I don't know of any (other) fixed horizontal sundial with that feature. I expect to though – quite soon after this article appears!

Under that third possibility I would be able to say something about when the dial was made. The variation was 8.5º W in London in 1710 and judging by Edmund Halley's 1701 'Chart of the Variations' reproduced in Hester Higton's book[13], in Blandford it might well have been much the same. Authorities have warned about using the variation to date pocket sundials because of the way it changes from place to place but 1710 seems a reasonable guess for this domestic dial. It has to be confessed that the variation was also 8.5° W in London in the 1950s!

Conclusions

I found studying this domestic dial increasingly interesting. It was surely 'country made' (of lead rather than expensive brass) with its delineation based on an accurate template, the allowance for magnetic variation suggesting a maker who kept in touch with contemporary 'philosophical' interests. I am comfortable with the 1710 date, the technicalities were known by then in Blandford and there would have been customers there as well.[10, 11]

The conventions expected of the outstanding London instrument makers in the early 18th century might not have been so well established away from the capital, allowing country makers to do things in their own way without confusing the user.

Positioning the numerals to be looked at from outside the chapter ring on such a small horizontal dial is not unreasonable, and neither is arranging them to be read clockwise as the shadow passes. Using the dial to find the time it would be enough to see where the shadow lines cross the chapter ring.

Why was the dial thrown away – and when? Clocks became more reliable through the 18th century and it would be easier to take the 'mean time' that they displayed as a basis for household management rather than the sun's time. It would, however, still have been prudent to have had a domestic 'time finder' together with a list of EoT correspondences as a check. William Emerson (mathematician, eccentric and dial enthusiast) wrote[14] in 1770

> "…yet these (*clocks and watches*) are often out of order, apt to stop and go wrong, and therefore require frequently to be regulated by some unerring instrument,.. And therefore whether we have any clocks or not we should never be without a dial".

There would be no need for that check though in many homes after a daily time signal was delivered down the 'electric telegraph' to country towns in the 1850s from the Greenwich Royal Observatory. In a letter[15] from the Electric Time Company on 30th October 1852, Station Masters and Telegraph Offices were told "You are at liberty to allow Clock and Watch makers to have Greenwich time providing…" . We know that indeed they proudly displayed it in their windows (passing on the time of day).

In 'Scientific Instruments 1500-1900' (page 18) Gerard L'E Turner wrote[16] "From then [the mid -19th century] on, the sundial ceased to be of any practical importance, and remained merely as a decorative object." The lead dial would not be saved by having any decorative value but it might have been used to regulate clocks for a further decade or two in a remote area.

Perhaps I have made too much of such a simple artefact but I have learned a lot. I would like to know more about who made and sold domestic dials. Were they made by clockmakers, or 'clock-assemblers' (many country clocks were made up from bits bought in from elsewhere)? Were they sold with clocks and displayed in clock sellers' windows, or were they only available from the hardware shop lower down the High Street?

ACKNOWLEDGEMENTS

I am grateful to David Green for the extended loan of his 'find', to Dr Michael LeBas of Blandford Forum Museum for showing it to me, to Nicky Butt for photography, to him and John Baxandall for many real-time conversations, to Lee Borrett for long 'clockie' emails, to the free photo editing software provided by IrfanView[17], and as ever to the *Bulletin* editor John Davis for encouragement and information and for the invaluable *Glossary*.[18]

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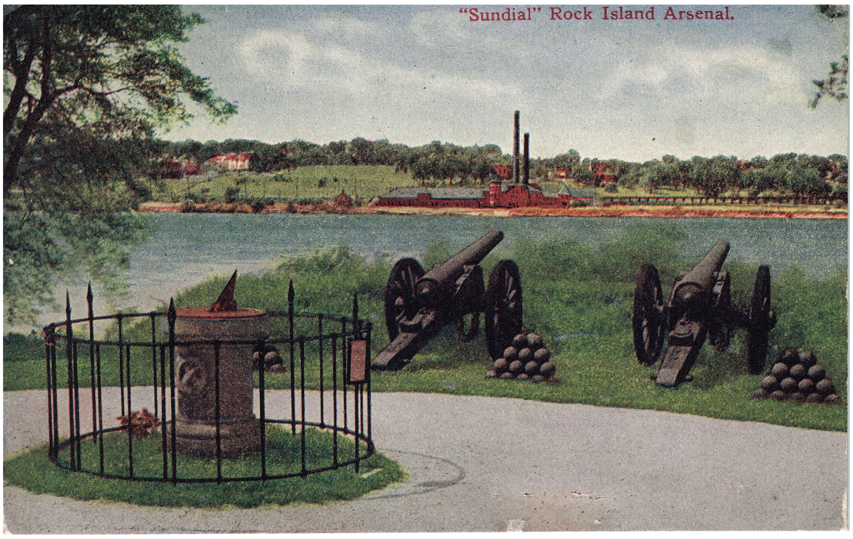
Postcard Potpourri 12 – Rock Island Arsenal, Illinois, USA

Peter Ransom

Here is an American dial for a change, celebrating the centenary of when this postcard was posted (November 8 1909). I was delighted to find this card, since it encapsulates three of my interests: dials, cannonballs and Johnny Cash!



Rock Island lies in the Mississippi, which separates Iowa to the north from Illinois to the south. It is about 150 miles west of Chicago.

The dial shown is a horizontal one. Little detail can be seen of the dial, but another postcard leads me to suspect the gnomon is quite ornate with a pierced design. The pedestal seems to have an armillary sphere carved on its side.

In teaching mathematics at The Mountbatten School, Romsey I like to incorporate some of its historical and practical uses into the classroom. Over the past 6 years I have worked with the mathematics of piling cannonballs and it is interesting to note the three triangular pyramidal flustra visible in the picture. The formula for the number of balls in such a pyramid is $n(n + 1)(n + 2)/6$ where n is the number of layers in the pyramid. Thus in the flustrum on the right-hand side there will be $5(5 + 1)(5 + 2)/6 - 1$ since the top ball of a 5 layer pyramid is missing. This gives a total of 34 cannonballs.

Oh, the Johnny Cash connection. This comes from hearing Cash sing 'The Rock Island Line' when I was a teenager and enjoying his songs ever since.

In the March 2008 edition of the NASS Compendium (15(1)), Steven Woodbury wrote about his investigations into this dial. He says it was dedicated in 1877 and restored in 1970. More information about the dial can be found in that excellent publication.

ALTITUDE DIALS FOR TROPICAL REGIONS

MIKE COWHAM

Having completed my monograph on altitude dials[1] last year, I made another trip to The Gambia, in West Africa. On my previous visit I had successfully used two versions of my universal altitude dial there so I wondered what a fixed latitude dial would look like, bearing in mind that the Sun is overhead twice each year and is in the north for around three months in between.

The latitude there is 13.5° N, so first I produced a set of tables for the Sun's altitude. Then, sitting under a palm tree, I started making rough sketches of several of the models described in the monograph for this new latitude. I am not sure that I was ready for what I found. I realised, of course, that when the Sun was near to the overhead, the shadows formed would be so long that they would fall off the edge of any gnomon-operated dial. My intention, however, was to keep the dials operational except, perhaps, for the two hours around local noon. Between 11am and 1pm, altitude dials are not very accurate, so very little would be lost. Note that I am basing these dials on local Sun time and not GMT that they use in The Gambia, which is 1 hour 7 minutes ahead.

When I returned home I reconstructed some of these dials using my computer. It is these plots that I have used in this article.

My table showed the Sun's altitude at noon going from 53.07° at the Winter Solstice, 90° when the Sun was overhead (28 April and 17 August) and 80.6° at the Summer Solstice. Interestingly, the Gambian Sun at the Winter Solstice is somewhat lower than the Sun at the Summer Solstice in Cambridge (61.44°)!

My first attempts were with the pillar dial, the vertical plate dial and several circular plate dials. Although these worked

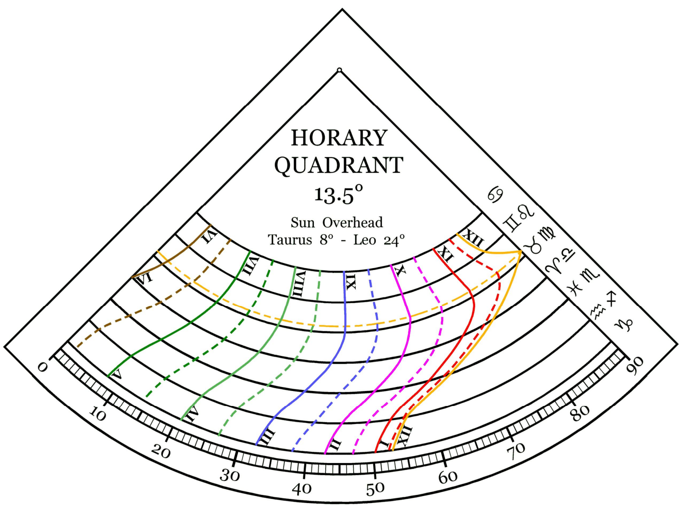


Fig. 1. Horary quadrant for 13.5° N.

quite well, I was looking for the 'ideal' type of altitude dial for use in the tropics. I then constructed a simple horary quadrant and found that this worked perfectly over the whole range of Sun's altitude (Fig. 1). With the Sun overhead, an interesting kink appeared in the lines around noon. My first thoughts were that this should not be a sharp corner but should be rounded until I thought more about it. Yes, the kink was correct, as the Sun at that time is moving quite quickly through the zenith. It does not hesitate or reverse. It is the user who reverses the direction of his observations. It therefore agreed with my calculations.

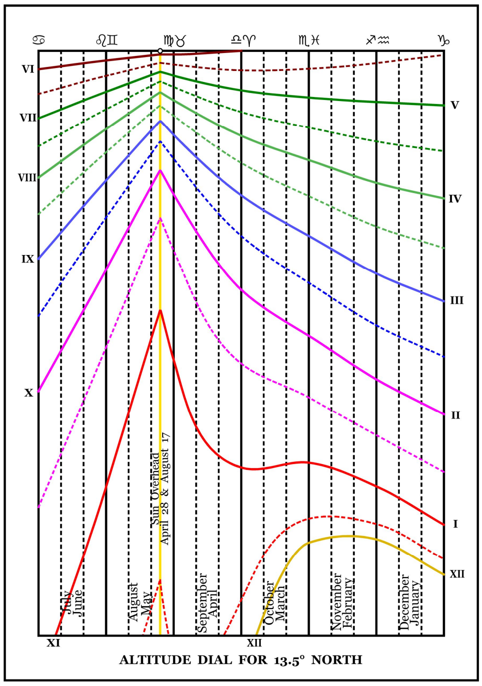


Fig. 2. Vertical plate dial with the gnomon positioned at the 'Sun overhead' point.

I tried several vertical plate dials, again getting this kink at the 'Sun overhead' position. In order to get as many hour lines possible, I set my gnomon directly above this 'Sun overhead' date position and produced the vertical plate dial of Fig. 2. This shows some 'wild' swings of the hour lines towards noon around this point and also the same sharp kink as the Sun transits between north and south. My aim to keep the XI-I line on the dial plot only failed towards the Summer Solstice. This could have been overcome by making the dial a bit taller, the gnomon a bit shorter or by making the horizontal date scale non-linear, effectively pulling in the left and right edges.

For another attempt to make a sensible dial for these latitudes, I decided to make a circular plate dial with its

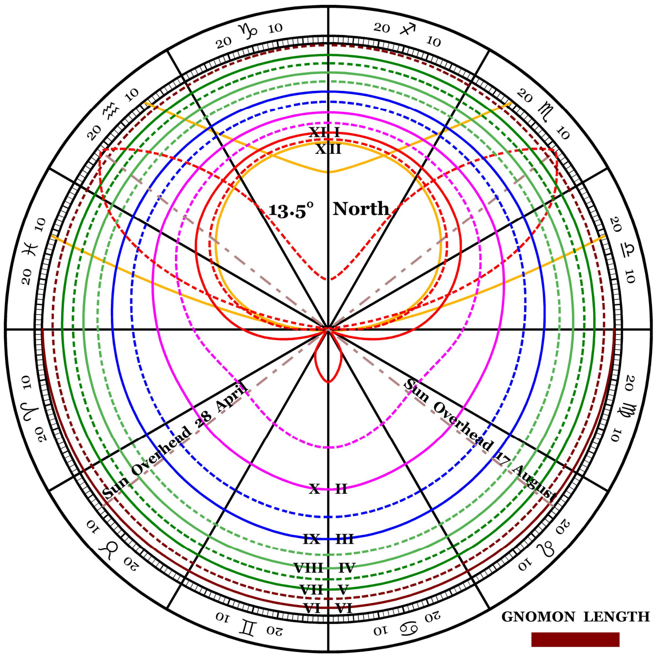


Fig. 3. Circular plate dial.

gnomon outside the hour line plot (Fig. 3). Although very similar to the vertical plate dial, it would allow me a bit more height for its overall size, especially if I were to run the summer midday lines onto the opposite side of the disc. In order to do this without too much confusion, I coloured each of the hour lines. I later used similarly coloured hour lines on the other dials as well. As can be seen from the layout, the lines from XI to I show some wild excursions, reaching infinity at the 'Sun overhead' points, but the 11:30 lines are *just* contained within the circle and the XII line towards the Summer Solstice reappears in the top half of the disc. Determination of the actual shapes of the lines close to noon was difficult and would have required further points to be plotted in this area but I think that what I have produced is somewhere near to the truth. In any case, it will make very little difference to the dial's timekeeping with the Sun approaching its zenith. (Note that the dial's gnomon should be positioned at the appropriate zodiac date on the line just inside the degree scale.)

I then attempted to make a vertical disc dial for 13.5° N (Fig. 4). The hour convergence points now stretch a good distance from the central disc and from the gnomon. Before the 'Sun overhead' position (right side of the dial), the lines follow a similar but much wider curve than those for European latitudes. After the 'Sun overhead' position, a reversal takes place and the convergence curve quickly leaves the plate of the dial, the various hour lines finally converging some distance away. However, the angle between these lines is very small so putting the hour marks around the border causes only very small errors in its timekeeping ability.

To sum up the results of this study, I find the circular plate dial the most attractive, particularly for the shapes of its calibration lines, and it would make a simple pocket device.

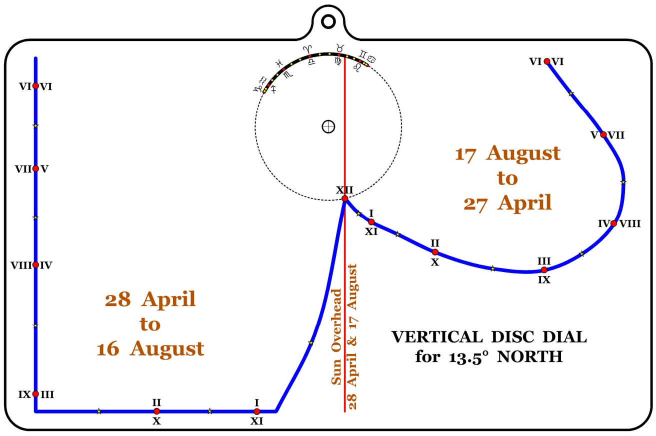


Fig. 4. Vertical disc dial.

But overall I think that the quadrant would make the most useful dial. This quadrant may be made without the usual sights if a pin is placed in the apex (with the plumb line attached) and its shadow is allowed to fall along the upper right hand line.

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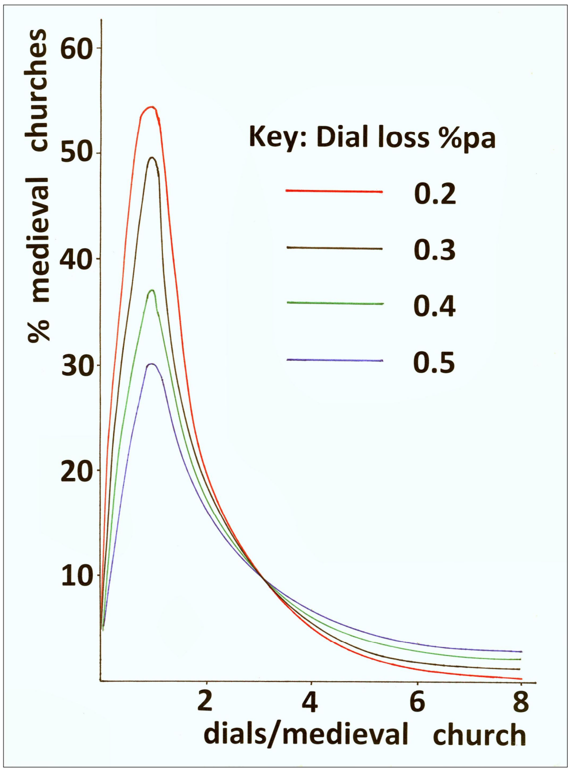
THE PREVALENCE OF ENGLISH SCRATCH (MASS) DIALS c.1650—Part 1

CHRIS H K WILLIAMS

By utilising the data and methodologies developed in earlier articles, this paper establishes a benchmark for c.1650. Broader discussion and consideration of the regional dimension is deferred to Part 2. Circa 1650 is of special interest because scratch dial displacement (by scientific dials and clocks) was then virtually complete; consequently their number was at its maximum with subsequent evolution explicable solely in terms of dial loss.[1]



Notes
1. Loss rates are applied to the median (% of medieval churches with listed surviving scratch dial(s)) grouping of the well surveyed counties. (See Chris H K Williams: 'The Geographic Distribution of Surviving English Scratch (Mass) Dials', *Bull BSS,* 20(ii), 75-6, (2008)).
2. Dial loss impacts all churches and all dials equally.
3. The surviving distribution is both shifted and stretched to the right and represents the higher dials/church portions of the c.1650 distributions.
4. The lower dials/church portions are derived via mathematical consistency constraints – ie each distribution has an average dials/church equal to that implied by total dial loss, is uni-modal, and relates coherently to those of different loss rates.
5. An allowance of 5% represents the earliest cases of displacement (cathedrals and churches attached to, or within earshot of, religious houses) whose former scratch dial(s) were lost prior to c.1650.

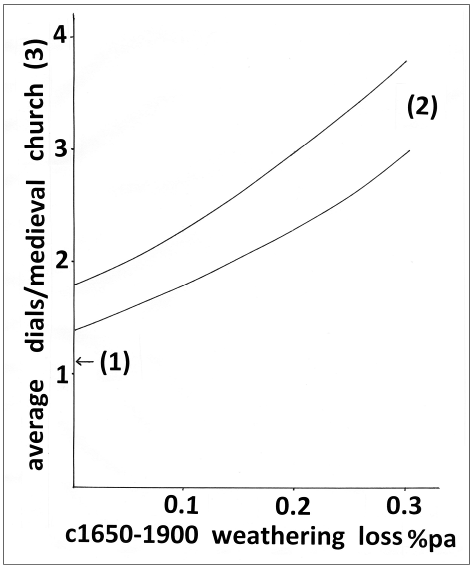
Fig. 1. Frequency distribution of scratch dials per church c.1650 for variant loss rates.

Loss rate c.1650 to listed surviving % pa	Dials lost post c.1650 %	Dials/church c.1650[1]	
		Average No.	≥6 % churches
0.2	45	1.7	2.5
0.3	60	2.3	10
0.4	70	3.2	20
0.5	80	4.0	30

Note
1. The median grouping of Bedfordshire, Hampshire, Kent and Norfolk has an average of 0.8 listed surviving dials/medieval church with 1.25% of churches having 6 or more dials.

Table 1. Summary scratch dial measures for variant assumed loss rates.

The c.1650 prevalence of scratch dials consistent with the surviving incidence is mapped, for variant assumed dial loss rates, in Fig. 1 and Table 1. Not surprisingly, as the assumed loss rate increases, the surviving incidence becomes consistent with both an increasingly higher original average number of dials per church as well as an increasingly higher proportion of churches with multiple dials.



Notes
1. The 1900 level (1.1 dials/medieval church) is based on listed surviving dials (Table 1 note) and twentieth century dial loss.
2. Circa 1650 levels for 0.1-0.2% pa range of building loss (the curves) on variant c.1650- 1900 weathering loss rates.
3. Cross referencing average dials/church to Table 1 and Fig. 1 permits the associated frequency distribution and overall dial loss (average % pa and cumulative) to be interpolated.

Fig. 2. Average scratch dials c.1650 using estimated loss rates.

Certain elements of dial loss have been estimated.[2] The combined weathering and church rebuilding loss amounted to 0.5% pa in the twentieth century. The loss over the centuries attributable to rebuilding is some 0.1-0.2% pa.[3] The implications of these estimates for the c.1650 reconstruction are shown in Fig. 2.

The major remaining uncertainty relates to pre-1900 weathering for which no direct estimate is currently possible. That said, related information and considerations can help to narrow and bound our uncertainty. Twentieth century weathering can be calculated as a residual - (0.5 minus 0.1 to 0.2)% pa. It is probable that twentieth century church rebuilding was below the historic average. After the Victorian climaxing of restoration some attenuation was only to be expected, not to mention the cumulative impact of a wave of crises[4] culminating in the current pressing backlog of necessary repairs. Actual twentieth century weathering may well have been above the 0.3-0.4 % pa residual. On the other hand, pollution during the twentieth century can be expected to have increased the rate of weathering above the pre-1900 rate.

How relevant are recent (to pre-1900) weathering rates? Much more so than might be apparent at first glance. Whilst intuitively it might be supposed much lower rates of weathering applied in the past as dials were then so much younger, on reflection this turns out to be uncompelling. In brief, this arises for two reasons. Firstly, redundancy led to dial age being spread throughout the entire scratch dial era, not concentrated at its commencement. Secondly, it is the oldest dials that weather out. As a consequence the average age of surviving dials advances at a major discount to the passage of time.[5]

The evidence has been presented with sufficient transparency to facilitate readers applying their own judgement. The author is inclined to the view that c.1650 there were on average between two and three scratch dials per church.[6]

REFERENCES AND NOTES

1. Chris H K Williams: 'The Life Cycle of English Scratch (Mass) Dials', *Bull BSS,* 20(iv), 164-5, (2008).
2. Chris H K Williams: 'English Scratch (Mass) Dials: The Ravages of Time', *Bull BSS,* 20(iii), 110-111, (2008).
3. The estimate of building loss *(ibid)* is in the form of the number of dials relative to those surviving. It can be converted into an equivalent annual loss rate given the average age of scratch dials. The main text range assumes an average age starting between 1400 and 1600. Although the average age is not currently known, dial age is less than implied by earlier students when due regard is paid to the completion of (rather than the earliest) displacement, the cumulative impact of redundancy, and the high rate of loss inevitably culling the oldest dials most-all significantly reduce the apparent perceived average age of surviving dials.
4. Two world wars, interwar depression, and financial pressures on the ecclesiastical economy spring to mind.
5. It can be shown on not unreasonable assumptions that the average age of surviving dials in the twentieth century was less than 100 years older than the c.1650 – 1900 average, and that a surprisingly high proportion of dials surviving between c1650 – 1900 were older than the twentieth century average.
6. Greater precision is contingent on extracting the age structure and weathering rates of dials from the database. It is hoped a cross sectional analysis of dial survival by type will permit this. If so we can return to this paper in the future in a less qualitative fashion.

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NEW DIALS

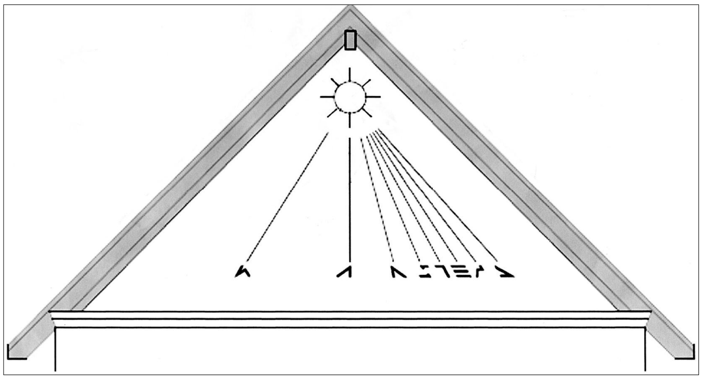
The Corner House, Wanstead High Street

Strange geometric patterns incised in plaster, enigmatic grotesque work, unidentified initials in terracotta – all this has been lovingly restored in recent work at one of Wanstead's most interesting buildings, the Corner House (1890).

When I approached architect Jason Harris about the possibility of adding a sundial to this heady mix, he was delighted. It turned out that the decoration on one of the gables (facing 63° West of South) was beyond restoration, and he had been wondering what to do with it anyway.

For aesthetic reasons we limited the hour coverage from 11 to 6 (any more would have disrupted the symmetry). For more mischievous reasons, and in keeping with the mystery of the building, we decided to replace the hour marks with symbols. In due course an explanation panel will explain what hour each symbol represents, without revealing their overall hidden meaning. [The editor would be pleased to know if you can crack the code!]

Producing such a dial, in situ, was not going to be easy, but luckily we had the right person to do the job, a local expert in pargeting and incised plaster-work, Marc Delea. Since it would be impractical to delineate the dial directly onto wet plaster, we decided first to lay it out on the hard under-



surface. Holes were then drilled for the gnomon posts, which were then inserted and glued in, making allowance for the thickness of the lime plaster yet to be applied. Pins marking the ends of the hour lines were then knocked in, to protrude through the subsequent plaster layer and show Marc where to incise the hour lines. The pins were then removed.

When dry, the dial surface was painted an attractive apple green and all the incisions were painted a charcoal colour. Unfortunately, due to a misunderstanding on the maker's part, the gnomon does not extend quite far enough towards the root. This results in the gnomon's shadow falling off the hour lines before noon in high summer. Only an hour is lost, but a shame nevertheless.

It is particularly fitting that the Corner House now has a sundial, since it bears a commemoration plaque to James Bradley (1693–1762), curate of St. Mary's Church, Wanstead, and famous astronomer. With his uncle the Rev James Pound he studied the heavens in nearby Wanstead Park, using a telescope mounted on a large maypole that had come from the Strand in London.

John Moir

New Moondial

David Harber Sundials are launching this new globe moondial at the 2009 RHS Chelsea Flower Show. Globe sundials with this form of swinging gnomon (swung to produce the minimum shadow) are not uncommon but this moondial version is novel. Formed from a 70 cm stainless steel sphere, a series of time rings either side of the equatorial ring show the time by the moon for the nine days of each month around the full moon. Each ring has a 48 minute offset from its neighbour. These calibrations are etched into the mirror-polished steel, a process of some complexity. The instrument can, of course, function as a standard sundial as well.

THE GRAVESTONE OF A SUNDIAL MAKER

ROGER BOWLING

John Wall in the article 'Graveyard and other Memorial Sundials' states he has not yet found the gravestone of a sundial maker.[1] But there is at least one, and it is probably unique as it is also the gravestone of a gravestone engraver. It is recorded, (SRN 3255) and situated in the churchyard of St Mary Arden, Market Harborough.

The gravestones in this churchyard are mostly slate and show the very beautiful engraved lettering common in that area, but which also occur elsewhere. One of these is the memorial to Samuel Turner, 1716-1784. The inspection, Fig. 1, tells his life story.

In Memory

of Samuel Turner

Who was Born at a Lone House in
The *Parish* of *Harrington* in the
COUNTY of NORTHAMPTON.

His Occupation a *SHEPHERD.*
His amusements were the beautiful scenes
of *Nature.*
His retirements the study of
Surveying. Dialing. Engraving.

In the 35th Y*ear* of his *Age* he removed to
M^{t}. Harboro and Changed the *Cottage* for
The *Shop* and the *Crook* for the *Pencil.*

His *Works* that are left will shew his *Abilities.*
He travelled through a rough and rugged
road of affliction and *Died* in hope of a
Happy Eternity the 13th day of *February Aged* 67

Fig. 1. Transcription of the engraving on the gravestone.

Fig. 2. The top of the gravestone with dial and dialling instruments.

Fig. 3. The direct west dial on the gravestone.

At the top of the stone, his story is told again in pictures, see Figs. 2 & 3. At the top on the left hand side is a map of his farm of four fields and farmhouse and the river forming the boundary. Next to this are his dialling tools, divider, protractor and rule. On the opposite side is a barn next to a tree, two sheep, and Samuel Turner himself seated by his easel, palette and brush in hand painting a picture of a house. In the centre at the top is a direct west sundial with Roman numerals and the motto Tempus Fugit: it is about 10 cm square.

I believe, due to the very personal nature of the details, that Samuel Turner must have created this monument himself, all that is except for the last line. It is triply unique, being the memorial of a sundial maker, with a sundial, and created by the dial maker himself.

The church of St Mary Arden was, when I visited it in 1996, in the care of The Churches Conservation Trust. The churchyard had been cleared of gravestones to make a large green space. The sundial, as you will have noticed, has been vandalised, but so have most of the other lovely engravings too. The gravestones have been moved nearer to the church, most placed in pairs back to back and joined by one or more large iron spikes driven through the centre of each with a sledge hammer. Samuel Turner's work suffered so. This is not the vandalism of the pointless act, but that of authority, of those entrusted to clear the churchyard—it is beyond belief.

REFERENCE

1. J. Wall: 'Graveyard and other Memorial Sundials', *BSS Bull* 21(i), 43-48 (2009).

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A NOVEL REFLECTING SUNDIAL IN SWEDEN

DINA HVIID and CURT ROSLUND

Sundials appear in great diversity and intricacy, not because of technical necessity but for intellectual enjoyment and artistic pleasure, felt not only by the artist but also by the viewers. Such a sundial, shown in Fig. 1, was devised by one of us, sculptor Dina Hviid, after calculations by astronomer Curt Roslund. It was set up in 2008 in the front yard to the Tolefors Farm, 10 kilometres by road west of Linköping towncentre in eastern central Sweden.

Fig. 1. The solar spot photographed on the Tolefors sundial at 12 o'clock local time on the winter solstice, December 23 in 2008. Note how dark the landscape is in Sweden in winter even in the middle of the day when the sun shines.

In the Tolefors sundial, a sunbeam is reflected by a plane glass mirror onto a wall serving as the *dial plate*. The mirror is resting with its underside on a stand 75 cm above ground and oriented exactly to face south. The inside surface of the wall is placed squarely on the *meridian* line 40 cm south of the mirror stand. The wall is part of a segment of a cylinder with a vertical axis placed at a point 60 cm on the meridian line north of the mirror stand. Its height is 72 cm above the south meridian line but increases to 90 cm at its ends. The wall is about 20 cm thick and extends 80 cm on either side ot the meridian. It was built from wedge-like 'lecablocks' and polished until the surface was smooth and shiny.

Both the wall and the mirror stand on a platform. As our sundial uses the ground surface for getting a coordinate H, great care was taken to make the platform flat and horizontal. To make the platform resistant to wear and tear by observers, it was made of concrete.

The glass mirror is an ordinary round mirror with a diameter of 8 cm that one can buy in any glaziers. We use a laminate of two glass plates sandwiched together, because this makes the glass resistant to rain and breakage, we were told. A mirror has one disadvantage, however, and that is that the solar spot becomes unnecessarily elongated for sunlight coming in sidewise.

When the construction phase was over, our next task was to calibrate the sundial by laying out a sun-grid on it. The position of a solar spot on the dial wall will then tell you the actual time. We began by computing the *altitude* a of the sun at a time T when the sun's hour angle is h at a place with known *latitude*, i.e. $\phi = 58°\ 25'$ N for Tolefors. The altitude can then be obtained from the formula:

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

The remaining variable is the *declination* δ which varies with the seasons of the year. Another important quantity is the direction to the sun, *azimuth* A. It can be obtained from a similar equation to the one above:

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

The coordinates a and A tell us where in the sky the sunlight comes from and next we shall investigate where this light is going. For this purpose an imaginary horizontal triangle BCD is introduced (see Fig. 2) with the angle B at the mirror stand, the angle C at the wall and angle D at the centre of curvature for the radii that ensure that the inside wall is part of a circular segment of a cylinder with a vertical axis. We instantly recognize that angle B is equal to 180° minus the azimuth A; that the side b opposite angle B has a length of 100 cm; and the side c opposite angle C**,** a length of 60 cm. We now know enough quantities in the triangle BCD to make it possible to calculate the others:

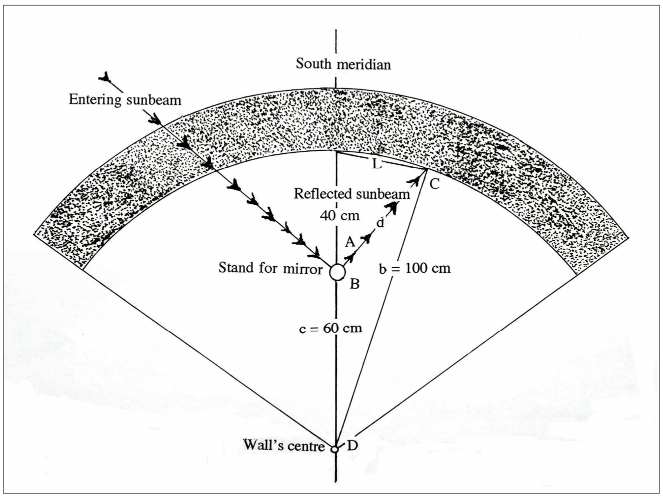

Fig. 2. Ground plan of the Tolefors sundial shows how it was designed to provide suitable parameters for making a sundial both æsthetic and scientific.

$\sin C = c \sin B / b, \quad d = c \sin D / \sin C = b \sin D / \sin B$

The parameter d is the *horizontal linear distance* between the mirror stand and the wall on which the light is projected by the mirror to make the solar spot. When choosing parameters for the sun grid, it might be easier to work with the horizontal linear distance L from the solar spot to the south meridian if the latter is shown on the wall. Similarly, the vertical linear height, H**,** of a solar spot from the floor is to be preferred:

$$L = \sqrt{40^2 + d^2 - 2d40\cos A} \qquad H = 75 - d\tan a$$

There are two main methods to calibrate a sundial: one is largely practical and the other theoretical. The time grid of the first one is made from actual observations of the changing position of the solar spot with time. This method is often very personal. A family who owns a sundial may for instance mark celebration days with a special colour.

The theoretical method is the one used here. We tried to find a way that allowed us to calculate how the solar spot moved during the day. With the help of the well-known slowly changing declination of the sun with the seasons of the year, we were able to establish the shift of the daily movement of the solar spot with the advance of the year (Fig. 3).

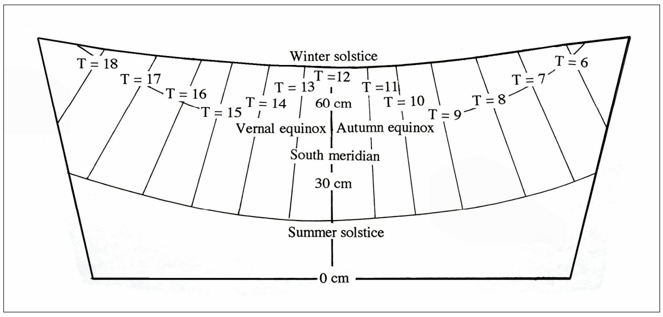

Fig. 3. The surface of the wall dial of the Tolefors sundial unrolled to a plane surface. The network of nearly straight lines rising up from the ground are the time lines and indicate whole hours.

How accurately a sundial shows the time during the day and date during the year depends naturally on how careful one has been when building it. In our case, the floor had to be smooth and exactly horizontal, while finding the vertical is more important for the mirror stand and the axis of the segment of the wall. If possible, optical instruments should be used to find the direction of due south. One should also remember that a mirror is prone to disturbances so it should be readjusted occasionally.

There are some effects which have to be taken into account when reading a sundial. The time shown by a sundial is always *local* or special for that place and must therefore be corrected to *standard time*. For instance, the longjtude correction for Tolefors is 1 minute and 48 seconds.

What made us to take up this unusual type of sundial? With a shape specially chosen out to fit the style of a 17th century

	LAT at Winter solstice		
	12h	15h	18h
Sun's altitude, a	8° 15'	0° 08'	-19° 48'
Sun's azimuth, A	0° 00'	40° 26'	77° 13'
$\angle B$ = 180° - A	180° 00'	139° 34'	102° 47'
$\angle C$	0° 00'	22° 54'	35° 48'
$\angle D = 180° - \angle B - \angle C$	0° 00'	17° 32'	41° 25'
d, cm	40.0	46.5	67.8
spot-meridian L, cm	0.0	30.5	70.6
vert. height H, cm	69.2	74.9	99.4

Table 1. Some details for constructing a Tolefors type sundial.

farmhouse in a landscape of old pasture-land with groups of ancient oak-trees, such a sundial would add to the natural beauty of the scenery so characteristic of this place. We believe that a cultural expansion of interest from the architecturally simple lines of the sundial to the refinements of a sculptural park would be the next step to bring nature and culture together.

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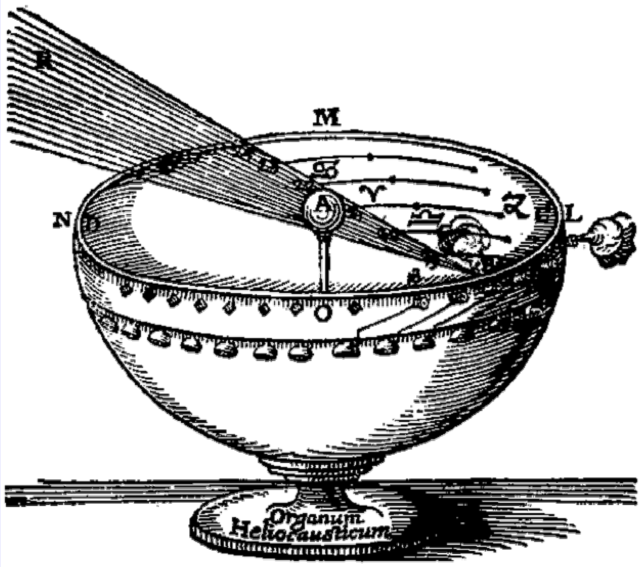
Chiming Sundial



There is nothing new under the sun! Just after we published Tony Moss's *Sundyal Alarme* in the last issue (Bull. 21(i) p.48), this 1645 drawing of an *Organum Heliocausticum* (a sundial for chiming the hours) was found in a book by Athanasius Kircher. It uses a spherical lens to focus the sun onto small piles of gunpowder, releasing an arm which strikes one of the hour bells. I want one!

JD


1641
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