M Cowham

Altitude Dials

BSS Monograph No. 4

A Study Of

ALTITUDE DIALS

Mike Cowham

The British Sundial Society

BSS Monograph No. 4

THE BRITISH SUNDIAL SOCIETY

A Study of

ALTITUDE DIALS

how to construct them

how to use them

their errors and accuracies

Make your own Altitude Dials
from examples on an enclosed CD-ROM

MIKE COWHAM

BSS Monograph No. 4

First Published in Great Britain by
The British Sundial Society

ISBN 978-0-9558872-0-8

Printed by CPI Antony Rowe
Designed by J Davis

CONTENTS

FOREWORD

The history of portable sundials starts probably around 1500 BC in Egypt with the construction of an altitude dial. This consisted of a horizontal stone with a small vertical block at one end. When turned to the Sun until the vertical block casts a shadow on the horizontal section, the time can be determined by the length of the shadow formed.

For the following centuries, measuring the height of the Sun in the sky remained the favourite method for determining time in the field of portable sundials. Several instruments, such as quadrants, pillar dials, vertical disc dials, Regiomontanus dials etc., were developed for this purpose.

Besides the height of the Sun, its changing direction in the sky in the course of the day can be used for indicating the time too, provided that one knows the direction of true north. It was not until the late Middle Ages that this second parameter of the Sun, its direction, was applied to portable sundials because of the lack of an easy-handling instrument telling true north. Therefore, the development of directional portable sundials was tightly linked with the invention of the compass, which was known in Europe from around the 11th century.

The directional dials, normally provided with a gnomon aligned with the Earth's polar axis, as in the well-known horizontal dials, diptych dials and later on the equinoctial dials, had several advantages compared to the altitude dials. The two main ones were their ease of use and relatively simple production. They soon became very popular and were produced in great numbers. Consequently many directional dials came to us and are now shown in the museums, where they sometimes overshadow the history of the altitude dials.

In the present book Mike Cowham draws our attention again to altitude sundials. By visiting numerous private and public collections in Europe and further overseas, he has gained a wide experience and profound knowledge not only of well known examples but also of some extraordinary dials. 38 types are listed and described in the book. For each of them a model was made and documented with a photograph. Fundamental considerations on the accuracy of each type and helpful advice on usage from the examination of each model are added.

Provided with valuable practical hints in the book and templates on the attached CD, the reader is well equipped for a special form of "learning by doing" i.e. is invited to choose a type of the presented dials for constructing his own model. It is a pleasure to accept this invitation.

Ilse Fabian *October 2008*
Sundials Group, Austrian Association of Astronomy

Other British Sundial Society Monographs in this Series

1. C. Daniel: *The Equation of Time: The Invention of the Analemma. A brief history of the subject*, (January 2006).
2. J. Wilson: *Biographical Index of British Sundial Makers from the seventh century to 1920,* (December 2007).
3. A. Cook: *Mass Dials on Yorkshire Churches,* (May 2008).
4. M. Cowham: *A Study of Altitude Dials,* (2008).
5. J. Davis and C.M. Lowne: *The Double Horizontal Dial,* (t.b.p 2009).

PREFACE

Why altitude dials? I have seen many of these over the years, mostly in museums and collections, but, until now, I had not fully understood how to use them, let alone how to construct them.

I then came across a most unusual dial, being neither a vertical dial nor what I thought was an altitude dial. It is the dial by Erasmus Habermel (dial 10 in this study). I then tried to make one but, unwilling to make a simple copy, I decided that it had to be made for the latitude of Cambridge, not that of Prague. This dial gave me many problems, some of which still need to be solved, but Frank King has been most helpful and, with his assistance, I am sure that the remaining problems can now be solved.

The pillar dial, perhaps the best-known of all models of altitude dial.

Following this dial, several others were made, each being something of a challenge due to wide differences in the configurations of altitude dials. Eventually, after more than three months of drawing and construction, I had amassed around 40 models of altitude dials, all except one (and the universal dials) made for the latitude of Cambridge.

On a recent holiday to The Gambia, in West Africa, I took along my sheaf of papers with many of the dial diagrams, determined to write some notes about each type. Two of these in particular were universal models, so why not see how they would work at a latitude of 16° N? I took the Regiomontanus dial (33) print, fitted it to my clip board, added a piece of cotton for a plumb line and an improvised plummet and bead in the form of a paper clip, set the thread suspension point to the correct longitude and date, and was pleasantly surprised that I could tell the time to within a few minutes (after allowing 1h 7m of longitude shift and for the Equation of Time). I then did the same with the Apian horoscopium (36), getting similar results. Both dials also told me the right time for sunrise and sunset. It seemed that I had constructed them correctly!

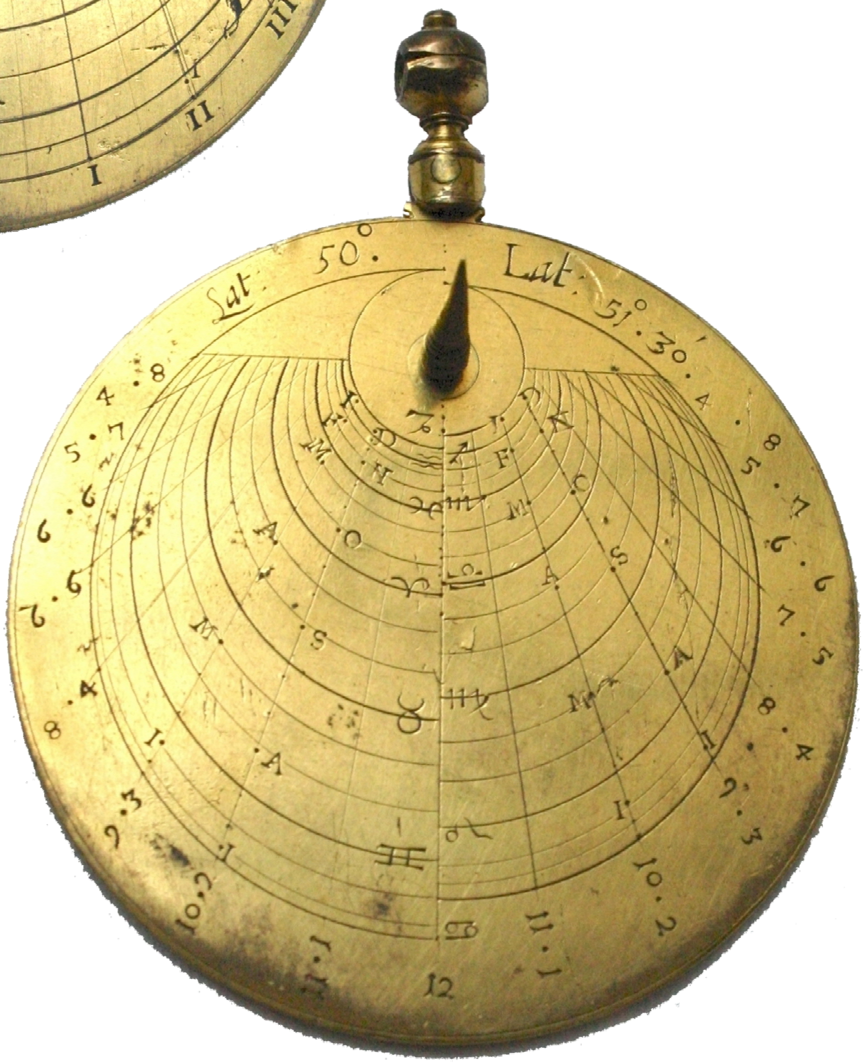
These dials have given me so much fun and interest that I decided to share my research with others in the form of this monograph. The dials are all made for 52° north but I hope that the notes given about construction methods will allow the reader to make similar dials for any part of the world. Try to make a few and see for yourself the problems and joys of using these fascinating little dials.

A CD-ROM is enclosed with high resolution images of each of the designs, plus some useful templates etc. When you make your own dials please try to make at least one for your own latitude, or if your latitude is the same as Cambridge, make one for a completely different latitude, so that you may experience the pleasure of making one of these interesting dials for yourself.

Mike Cowham
Cambridge, 2008

The two sides of the dial by Erasmus Habermel, dial type 10. The first side shows a full calibration for its primary latitude of 48º 30' and the reverse side has calibrations for two latitudes, 50º and 51 30' (London), each using half of the dial with the hour lines retracing their paths to keep them separate.

Augustinermuseum, Freiburg-im-Breizgau.



AN INTRODUCTION TO ALTITUDE DIALS

Most people are familiar with the dials that are frequently found in gardens, on churches and on other public buildings. Nearly all of these have sloping gnomons with the sloping edge parallel to the axis of the Earth. These dials rely on the rotation of the Earth to make the apparent position of the Sun in the sky form a large arc during the course of the day. The arc follows an imaginary line, known as the Ecliptic, and the Sun appears to move by 15° each hour between sunrise and sunset. These are generally known as ‘dials of direction’.

The ‘altitude dial’ relies solely on the height of the Sun above the horizon. As we know, the Sun rises (approximately) in the east, climbing to a maximum altitude at noon before falling back to the horizon at sunset. The height of the Sun depends on two factors; the latitude of the observer, north or south of the equator, and the time of the year. In winter the Sun is much lower than in summer, actually by almost 47°. Therefore, any dial using the height of the Sun needs also to take into account the time of the year.

Since antiquity, the Ecliptic has been divided into 12 ‘Houses of the Zodiac’. Each of these houses is divided into 30 degrees making a total of 360° in the complete circle. The Zodiac year traditionally begins at the ‘First Point of Aries’, ♈, when the Sun crosses the equator from south to north. This is the ‘Vernal Equinox’, which is set by our calendar ideally at 21 March but, due to the small corrections to our calendar by insertion of leap years, there may be a difference of around one day either side of 21 March. The older Julian calendar which was phased out in Europe from 1583 (1752 in Britain) had the vernal equinox 10 days or more earlier. Therefore, old dials will often carry the equinox date of 10th or 11th March.

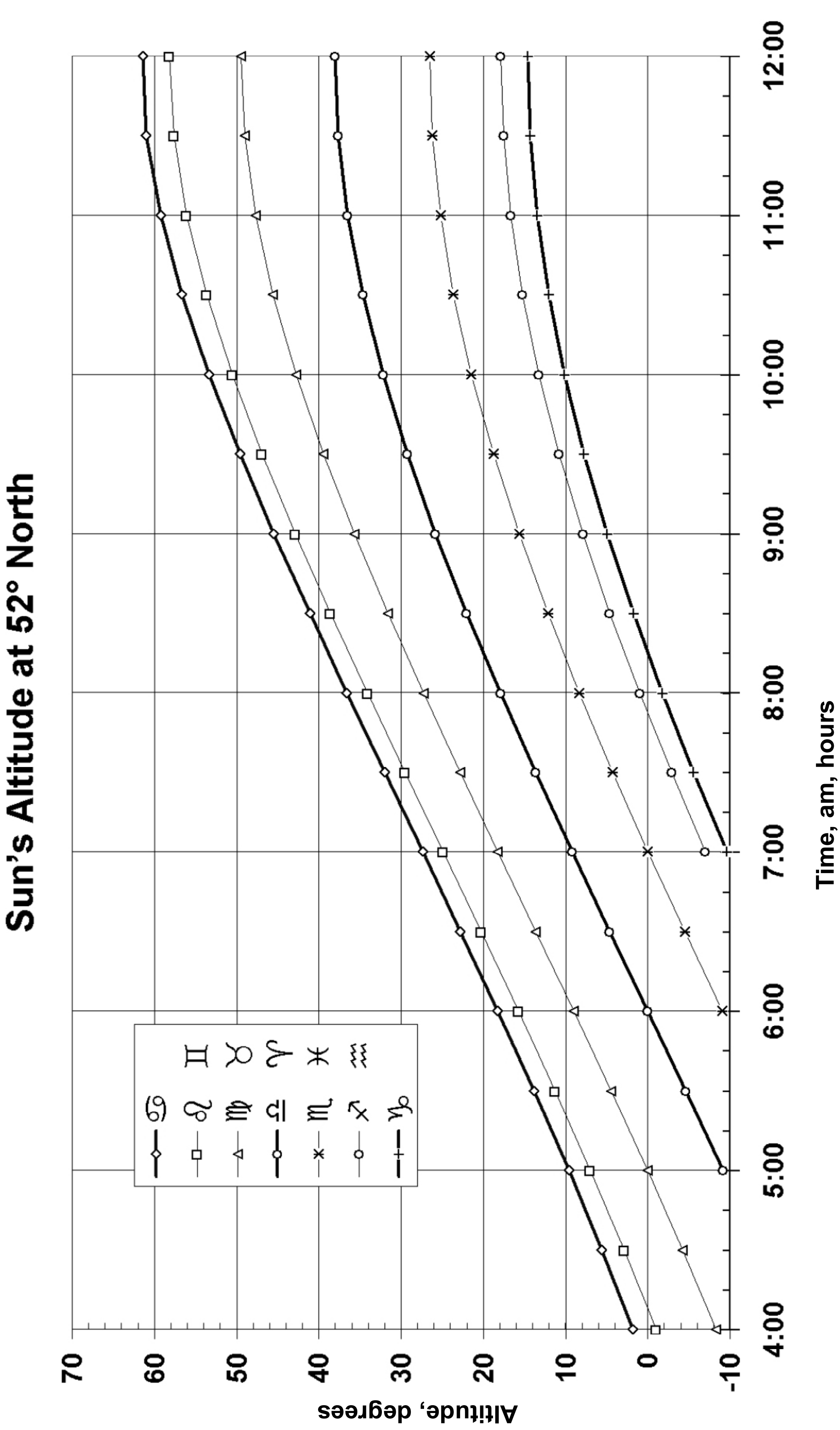
SYMBOL	SIGN	NAME	DATE OF ENTRY
♈		Aries	21 March
♉		Taurus	20 April
♊		Gemini	20 May
♋		Cancer	21 June
♌		Leo	23 July
♍		Virgo	23 August
♎		Libra	22 September
♏		Scorpio	24 October
♐		Sagittarius	22 November
♑		Capricorn	22 December
♒		Aquarius	20 January
♓		Pisces	19 February

Furthermore, due to the slight eccentricity of the Earth’s orbit around the Sun, each degree of the Zodiac will differ slightly in duration when measured by an equal time clock. However, it is generally assumed that each degree of the Zodiac is roughly equivalent to one day of our solar year (although this has around 5¼ days more than the degrees of the Zodiac). The small differences in time caused by these approximations are, in the short term, generally negligible.

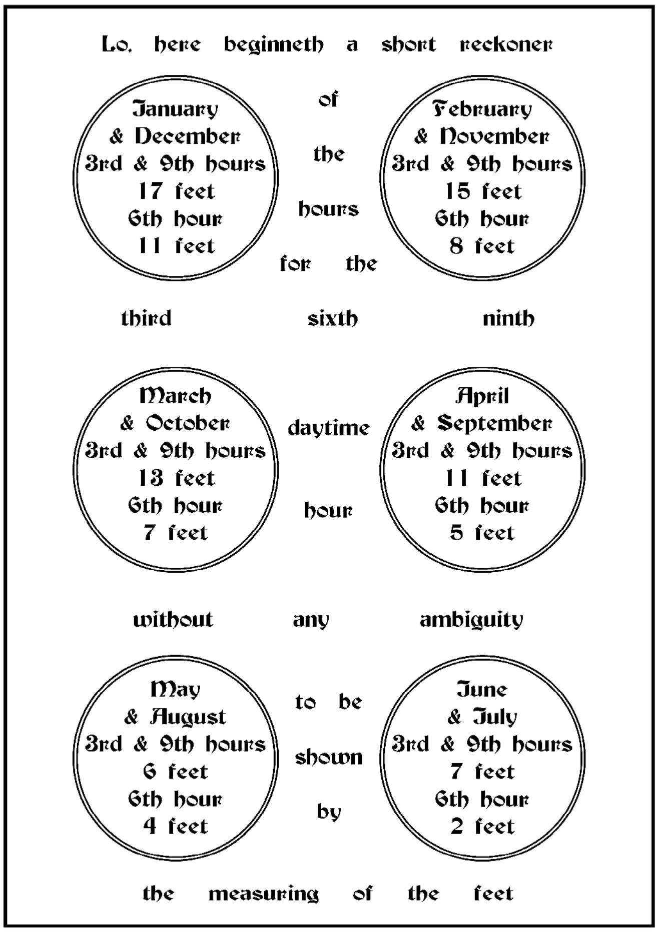
Is the measurement of time by ‘altitude’ rather than by ‘position’ any more accurate? If we take as an example a day at the Equinox, the Sun rises in the east at 6am, travelling at a constant speed of 15° per hour to sunset at 6pm. Therefore, during the course of the day it has travelled through an angle of 180°, exactly half of a circle. At the same time, the Sun climbs from an altitude of 0° at sunrise up to a maximum of the co-latitude of the observer, before falling again back to the horizon at sunset. In all of the examples used in this study I am, for convenience, using the approximate latitude for Cambridge of 52°. This latitude will be valid for a large proportion of the British Isles with only small errors between, say, the south coast and the Humber (approximately 50° to 54°). The co-latitude of Cambridge is 90° - 52° = 38°. This means that in one day at the Equinox the Sun’s altitude will change by +38° rising and -38° setting, a total of 76°. This is hardly over a third of the angular difference recorded by a dial of direction, so inherently it is likely to be less accurate. At other times of the year, the ratio between the two methods remains much the same. However, there is a further factor that will change the real ratio between the two. The rise and fall in altitude is

	04:00	04:30	05:00	05:30	06:00	06:30	07:00	07:30	08:00	08:30	09:00	09:30	10:00	10:30	11:00	11:30	12:00
♋	1.78	5.57	9.61	13.87	18.27	22.78	27.36	31.99	36.61	41.10	45.53	49.60	53.38	56.65	59.21	60.98	61.44
♌ ♊	-1.00	2.87	7.00	11.30	15.75	20.30	24.9	29.53	34.09	38.56	42.85	46.88	50.53	53.65	56.07	57.61	58.15
♍ ♉	-8.34	-4.27	0.03	4.47	9.01	13.62	18.23	22.82	27.28	31.6	35.68	39.44	42.78	45.57	47.68	49.01	49.47
♎ ♈			-9.17	-4.61	0	4.61	9.17	13.64	17.93	22.01	25.82	29.24	32.22	34.67	36.49	37.62	38.00
♏ ♓					-9.01	-4.47	0.03	4.27	8.34	12.16	15.66	18.78	21.46	23.62	25.22	26.20	26.53
♐ ♒							-7.00	-2.87	1.00	4.61	7.89	10.78	13.24	15.22	16.67	17.55	17.85
♑							-9.65	-5.57	-1.78	1.74	4.93	7.74	10.12	12.03	13.42	14.27	14.56

Table of the Sun’s altitude in degrees for Cambridge at 52° N.



The Sun's altitude at 52º N at the point of entry into each zodiac sign.



Shadow length tables from Leofric's 10th century Missal, showing shadow lengths of a man for the third, sixth (noon) and ninth hours.

not constant, being greater near to the horizon, slowing down as the altitude increases until at noon a reversal takes place. In practice, this improves the early morning and late afternoon accuracy (being 9.25º/hour in summer and reducing to 6.5º/hour in winter) but makes any readings around noon very inaccurate. Readings taken from altitude dials are best disregarded between perhaps 11am and 1pm where very little change occurs, and are somewhat unreliable between 10am and 2pm. A plot of the Sun's altitude from sunrise to noon at the time of entry into each of the zodiac signs is shown. The time from noon to sunset is a mirror image of this so it has been ignored here. Note that a few points below the horizon have also been plotted. As will be seen later, these are often useful when designing these dials.

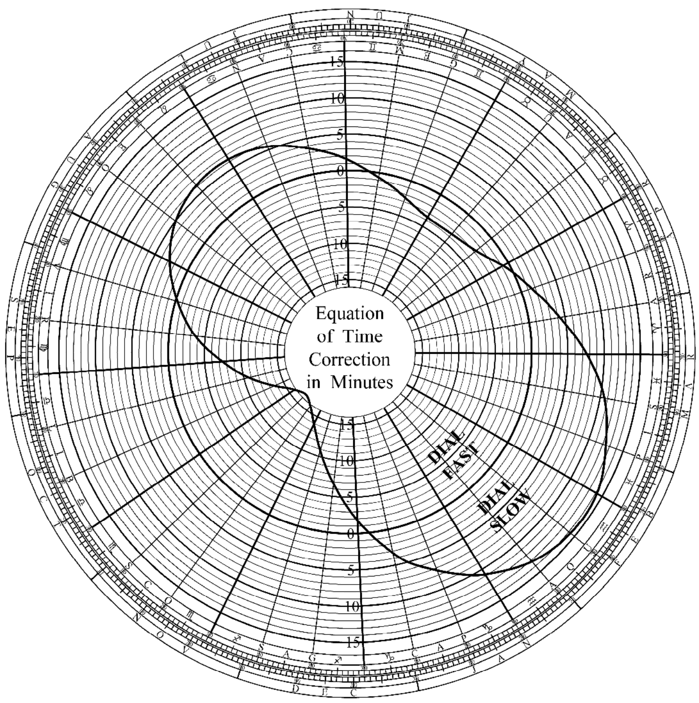
One important advantage of the altitude dial is that it immediately gives the user times for sunrise and sunset. These occur when the Sun's altitude is zero and may be read off against the date scale. Times of sunrise and sunset were most important in the days before adequate street lighting. A gentleman would hope to be safely home in the daylight hours away from the threats of robbers who often operated in the dark. Travelling at night had its dangers too, with roads that were frequently full of large holes, puddles etc.

Altitude dials therefore appear to be somewhat more complex than their directional counterparts and many different types have been produced to record the height of the Sun.

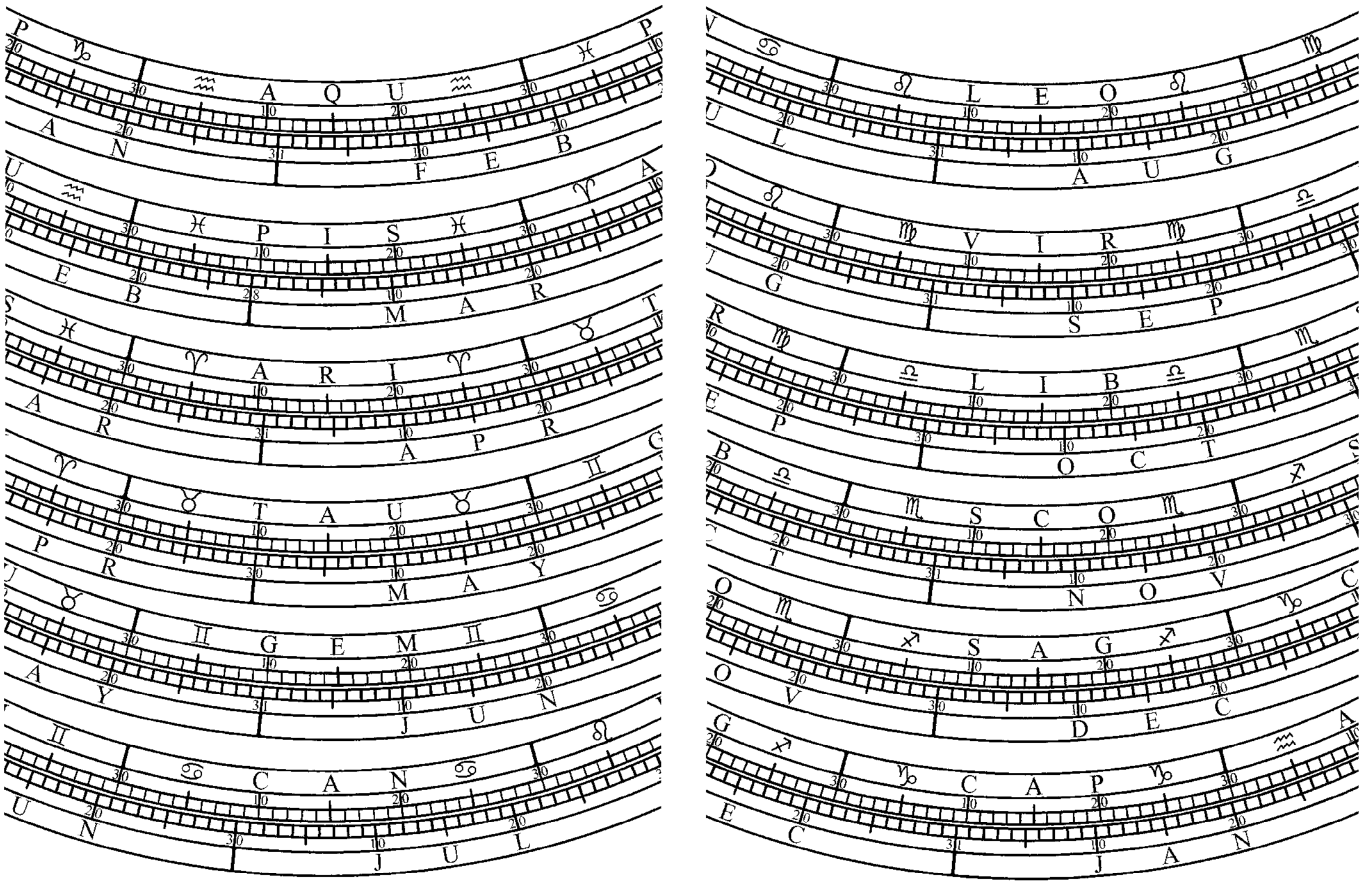
The altitude dial probably appeared many thousands of years before the directional dial. Records do not generally exist of the very early dials but some figures are recorded from more recent times showing how the length of a man's shadow could be used for time telling. The 10th century *Leofric's Missal* gives such tables. This is one of the rare examples of a horizontal altitude dial. In the horizontal plane, it is not possible to record hours when the Sun is low as the shadow would be of infinite length at sunrise or sunset. Leofric's shadow table shows that the length of a man's shadow at the third or ninth hour in December or January is already 17 feet long, compared with the sixth hour (noon) in June and July where it is only 2 feet long. Therefore, virtually all portable altitude dials were constructed in the vertical (or near vertical) plane.

Construction of Altitude Dials

There appear to be many examples of altitude dials in various museums and collections and they vary dramatically in size, complexity and accuracy. They are all portable dials (mainly because they need to be turned to follow the Sun) and do not need the use of a compass for correct alignment. It was therefore my intention to replicate as many of these as possible in order to find out how they were made, how they were intended to be used and how accurate they really were. Some of my findings are surprising.



Calendar ring converting dates to zodiac degrees with corresponding Equation of Time corrections.



The calendar ring converting the date to zodiac degrees, split into 12 parts for extra clarity.

The most important information that was required for this study was a table of the altitude of the Sun at different times throughout the year for my latitude. Although such tables are published, I did not have access to one, so it became necessary to calculate the figures for myself. The general formula for this is given by *Waugh* and others:

$$\sin a = \sin d \sin \Phi + \cos d \cos \Phi \cos h$$

where a is the Sun's altitude, d = Sun's declination (in the range ±23.44°), h = Sun's hour angle (from noon at 15° per hour) and Φ = latitude (52°).

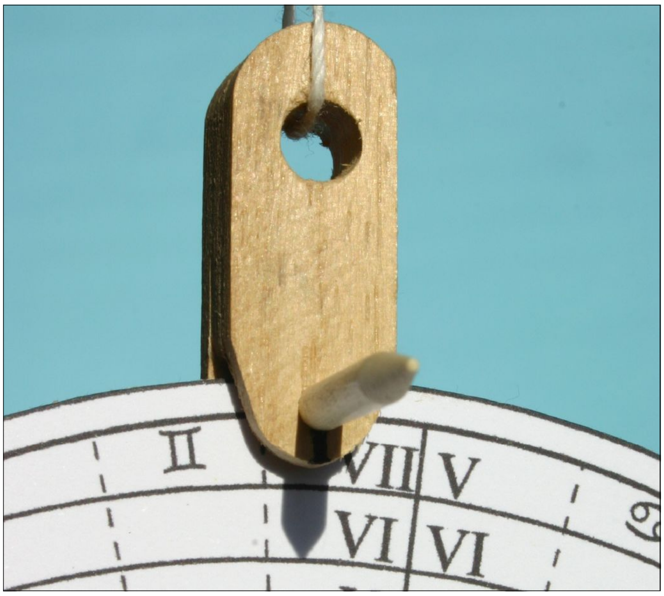
From this formula, a table was produced at half hourly intervals at the time of entry into each zodiac sign. This was used to produce the table of the Sun's altitude shown on page 1 and its graphical representation on page 2.

Calendar

The signs of the zodiac conveniently split the solar year into 12 equal portions of 30° each, and have been used on most dials in preference to the civil calendar which does not divide so conveniently. Therefore, it is often necessary to convert from our current date to degrees of zodiac. To simplify this, an annual calendar/zodiac scale has been produced in the form of a ring, shown on page 3. As this is so detailed, it makes the individual days so small that they are difficult to read in a publication like this, so the calendar ring has been divided into 12 sections which are shown separately above. With these, it is relatively simple to convert any date to degrees of the zodiac. We can never get an exact date because changes of up to one day occur at every leap year, so a true correspondence can only be within a day or so, but this is not too important in these simple dials.

Accuracy

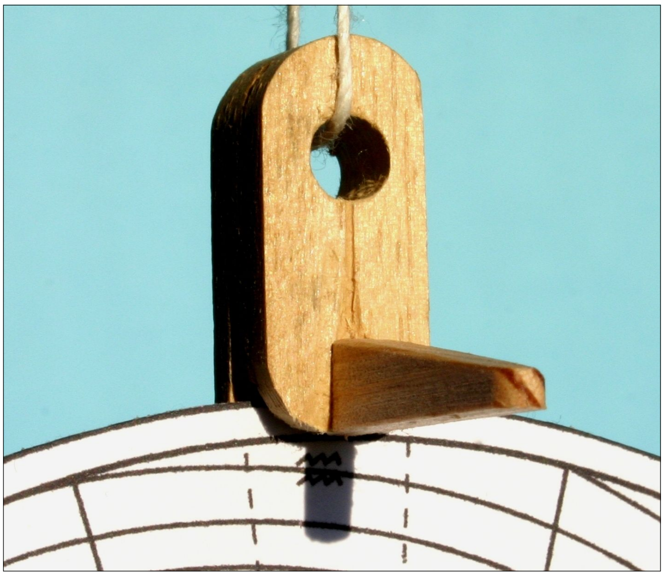
The dials detailed in this study vary greatly in the way that they use the Sun's altitude, some being more accurate than others. Most of the dials that have been analysed or replicated are based on actual dials from museums, collections, catalogues or illustrations. Some dials are very basic and can never give an exact time, but the time given would have been adequate for their users so many years ago. Actual accuracies are discussed for each type. Other errors creep in with certain designs. In particular, a horizontal gnomon should ideally be kept to minimum diameter so that its size does not impede the Sun's rays from reaching the calibrated surface. Its support, if in front of the dial scale, also needs to be kept to a minimum size. This is particularly important where a low Sun is being used, either near to sunrise or sunset, or during the winter months when the Sun is particularly low in altitude. A vertical gnomon overcomes many of these problems but is generally impractical. Only one dial in this study uses one - the chalice dial 2. The dial



The shadow from a horizontal gnomon with a low Sun angle.

illustrated above, showing the problem of the horizontal gnomon, was later modified to a blade gnomon with a flat underside, thereby overcoming this limitation. In many cases, the ideal gnomon would be a small ball suspended in space at the position necessary for the gnomon tip. Practicalities dictate that a gnomon must have enough strength and rigidity to withstand the rigours of use and most needed to be made foldable or at least removable to facilitate transport, often in the user's bag or pocket. Therefore, a practical gnomon will have a sturdy base but will be finely tapered towards the tip, sometimes making it a rather dangerous instrument.

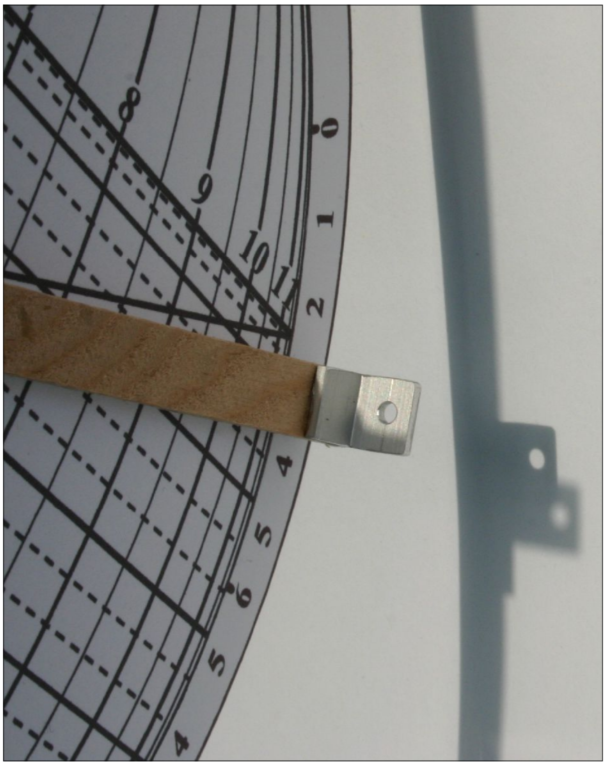
Dials using sights overcome many of the problems associated with traditional pin gnomons, but introduce a few problems of their own. Generally, they allow a much more accurate reading to be taken. All of these dials need to be tilted, or have the arm (alidade) tilted, so that the Sun's rays pass through the first sight (pinnule) to fall on the second one. As it is dangerous to look through the sights at the Sun, they need to be used from one side, generally just above waist level, as in the illustration by *Lansberg*. However, an advantage of the sight is that in cases where the Sun is mainly hidden behind a cloud or by mist, times when a crisp shadow would not be possible, direct viewing through the sights can be an advantage. In normal use it is particularly difficult to get both sights in line in this way and a simple method has been found for facilitating this. It helps to have a white 'screen' placed immediately behind the dial so that the shadows of both sights can be brought together in the first instance. This 'screen' may be an article of clothing, perhaps the white skin of a hand, a nearby wall or if necessary a piece of card held or stuck on the back of the instrument. It is not known how users would have done this in the past but it is certain that each may have devised his own method. Further problems often occur when the sights are lined up because the disc of light virtually disap-



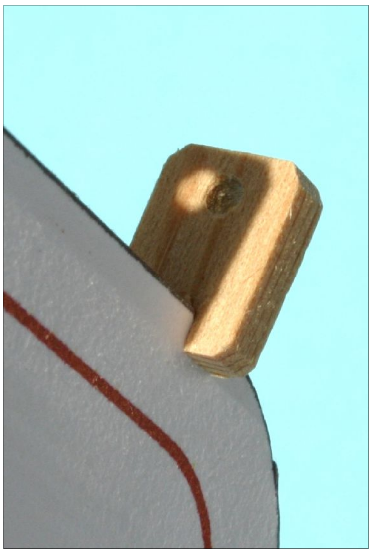
The same dial as illustrated on the left but now modified to take a blade gnomon, no longer restricting the low angle Sun.

Using a quadrant for telling the time from the Sun. After Lansberg.

pears through the lower pinnule. A good solution is to set the disc of light slightly to one side and alignment is achieved much more simply.

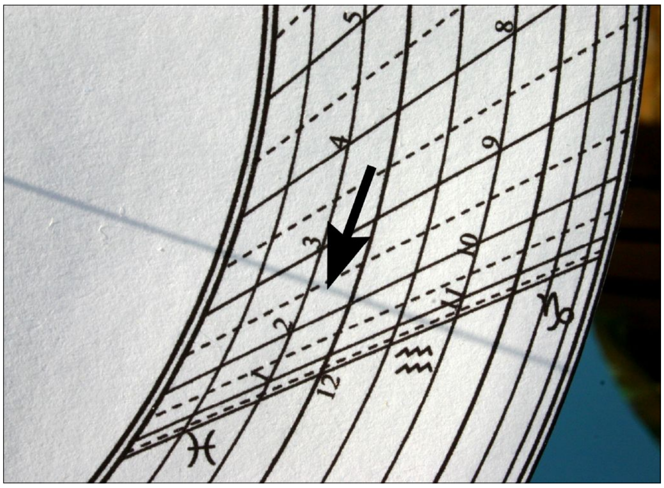


White card behind the dial used to help with lining up the two pinnules.



The solution to perfect alignment of the two pinnules with the disc of light offset.

Other difficulties exist when taking measurements. One of the commonest and most difficult to manage is windy weather. Most of these dials are either suspended from a cord or shackle, necessary to get them hanging vertically, and so will blow around in the wind. Those with plumb lines will also suffer from wind disturbance. The ideal dial will therefore be one that is relatively heavy and of small size such that it offers the minimum of wind resistance. Perhaps the best dial for overcoming the problem of wind is the pillar dial (dial type 3). It is relatively heavy and, due to the fact that its scale is wrapped around its cylindrical body, it presents a minimum surface to any wind for a maximum scale length. Similar problems will often be experienced when using these, or any dials, on the rolling deck of a ship.



The problem of judging the shadow position between two sets of lines: in this example, Pisces 4º is about 9:40am or 2:20pm, as indicated by the arrow.

Altitude dials often have two sets of calibrations that must be used together to find the exact time. The user is therefore not only estimating the portion of the hour past or to the nearest calibration line, he also needs to estimate a similar fraction of the space between date lines.

Very few altitude dials were made 'universal'. They were generally made for one specific latitude. This made them unsuitable for use by the travelling man. Certainly, if he wished to travel to another country, maybe on a pilgrimage to Rome or the Holy Land, these dials would be of little use after a few days travel. If he was familiar with the science of gnomonics, in some cases he would have been able to tilt his dial by the necessary number of degrees, but this would have been beyond the capabilities of most users.

In order to help with interpretation of results in ths publication, arrows have been added to certain photographs showing the points where readings have been taken.

Another problem often encountered with these dials is that of balance. Each suspended dial has to hang vertically. Some have moving parts and, as these are shifted around when set to different dates, a serious imbalance can occur if the dial body does not have enough weight. In the case of some dials, the stepped poke dial in particular (dial 19), although with no out-of-balance moving parts, it seems that their makers did not even think about the imbalance caused by the inserted hour scale when they were calibrated.

When trying to use many of these dials, it was often difficult to decide which hour line was next to the shadow because often the hour numerals were some way removed from the shadow tip. This was particularly a problem in the chalice dial (5) and the pillar dial (3).

Ease of Use

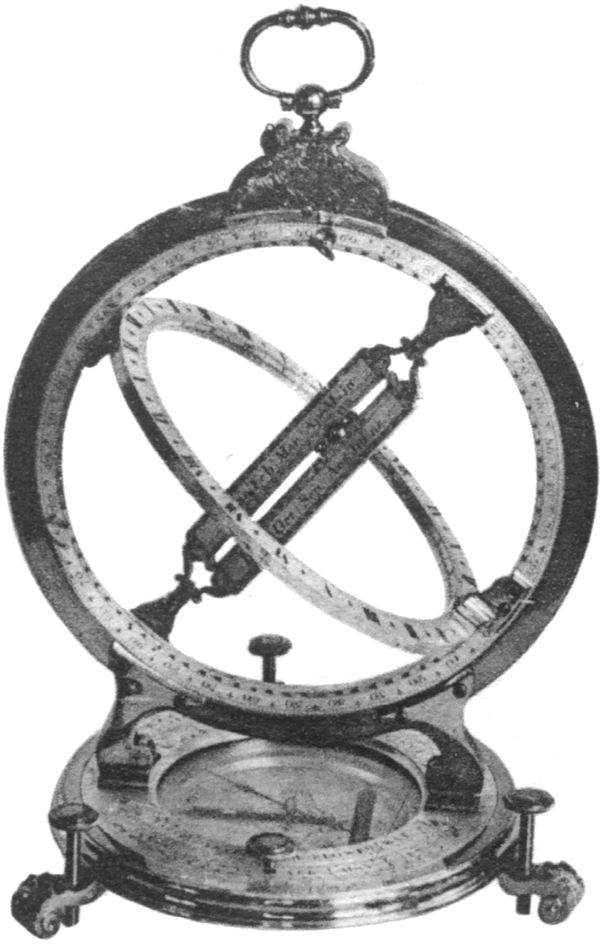
Some of the dials described are very basic and may simply be held up to get a reasonable note of the time whereas others are much more complicated. This does not mean that the complicated dials are any better than some of the simple ones, these often being multi-function instruments. The pillar dial and some of the small disc dials are simple to use and are able to give accurate results. Those with sights, as has already been explained, can be rather tricky to use and others need so many settings to be made that they are beyond the average user.

Some of the more complex dials are the quadrants, but these usually have other functions besides time telling. Many will have a shadow square for simple surveying tasks and most will have certain star positions noted so that they could be used at night for finding the time. Furthermore, these are portable dials and thus need to fit snugly into a pouch or bag, so that they will generally need to have their gnomons folded making them essentially two-dimensional for transit.

The universal equinoctial ring dial; accurate but often quite tricky to read. The spot of light can just be seen on the inside of the chapter ring at about 2:15pm.

Comparison with Azimuth Dials

As has already been noted, the azimuth dial is generally capable of higher precision than an altitude dial. However, we are considering here portable dials, which is the basic use of the altitude dial. Portable azimuth dials need some means of setting them precisely to line up with south. Usually they are fitted with a magnetic compass for alignment. The compass, although a fine and useful tool, has its drawbacks. Often, due to its small size when included in a portable dial, accuracy is lost, perhaps by up to 5°. Furthermore, magnetic declination (or deviation) changes with both time and position. Even after a year or two the magnetic declination could change by one or more degrees and by moving only a few hundred kilometres the figure could



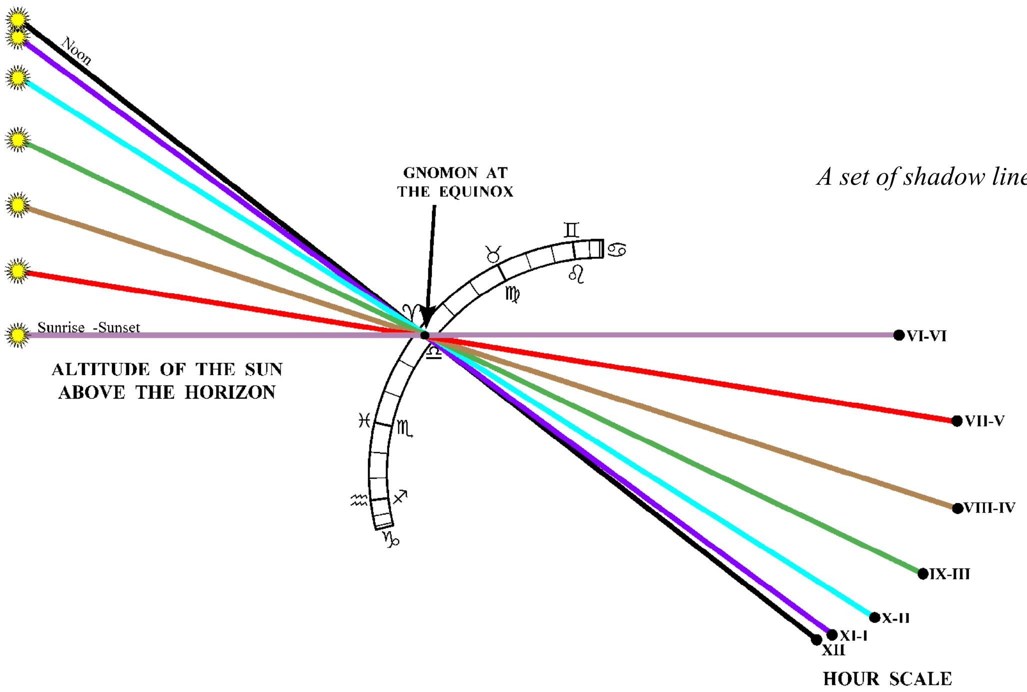
The universal equinoctial standing ring dial.

change again. The Earth's magnetic field can also be affected by deposits of iron ore, mountains, other magnets – possibly other dials in close proximity – and even by electromagnetic storms caused by solar radiation. Therefore, a compass is perhaps less precise than we may expect. An error in the direction of north of 10° could represent an error on the dial of around half an hour.

An altitude dial, on the other hand, only relies on the height of the Sun above the horizon. This is fixed and predictable for any latitude. The only exception is atmospheric refraction at the lowest Sun angles. This, however, only applies during the first 5° or less of Sun's altitude.

The universal equinoctial ring dial is often considered as being one of the most accurate dials around. This uses the altitude of the Sun for setting it correctly to face south. However, it can be tricky to use, especially on a windy day, and it needs to be held so that the spot of light can be seen inside the chapter ring at the same time as the hour numerals, on top of the chapter ring, as seen opposite.

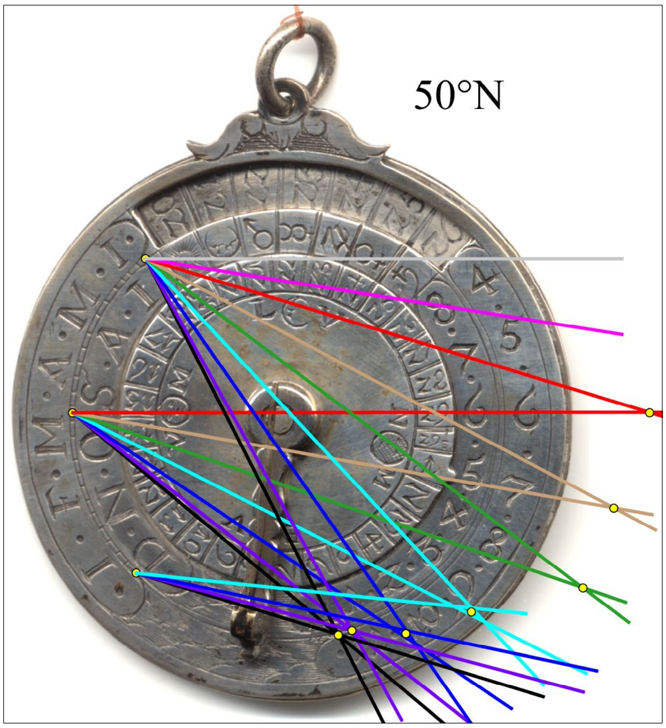
The best ring dials are those set up on a rigid stand with three levelling feet and built in spirit levels allowing them to be set precisely. Having a compass set into the base also gives the user double security.



A set of shadow lines at the equinox for Cambridge.

Shadow Lines

In order to explain the errors found when analysing the designs of some of the dials in this study, lines showing the angle of the Sun (hence the angle of the gnomon's shadow) for various Zodiac signs are sometimes superimposed on a dial picture. A simple analysis may be done at just three points, the equinoxes and solstices. To avoid confusion, where up to seven sets of lines may cross, each hour has been assigned a different colour. Some lines will be shown dotted and these represent the position of the Sun below the horizon. These lines can sometimes be useful in determining the correct calibration of a dial. More details of the technique will be found in the section 'How These Dials Were Constructed'.



A check of the calibrations of the vertical disc dial.

Reading the Dial

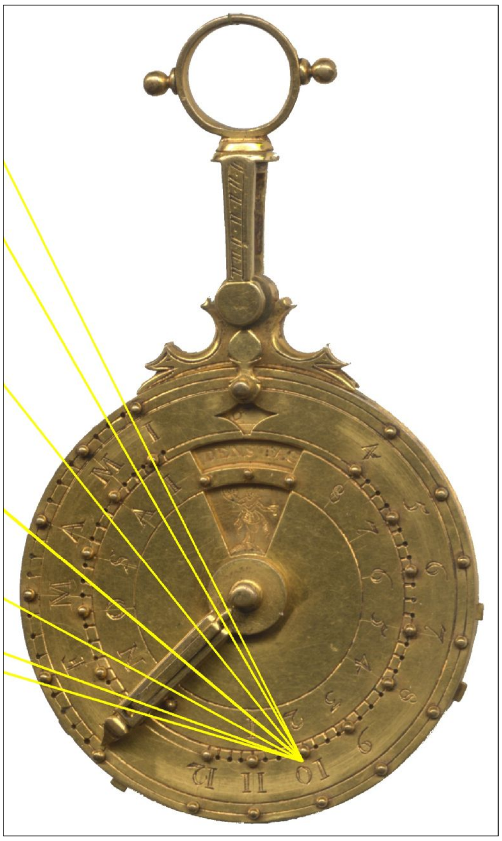
There is possible ambiguity when reading most altitude dials. Generally, the date is repeated, with the second half of the year being superimposed on the first half, it being an exact replica of this. Similarly, the afternoon hours are often superimposed on the morning hours. In some dials one or the other are separated, but in most the scales are common allowing a better utilisation of the limited surface area of a dial thereby leading to increased accuracy.

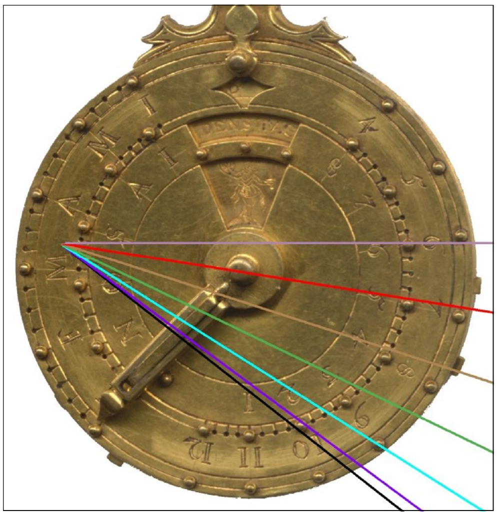
In order for the reader to confirm the readings shown in the photographs, most examples have the time that they are showing written in the caption beneath.

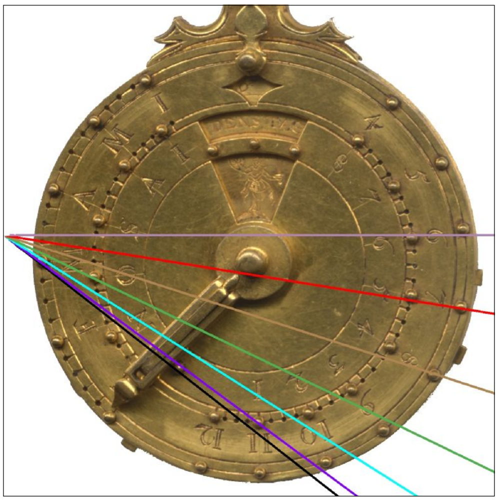
Analysis of Dial Calibrations

Before commencing work on any antique dial it is best to check which calendar is being used. This is simply done by comparing the dates of the two equinoxes. If these are not clearly marked, take March and September and find whether March 10 and September 10 come together or if March 21 and September 21 are adjacent on the calendar scale. There may be some variation between dates, but generally no more than a day or two. March 10 was the equinox in the old Julian calendar and March 21 is the equinox date for the present Gregorian calendar. The vertical disc dial illustrated has its equinox around March 10 which is adjacent to September 10, showing that it corresponds to the older Julian calendar. As the dial is German, this dates it before 1700 when the German Protestants finally changed to the Gregorian calendar. In England the reform date was later, in 1752. Another check that can be made to find the equinox is to draw a horizontal line from the VI–VI calibrations. This line should pass through the equinox date.

It is now a simple job to determine the latitude of any dial. Hang the dial vertically and measure the angle from the equinox point on the date scale to the XII noon mark on the hour scale. This angle is the co-latitude of the intended







Gilt brass German disc dial, c.1700. This dial is clearly incompetently made, with errors exceeding one hour at certain times of the year. The added declination lines are for a dial for 50º (Germany) but these make noon at X or II.
The two lower pictures have the equinox hour lines for 50º superimposed to show that these can never agree with the hour markings on the dial. A slightly better fit can be achieved by moving the (gnomon) origin off the left edge of the dial.

place of use. The dial in the example has its line at about 40° making its latitude 90° - 40° = 50°. In order to determine the accuracy of calibration, the hour lines were superimposed on the illustration. So as not to clutter the picture unduly, only three sets of lines were used, those at the equinoxes and the solstices. (Note that by checking only these three points it will show the maximum errors, so the intermediate points will lie somewhere between these.)

It will be seen that the lines converge at different points, some outside the dial disc, and a spot has been placed at the midpoint of the intersections. The lines would intersect perfectly (but still not on the disc) if the dial had been arranged so that the equinox noon line went exactly through its centre. The errors caused by the delineation of this relatively simple dial can be seen where the rays pass the hour numerals. These errors amount to around one hour or more at certain times of the day. Even so, such timekeeping was generally acceptable to the average man of around 1650, when this dial was made.

Another dial of this type that was tested for this study is the gilt brass dial (illustrated left), also from Germany and made around 1700. Analysis of this dial showed that it has not been competently delineated. For a start, the intended latitude was measured at around 35°, perhaps a confusion with co-latitude. Then it was noticed that both the date and hour scales appeared linear. There was very little bunching of the date lines towards the solstices and virtually no bunching of the hours towards noon. Otherwise, it is a well-made and originally expensive dial with a perpetual calendar on it. The maker obviously had no concept of dialling techniques, but the calendrical information appears correct.

Examples of various errors in delineation will be described for some of the other dials in this study with the theoretical hour lines shown as necessary.

Dial Names

Each of the dials in this study have, where possible, been given a name so as to identify them. Some of these names are not necessarily those that they are generally known by but it helps to get an idea of what the dial does from its name. Other dials have just been given numbers where there is little difference between models. The new names that have been invented are generally set in ‘single inverted commas’.

TYPES OF ALTITUDE DIAL

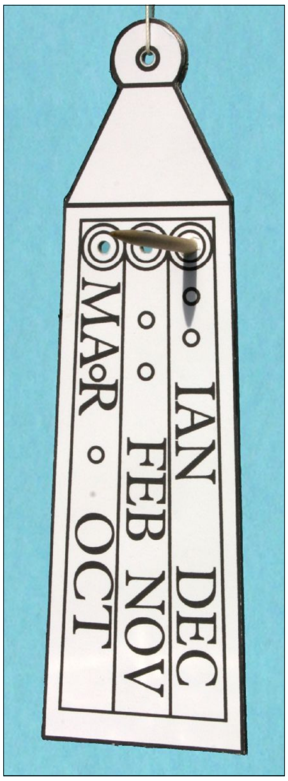
FIXED LATITUDE DIALS

SIMPLE ALTITUDE DIALS

These dials use basic principles, as do chalice dials and vertical plate dials. They rely on the gnomon or the dial being moved so that a vertical shadow may be formed on the correct date line.

1 Anglo Saxon Pendant

This pendant was modelled on a dial found near to the cathedral in Canterbury in 1938 and is believed to date from the Saxon period, probably 10th century. This fine dial is made in silver and gold and shows just the noon and mid-morning/mid-afternoon marks. The gnomon is fitted into a



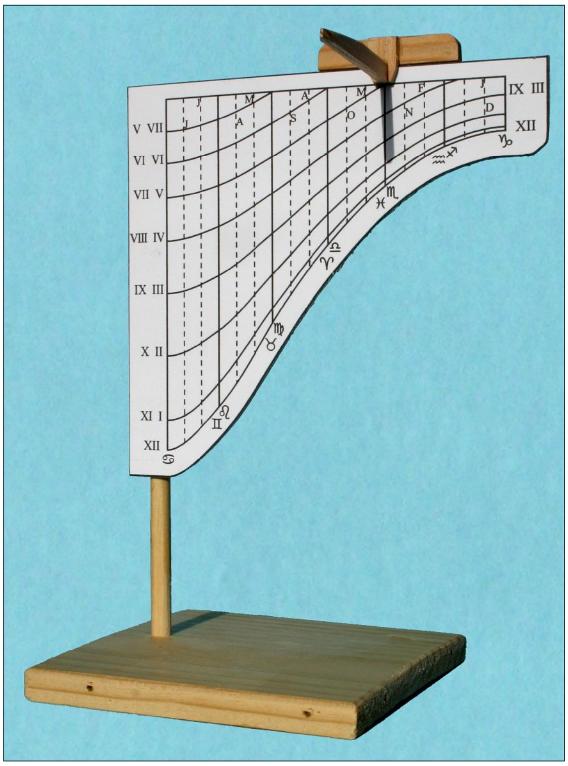
Anglo Saxon pendant.
[Just before or after noon in January or December.]

hole above the appropriate column. The original gnomon has an animal's head and was designed to be stored, when not in use, in a hole at the bottom of the pendant drilled vertically upwards. The model made for this study has not been calibrated for 52° like the others; because of its simplicity it has been left with the original calibration marks. These original markings were not precise and were probably determined empirically.

The Canterbury pendant has been fully described by *Mills*.

2 'Signpost' or 'Flag' Dial

This is perhaps the simplest, yet most effective, of all altitude dials and its calibrations are basically an inverted version of the graph of the Sun's altitude, already



'Signpost' or 'flag' dial.
[Aquarius 28° or Scorpio 2°, X or II.]

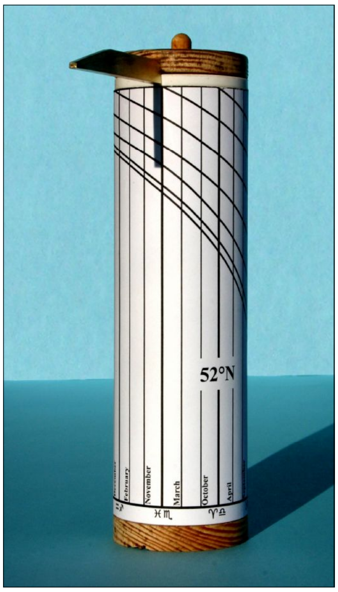
described. The dial face is fitted to a vertical pillar so that it may be rotated to make the shadow from the gnomon vertical. The Sun's altitude has been plotted directly at equal intervals to correspond with the date. In order to make the dial more compact and hence more accurate, the two (identical) halves of the year have been plotted on top of each other. The gnomon itself slides along the top of the dial to sit above the correct date. The time is then read from the lowest point of its shadow.

3 Pillar Dial, Shepherd's Dial or Cylinder Dial

This is essentially the same as the signpost dial but it is constructed around a cylinder instead of on a flat plate. The sliding gnomon is now replaced by one that is fitted into the top of the cylinder and is rotated to be directly above the appropriate date. In use, the dial is rotated to point the gnomon towards the Sun and is adjusted to give a vertical shadow. The time is read from the lowest point of that shadow. These dials are frequently found with hour scales for the entire year as well as those with the two halves folded on top of each other.

The gnomon is hinged to the top cap so that when not in use it may be folded down vertically and can be fitted into the hollow cylinder for safe storage. Some dials of this type are found with two separate gnomons of different length, the shorter one for the summer months and the longer one for the winter months. These enable a higher accuracy to be achieved giving a longer shadow in the winter months. Such dials have two sets of hour scales.

Roman pillar dial in wood, from Museo Atestino, Este, Italy. Seen during the BSS visit in October 2004.



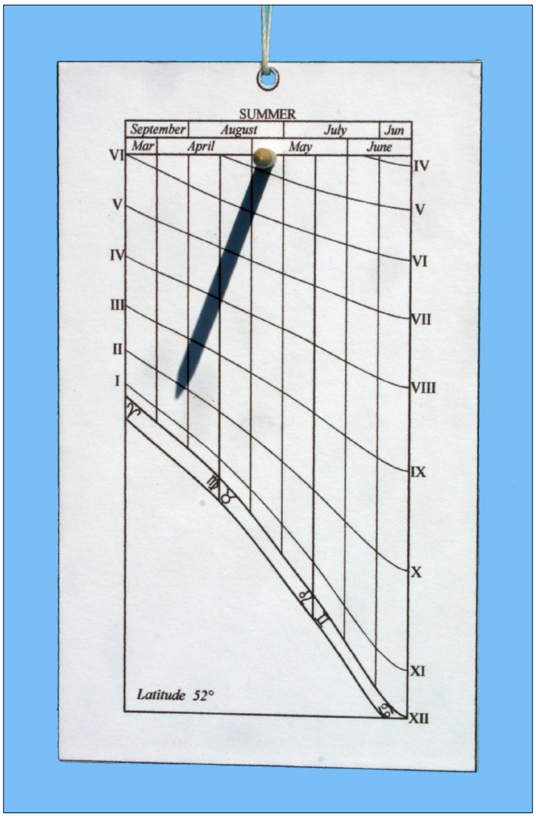
Pillar or shepherd's dial. [19 February or 21 October, 10:10am or 1:50pm.]

Many pillar dials were intended to be supported by a flat base but some versions were made that can only be used when suspended by a cord. These would probably be worn around the neck of the user.

The shepherd's dial is one of the earliest made types and examples are known from Roman times.

4 Tablet Dial

Looking very similar to the signpost dial, this dial is usually constructed on two sides of a tablet or pendant, intended to be hung around the neck. One side is used for the winter months and the other for the summer months. To use the dial, a pin gnomon, stored perhaps within the thickness of the dial itself, is inserted into the hole at the top. Unlike the signpost or shepherd's dials, this gnomon is not moveable but is fixed in the centre. The scales are therefore adjusted to account for the increased length of the shadow towards the edges, creating a slight undulation in the lines, noticeable particularly in the summer hours of VII - IX and



Tablet dial - summer side.
[April 7 or September 3 - 10:20am or 1:40pm.]

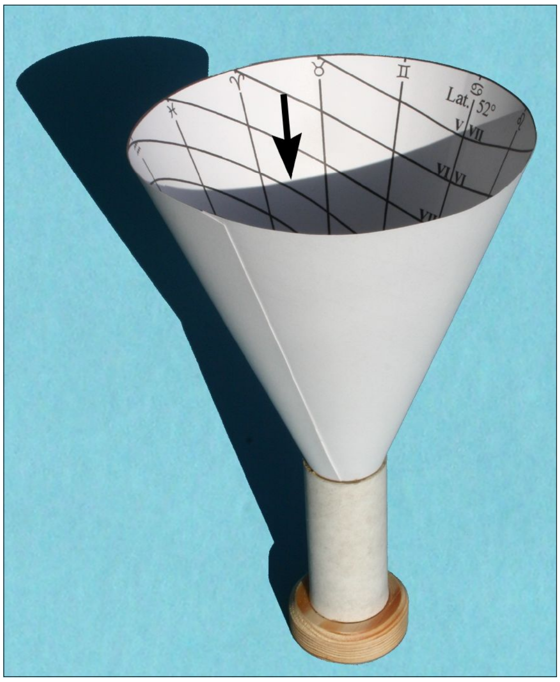
III-V. In use, the dial will need to be rotated until the shadow tip corresponds to the appropriate date line and may no longer be vertical. This complication, requiring two separate settings to be made at the same time, makes this dial a little more difficult to use.

CHALICE DIALS

This is a rare form of dial usually associated with an ecclesiastical chalice. There are four forms of these as altitude dials and at least two forms are known as directional dials. The simpler altitude dials are types 1 & 2 below: types 3 & 4 are just 'clever' adaptations of these. Chalice dials are particularly good for use at low Sun angles as the gnomon does not get in the way of its own shadow.

5 Chalice Dial Type 1

This is very similar to the signpost and pillar dials but constructed on the inside of a conical cup. In this case no separate gnomon is used as the front rim of the chalice forms the shadow on the opposite inner surface. This means that the lowest point of the shadow should be taken for the time indication. The chalice will therefore need to be rotated so that the lowest point of the rim's shadow will fall across the appropriate date line. The main limitations of this type of dial are that, in order to get a sufficiently long hour scale, the summer solstice line needs to go deep into the cup. In lower latitudes the shadow will go even deeper, resulting in a very narrow, flute-like cup, difficult to read without obscuring the dial's shadow. In all cases, the slope



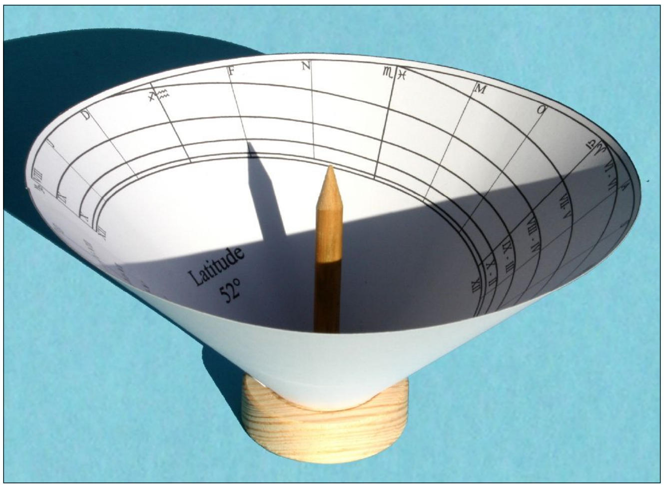
Chalice dial type 1.
[Just after the Vernal equinox, 7:40am or 4:20pm.]

of the sides of the cup must exceed the highest summer altitude for the Sun.

6 Chalice Dial Type 2

To overcome the problems of the over-deep chalice, this form is fitted with a central pin gnomon terminating usually at the height of the rim of the cup. This immediately allows a cup to be used with a much wider neck making the readings easier to see. As the cup is rotated, the shadow of the gnomon tip also points directly at the appropriate date line. The slight disadvantage is that the chalice is now no longer suitable as a drinking vessel, in fact even dangerous, unless the pointed gnomon is removed first.

Other types of chalice dial are types 3 and 4 (not illustrated). These are two clever variants on the above designs that were occasionally made whereby the dials will only tell the correct time when filled with water (or



Chalice dial type 2.
[Beginning of February, just after X or before II.]

What The Bible says about The Dial of Ahaz

2 Kings 20, v8-11.

8 And Hezekiah said unto Isaiah, What *shall be* the sign that the Lord will heal me, and that I shall go up into the house of the Lord on the third day?
9 And Isaiah said, This sign shalt thou have of the Lord, that the Lord will do the thing that he hath spoken: shall the shadow go forward ten degrees, or go back ten degrees?
10 And Hezekiah answered, It is a light thing for the shadow to go down ten degrees: nay, but let the shadow return backwards ten degrees.
11 And Isaiah the prophet cried unto the Lord; and he brought the shadow ten degrees backward, by which it had gone down in the dial of Ahaz.

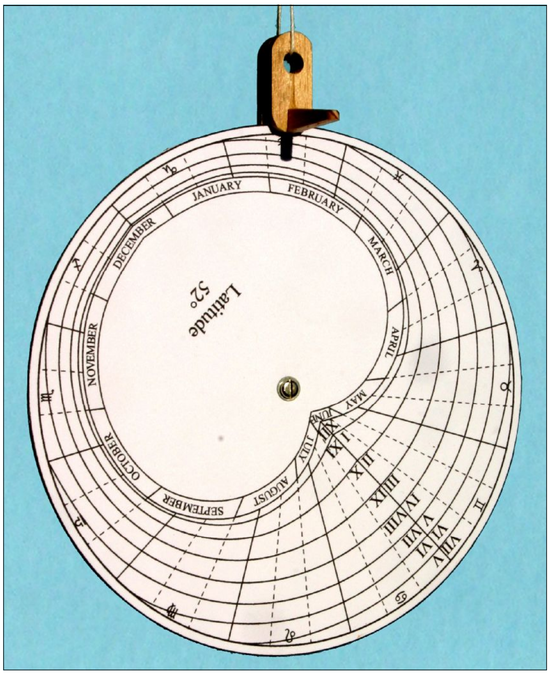
Isaiah 30, v7-8.

7 And this *shall be* a sign unto thee from the Lord, that the Lord will do this thing that he hath spoken;
8 Behold, I will bring again the shadow of the degrees, which is gone down in the sundial of Ahaz, ten degrees backward. So the sun returned ten degrees, by which degrees it was gone down.

possibly wine). The refractive index of the water bends the light allowing an even wider neck to be used. This type of dial is also known as the Dial of Ahaz In the bible (2 Kings 20, v8-11 and Isaiah 30, v7-8.), the Lord caused the shadow to be set back by 10 degrees as a sign to Hezekiah that his illness would be cured.

CIRCULAR PLATE DIALS

These generally use the same principals as the earlier dials discussed. The first three are made as a rotating disc, each with different gnomon positions and each giving different

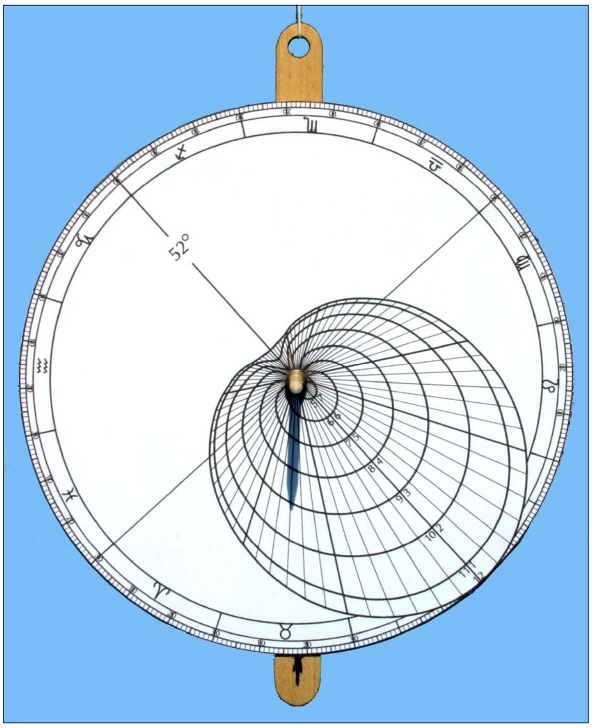


Circular plate 1.
[5 February, 9:15am or 2:45pm.]

accuracies and ease of use. The disc is pivoted at its centre and is turned to line up with the correct date setting. In use, they are suspended and turned towards the Sun to get the hour reading

7 Circular Plate Dial 1

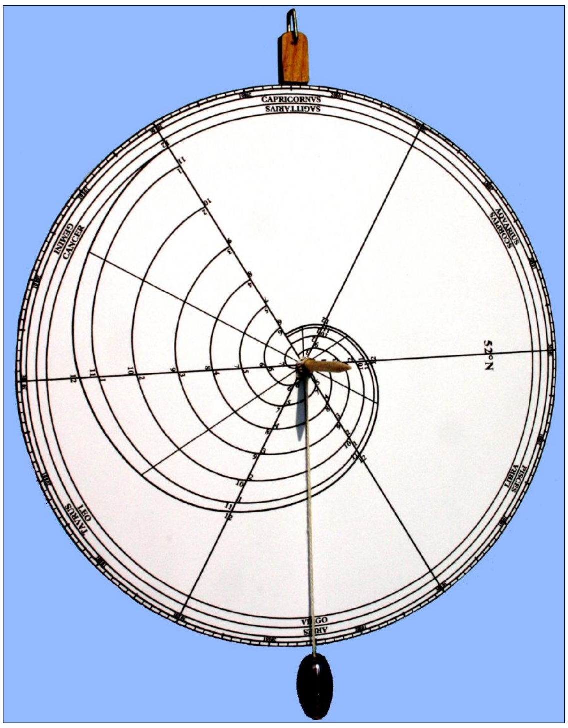
The gnomon is at the top edge on this dial and the date setting is just below the gnomon. The dial would be turned to face the Sun and give a vertical shadow below the gnomon. Dials like this would have a backing plate or at least a strip of metal to allow suspension and fixing of the gnomon. The result of a full year's plot of the hour lines gives an attractive heart-shaped pattern. This dial is known from a model made by G Emmoser, dated 1571 (see *Zinner*). A similar dial at Greenwich by M F Poppel was made in the late 17th century (see *Higton*).



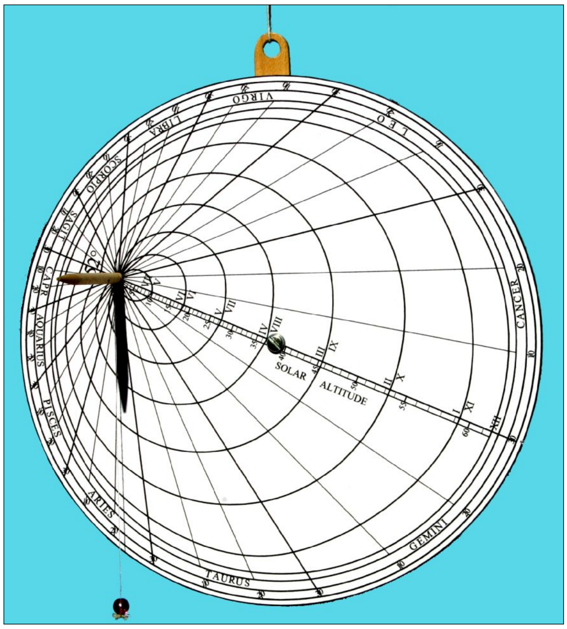
Circular plate dial type 2a.
[Taurus 18°, 9:10am or 2:50pm]

8 Circular Plate Dial 2

A similar dial to the circular plate dial 1, this version uses a centrally placed gnomon. The date on this dial is set on the lower edge of the disc. This plot also results in a something resembling a heart-shaped pattern of hour lines, but they are somewhat cramped for low Sun angles. This model is based on a version produced by Erasmus Habermel in 1586 (see *Zinner*). An alternative version, 2b, also by Habermel, has just half of the year plotted around the complete circle.



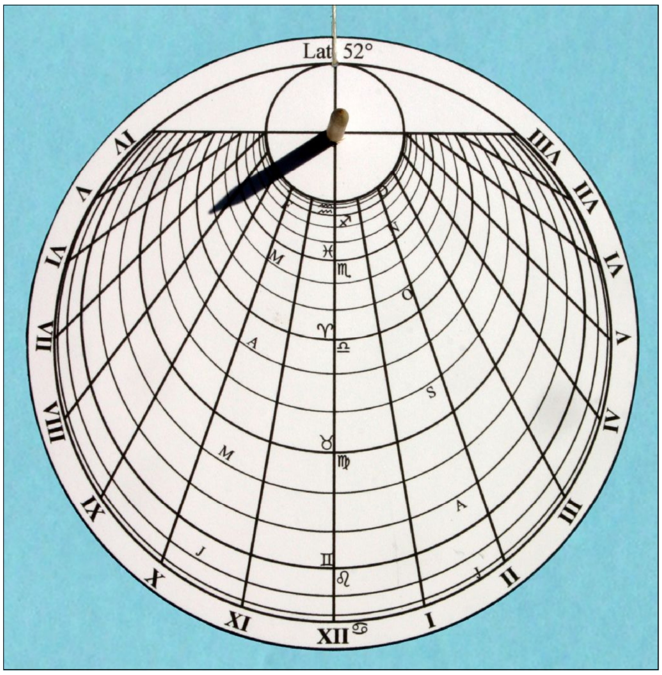
Circular plate dial type 2b.
[Aries 15° or Virgo 15°, 8:40am or 3:20pm]



Circular plate dial type 3.
[Aries 22°, 8:40am or 3:20pm.]

9 Circular Plate Dial 3

Both of the circular plate dials above have large areas of the plate that are not being used so, in an attempt to remedy this (and to produce a more accurate result), this dial was constructed using the whole dial plate. The original model of this dial was by Erasmus Habermel. It is very similar to circular plate dial 2 but with the gnomon now offset. However, the attractive heart shape has been lost by changing the angular spacing between the date lines to make the outer hour ring, XII, truly circular. This distortion of the date lines, if correctly done, does not cause any loss of accuracy. When testing this dial there was some difficulty getting a truly vertical shadow, especially when the shadow was short and not near to the edge. In order to make this simpler, a plumb line has been added here, suspended from the gnomon. The shadow should now fall on top of the plumb line. This dial also has a vertical scale giving solar altitude.



Circular plate 4. [March 12, or Sep 28, 7:45am.]

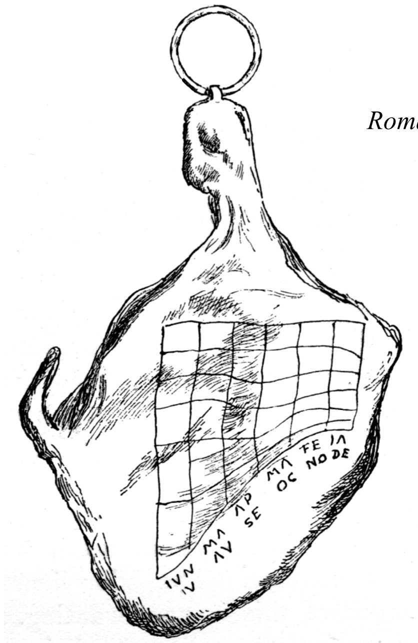
10 Circular Plate Dial 4

This dial is completely different to the circular plate dials already described and has only been included here as it appears to resemble them. In many ways it looks like a vertical direction dial but the results are strictly obtained through the Sun's altitude rather than its azimuth. In use, the flat face of the dial with its pin gnomon are pointed towards the Sun, the dial being suspended from the top. It is then turned slightly until the tip of the shadow falls on the correct date line. The time is then indicated by the straight radial lines passing through the circles. It is certainly more accurate in the summer months when the Sun is high in the sky and gets less accurate towards the winter solstice. Although this dial has been made with straight hour lines, theoretically they should be just slightly curved for perfect results. The errors involved are quite small and are worse in the winter months. The original dial is by Erasmus Habermel (c.1600) and is in the Augustinermuseum, Freiburg (see *Wagner & Fowler*).

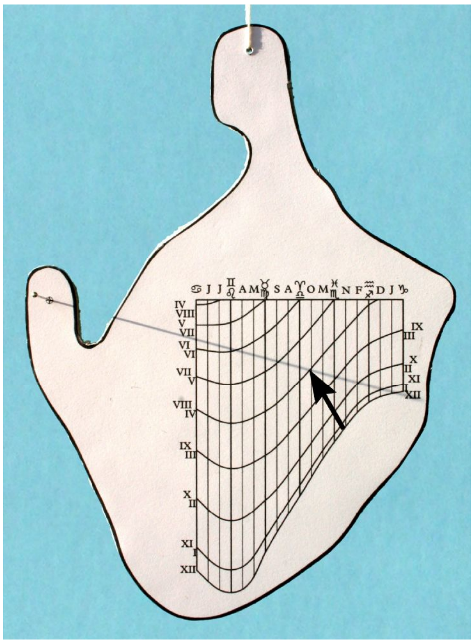
Circular plate dial type 4 by Erasmus Habermel.

'HAM' AND VERTICAL DISC DIALS

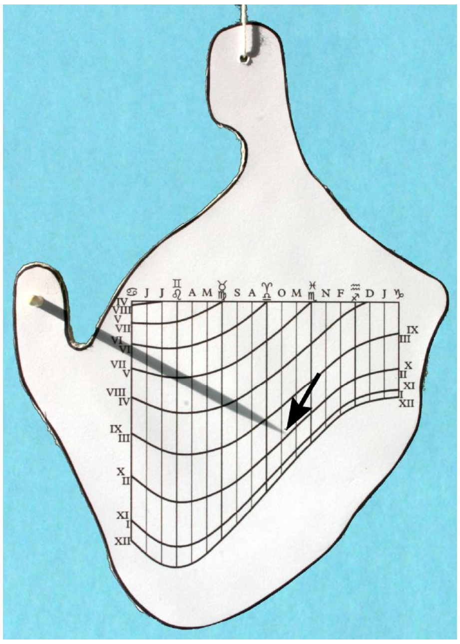
The 'ham' dials are simple dials usually formed on a plate or a disc, with a pin gnomon towards one edge. They have been named after a Roman dial found at Herculaneum, so called from its being shaped like that of a leg of ham. Their later counterparts, vertical disc dials, were similar but with the gnomon usually attached to an arm that is pivoted from the centre of the disc. The gnomon folds flat for transit. The principle of these ham and disc dials is essentially the same as that of the poke dials (which will be described later) where the pin gnomon is replaced by a pinhole and the hours are read from inside a broad ring. Some of the disc dials, like the simple poke dial, are unable to give times to better than about half an hour at certain times. This can be shown with a ray diagram where the angles of the Sun's rays are applied to the dial (page 16). It will be seen that except for the hour of XII few of the lines cross the edge of the disc close to the numerals. However, with a careful arrangement of the gnomon such that it moves equally either side of the ring with the equinox correctly set at the co-latitude of the place, the lines will actually cross at common points, but not necessarily on the face of the disc. This has led to other versions being made that have a calibration line, extended from the disc, as necessary, that will correctly cover all times. The modern replica 'Heliochron' does just this and other copies are known from much earlier types. With all of these dials, the balance may be affected by the gnomon arm as it is rotated and this is likely to cause further errors due to the vertical axis being misaligned.



Roman 'ham' dial.



'Ham' dial a.
[March 11 or September 29, VIII or IV.]



'Ham' dial b.
[March 9 or October 1, 9:50am or 2:10pm.]

Two versions of the ham dial.

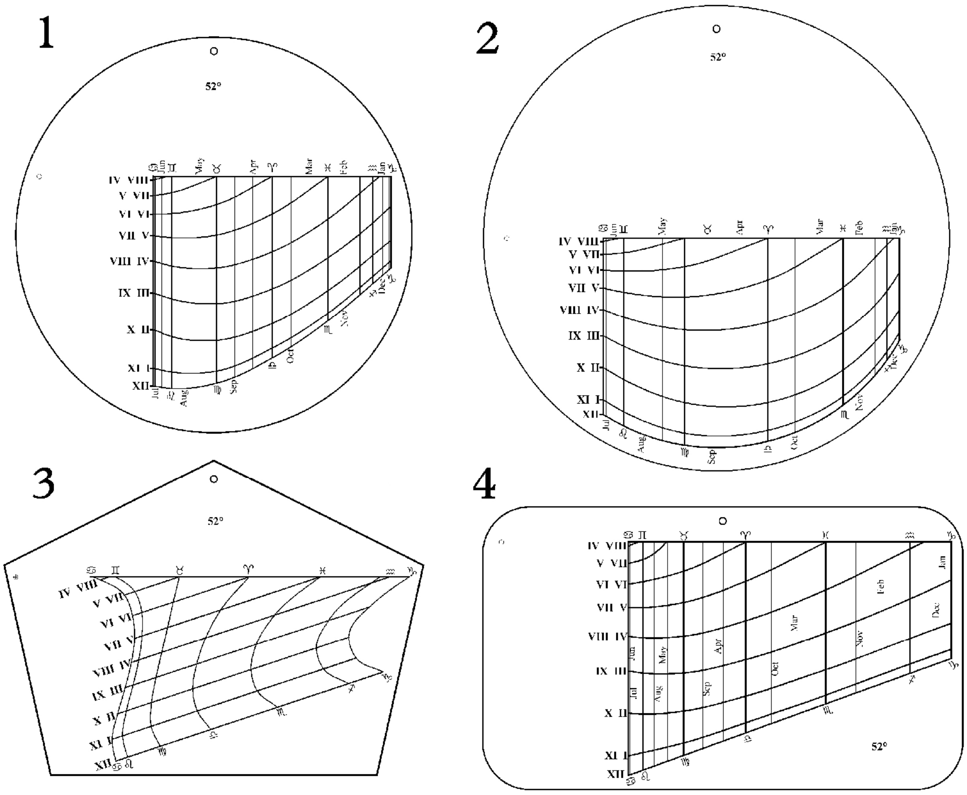
Left. With a pin gnomon, the time is read where the shadow crosses the appropriate date line.

Right. With a peg gnomon, the time is read from the tip of the shadow where it touches the date line.

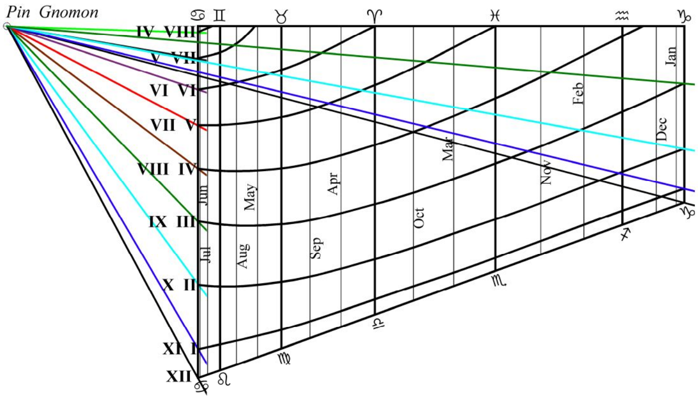
11 Roman 'Ham' Dial

The original Roman 'ham' dial was found at Herculaneum in 1754. It is made of bronze and its fixed gnomon on the left is now mostly missing. When the replica was made for this study, it was decided to keep the ham-shaped outline of the original dial and this worked out just right for its hanging balance. Its original shape may therefore have occurred when pieces of the bronze were successively removed to get it to hang with the date lines perfectly vertical. We are not absolutely sure how these dials were intended to be used and it may have been that they were read from the shadow of the gnomon tip rather than its position. Therefore an alternative version has been produced with the gnomon length conveniently set so that it is the same as the distance to the left edge of the main scale. This change allows the dial layout to be more spread across the ham surface. Reading the time from the shadow of the gnomon tip is easier but the layout is more difficult to delineate. The original Roman dials were almost certainly made empirically and were calibrated in antique hours with dawn at 0, noon at 6 and sunset at 12.

This simple dial has prompted the design and manufacture of several modern replicas for this study, to see if any improvements could be made. Surprisingly, there do not appear to be any such antique versions of this most effective little dial.



Some 'ham' dial varieties made for this study.



'Ham' dial design optimised to keep the hour lines at similar spacings throughout the year. The shadow paths are shown for Cancer, ♋, and Capricorn, ♑.

One great advantage of the design over most of the others considered is that the summer hours are nearest to the gnomon with the winter hours furthest away. This means that a larger triangle of shadows from the gnomon will be thrown onto the winter calibrations, effectively increasing the size of each hour division.

With this simple dial design, it is possible to change the layout parameters and four such designs were made, each of them described below.

1. Similar to the 'ham' dial but with the date lines compressed at the winter and summer ends giving a more gentle curve in the hour lines.

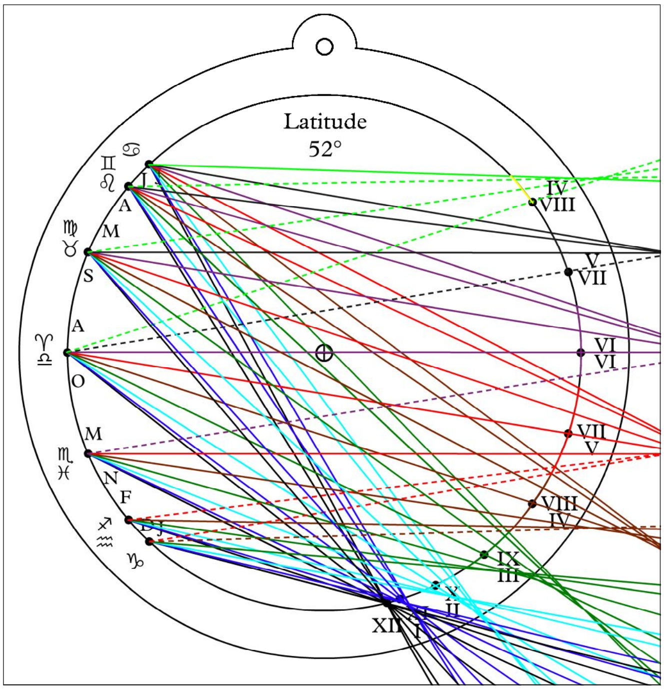
2. A similar calibration but with the XII line as part of a circle. To achieve this, it was necessary to adjust the spacing of the date lines to suit. This layout pattern was later applied to a 'fish outline' dial—see the accompanying CD.

3. Although looking completely different, this dial was made with equally spaced hour lines. To achieve this, it became necessary to bend the date lines.

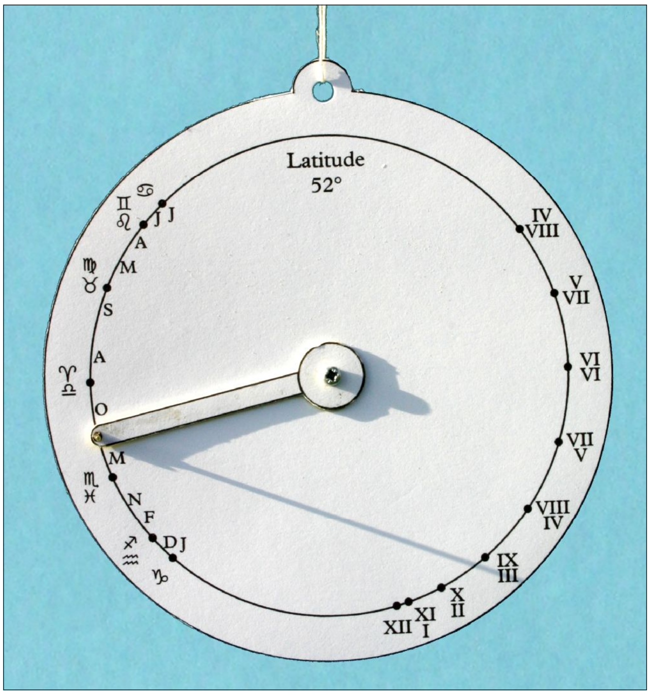
4. As it is possible to accentuate the winter hours, a model was produced with approximately equal hour spacing throughout the year. This started with the 16 hours of summer on the left, nearest the gnomon, and the 8 hours of winter on the right. Therefore the 8 winter hours are equal to exactly half of the 16 summer hours. The XII line was made straight between these two points. A straight line at IX and III was also tried but this made the dates too cramped in the summer months. The main problem with this layout is that the dial has become rather wide making the correct balance that bit more critical.

12 Vertical Disc Dial 1

This is a disc suspended from the top with a pin gnomon set to the correct date. When held edgewise to the Sun, the gnomon's shadow crosses the appropriate hour line. Unfortunately, this design does not give very accurate results, but these were near enough for the average person at the time that these were made. A plot of the hour lines shows the errors in this dial. The original dial also carries perpetual calendar scales on both front and back.

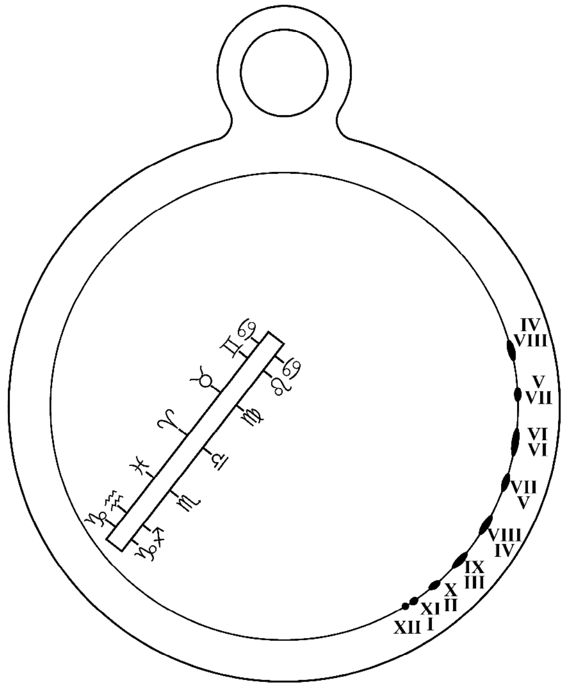


Vertical disc dial 1. A plot of the shadow lines at each zodiac sign showing errors of up to one hour, especially in the early morning and late afternoon.



Vertical disc dial 1.
[March 12 or October 8, just after IX or before III.]

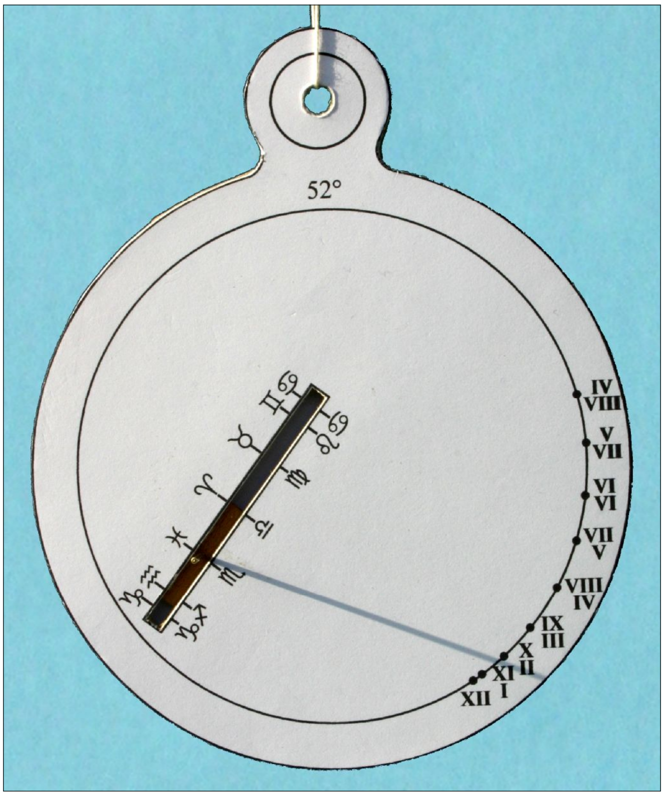
Vertical disc dial 1. Silver, Germany, c.1680.



Vertical disc dial 2. The hour calibrations have been deliberately elongated to show the spread of errors in each of the hours during the course of the year.

13 Vertical Disc Dial 2

Similar to vertical disc 1 but with the gnomon placed in a straight slot so that it may be moved to the appropriate date. This dial also suffers from similar errors to the previous dial.

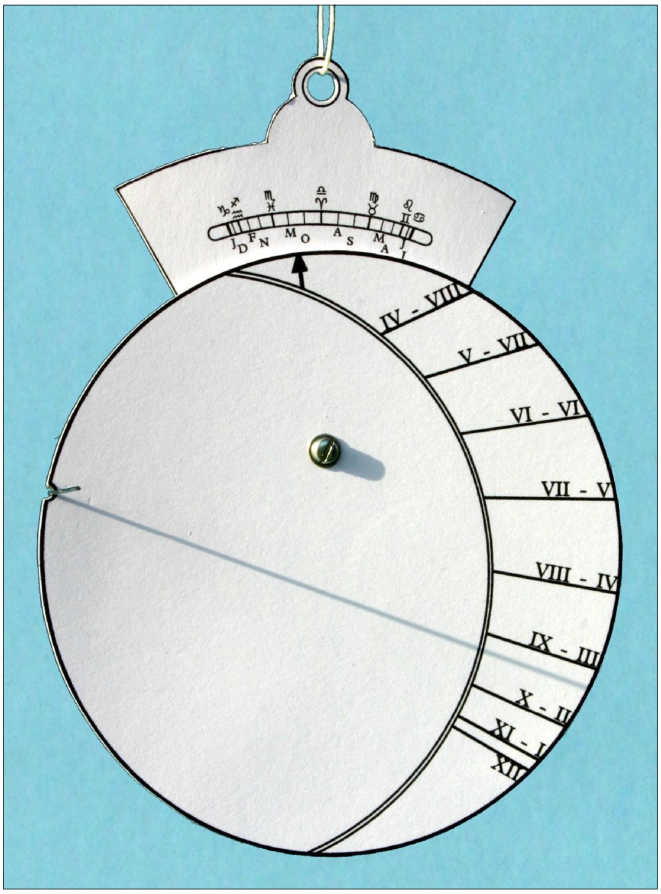


Vertical disc dial 2.
[Start of Pisces or Scorpio, just after X or before II.]

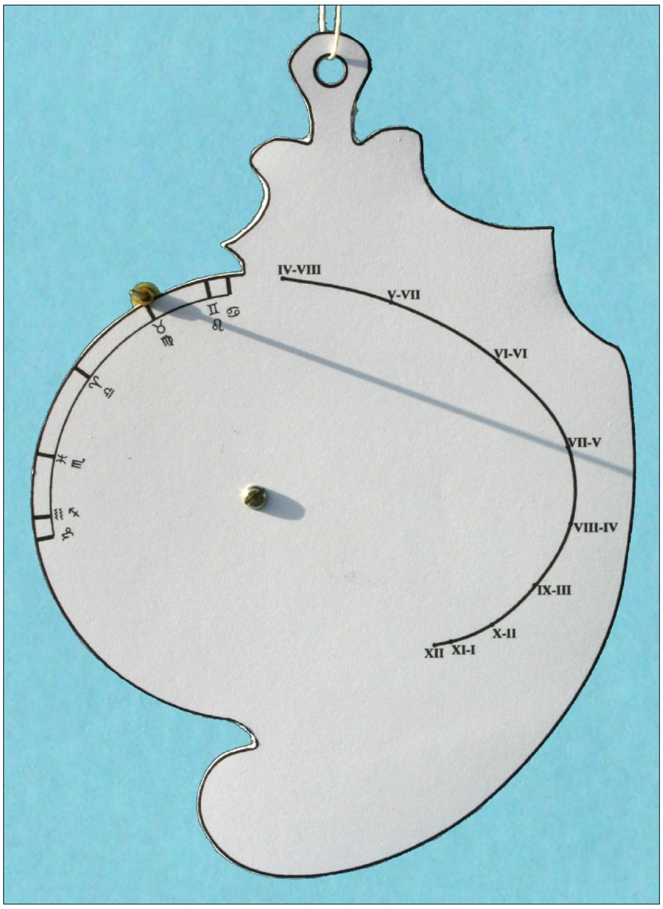
14 Vertical Disc Dial 3

Another variant on the theme of the two former dials, this has a fixed gnomon at the edge of the disc which is pivoted so that it may be tilted to read against the calendar scale at the top. This dial also suffers from the same errors as the previous two dials.

Vertical disc dial 3. Probably Italian c.1650.



Vertical disc dial 3.
[March 2 or October 8, 9:20 or 2:40.]



Vertical disc dial 4 - 'Heliochron'.
[Start of Taurus or Virgo, VII or V.]

Vertical disc dial 4 - 'Heliochron'. A modern replica by Muster Gesetzl Gesch.

15 Vertical Disc 4 - 'Heliochron'

When the date scale is set equally around the centre point of the dial, the shadow lines for each hour will converge at common points. These form a curve whose shape will vary with latitude and the general geometrical construction of the dial. This dial has now been corrected for the errors found in the former three dials because the hour-scale line traces the crossing points for the hour rays. The general shape of the dial is so arranged to try to keep the whole in balance in order that it shall hang vertically. Moving the gnomon support arm should make little difference to the balance.

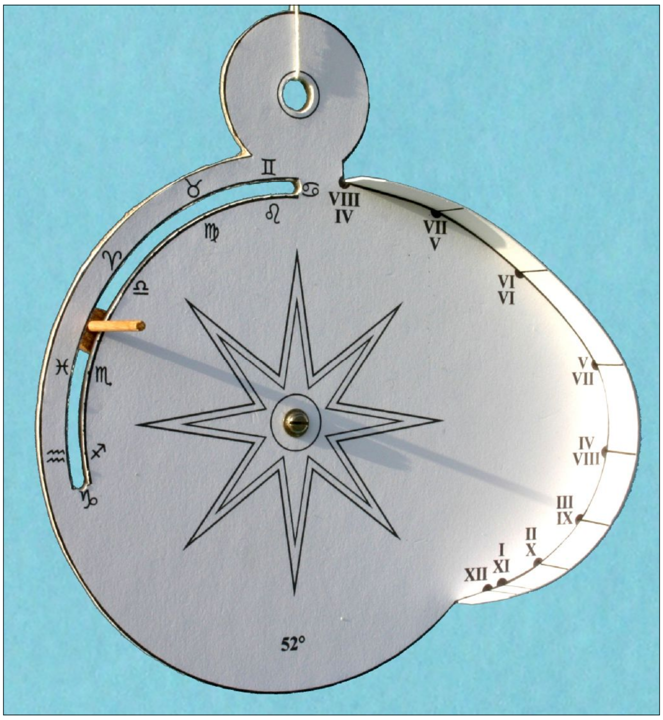
16 Vertical Disc Dial 5 - 'Fence Dial'

This dial is very similar to the 'Heliochron' but has an additional 'fence' around the right hand edge. This helps to form a clear shadow making the dial easier to use.

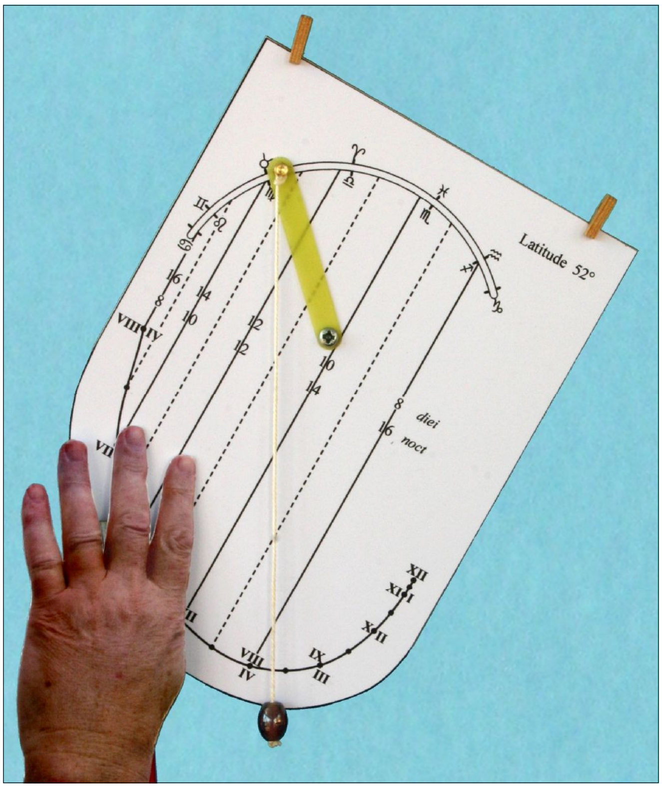
17 Vertical Plate Dial

Essentially the same as the 'Heliochron' but used with a plumb line to show the time. Note that the arm should ideally be behind the dial with just the plumb line support protruding through the circular slot.

The plumb line is firstly set to the correct date on the arc, which carries a sliding support. The dial is then tilted to



Vertical disc dial 5 - with 'fence'.
[Pisces 12° or Libra 18°, just before IX or after III.]



Vertical plate dial.
[Aries 25° or Virgo 5°, 8:20am or 3:40pm.]

sight the Sun through its two sighting vanes. Here I must stress that the Sun should never be sighted directly through these vanes as this will cause blindness. In practice, the dial is held low down, typically at waist height, and the Sun is allowed to pass through the upper sight with its small spot of light falling in the centre of the lower sight. When the dial is correctly aligned, the thumb may be used to clamp the plumb line to the face of the dial to read off the time.

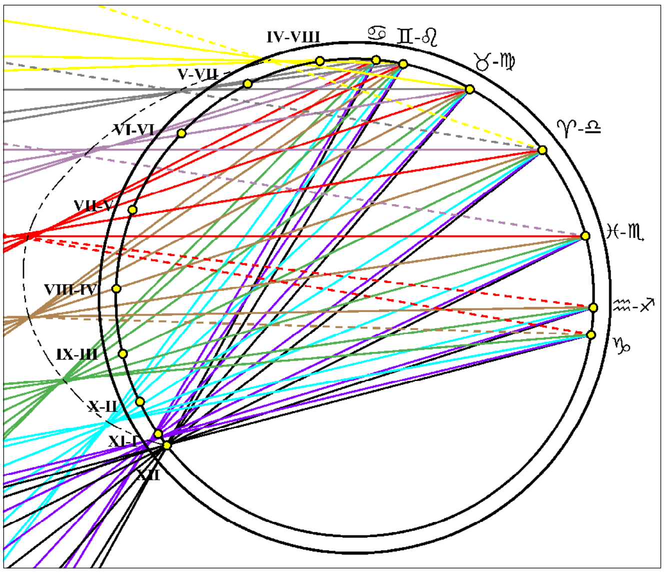
SIMPLE RING OR 'POKE' DIALS - also known in Germany as Bauernring (Farmer's Ring)

The poke dial is found in several versions each giving slightly different accuracies. The basic dial is formed like a ring and has a pinhole gnomon, cut into a thin band that runs right around the outside of the ring in a groove. This means that the gnomon hole may be slid to line up with a date scale, also marked on the outside of the ring. The hour scales are cut on the inside of the ring. In use, the pinhole gnomon is adjusted and the dial is turned so that the Sun will pass through the hole and produce a small spot of light on the internal scale. This is a relatively simple dial and quite cheap to produce. Extant examples of this type are not numerous but, being cheap, they were expendable. This is proved by the relatively frequent findings in modern times of the remains of these dials by metal detectors.

18 Simple Poke Dial

The simple poke dial is similar in design to the vertical disc dials and the same errors occur with the convergence points for each of the hour shadows as these do not lie exactly on the ring opposite the gnomon.

Simple poke dial by 'TW', c.1720. The lower picture shows the indications for scales A, B and C.



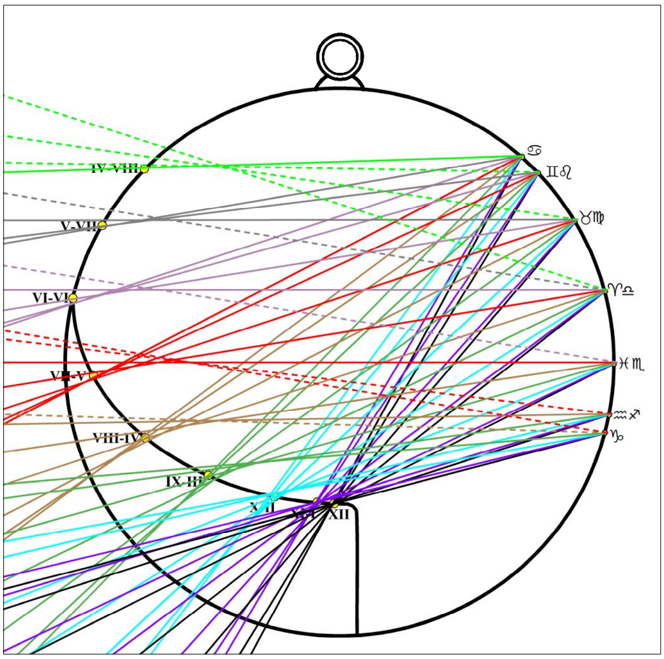
Hour lines applied to the simple poke dial, showing their convergence points mostly outside the ring. Accuracy can be improved by making sloping lines as described in the text.

The internal scale consists of simple hour lines across the width of the ring. The accuracy of this device is quite poor, giving the time to within half an hour.

In the dial illustrated by the as-yet untraced maker 'TW', the internal scale consists of sloping lines across the width of the ring, their slope giving an improvement in accuracy. The lines are divided across the width of the ring into three strips labelled A, B and C. The band supporting the pinhole gnomon is joined at the bottom and where the joint occurs, the ring is labelled also with A, B & C alongside. As the ring is moved to set the current date for the gnomon hole, the appropriate letter shows which part of the hour scale to use. This dial also has two pinhole gnomons on opposite sides of the ring, one each for summer and for winter, with two internal hour scales to go with them, thereby giving increased accuracy.

19 Stepped Poke Dial

This dial is similar to the simple poke dial but has a stepped scale on its inside that closely replicates the shape of the calibration line of the 'Heliochron' family of dials. Most models of this type appear to originate in Germany. It is still not exact but it gets quite close to the correct time. To get an exact calibration, the XII point would not be at the lowest point of the inserted scale, the equinox noon needing to pass through the centre of the ring and the scale would not be such a perfect curve. However, this dial was a great improvement on the standard poke dial and accuracies could be within ±15 minutes or so throughout the course of a year. A plot showing the rays for this dial, based on the dimensions of the model illustrated, shows its errors which are greatest in the earlier or later hours when the Sun's altitude in lowest. It is at these times that an altitude dial should be capable of producing its most accurate results. A



Ray diagram for the stepped poke dial showing the improvement over the simple poke dial.

further problem with this dial is that the weight of the stepped insert causes the dial to hang to one side when suspended which, if not considered when it is calibrated, will lead to even greater error.

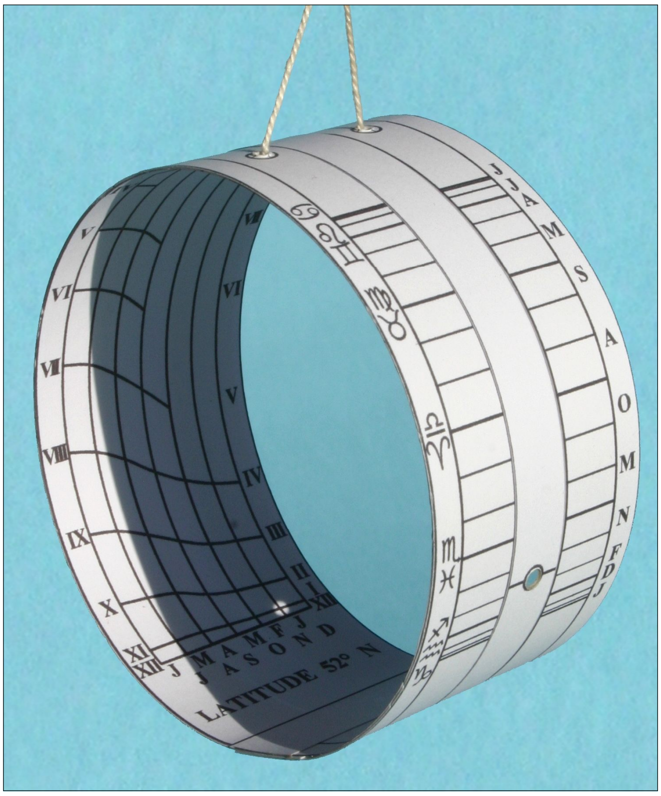
20 Poke Dial (correctly calibrated)

The various errors of the simple poke dial have been discussed but this model has been correctly calibrated so that it will give the right time. In order to achieve this, the

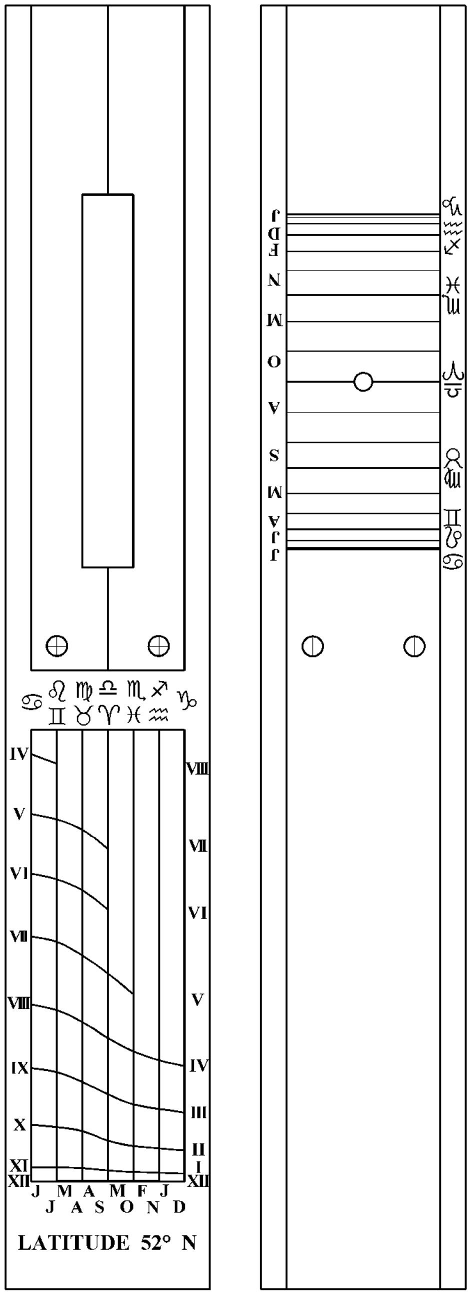
A stepped poke dial from Germany, c. 1680.

Poke dial or Bauernring.

hour lines are curved so that they are correct for each month of the year. In the model produced, the gnomon hole position has been offset downwards in an attempt to expand



Poke dial made from the scales shown opposite.
[Sagittarius 14° or Pisces 16°, XI or I.]

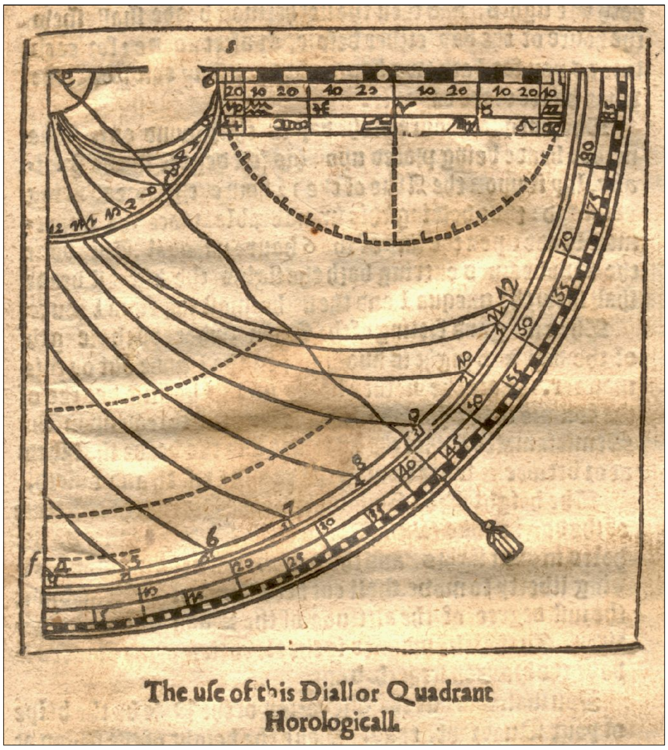


Correct calibration for a poke dial applied to each side of the strip before it is formed into a ring and joined.

the scale length towards noon. This means that the equinox noon no longer goes through the centre of the ring, but the curved hour lines adequately compensate for this. The small errors caused by the slightly increased shadow length towards the edges of the ring have been ignored.

QUADRANTS

These are generally multi-purpose devices, often used for surveying as well as time telling. Thus, showing the hour may not be their prime function. Often they include star positions so that they may also be used at night to tell the time. It is not possible here to replicate all of the available models, but those chosen will show some of the differences between the various types. They are generally single latitude devices but the quadrans novus and the panorganon may be used at any latitude, so their details have been placed in the later section describing universal dials. The names used here for some quadrants are those used in various books. In particular, the names horological, horary and horodictical really refer to the same thing, a time-telling quadrant, but have been used separately in order that each has a distinct name.



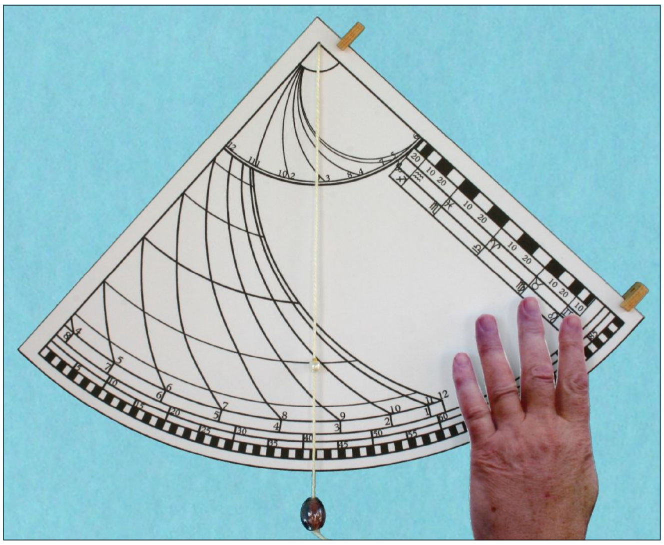
The horologicall quadrant from 'The Art of Dialling' by Thomas Fale, 1652.

21 Horological Quadrant

This device is essentially the same as the following simple horary quadrant but with its date scale reversed. This means that the winter hours are more cramped with the summer hours more spread. The quadrant is fitted with two sights on its top edge with which to sight the Sun and a plumb line fitted with a sliding bead from its apex. The two sights are then lined up with the Sun, not directly due to the danger of blinding, but as formerly described. When the spot of light falls exactly on the centre of the lower sight the plumb line is clamped to the plate with the thumb and the time is read from the position of the bead. The calibrated hour lines are computed for one fixed latitude but, by finding the height of the Sun on the outer degree scale and reference to appropriate tables, this and any other quadrant may be used at any latitude.

The bead is set to the date on the right hand scale and will indicate the correct hour when the sights are aligned with the Sun.

In the apex of this quadrant is a scale for planetary hours, dividing the day into 12 equal parts from sunrise to sunset. To use this scale, the thread is set to the Sun's noon altitude on the outer scale and the bead is slid to cross the 6 hour (or noon line) of the planetary hours. Then, with the Sun lined up through the sights, the time in planetary hours may be found.



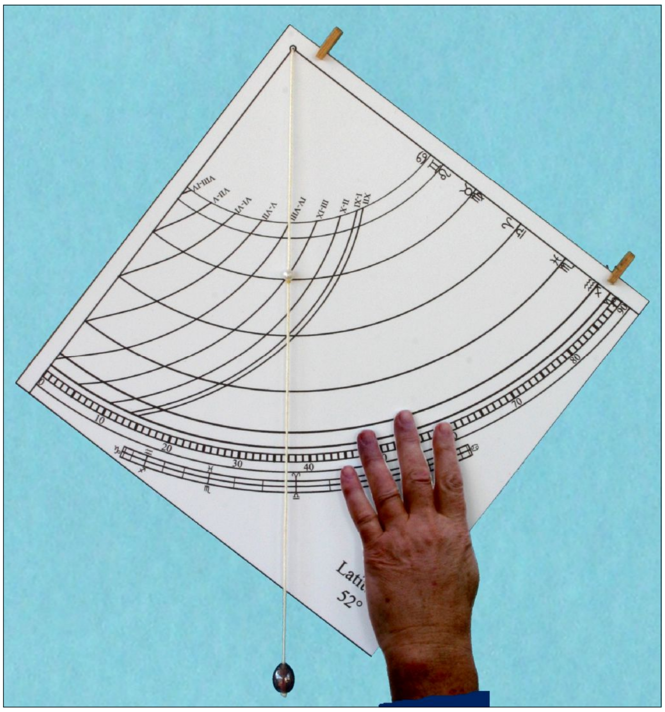
The horological quadrant in use.
[Taurus 2° or Leo 28°, 9:50am or 2:10pm.]

22 Simple Horary Quadrant

This dial is similar to the horological quadrant but with the date scale reversed to give a better spread of calibrations. In use, the line should be stretched taut so that it crosses the XII line at the current date and the sliding bead is set to this point. The date may be found in two ways, either from the concentric arcs, here labelled with zodiac signs, or the date scale below, next to the outer degree scale.

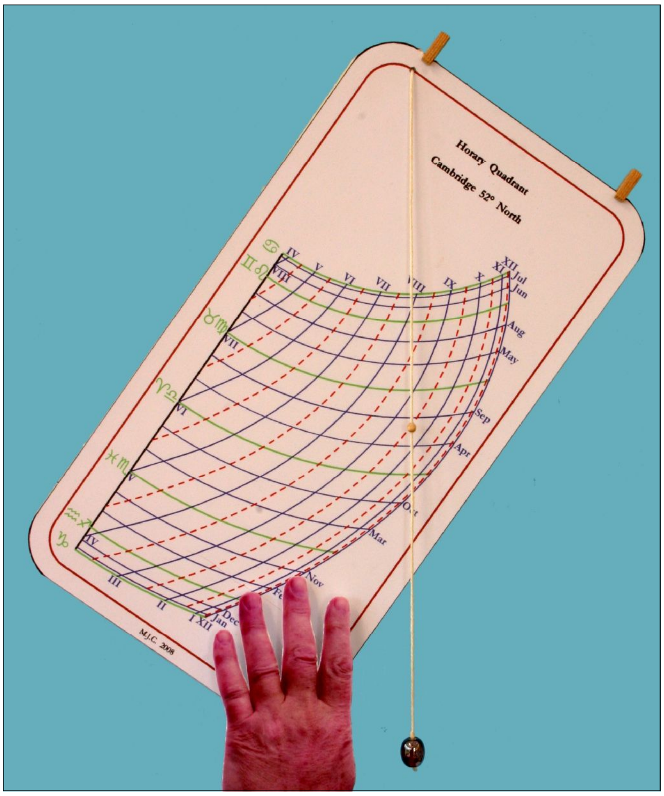
Similar dials (mainly Italian) are found that are based on this quadrant but consist of just the left hand half of the present design, the right hand half being superfluous for a simple time-telling instrument.

Another version of the simple quadrant is one calibrated in Italian hours. Italian hours begin at sunset and the day is then divided into 24 equal divisions (hours). Therefore, in the summer when the nights are short, dawn can be as early as 8 hours but in winter can be as late as 16 hours at our latitudes. These figures can be seen along the left-hand axis of the quadrant. One advantage of Italian hours is that they show immediately how long it is until sunset. Therefore it is possible to say that you 'have three hours of light' to complete a certain job or, if travelling, that you have 'four



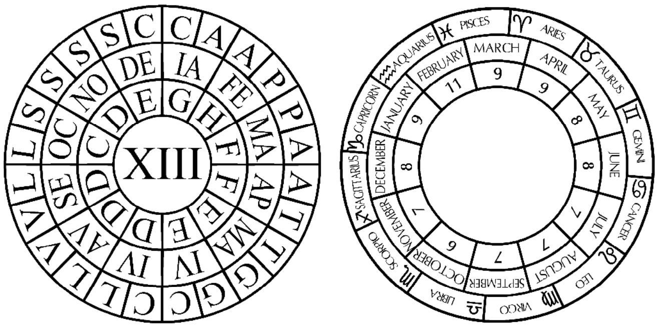
Simple horary quadrant.
[Taurus 5° or Leo 25°, IX or III.]

hours before dark' which brings with it the real possibility of being robbed. Note also that MERIDES or noon is represented by a theoretical line, with several of the hour lines joining this line, but no one Italian hour can represent noon which could be anything from 16 hours to 20 hours during the course of the year at latitude 52° north. The quadrant shown is modelled on one made by Benvenuto Vulparia of Florence and is dated 1516. In use, the bead is



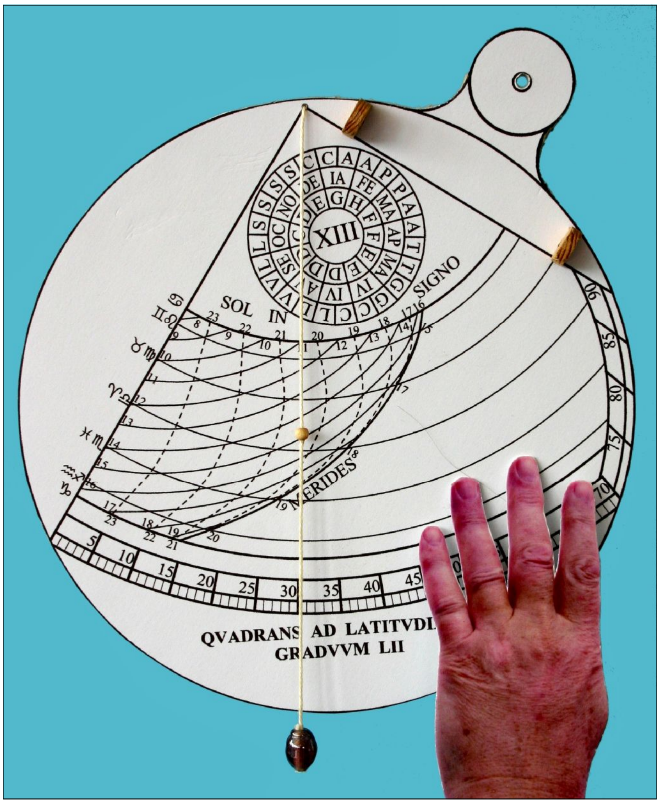
Simple horary quadrant with surplus area removed.
[April 7 or September 3, 9:35am or 2:25pm.]

set to the correct date at the left edge and when the sights are aligned with the Sun the bead will show the time (in Italian hours). Note that the hour lines after noon are dotted to avoid confusion with the morning hours. Because the model was made for 52° north instead of 42° north the pattern of hour lines is somewhat smaller, leaving more space on the right of the quadrant. With this instrument, the top right of the quadrant is clipped by the outer circle of the mounting disc, so the sights are positioned much closer together, thereby reducing the accuracy of measurement somewhat.



Solar course diagrams. Left: as found on old Florentine quadrants. Right: a version for the Gregorian calendar.

The circular diagram at the apex is of some interest. It is known as a 'solar course diagram'. It has been reproduced on the quadrant shown below in its original form when the Julian calendar was in use. The outer ring of letters gives the initial letter of the zodiac sign, the next ring the first two letters of the month and the inner ring has a letter that must be converted into a number (A=1, B=2, C=3 etc.). On some

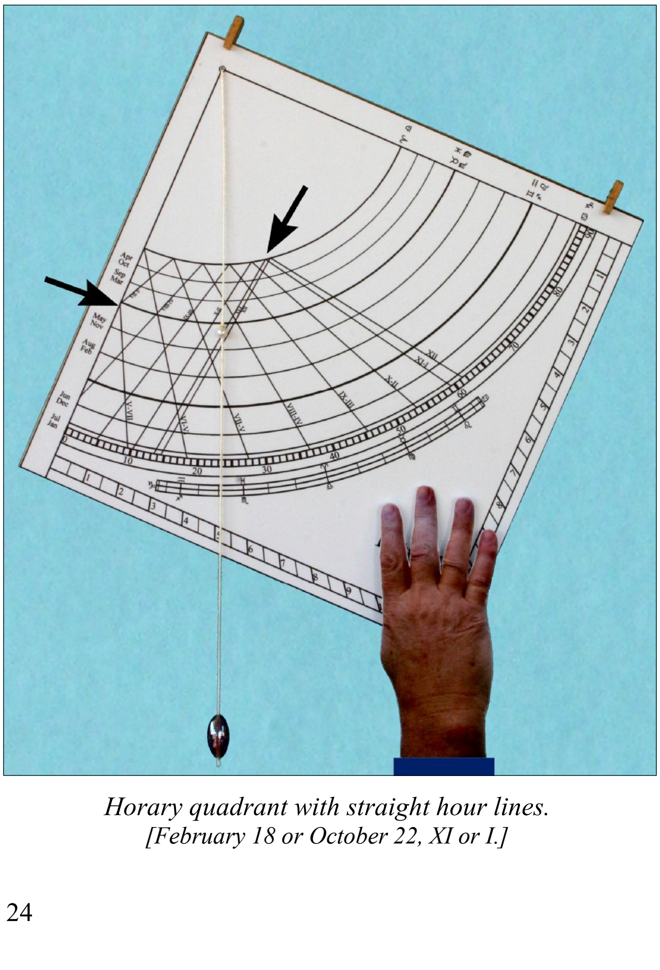


Simple horary quadrant for Italian hours.
[Aries 10° or Virgo 20°, 15 hours or 20½ hours.]

solar course diagrams, numbers are given directly in place of these letters. Its use is to find the degrees of the zodiac that agree with the current date. To operate this, the current date is added to the number indicated by the inner ring of letters, which in turn is added to XIII (or 13). This gives directly the number of degrees, but if the number exceeds 30, then 30 needs to be subtracted from the total. To give an example, we must first convert the Gregorian date into its Julian equivalent by subtracting 10 days. Therefore, if today is April 2 we have the Julian equivalent of March 23. Adding 6 (F) plus 13 we get 41 from which we must subtract 30 giving 11. We are therefore at Aries 11°. This appears to be wrong by just one day, but these figures will vary by a day or two depending on where we are in the leap year cycle. A modern equivalent of this diagram is also shown. This time the number on the inner ring does not need adding to XIII, just the current date, to get the zodiac degrees (April 2 + 9 = Aries 11°).

23 Horary Quadrant with straight hour lines

This quadrant uses a folded date scale to give increased accuracy. In order to get straight hour lines, the arcs of the date calibrations have been re-positioned. Otherwise, this quadrant is similar to the others described in this section. The straight lines sloping down to the right are for the summer months and those sloping down to the left for winter months. These expanded scales make this quadrant quite accurate in use but care must be taken when using it in the region to the left, where the hours for both summer and winter are mixed together. It is essential to follow the correct hour line.

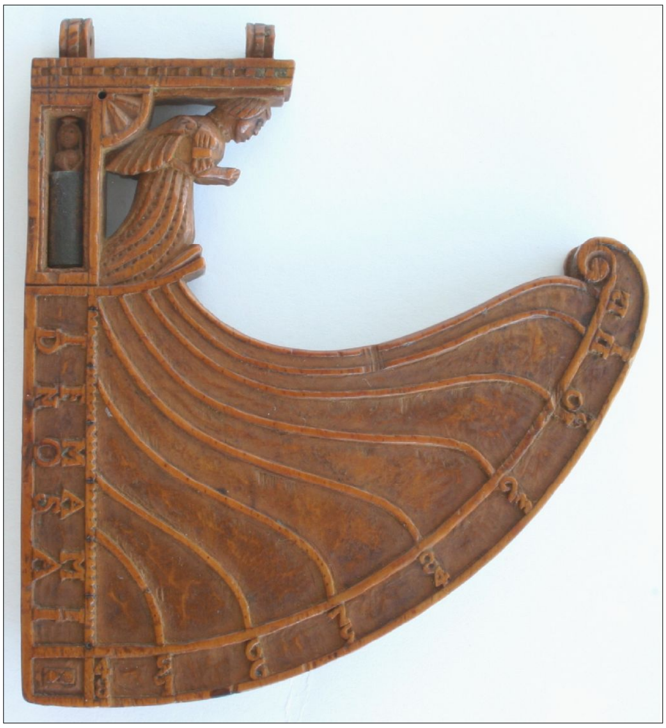


Horary quadrant with straight hour lines.
[February 18 or October 22, XI or I.]

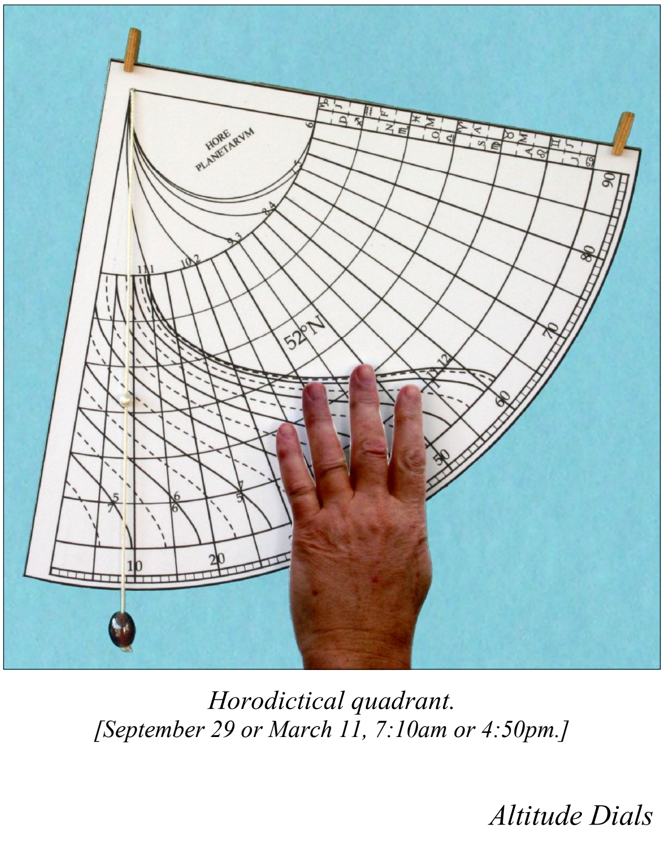
An additional scale often found on many instruments of this type is the shadow square. In this case it is along the two lower edges of the square. Details for its method of use are given below for the Gunter's quadrant (type 25).

24 Horodictical Quadrant

The name simply means a 'time telling quadrant' It is similar to the simple horary quadrant but with its date scales reversed and with an equal spacing between each of the zodiac lines, making the date setting easier. The scales have now become 'S' shaped. In addition to the equinoctial

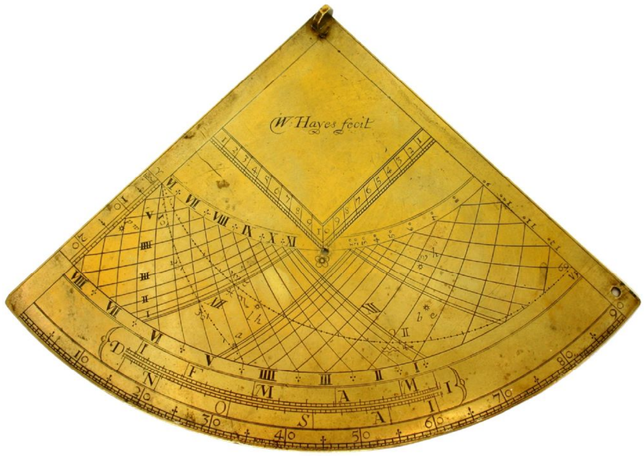


An horodictical quadrant dated 1725.



Horodictical quadrant.
[September 29 or March 11, 7:10am or 4:50pm.]

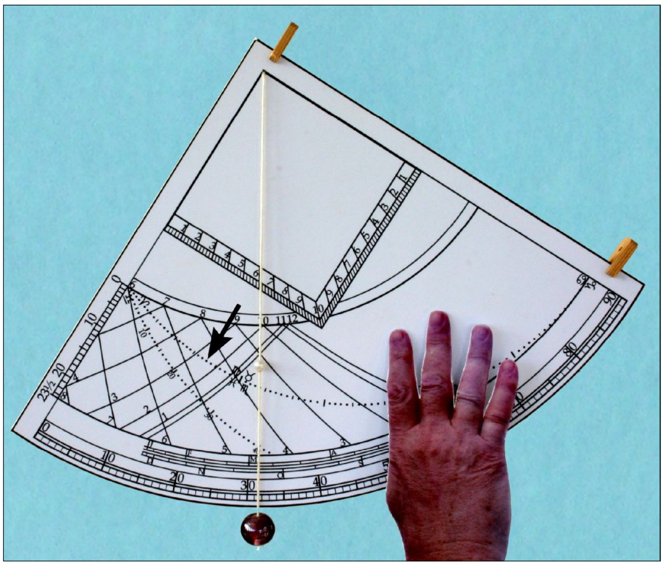
hour lines, a scale has been added near to the apex that gives planetary hours. These effectively divide the day into 12 equal portions from sunrise to sunset. The scale is used in a similar fashion to the main scale but the thread is first adjusted to cross XII (noon) at the appropriate date on the main scale and the bead is adjusted to the 6 (noon) line on the planetary hours scale.



A typical Gunter's quadrant in brass by Walter Hayes.

25 Gunter's Quadrant

This quadrant is to the design of Edmund Gunter, being a stereographical projection of the sphere on the plane of the equinoctial. Its calendar scale (ecliptic) is spread across the quadrant, folded twice enabling every degree of the zodiac to be discerned. This makes for a precise setting of the bead. The first stage is to set the bead at the correct date on the ecliptic. When set, the Sun should be aligned with the sights and the plumb line should be clamped against the quadrant, the time being read from the position of the bead. As with the horary quadrant (23), care must be taken to ensure that the correct hour line has been chosen. Basically, the lines sloping down to the left are for the winter months and those sloping down to the right are for the summer months. An alternative method of setting the quadrant is to set the line on the date scale near to the lower edge and then set the bead to the XII or noon line. Then proceed as before.



Gunter's quadrant.
[Aries 23° or Pisces 7°, 8:50am or 3:10pm.]

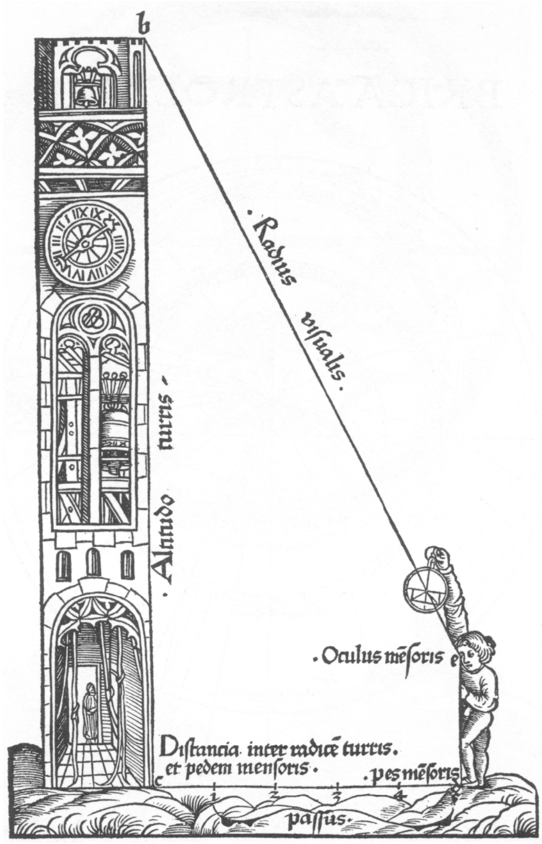
The model produced has been simplified from the original, showing just the basic time telling lines when used as a sundial. Quadrants would also be used for telling the time at night, often with certain stars marked on them. To find the Sun's meridian altitude, move the thread so as to cross the date scale, just inside the degree scale, and read the altitude directly from the degree scale.

To find the RA (right ascension) of the Sun, set the Sun's place in the ecliptic and read the RA from the degree scale, adding 180° if necessary. Degrees may then be translated to hours and minutes at 15° per hour.

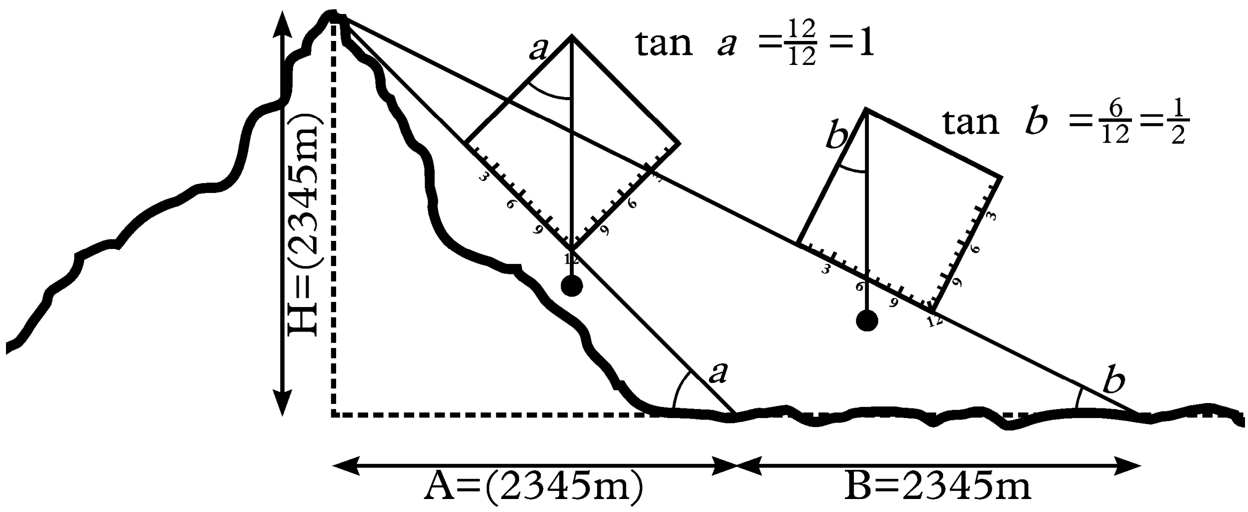
To find the Sun's declination, set the bead to the date on the ecliptic, then swing the thread to the left hand scale to read declination in the range ±23.5°.

The other scale on the face of the quadrant is the horizon line. Set the bead to the date on the ecliptic, then swing it to the horizon line. Get a reading of degrees from the main degree scale: from this it is possible to calculate times of sunrise or sunset (at 15° per hour).

An additional scale often found on quadrants is the shadow square, located on this instrument near its apex. It may be



Using a shadow square on an astrolabe to find the height of a tower. From Stöffler's 'Elucidatio fabricæ ususque astrolabii' of 1524.



Using a shadow square to find the height of a remote object.

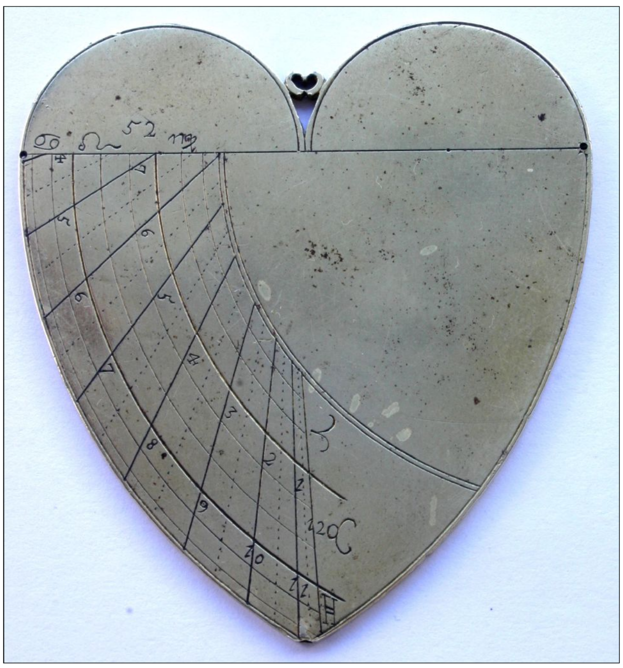
used for simple surveying purposes. Here both sides are divided into 10 equal divisions, further sub-divided by 5, but in other versions various numbers of divisions may be found, often 12 as it is easily divided by several factors. With this scale it is quite simple to find heights and depths of many distant objects. A typical use may be to find the height of a tower. In this case the tower top is viewed directly through the sights and a reading taken from where the plumb line crosses either of the scales. A measurement is then made from the observing point to the base of the tower. If the reading on the scales is in the lower section, the angle is less than 45° and the distance from the base of the tower is multiplied by that reading divided by the total of that limb of the square. For example, if the distance to the tower was 100 m and the plumb line crossed at 3, then its height would be 3/10 × 100 or just 30 m. To this figure we then need to add the height of the observer. If the reading had been taken from the right hand limb of the square, the tower would have been more than 45° high and a reciprocal would give the correct answer. For example, if the distance to the tower was 10 m and the line crossed at 8, the height of the tower would have been 10/8 × 10 or 12.5 m, plus the observer's height. The figures that we are getting from these two scales are essentially tangent and cotangent figures.

The shadow square may also be used to find the height of an unapproachable object, such as a tower across a river, a castle occupied by the enemy or to find the height of a mountain. In the illustration the height of a mountain is found from nearby flat land by taking two readings with the shadow square, at 12 and 6 and by measuring the distance between them, B. This is conveniently the same as distance A and height H. Other sensible figures could also have been used to avoid complicated mathematics, such as readings at 3 or 9, allowing them to take a simple fraction of the measurement between both points. If such steps were not taken the surveyor would be faced with solving two equations:

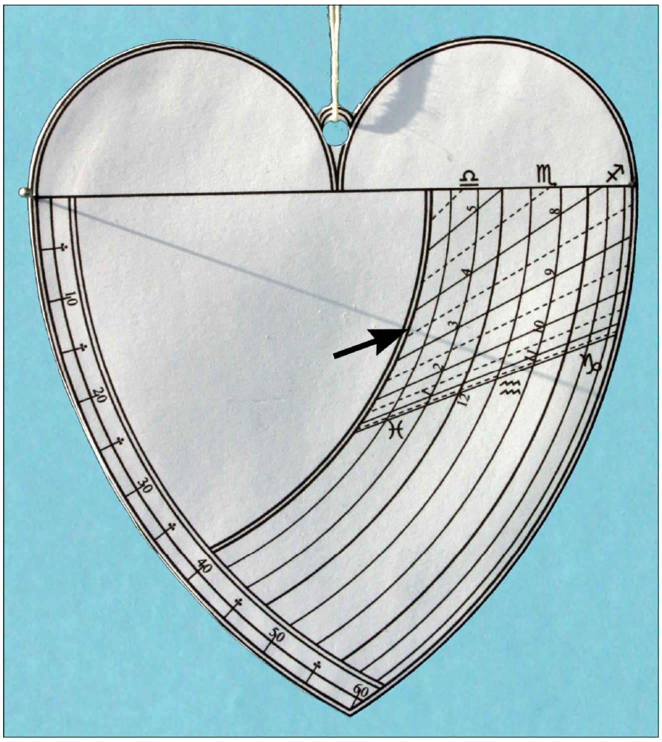
$$A = B \times (\tan b / \tan a - \tan b)$$
$$H = \tan b \times (A + B)$$

26 'Heart' Quadrant

This dial is heart-shaped and is not a full quadrant, only covering the range 0–60°. The dial has been arranged on two sides of the heart, one each for summer and for winter. Unlike the others, this quadrant is not aligned with sights and does not use a thread and plummet. The dial, intended to be worn around the neck on a cord, is not even tilted, but is suspended vertically. A short pin gnomon is inserted into the hole at the end of the horizontal line on the appropriate side and the heart is turned edgewise to the Sun so that the shadow crosses its face. The time is then read from where the shadow crosses the appropriate date line. Note that, as in the horary quadrant (23), the hour lines are straight, achieved by manipulation of the spacing of the date lines.



A 'Heart' quadrant of c.1650 showing the summer months.



A drawing of the reverse side of a heart quadrant (for the winter months) and a 0-60º quadrant scale.
[At the Equinox, 8:25am or 3:35pm.]

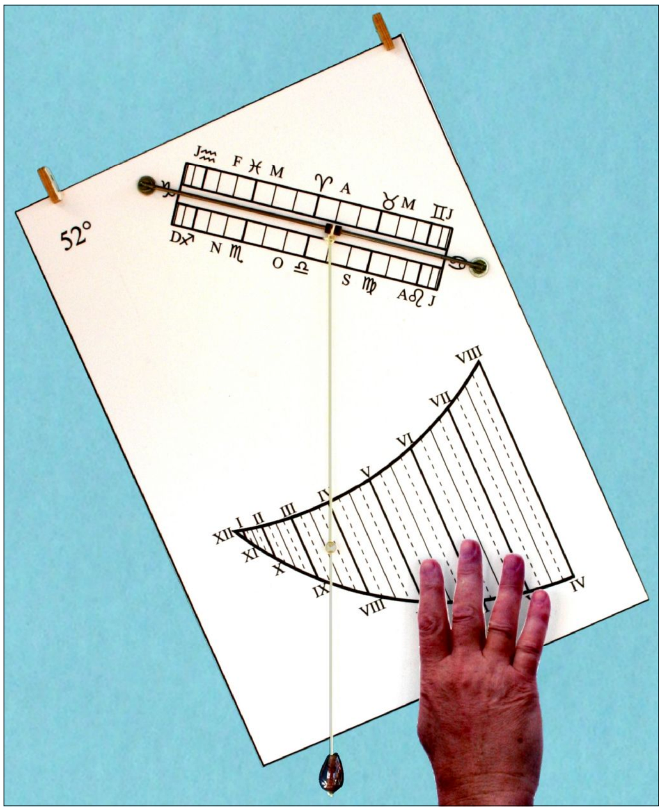
On the winter side of the dial is an altitude scale 0–60° that may be used with the pin gnomon placed on the opposite side of the heart. This scale may be used to find the altitude of the Sun. When not in use, the pin gnomon may be stored in a hole drilled vertically into the plate from its lowest point. It will be noted that the height of the Sun at noon around the summer solstice is a little too high for this dial, designed for 52° north, being up to 61.44° high. Dials of this pattern are therefore unsuitable for lower latitudes unless the heart is widened.

OTHER DIALS

The following four dials fall into none of the former categories, but the Capucin dial may be considered as a forerunner to the Regiomontanus dial (dial 33).

27 Capucin Dial

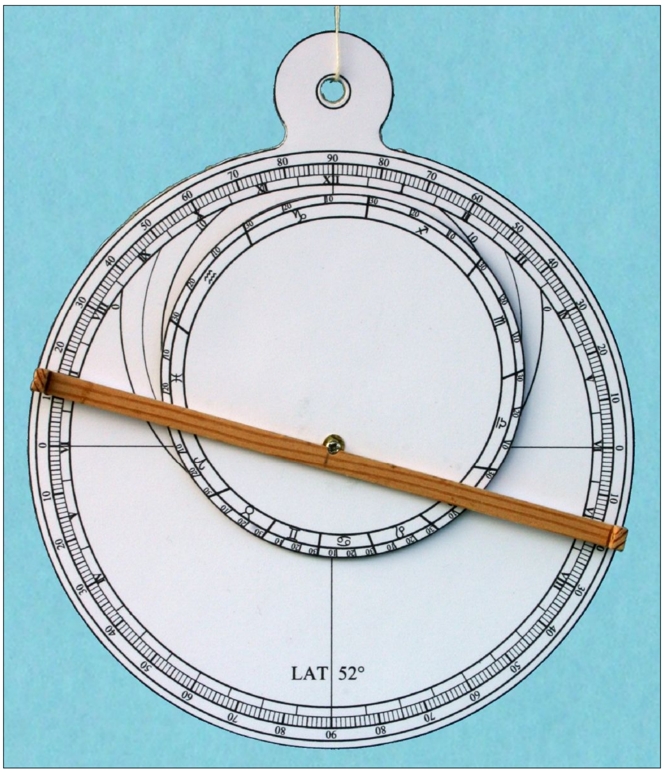
The common name for this dial is derived from the characteristic shape of the hour scale, similar to the head covering of Capucin monks. The slope of the date scale is set at the co-latitude of the intended place of usage, the XII point lying on a projection of the equinox line. The plumb line is supported from a slider in the slot of the date scale. In use, the correct date is set on the slider and the bead on the plumb line is set exactly to the XII point. The dial is then aligned with the Sun using the sights and the time read from the position of the bead on the attractively shaped scale.



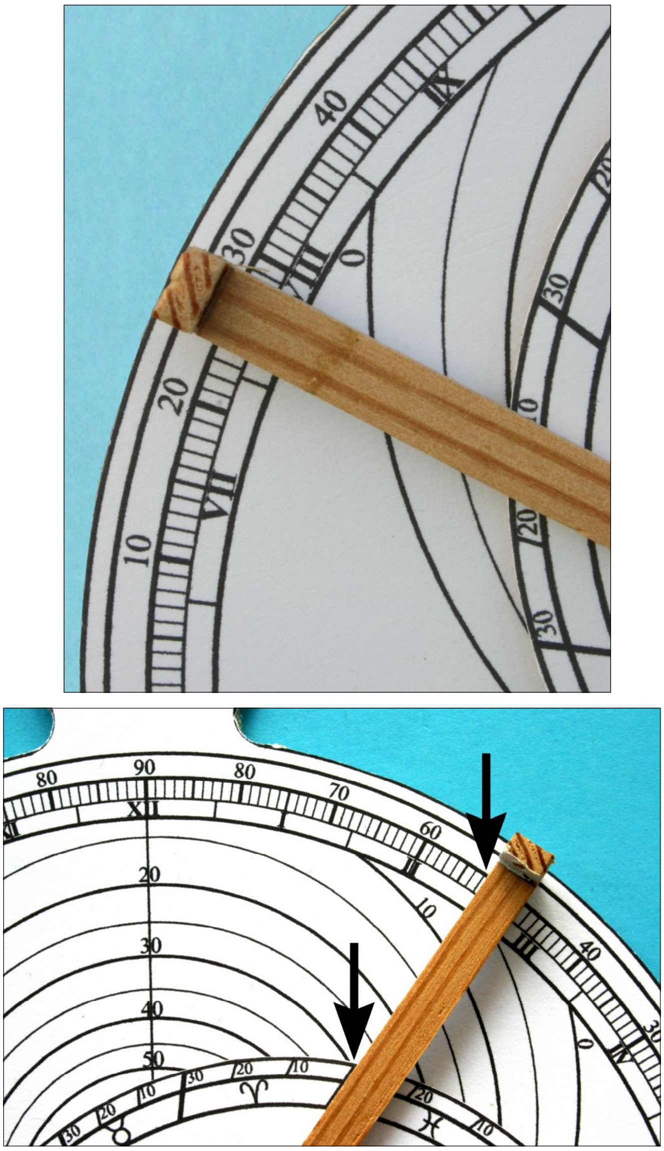
A Capucin dial.
[March 30 or September 10, 8:25am or 3:35pm.]

28 Planispheric Astrolabe

The astrolabe is also an altitude dial but, of course, it does much more than this. However, so as not to confuse, the relevant parts for simply telling the time by the Sun have been ‘extracted’ and made into a simple instrument. It is essentially a single latitude dial but by providing it with a



A planispheric astrolabe.



The planispheric astrolabe. Top, set for a solar altitude of 29°. Bottom, the 29° almucantar aligned with Aries 0°, 2:25pm.

selection of plates it may be made into a universal instrument. The reconstruction here is of a dial made for a fixed latitude of 52°.

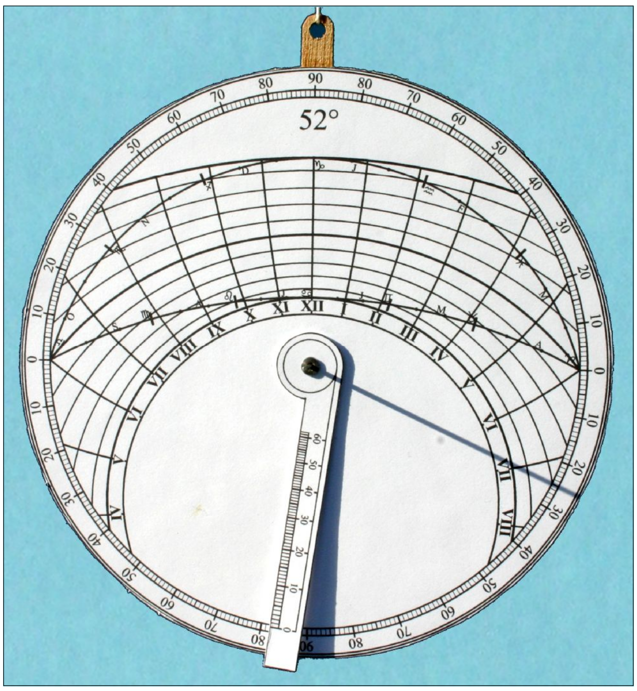
There are three parts to this dial, the plate (usually consisting of mater and plate), the zodiac ring (normally part of the rete), and an alidade with pinhole sights at each end (normally fitted to the reverse of the astrolabe and read against a degree scale there).

In operation, the altitude of the Sun is found by suspending the dial from its handle (shackle) and by setting the alidade so that the angle may be read from the outer scale (limb). When the angle of the Sun has been found, the zodiac ring is then turned until the current date coincides with the ring (almucantar) on the plate corresponding to the Sun's altitude. When the two points coincide, the rule is set to extend this point to the outer hour scale to get the time reading. Unlike many of the dials in this study, the astrolabe can be set to give both morning and afternoon readings. Due to the bunching of the date scale in the summer months and also of the almucantars (as the Sun gets higher), the dial is potentially more accurate in the winter months.

Rev. William Oughtred.

29 Oughtred's Horizontal Instrument

The Reverend William Oughtred designed this instrument for telling the time from the altitude of the Sun. It has sometimes been wrongly called 'Oughtred's astrolabe'. It is a stereographic projection of the celestial sphere onto the observer's horizon, its centre being the observer's zenith. Its layout is incorporated in the design of his well-known double horizontal dial. However, it may be considered as a stand-alone instrument functioning satisfactorily as an altitude dial. It is perhaps not the simplest dial to use, but no worse than the planispheric astrolabe.

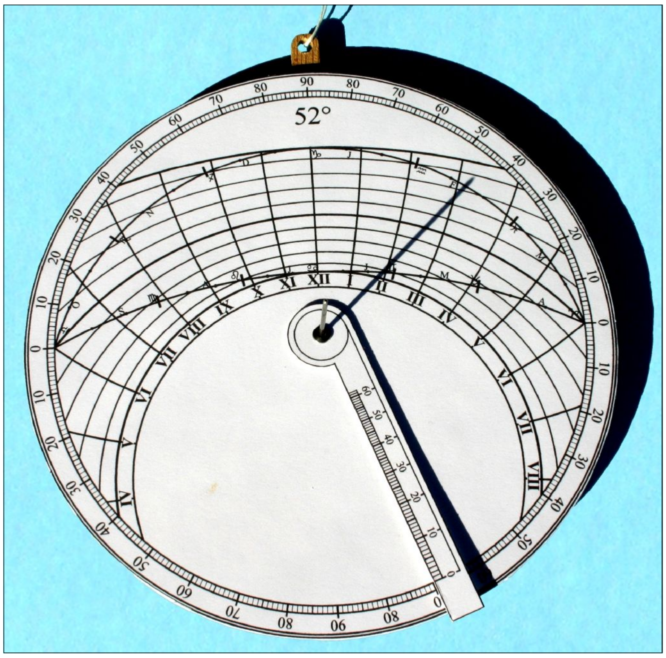


Finding the Sun's altitude—25°.

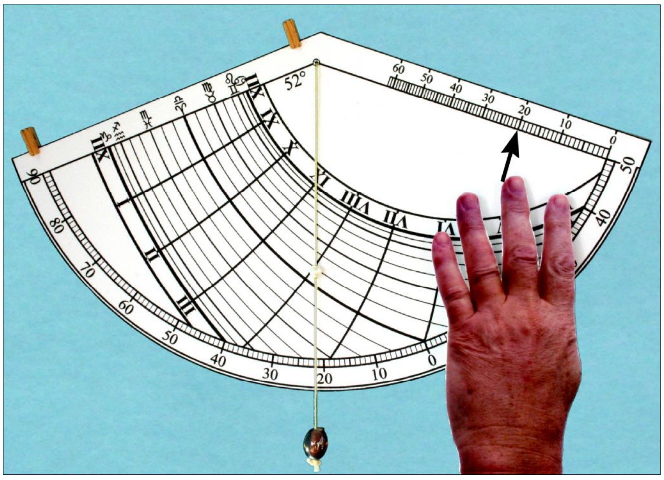
Oughtred's horizontal instrument.
[Sun at 25º, Pisces 22º, 2:40pm.]

Initially, the Sun's altitude is found from a pin gnomon in the dial's centre, when the dial is suspended from its top edge. This figure is then transferred to the rule or regula which is then turned to coincide with the line of declination according to the current date on the ecliptic scale, the time being given where both points coincide. Once the time is found, the instrument, as its name implies, may be placed horizontally with a vertical pin gnomon, set to the time just found and it will function as a horizontal pin gnomon dial. It will also be correctly aligned north-south giving useful directional information. On the model instrument, the declination lines are at intervals of 5° but if space permits lines at 2° or even 1° may be drawn.

The time will then be shown, either in the morning or the afternoon. It can show other solar information too, such as the times and azimuths of sunrise and sunset. To do this, take the date from the appropriate ecliptic line, following the declination line from this point to the horizon (edge of disc). The hour lines will then give sunrise on the left and sunset on the right.



Oughtred's horizontal instrument set horizontally.
[25º altitude, Pisces 22º, 2:40pm.]



A 'triens'.
[Sun at 20º, Aries 9º or Virgo 21º, 7:55am or 4:05pm.]

Construction of this instrument is quite complex but is well documented by *Lowne*.

Oughtred claims to have invented the horizontal instrument when he was a student, c.1595, but similar instruments were known on the Continent before this. *Zinner*.

30 Triens or Delmain's Quadrant

The *Triens* was first described in a sketch of 1485 in a Viennese document but details of a solar quadrant based on this was later described in 1586 by Philip Apian (son of Peter Apian). Triens in Latin means one third, and the device is approximately one third of a full circle. Instruments of this type were also made by Christopher Schissler and one dated 1569, with scales for equal and unequal hours, is illustrated by *Zinner*. The triens is virtually identical to half of the Oughtred horizontal instrument. It is used with two sights on the upper edge and the Sun's altitude is found from the quadrant scale on its outer edge or limb. The bead on the plumb line is then set to that same altitude on the top right hand scale and, when allowed to hang across the main scale with the bead at the current date, its position gives the time in equal hours. On the model, the declination in degrees (as used on the horizontal instrument) has been replaced by date lines of the zodiac at 30° and 10° intervals of solar longitude. Like the horizontal instrument, the triens can also be used for finding sunrise and sunset times, where the declination lines cut the outer scale.

Virtually the same design was produced by Richard Delmain, the only real difference being that the plumb line was replaced by a graduated rule pivoted at the top right. Makers of Delmain's quadrant include John Allen, 1633, Henry Sutton, 1658, Pigot, undated and John Prujean, also undated. *Turner*. Delmain, in 1628, claimed it to have been his own invention and disputes with Oughtred over its origin are well documented. *Turner*.

UNIVERSAL DIALS

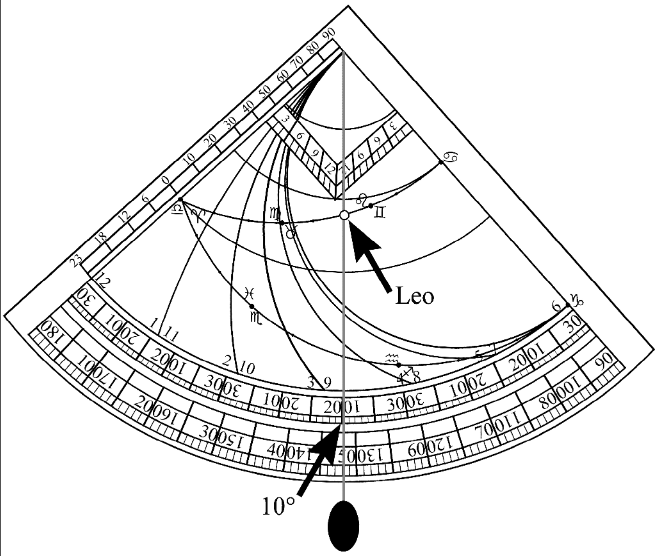
DIALS FOR A WIDE RANGE OF LATITUDES

Universal dials are designed to operate over a range of latitudes. Sometimes the range is quite narrow but in the case of altitude dials, those made 'universal' normally operate from the equator to the arctic circle.

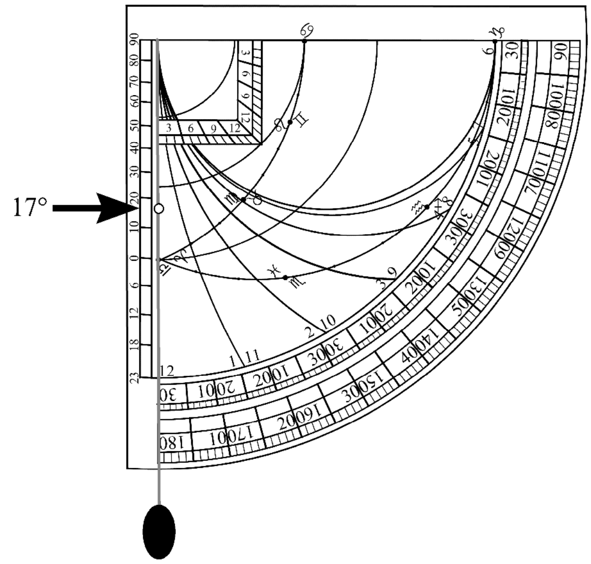
31 Quadrans Novus

As its name suggests, this quadrant is based on the earlier quadrans vetus. However, it still dates back to c.1300 when it was first described by Jacob ben Machir ibn Tibbon. Only about eight of these are known to have survived. It tells the time in planetary or unequal hours, dividing the day into 12 equal parts with 6 hours representing noon.

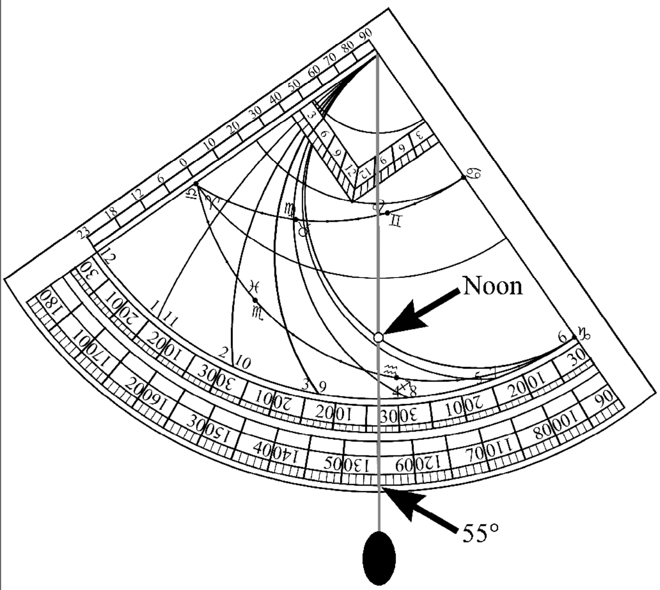
To determine the time, it needs setting to the current date on the zodiac scale. An exact read-out in degrees of zodiac can be achieved from the scale placed just inside the main scale. With the line taut over the current date, the bead is set to where it crosses the zodiac line. The line is then moved to the left side scale of latitude where the declination may be read. This figure then needs to be added to that of the co-latitude of the place of observation in the summer months or subtracted in the winter months to give the height in degrees of the Sun at noon. Next, the line is stretched taut over this figure on the outer scale and the bead is set to the 6 or noon line. The Sun is then allowed to



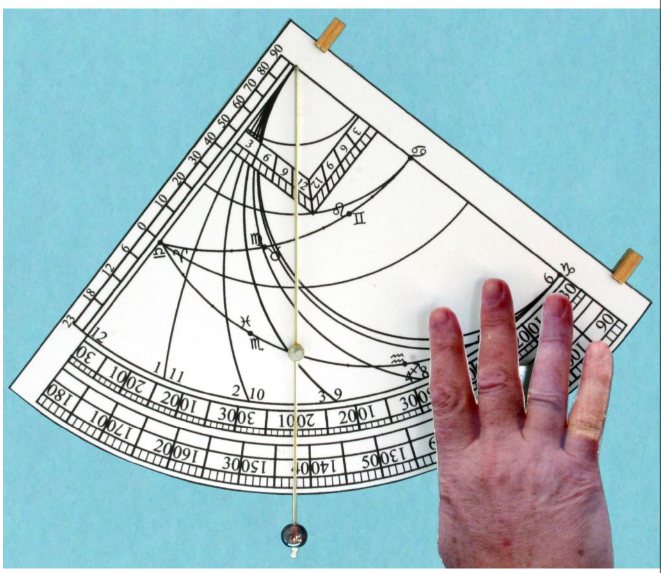
1. Set bead to point on ecliptic (Leo) and cord over degrees (20º).



2. Swing cord to left and measure declination from left scale (17º).



3. Add declination (17º) to co-latitude (38º for Cambridge) and swing cord to this angle (17+38=55º) on the outer scale. Set bead to noon.



4. Line-up the sights with the Sun and the bead will record the time (3h or 9h) in planetary hours.

Four steps for finding the time with the quadrans novus.

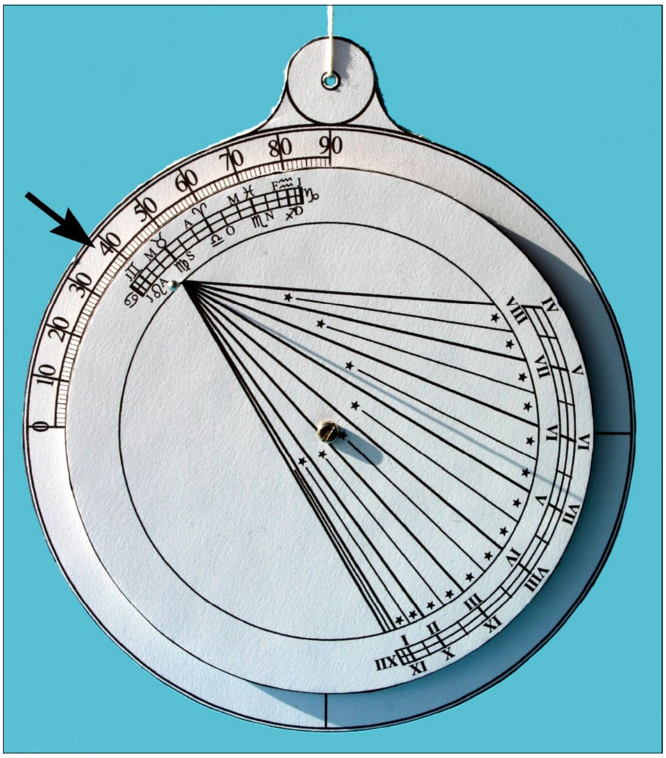
Quadrans novus, c.1380.

shine through the sights and the bead will fall at the correct time on the quadrant face.

The original quadrant illustrated is also fitted with a shadow square, tables of sine, cosine and versine and, on its reverse, is an Easter calendar using Roman date notation.

32 Universal Vertical Disc

This vertical disc dial is almost identical to the 'vertical disc dial 3' (no. 14) already described but is made to be adjustable over a range of latitudes. It is modelled on a dial dated 1554, unsigned but with the caption "A PARIS" written on it. To use the dial, the current date is first set against the co-latitude on the outer scale and the shadow of the gnomon will indicate the time on the hour scale. This



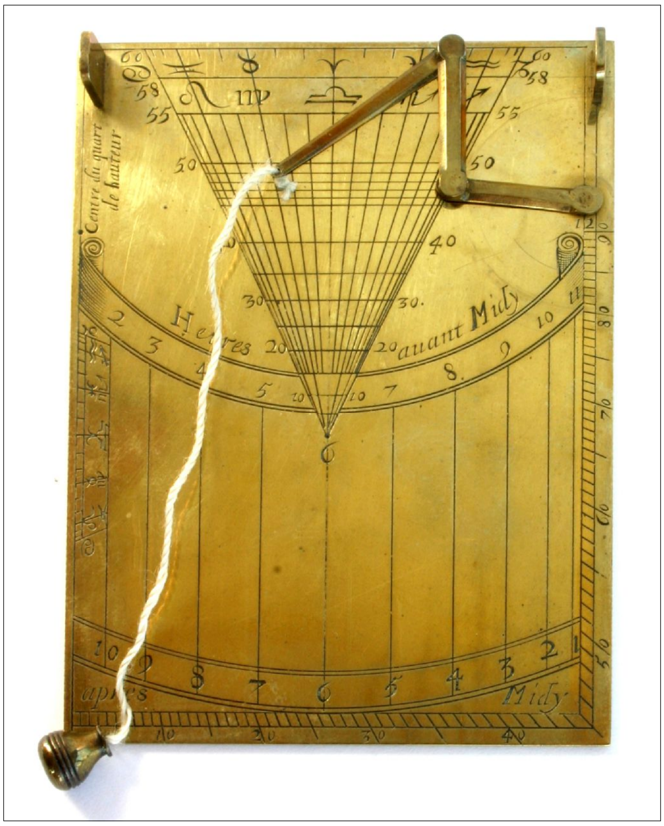
Universal vertical disc.
[at 52° N (co-lat 38°), Gemini 7° or Cancer 23°, 6:43am or 5:17pm.]

dial is no more accurate than the former vertical disc, with errors of up to one hour at certain times of the year. The fact that it has been made 'universal' makes the dial even less accurate except at the actual design latitude. What its original maker does not seem to have appreciated is that the pattern of hour lines must change as latitude is changed. For example, if used at the equator (co-latitude 90°) the hour lines should cover a full 90° of quadrant with the lines evenly spaced at 15° spacing. The noon line will be vertical and the VI-VI line will be horizontal. At the North Pole (co-latitude 0°) all hour lines will merge and lie in the same direction, effectively showing as one horizontal line which will be totally unusable as a dial at this latitude as the Sun only changes in altitude with the season and not with the hour. However, at mid latitudes, perhaps ±10° either side of its design latitude of 52°, it will function relatively well and should give the time to within an hour or so for most of the year.

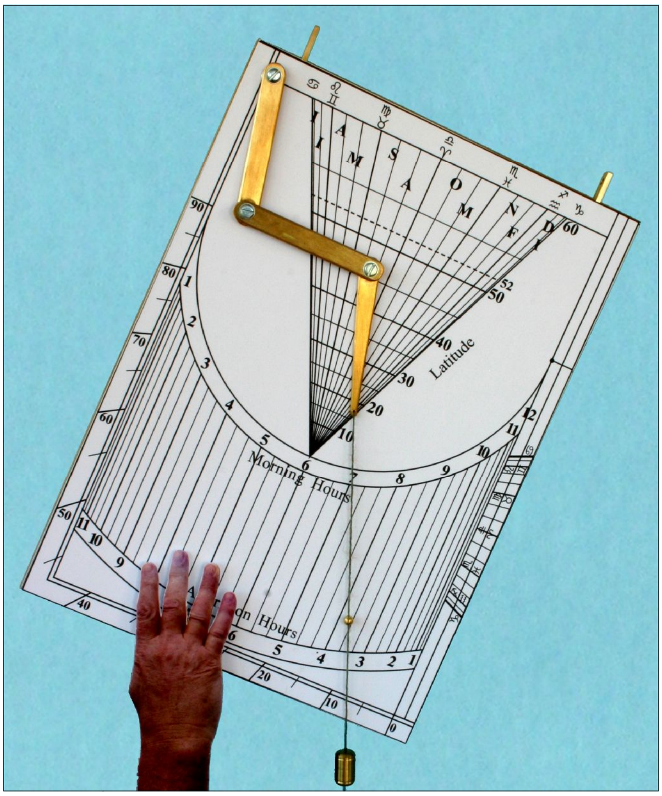
Regiomontanus holding an astrolabe. From Schedel's 'Nuremberg Chronicle', 1493.

33 Regiomontanus Dial

This dial design was originally made by Johannes Müller from Königsburg. His name is better known in its Latinised version as Regiomontanus. He lived from 1436 to 1476. He had used the basic principles of the Capucin dial but has now made this dial 'universal' or capable of being used over a wide range of latitudes, in this case from the equator to 60°. The dial has two date scales, one in the vee at the top and the other to one side of the hour scale, both scales converging at a point on the equator. The latitude scale is vertical in the top vee. The plumb line is designed to be suspended from any point in this top vee section and a simple three-section arm or brachiolus (bracchium is Latin for arm) is used to suspend it in this position. The suspension point is set for both latitude and date and, with the plumb line held taut, the bead is also set to the correct date on the other scale. Using the sights, the dial is aligned to the Sun, the time being given from the position of the bead. Other useful information is readily available from this dial, particularly the times of sunrise and sunset for any latitude within its range. This is simply done by holding the dial vertically so that the plumb line hangs straight down from the correct suspension point. The two times read from



Regiomontanus dial in gilt brass by "Roch Blondeau a Paris", dated c.1700.

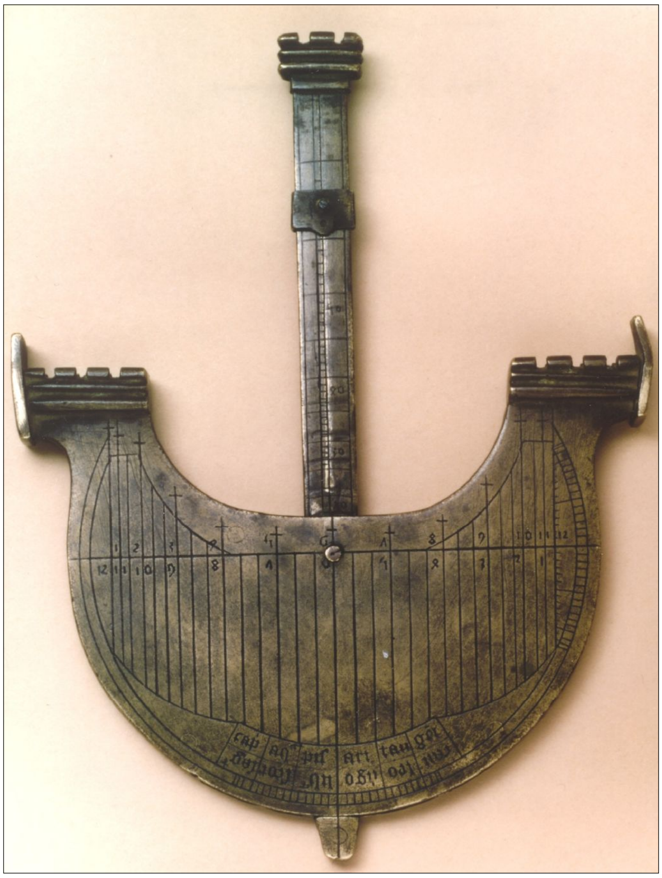


Regiomontanus dial.
[At 16° N, Winter solstice, 8:10am or 3:50pm.]

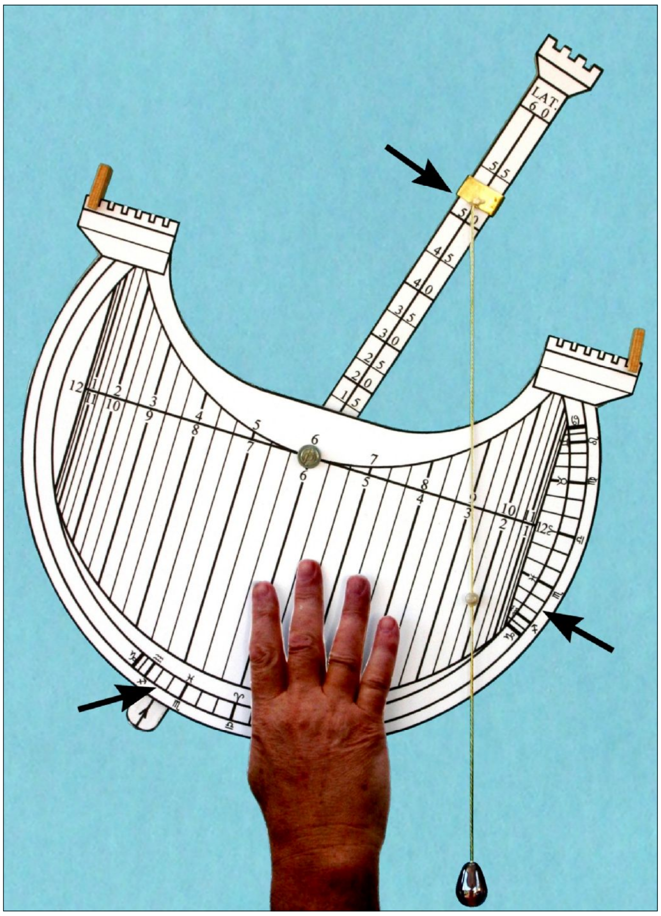
the hour scale are for sunrise and sunset. A quadrant scale is also included around the edge for measuring altitudes, when the brachiolus suspension point set to the 0° - 90° point near the top right.

34 Navicula (Navicula de Venitii or Little Ship of Venice)

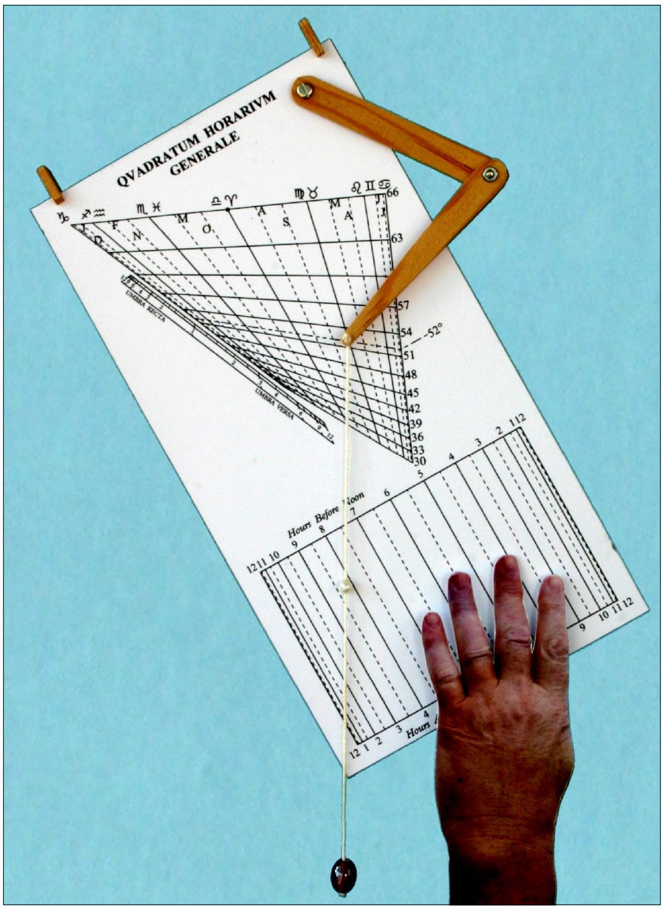
The navicula is essentially the same as the Regiomontanus dial. It is constructed on a partial disc with an arm vertically above, which is used to support the plumb line. Its form suggests that of a ship, and both fore- and aft-castles have been added for ornamentation. These 'castles' also support the sights. The 'mast' swings left and right to agree with the date scale engraved on the ship's 'keel'. The latitudes are marked vertically up the mast. This swinging mast essentially traces out the vee scale that we see on the Regiomontanus dial except that the latitude lines are no longer straight but have a slight curvature. Like the Regiomontanus dial, the bead is set to the date scale on the right (sometimes left - but then inverted) and the time is read from the position of the bead. Navicula dials are quite rare, most being made around 1500. The changing of the straight horizontal latitude lines to a curved shape results in small errors in this dial. These are worst around the equinoxes. However, by setting the height scale on the mast so that the calibrations correspond to the points mid way between the equinoxes and the solstices, the error will be halved. It is not known if the makers of these dials actually made these slight adjustments.



An early Navicula dial, shaped like the hull of a ship, its mast with a latitude scale, fore- and aft-castles holding the sights and a keel for setting the date.



A Navicula
[at 52º N, Aquarius 15º or Scorpio 15º, 9:45am or 2:15pm.]



Quadratum horarium generale.
[At 52º N, start of Taurus or Virgo, 8:15am or 3:45pm.]

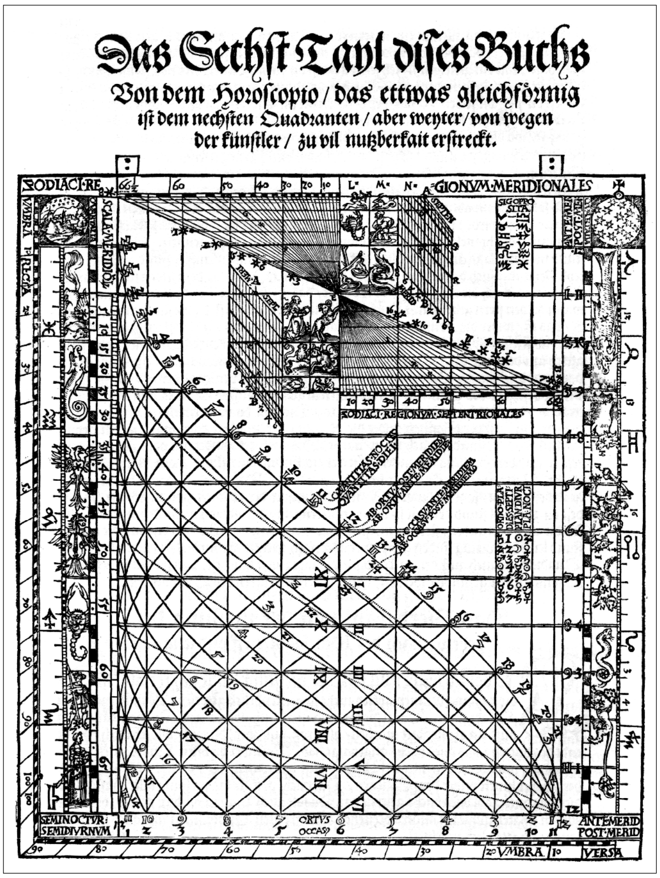
35 Hartmann Dial (Quadratum Horarium Generale)

This is another dial based on the Regiomontanus dial but its use has been simplified so that only one adjustment needs to be made before use. Both date scales have now been combined in the vee section giving the effect of a twisted vee. In use the brachiolus is set at the point corresponding to the correct latitude and date and the line is held taut over the top left corner of the hour scale, 12 noon, the bead being adjusted to this point. With its sights aligned to the Sun the dial will now give the time from the position of the bead.

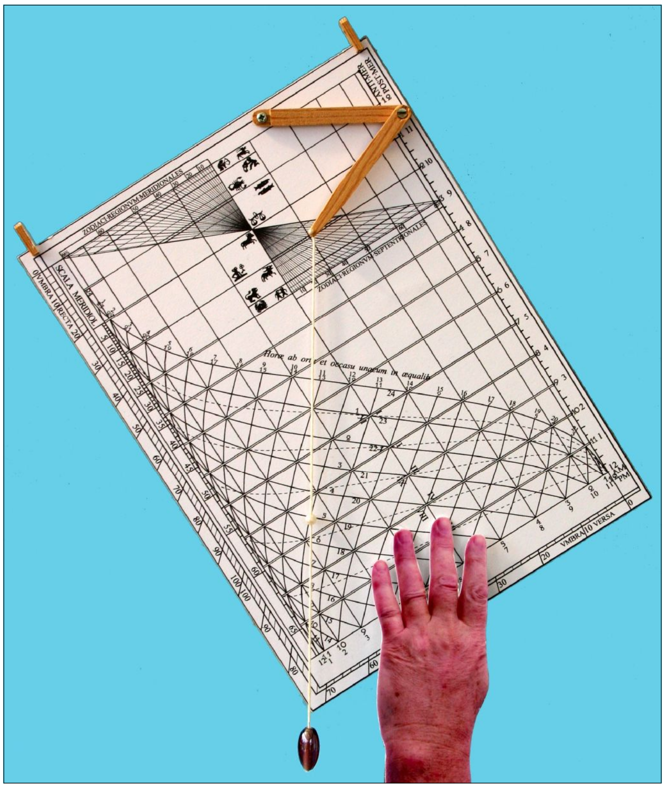
An interesting variant on the shadow square is incorporated in this dial. The two halves of the scale, in a straight line on the left of the 'vee', are labelled UMBRA VERSA and UMBRA RECTA. These are not tangent and cotangent scales as normally found but *1/tan* and *1/cos*, making the calculations much simpler. Therefore, at 45° (from the suspension point, top right), the multiplication factor is just 1. As angles increase or decrease, the figure given is a straight multiplication factor compared to the horizontal measurement. Details of the standard shadow square were given above for the Gunter's quadrant (**25**).

36 Apian Horoscopium

The design of this dial was first published by *Peter Apian* in his Instrument Book of 1533. At first sight this is a most complicated dial, containing scales for Equal hours,



Apian horoscopium as illustrated by Peter Apian in his Instrument Book *of 1533.*



Horoscopium.
[52° N, Taurus 1° or Leo 30°, 8:35am or 3:25pm.]

Temporary (Planetary) hours, Italian hours and Babylonian hours. To use it for equal hours it is necessary to set the brachiolus to the correct date and latitude in the triangles at the top ❶ and set the bead to coincide with noon and the user's latitude at the scale to the left ❷. The plate is then tilted to let the Sun shine through the sights and the time is read from the bead position with respect to the vertical hour lines ❸.

If the dial is held vertically so that the plumb line hangs straight down ❹ the times of sunrise and sunset may be found from the hour scale below. Furthermore, the day length and night length may be read from the upper line of the 'S' shaped scale.

To find the time in Babylonian, Italian or Planetary Hours it is necessary to extend a line horizontally from the reading of day and night lengths and extend vertically a line from the bead showing Equinoctial Hours. The crossing of these two lines ❺ gives the times as shown in the diagram.

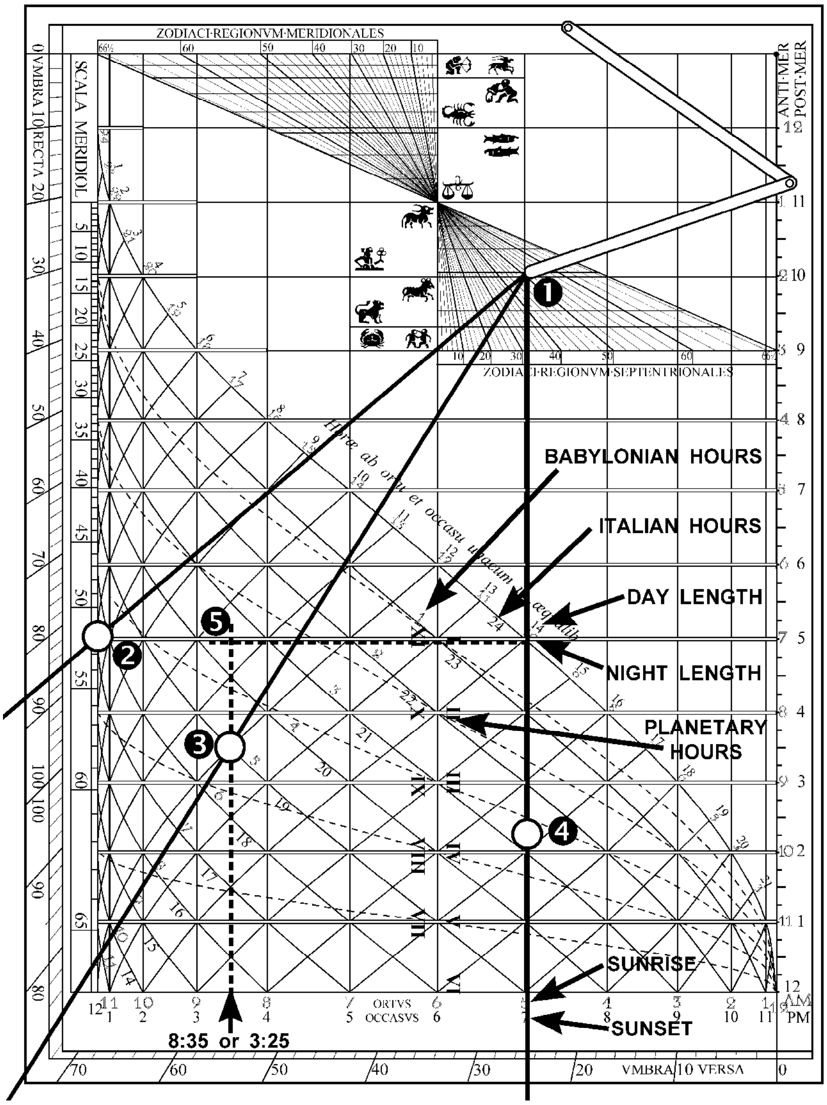
Babylonian Hours are 24 equal hours starting at sunrise.

Italian Hours are 24 equal hours starting at sunset.

Planetary Hours divide the day period between sunrise and sunset into 12 equal portions, and the night period, between sunset and sunrise into a further 12 equal, but normally different, portions. Planetary Hours are shown by the dotted lines and are labelled I to VI to XI in the centre of the dial. (The final XII is not marked.)

The Shadow Square is situated on the left and lower edges and is read by the plumb line suspended from the top right corner. It is divided into 100 parts.

See *Hagen* for a detailed description of this type of dial (in Dutch).



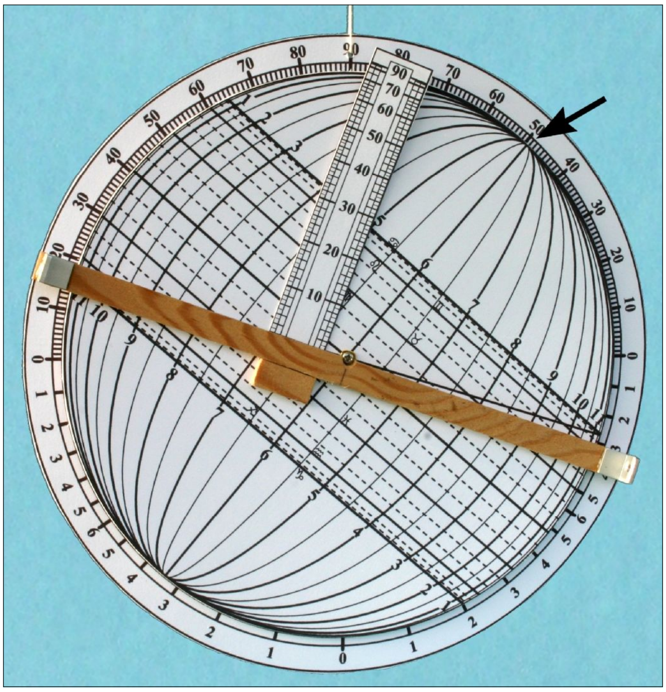
Reading the Horoscopium.
[At 52°N, Taurus 1° or Leo 30°, Equal hours are 8:35am or 3:25pm; Babylonian hours are 3½ or 10½; Italian hours are 13½ or 20½; Planetary hours are 2½ or 9½. Day length 14 hrs, Night length 10hrs; Sunrise 5am; Sunset 7pm.]

37 Organum Ptolemaei or De Rojas Dial

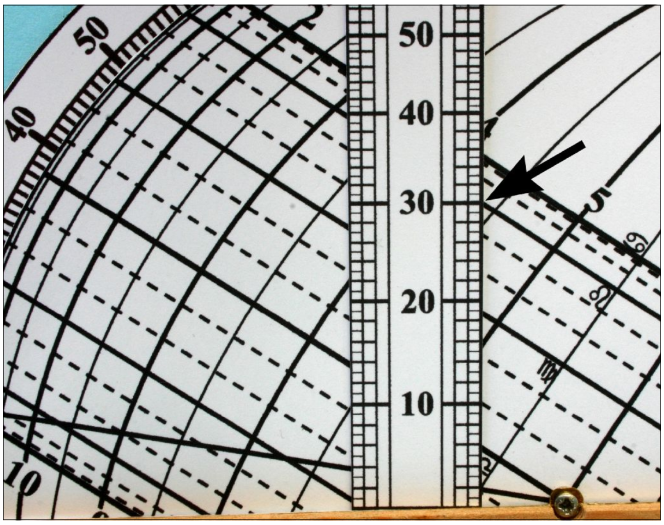
The Organum Ptolemaei was described by Regiomontanus in 1457. It was later described (again) by de Rojas in 1550 and is now frequently known as the de Rojas projection. It is essentially a projection from infinity of the part of the celestial sphere bounded by the solstitial circles onto the plane of the solstitial colure. This projection gives a fully universal dial, including the southern hemisphere. This Organum Ptolemaei is most frequently found on the reverse of quadrants and astrolabes.

English quadrant with Organum Ptolemaei on its reverse.

The projection is inscribed on a circular disc that is mounted on a backing plate. This plate has an altitude scale around the disc. In the centre of the disc is a regula with a cursor at right angles to it. In use, the line vertically through the projection (north pole) is set to the latitude, putting the equinox (or equator) line at the co-latitude. The regula (or alidade) is used to find the altitude of the Sun and is then returned to the horizontal at 0°. The reading taken is now



The Organum Ptolemaei, set to 50°.



Organum Ptolemaei.
[Solar altitude 30°, start of Gemini or Leo, 7:40am or 4:20pm.]

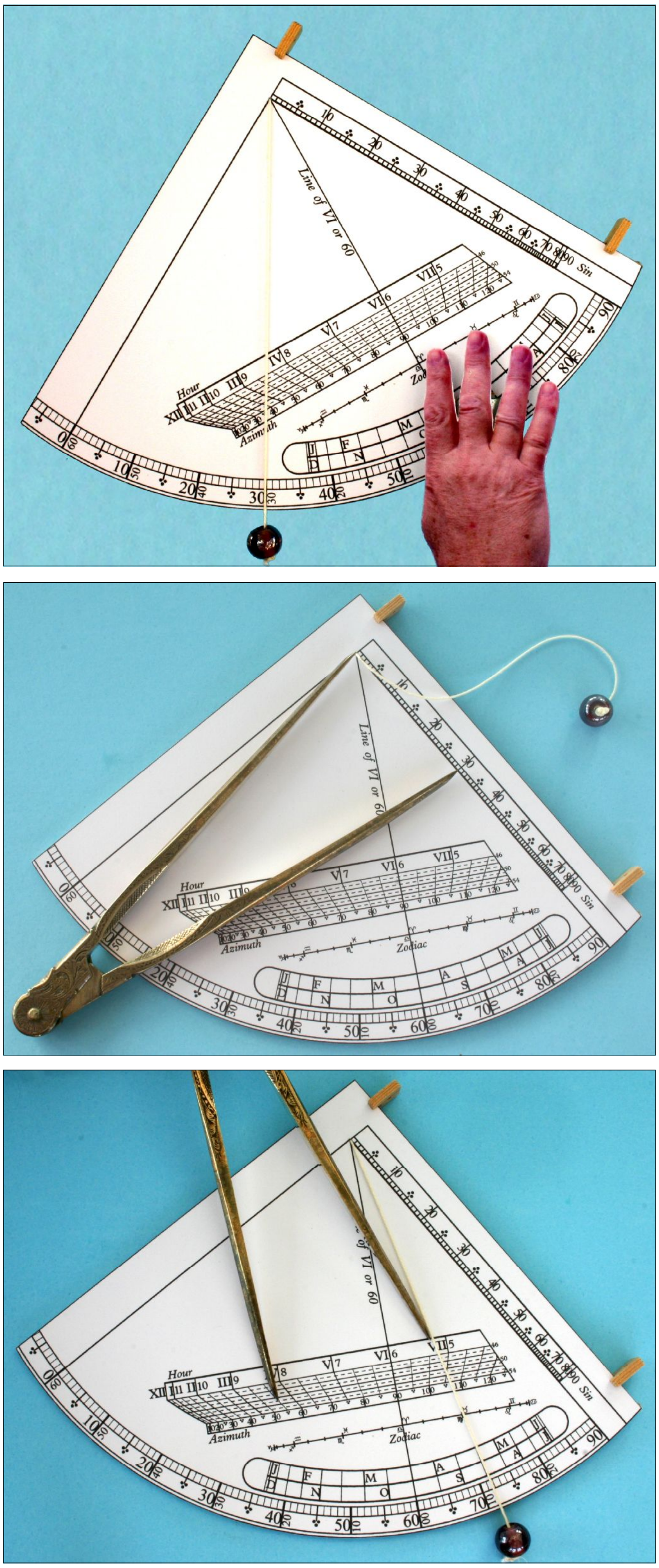
transferred to the rule, which is slid along the regula until this reading coincides with the current date line. Note that the same result may be achieved by drawing horizontal parallels across the dial, but this is then only valid for one latitude. An alternative way to achieve this may be obtained by stretching a cord from the degree scale to the same figure on the opposite side. The point at which the cord crosses the date line gives the time. The dial may also be used for determining the times of sunrise and sunset at any latitude. To do this, the centre line is again set to the latitude and the regula to horizontal. Where the regula crosses each of the date lines gives times of sunrise and sunset throughout the year. The projection may also have various stars placed upon it allowing the time to be found from these at night. The lower part of the disc has had a shadow square added, in this example divided into six parts.

38 Panorganon

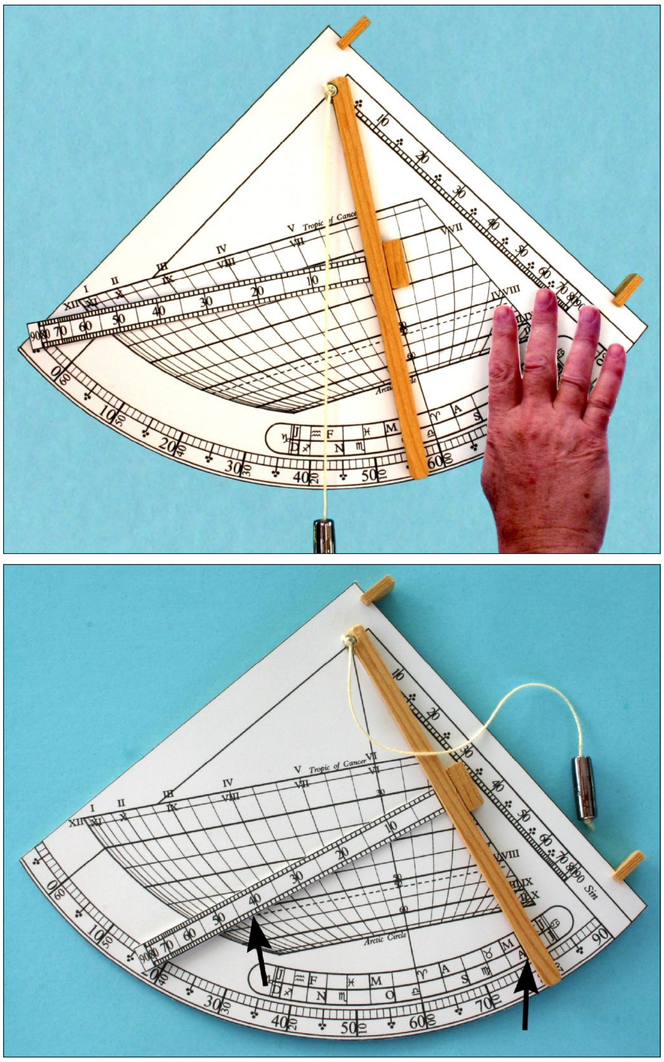
The Panorganon is a quadrant-like device that may be used over a small range of latitudes, generally from 46° to 54°. It was described by *William Leybourn* in 1672. It uses an orthographic projection of the celestial sphere similar to that used in the Organum Ptolemaei (or de Rojas projection). It is a little tricky to use which may account for its comparative rarity.

Firstly, the Sun is sighted and then its altitude is found on the outer scale from the position of the plumb line. A pair of dividers are then necessary to set the distance from the apex of the dial to the sine of the Sun's latitude on the right hand scale. The plumb line is then held taut over the current date and with the dividers the distance obtained from the sine scale is marked at right angles to correspond with the appropriate latitude line. This point gives both the time and the Sun's azimuth. It is quite difficult to set a perfect right angle by sight in this process and to get the necessary points to coincide. However, if a perfect right angle is not achieved the error caused will still be quite small.

In addition to the horary scales already described, there are several scales on the reverse showing star positions, right ascensions, sector scales and others, so it was quite a complex astronomical and surveying instrument. Examples are shown by *Higton* and *Webster*.

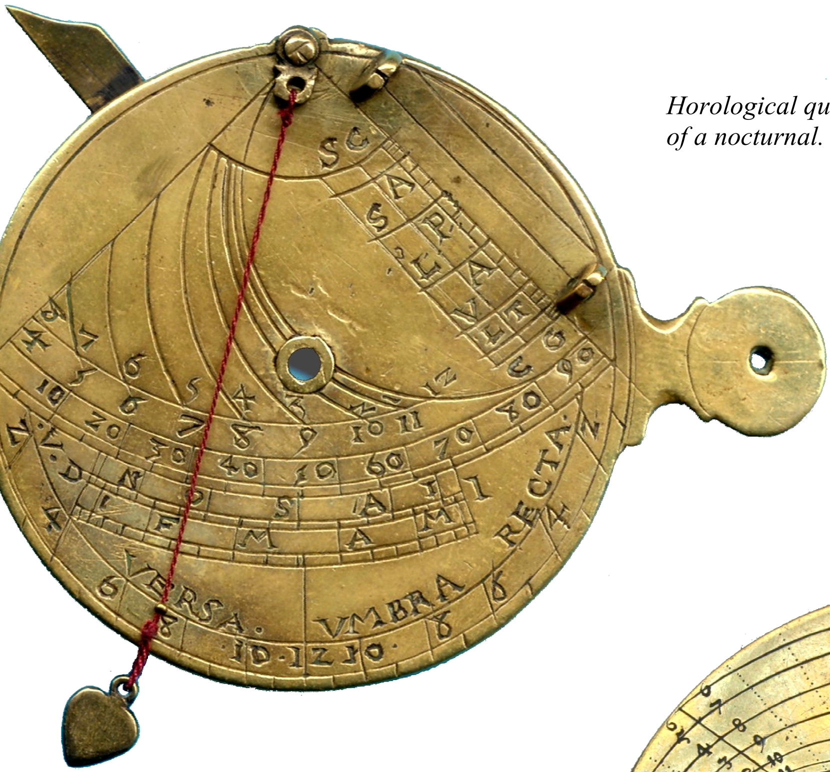


The Panorganon. Top: with a solar altitude of 30°. Centre: Set dividers to sin 30°. Bottom: Transfer sin 30° from plumb line set at April 20 or August 20 at right angles to the 52° latitude line to give 8:20am or 3:40pm.



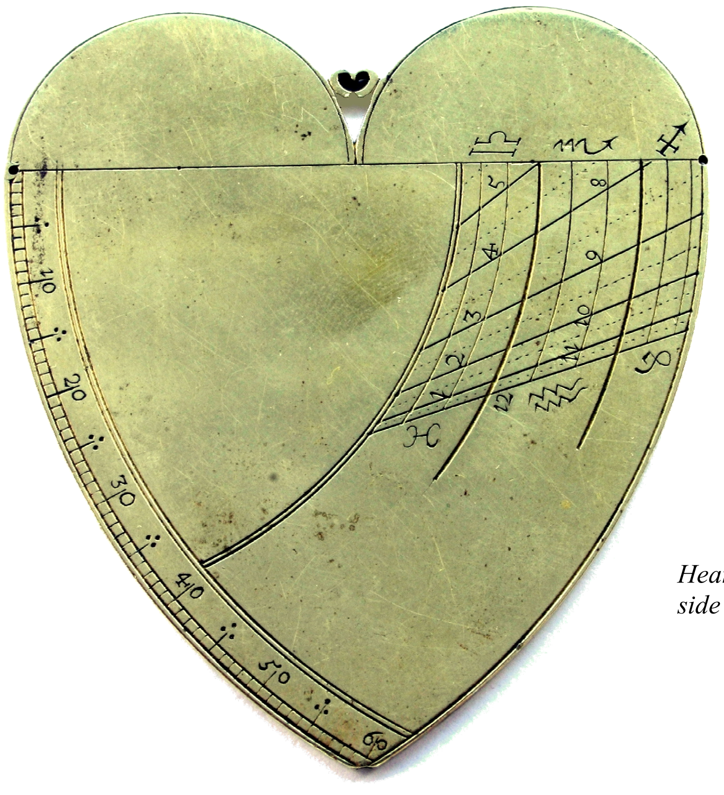
The Panorganon Plus. Top: solar altitude 42°. Bottom: May 10 or August 1, IX or III at latitude 52° N.

The dial would function much more sucessfully with a rigid cursor, hinged from the apex with a rule calibrated with sines (latitudes) set at 90° to it. There seems to be no evidence of such a cursor ever having been fitted on extant examples of this dial. Furthermore, there seems to be no good reason why the projection should not be expanded to cover a much wider latitude range, at least from the Tropic of Cancer to the Arctic Circle. A second model, called here a ‘Panorganon Plus’, has been constructed addressing these points making a much simpler to use instrument. The new instrument also shows more clearly its association with the former Organum Ptolemaei.



Horological quadrant (dial type 21) on the reverse of a nocturnal.

Circular plate dial (dial type 7). Augustinermuseum, Freiburg-im-Breizgau.



Heart quadrant (dial type 26) showing the winter side and altitude scale.

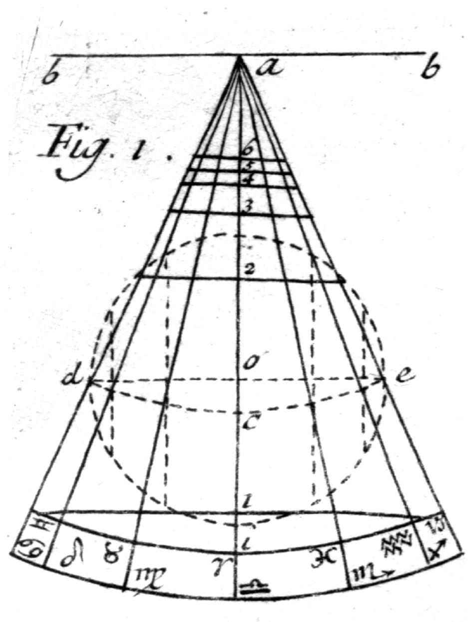
HOW THESE MODELS WERE CONSTRUCTED

I decided to use my PC to produce these replica dials and had available a general drawing package from Greenstreet (GST) called ‘Draw 3’. This may not be the ideal program but it served my purpose. With this I made most of my models to fit comfortably onto an A4 sheet. This has made many of them much larger than the original instruments but, if necessary, they may be scaled down to a more compact size. For the moment, the larger size suited my requirements for accuracy determination.

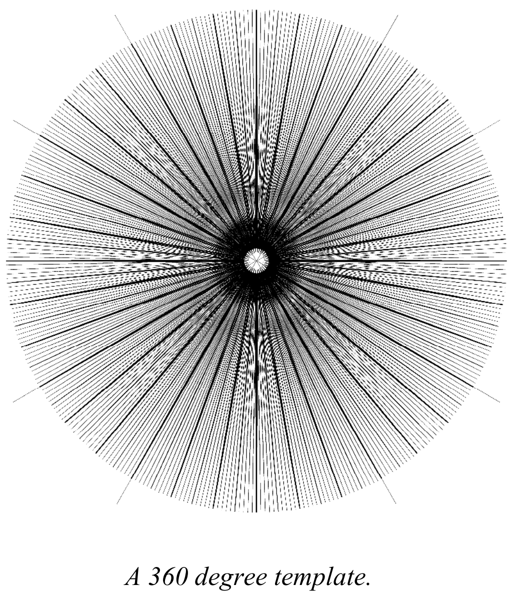
Although I used a PC for this purpose, the techniques used will also apply to a conventionally drawn dial. Instead of my templates, just substitute a protractor, but as an aid to multiple dial construction, the use of templates, perhaps drawn on card, should be considered.

I have also given some remarks about general construction techniques and the problems I found when making these models. Many of these details will be obvious to most experienced dialmakers and modelmakers.

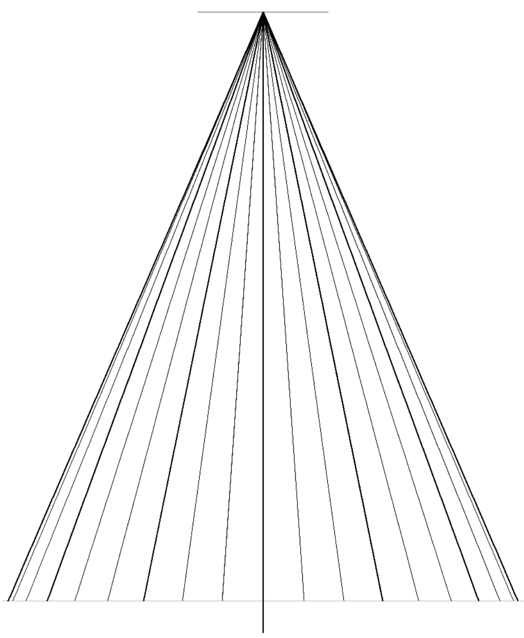
The models were drawn graphically using ‘templates’ for both angles and declinations. The two most important templates were a 360° star and a ±23.5° declination diagram, or ‘trigon’, sub-divided for each 10° of zodiac. The trigon was constructed following the instructions given by *Bion* in 1758. He draws the line *bb* with a perpendicular from *a*. From *a* he draws two lines diverging by 23.5° from the vertical. With centre *o* (at any convenient position) he draws a circle to touch the two angular lines at *d* and *e*, then divides the circle into 12 points. These points are then projected vertically (dotted lines) onto the curve *dce* with its centre at *a*. He then draws radial lines through each of



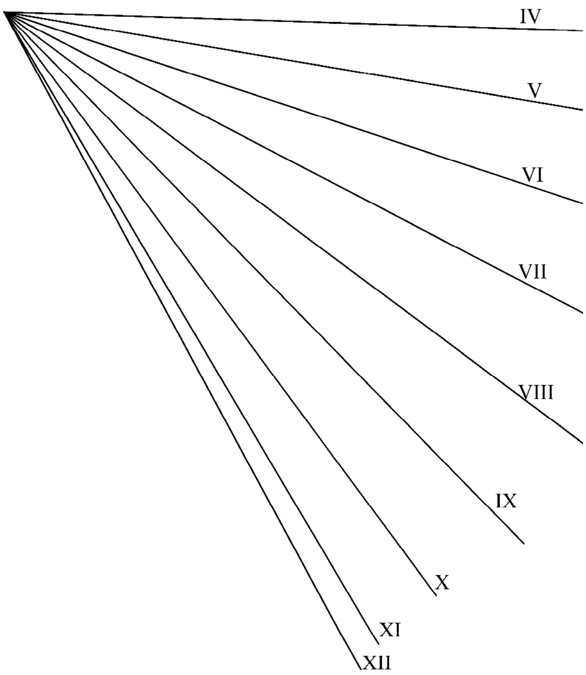
A trigon as illustrated by Bion in 1758.



A 360 degree template.



A trigon for ±23.5° sub-divided into 30° and 10° zodiac intervals.



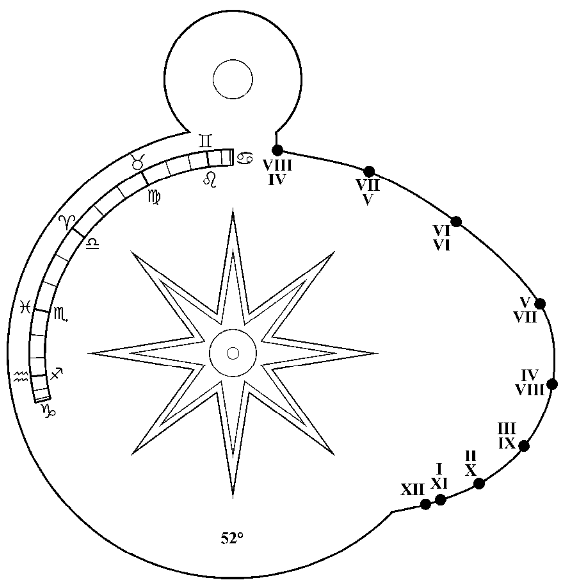
Template for the Sun's rays for each hour at the summer solstice (Cancer). Similar templates were made for each zodiac sign, each hour in a different colour to avoid confusion.

these points on the curve *dce* to the trigon scale, adding the appropriate zodiac sigils. In my case I have added lines for every 10° of zodiac by dividing my circle into 36 points. The templates so produced were moved and rotated as necessary for each dial that was constructed. Furthermore, the 360° star was used directly where a scale of degrees was necessary, such as around the edge of the quadrants. With these two templates and the tables for the Sun's altitude (see page 1) it was possible to make most of the dials in this study. As a further aid to making several dials to the same latitude figures, each zodiac sign was plotted individually with hour lines in fixed colours so that each of the seven plots could simply be superimposed as required. When these were assembled it was relatively easy to see immediately if the dial design was viable. For existing designs it was possible, in certain cases, to see the magnitude of any errors. In particular, some of the simple disc dials can have errors up to one hour at various times of the year.

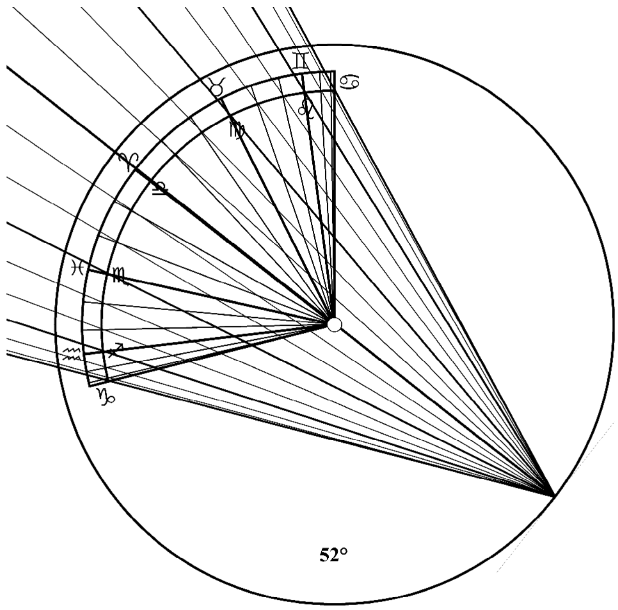
Design of a Typical Dial

The design of each dial was a challenge and usually needed a slightly different technique to those that had gone before. To illustrate the process of designing a dial, an example is given for the 'fence disc dial'.

The process usually began with a photograph of the dial (but not in this case). The photograph would be placed on the drawing page at a convenient size and the basic pattern of the new dial was constructed over it, the photograph then being removed to avoid unnecessary clutter. The outer diameter was drawn. The trigon was applied to the diagram

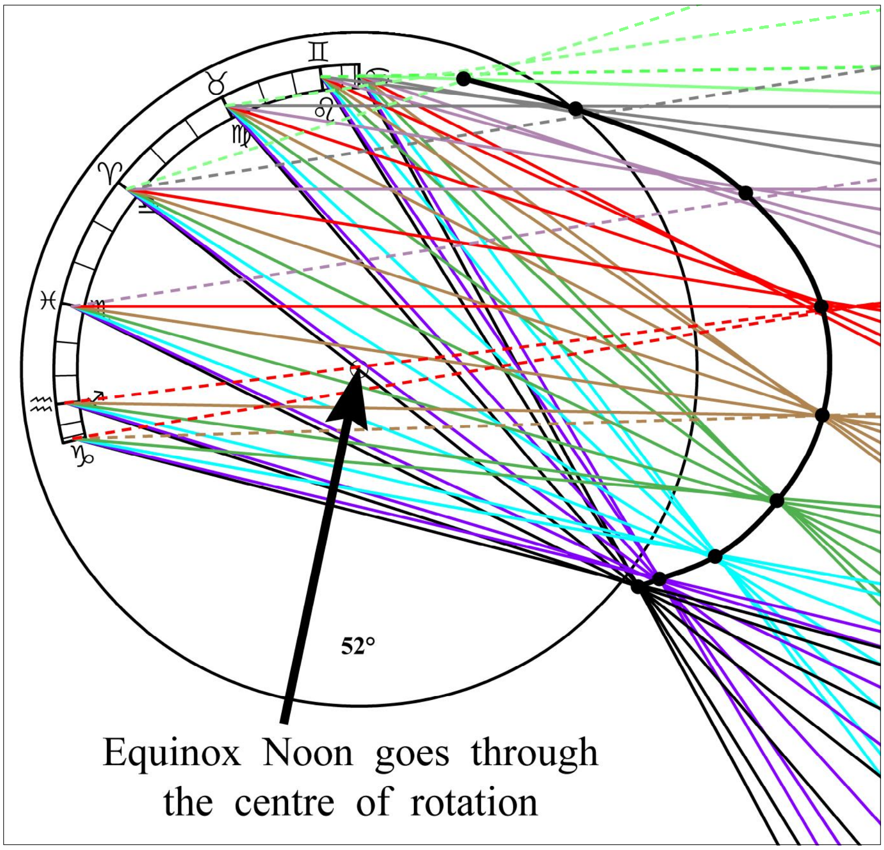


The completed layout for the 'Fence disc dial'.



The first stage of construction.

being rotated to the co-latitude, in my case 90° - 52° = 38°. The central (equinox) line was made to pass through the centre of the disc, essential to get correct convergence of the hour lines. The origin of the trigon could be placed anywhere but in this example it has been placed on the outer diameter of my circle. The gnomon must move between the two extremities, ±23.5° either side of the centre line. This can be at the edge of the disc or, as in my example, protruding through a slot in the disc. The next process is to draw the declination scale with lines going back to the pivot point for the gnomon arm (centre of the disc). The zodiac sigils are then added to the scale. Months too could be added if required and if space permits. The lines inside the zodiac arc radiating from the centre do not need to be shown and were later erased.



Line convergence points are marked with dots and a smooth hour line curve is drawn through these on the right.

The templates for each of the zodiac signs are then added to the diagram, originating at the exact centre of the pin gnomon. If correctly constructed, these should converge in an arc but one that does not lie on the circumference of the disc. For this reason many of the simpler disc and poke dials, both round, have been found to be somewhat inaccurate. However, the noon lines should always merge perfectly together at the point chosen for the apex of the trigon. The equinox line should always pass through the centre of the disc. If not, there will be an offset due to asymmetry and the other lines will not converge accurately. Note that the lines showing the Sun below the horizon, here dotted, are sometimes useful in marking the convergence points. Errors seem to increase away from noon and may be attributed to slight errors in drawing the angles of the shadow lines.

Each of the convergence points are then marked with a dot and a curved line is drawn through these. This marks the convergence points for the shadow at any time or date throughout the year. This line now becomes the outer edge of the dial and it may be marked with hour numerals. It is also along this edge that the 'fence' is placed. The reason for the fence is that the shadow is seen much clearer when it falls at right angles rather than being allowed to streak across the dial face at a low angle.

Once the outline is completed the dial may be printed onto a card or onto paper if it is to be used as a template for making a metal dial.

In my case, I constructed most of my dials on white card, usually 200 gsm, and the following notes may be found useful.

As the card is too thin to be used on its own it was necessary to stick this onto a thicker base. I tried plywood, MDF and finally chose a thick card about 2.5 mm thick. In the first instance I pasted the back of my prints with PVA glue and stuck them to the backing card. When the glue had dried, the card was heavily warped and not suitable for use as a dial. I then stuck the prints to the backing card using strips of double-sided adhesive tape. Luckily, this is available in quite wide reels and I chose 50 mm width, thereby reducing the number of strips required to between two and four.

After applying the strips to the back of the print I cut out the dial shape with scissors leaving a border of 5 - 10 mm. I used this as a template to mark the backing card, cutting this to a similar size with heavy scissors and sometimes metal shears. The pattern was then stuck on the card. With sharp scissors it was possible to crop away the outside border, if necessary by first reducing it to about 2 mm. This helped the final cutting process. Difficult parts of the profile were cut out with a sharp craft knife. This knife was also used for cutting straight edges on some of the other dials. The fence was then added in thick card cut to between 5 mm and 10 mm wide stuck onto the edge of the main dial plate with PVA adhesive.

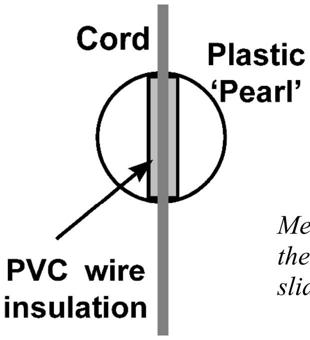
For the rotatable volvelles used on some dials, I mounted these on thinner card, 300 gsm, as the greater thickness would have been rather too much for accurate use.

The fence disk dial then required a curved slot to be cut out to allow the gnomon to poke through. This was a difficult job but I did it using a circle cutter in conjunction with my craft knife. The central and the suspension holes were drilled and the ragged edges formed were trimmed with a round needle file. The gnomon used was a cocktail stick, mounted on a thin wooden arm pivoted at the centre from the back. Various thin strips of wood are available at model shops and I found the 10 × 3 mm or 12 × 3 mm section the most useful for many of my dials.

The dial was now ready for testing but when suspended it did not hang vertically due to the large protrusion on the right hand side and the weight of the added fence scale. The dial was simply out of balance. There were two ways of fixing this, a re-design with more material on the left or to add some weight to the left side. The latter was the simpler solution. The final balance was checked by hanging a plumb line from the top suspension loop.

Plumb Lines

Other construction techniques were necessary to complete this wide range of altitude dials. The plumb lines use a thin cord, but not too stiff. I used white cord and a white bead, ideal for a wooden or metal dial but when used with white card the contrast between them was poor. A dark cord would have been better in these cases.



Method of fitting the bead to the plumb line to ensure a sliding friction fit.

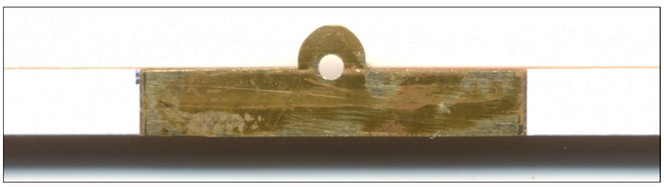
The sliding bead posed a problem as it needed to be a good fit holding its place by friction. I obtained some small 'pearl' beads moulded in plastic (bone was the material originally used) from a craft shop but the holes were too large for direct use. Therefore I found some PVC electrical wire that I could expand slightly over a tapered pin to fit onto my cord (with the cord end first dipped in paper glue to stiffen it for easier threading). I then reamed out the holes in the beads to be a tight fit over the outside of the PVC, the whole being assembled with the PVC sleeving in place first. This gave the friction fit that I required. The plummet, as its name implies, should be made from lead but I chose some glass beads from a craft shop, available in various spherical and elliptical shapes. Although much lighter than lead they were heavy enough if the cord chosen was sufficiently flexible.

Other Techniques Used

The poke dial was assembled around the parallel part of the body of a plastic bottle, so was originally designed for this diameter. With the top part of the bottle cut off, the finished dial could simply be slid off retaining its circular shape.

Various formers and bases were turned on a small lathe, particularly those for the pillar and chalice dials. The main body of the pillar dial was made from a short length of plastic drainpipe.

Alidades and many supports were made with stripwood. In certain cases, alidades needed to be offset so that one edge lay exactly through the centre pivot. This was done by epoxy gluing a thin piece of shim brass to the back with the pivot hole offset. To avoid having to recess the shim brass into the alidade, strips of card were stuck on the back either side of the brass, also helping to avoid dial surface abrasion.



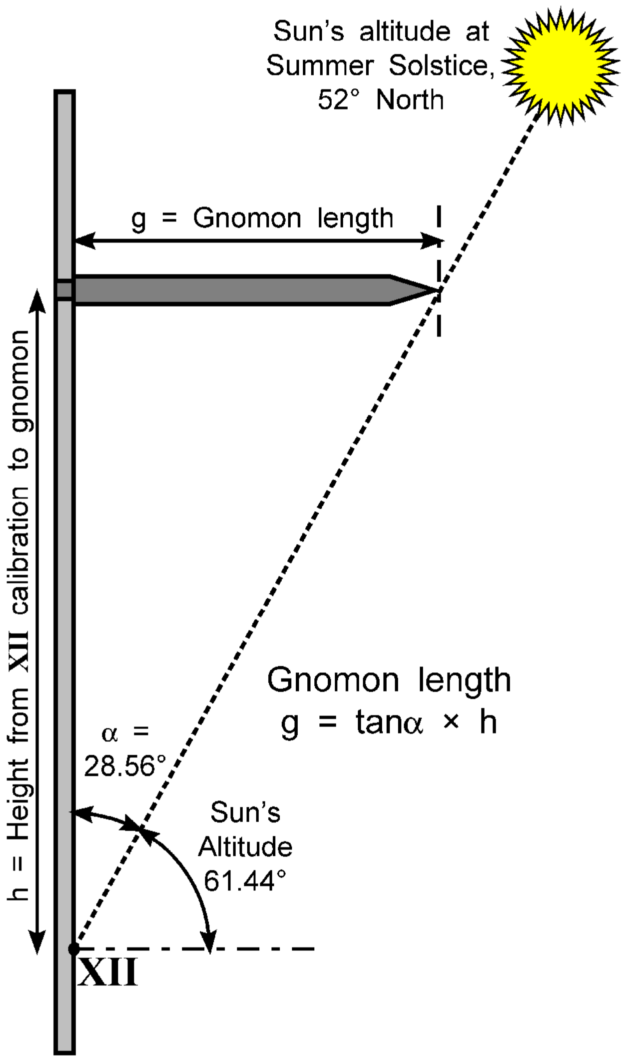
The back of an alidade with offset pivot made from brass shim. The arms were backed with card.

All moving parts were fitted with small screws, usually M2 or M2.5, their nuts being locked with a small spot of glue once the correct tightness had been determined.

The cord suspension slider on the mast of the navicula was also formed from brass shim being suitably bent to form a good friction fit.

Gnomon Lengths and Forms

For those dials that use the shadow of the tip of the gnomon to show the time, it is important to get the gnomon exactly the right length and to get it perpendicular to the dial plate. Its length is shown on most of the dial layouts but when the dial is printed, perhaps at a different scale to the original, it may be wise to check the finished dial before making its gnomon.



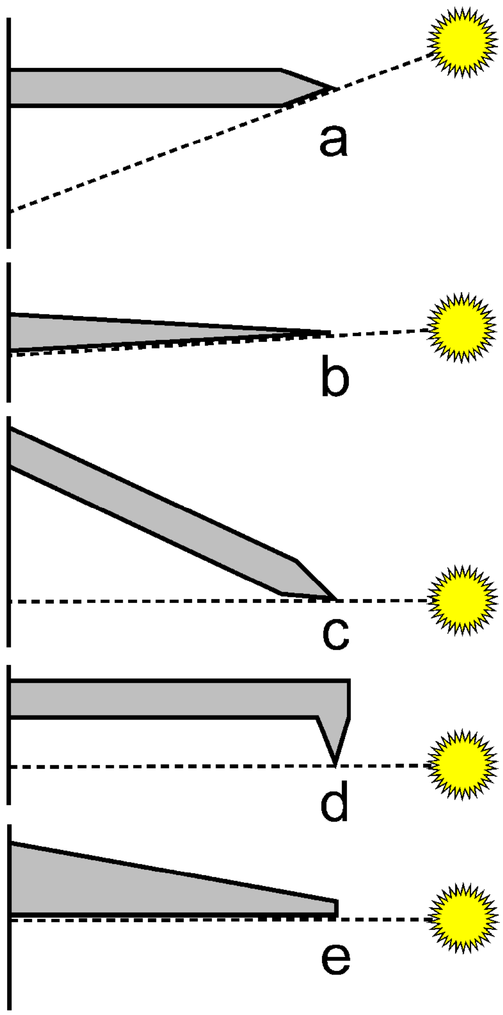
Determining gnomon lengths.

Take the length of the vertical from the gnomon centre to the XII calibration, preferably at the summer solstice for best sensitivity on a vertical dial, and multiply that by the tangent of the Sun's angle with the vertical plane to get the gnomon length. For Cambridge, the maximum angle of the Sun is 61.44° making $\alpha = 90° - 61.44° = 28.56°$.

The gnomon length is therefore 0.5443× the height between the XII and the gnomon.

The gnomon needs to fit tightly into the dial plate extending by the calculated amount. To achieve this, the portion that was pushed into the dial plate was turned down on a lathe to form a positive shoulder, leaving the extending part the correct length.

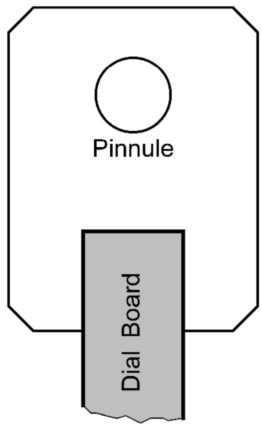
The diagram of gnomon shapes also stresses the importance of having a fully tapered gnomon. Types **a** to **d** are peg gnomons of round section, made from meat or kebab skewers about 3.5 mm diameter, and **e** is a blade gnomon of rectangular section. The best gnomons for use are those drooping downwards or at least with a horizontal lower edge. A blunt taper like that shown in **a** will limit the gnomon's effectiveness to Sun angles less than the taper of the tip. That in **d** could interfere with high Sun angles unless properly executed. The blade gnomon **e** is probably one of the best to use but is not always convenient to fit or to make removable. If fitted into the centre of a circular plate dial it will require some method of keeping it upright when the dial plate is rotated. In practice, most gnomons found on antique dials will be similar to types **a**, **b** or **e**. For dials that do not use the tip to indicate the time, the best are pin gnomons of minimal thickness, around 1 mm, and of a length approaching the semi-diameter of the dial. Suggested materials are cocktail sticks, a straightened paper clip or a dressmaking pin.



Gnomon shapes:
a severely limits readings with low solar altitudes.
b much better with minimal limiting
c avoids limiting with low solar altitudes
d like c but could cause limiting at high solar altitudes
e blade gnomon with underside horizontal.

All gnomons should ideally fold flat or be removable for storage and transit. If removable, a storage hole or clip on the main dial plate is recommended. Plummets on old quadrants were nearly always fitted into a hole drilled in the edge, there generally being sufficient thickness for this.

Construction of sights.



Sighting Vanes

Sights may be constructed in several ways. Originally they were in brass and had a pin on their lower side to fit into a hole drilled into the edge of the dial. Some also fitted into the dial face near to the edge, again with a pin inserted into a hole. With the thinner dials constructed in cardboard (or metal), an alternative is shown, the sight being glued (or soldered) into position. The pinnules should be of small size, especially if to be used for sighting stars etc., but I found that 1mm should be considered minimum and about 2mm was ideal for most applications. Also, the sights show the rays of light from the Sun through the upper sight onto the lower much more clearly if painted white.

I generally used 10 mm × 3 mm wood strip, although not ideal because the hard fibres of the wood grain tended to pull the smaller drills to one side. Plastic strip would help to overcome this problem. The sights were prepared in pairs, with an M2 screw to hold them together, then were shaped with a fine file to make them identical. Any roughness around the hole was removed with a needle file. Each pair were marked to identify them and to allow me to assemble them both the same way round.

TO CONCLUDE

This study of altitude dials has taken me a great deal of time, perhaps three months of almost continuous work. It has been very interesting and I have learned a lot about these dials, and also how to draw them on my computer. Now that it has been concluded, unless a few more new examples come to my attention, I feel that I should come out with recommendations for the best models; a sort of 'consumer's report'.

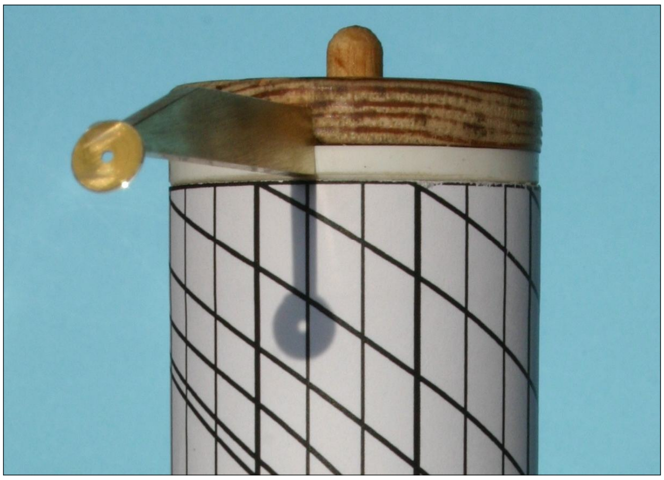
I immediately have two models that are my own favourites, and the reader will probably also have formed similar opinions, but perhaps not of the same two dials.

I will start with the simplest dial, which has to be the pillar or shepherd's dial. It is so simple to use and is as accurate as most. It will allow the gnomon to be set unambiguously at the current date. It will stand on a solid surface, keeping it stable, and may be rotated so that its gnomon shadow is perfectly vertical. Its time can be read from a series of gently sloping lines. Furthermore, it may also be suspended from its top cap, so may be used directly from the pocket without too much preparation. Being cylindrical, its scale length is three times more than a flat plate of similar dimensions and is therefore less prone to wind disturbance. When not in use, the gnomon may be safely hinged down so that it fits inside the cylindrical body. It is simple, cheap to produce and very effective. Its main drawback is that it can only be used at one latitude.

To overcome the single latitude problem, I have made my second choice a universal dial. This has to be the Regiomontanus dial. Perhaps it is not such a clear choice as the pillar dial, but I would prefer to use this dial rather than the others in the study. All that it lacks is a shadow square, a most useful instrument that I am particularly fond of, but that could be added around two of its sides instead of, or as well as, the quadrant scale that is often included. I have used the Regiomontanus dial in Africa where it reliably told me the correct time. It is a little more complex to set up, but once set for the latitude and date it may be used very simply giving the time quite accurately. It also gives me the times of sunrise and sunset for any locality. It is not intended for use in the southern hemisphere, but could even be used there by reversing the date settings, winter for summer, but perhaps this is a little complicated for most users. Furthermore, it will not function north of the Arctic Circle, but these small limitations do not deter me, and most dials in the study also have similar limitations. My main problem with this dial, and of any with sights, is that it is often quite tricky to get initial alignment of the two sights, but this may be helped by the addition of a small 'screen' behind them. It is not quite so portable as the pillar dial and to prevent the line, plummet, bead, brachiolus and even the sights from being damaged or tangled in the pocket or in transit, it would need a good leather carrying case.

Other dials that I have looked at in this study hardly come close to these two, but to be fair, some of these, like the quadrants, have other functions in addition to time telling, in fact the ability to tell the time is often a secondary function.

I would also like to improve some of the dials in subtle ways, as I have done with the 'panorganon plus'. Most are sufficiently accurate to warrant a correction from the Equation of Time. This would need to be available to the user; on some it could be pasted on the back. Another point is that most of the dials use the zodiac for a calendar and would benefit from a civil calendar to zodiac convertor. This too could be pasted on the back of some dials. A form like that shown on page 44 or page 3 would be ideal in many applications.

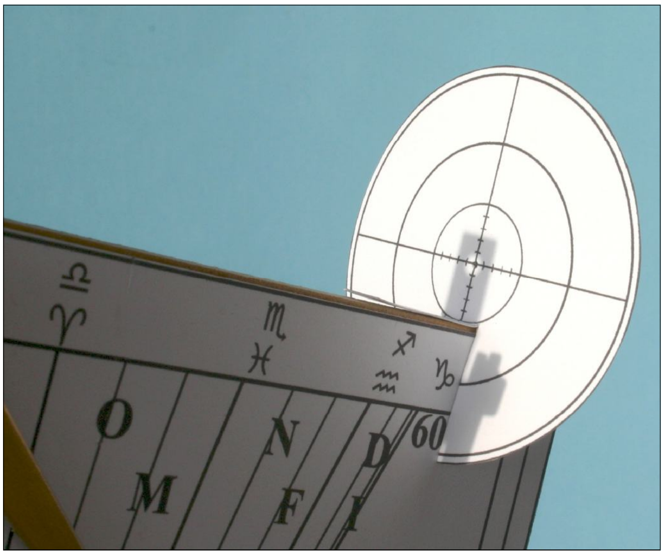


A pillar dial with modified gnomon.

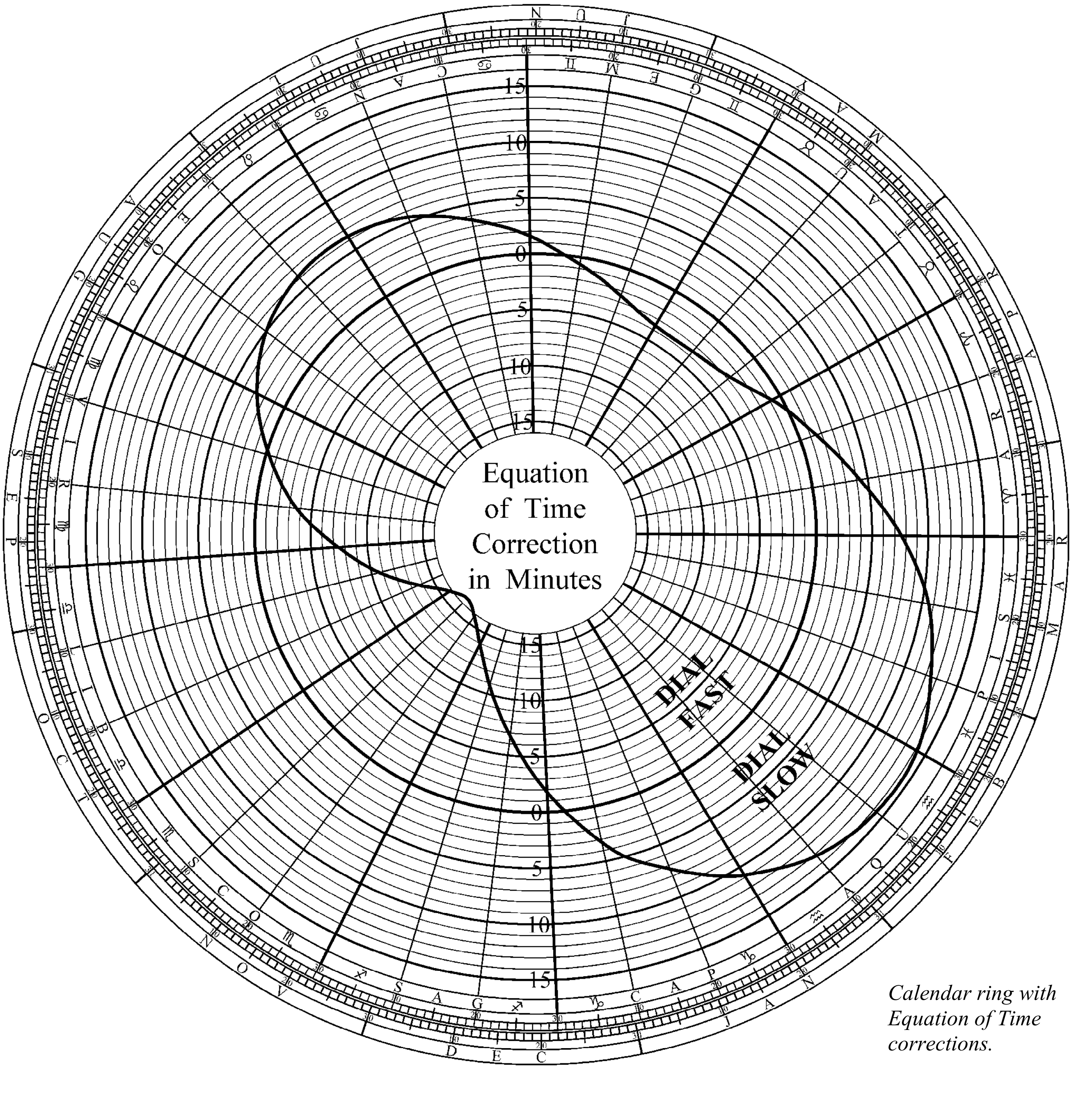
Further improvements would include ways of shadow sharpening. Dials like the pillar dial still have a fuzzy end to the shadow giving around half a degree of indecision. This is most significant, especially around noon when there is little change in solar altitudes. A simple fix would be to fit a small pierced disc (or aperture) at the end of the gnomon, because it is much easier to bisect by eye a thin shadow or a spot of light. This has been done with the dial illustrated above. The disc set at the end of the gnomon has a 1 mm diameter hole. It provides a fine spot of light that is easy to see and determine its exact position.

For the Regiomontanus dial, instead of the screen suggested earlier, I have fabricated a removable and enlarged sight to fit over the back sight. It is large enough in diameter to pick up the shadow of the fore sight, even when poorly aligned. On its face are a series of calibrations, the inner ones representing a alignment errors in 1° steps and the outer ones (rings) in 5° steps (assuming that the distance between sights is 10 cm). In the very centre of this new sight I have placed a pinhole of about 1 mm diameter so that the instrument may still be used for direct sighting of the Sun.

My studies into these dials have given me a great respect for them and I think that, for a portable dial, I would rather use an altitude dial than a directional dial, in spite of its lack of accuracy around noon.



Enlarged sight on a Regiomontanus dial.



Calendar ring with Equation of Time corrections.

REFERENCES

Apian, Peter: *Instrument Buch*, Ingoldstadt, 1535.

Bion, Nicolaus - Ed. Stone: *The Construction and Principal Uses of Mathematical Instruments,* Richardson, London 1758.

Fale, Thomas: *The Art of Dialling,* 1652.

Hagen, Marinus: *Zon & Tijd*, Zonnewijzerkring, 1998. (In Dutch).

Higton, Hester: *Sundials at Greenwich*, Oxford University Press, 2002.

Lansberg, Phillip: *Dan't Gebruyck des Astronomischen ende Geometrischen Quadrants*, 1633.

Leofric: *Missal,* (10th century).

Leybourn, William: *Panorganon: A Universall Instrument*, London, 1672.

Lowne, Michael: 'The Design and Characteristics of the Double-Horizontal Sundial', *Bull BSS,* 13(iv), 138-146 (2001).

Mills, Allan: 'The Canterbury Pendant: A Saxon Seasonal-Hour Dial', *Bull.BSS,* **95.2**, 39-44 (1995).

Schedel, Hartmann: *Nuremberg Chronicle (Liber Chronicarum)*, Nuremberg, 1493

Stöffler: *Elucidatio fabricœ ususque astrolabii*, 1524.

Turner, Anthony: 'William Oughtred, Richard Delmain and the Horizontal Instrument in Seventeenth Century England'. *Of Time and Measurement*, Variorum 1993.

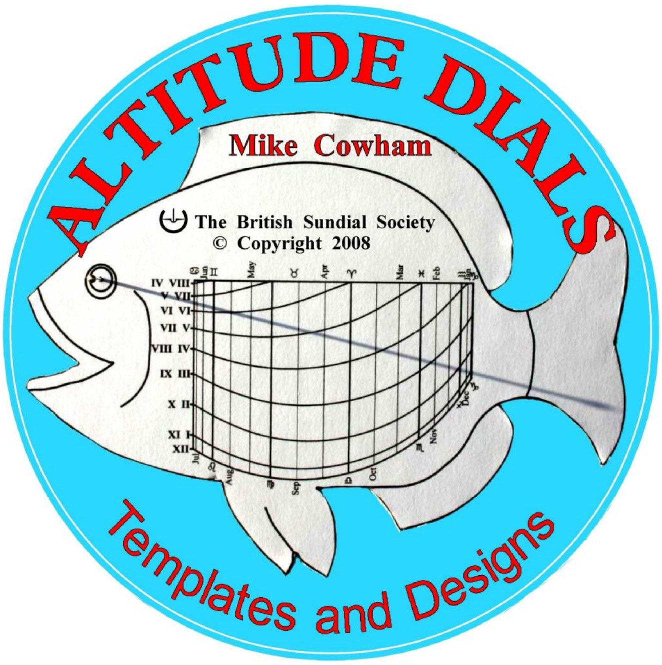
Wagner, Gerhard and Fowler, Ian: *Uhren aus vier Jahrhunderten - Sammlung Ehrensberge*, Augustinermuseum, Freiburg, c.2006.

Waugh, Albert: *Sundials Their Theory and Construction*, Dover, New York, 1973.

Webster, Roderick & Marjorie: *Western Astrolabes*, Adler Planetarium, Chicago, 1998.

Zinner, Ernst: *Astronomische Instrumente*, Beck'sche Verlagsbuchhandlung, München, 1972.

ALTITUDE DIAL DESIGNS AND PATTERNS ON CD-ROM



The ‘Templates and Designs’ CD-ROM supplied inside the back cover may be used to fabricate the altitude dials illustrated in this publication.

It is supplied with useful templates and each dial design shown may be printed directly from the CD. The primary files are in TIFF format (LZW compressed) at a resolution of about 600dpi for an A4 size dial. These are recommended for the best results. For those who may not be able to use these TIFF files, copies are also available as JPEG files with just a small amount of compression applied.

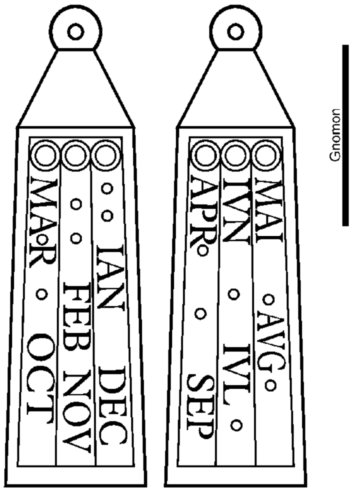
The general file structure is as shown in the diagram and small scale images of each file are printed in the following pages. Note that most dials and templates are made for a latitude of 52° north. These will only work satisfactorily at latitudes between perhaps 50° and 54°. However, details given in the text of this book should enable the reader to make versions to suit any other latitudes.

Copyright

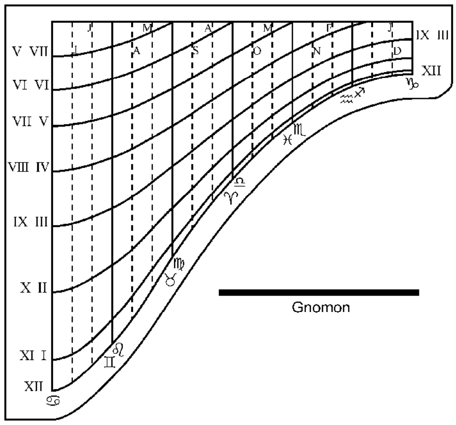
Dials to the designs on the CD may be made freely by the original purchaser of this book but they must not be given, lent or otherwise distributed without the express permission of the Author. Furthermore, any dials made from this CD should not be sold commercially.

- JPEG FILES
    - DIAL LAYOUTS
        - Single Latitude Dials
        - Universal Dials
    - MISCELLANEOUS
    - TEMPLATES
- TIFF FILES
    - DIAL LAYOUTS
        - Single Latitude Dials
        - Universal Dials
    - MISCELLANEOUS
    - TEMPLATES

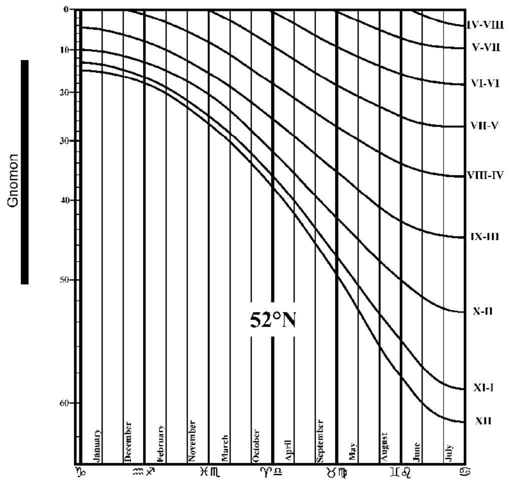
INDEX TO CD IMAGES



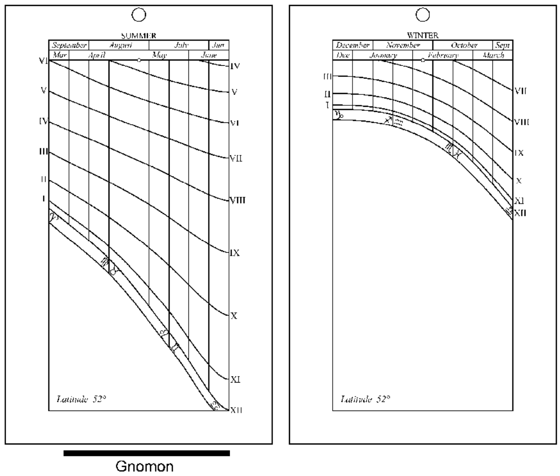
1- Anglo-Saxon Pendant.tif



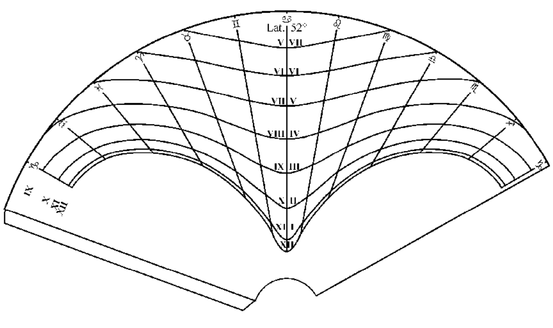
2 - Signpost Dial.tif



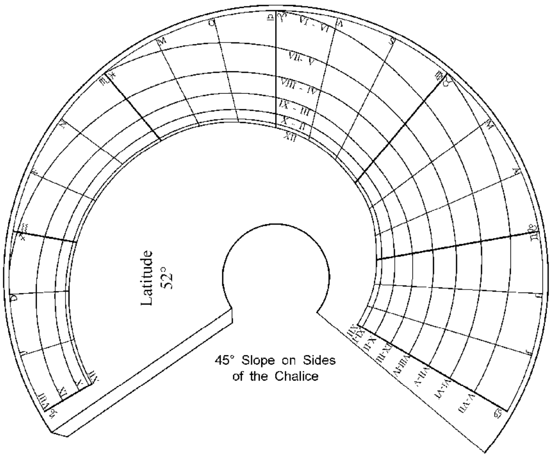
3 - Pillar Dial.tif



4 - Tablet Dial.tif

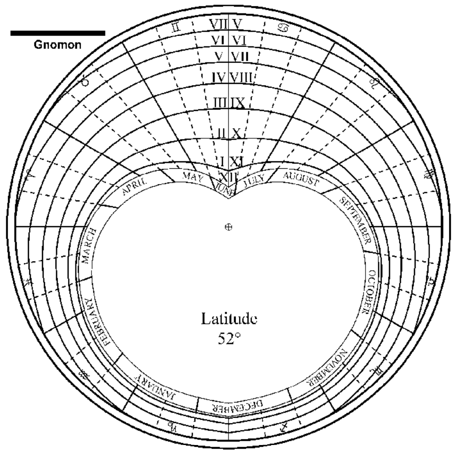


5 - Chalice Dial 1.tif

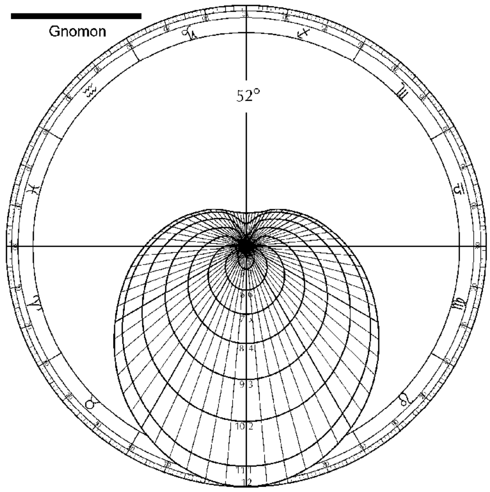


6 - Chalice Dial 2.tif

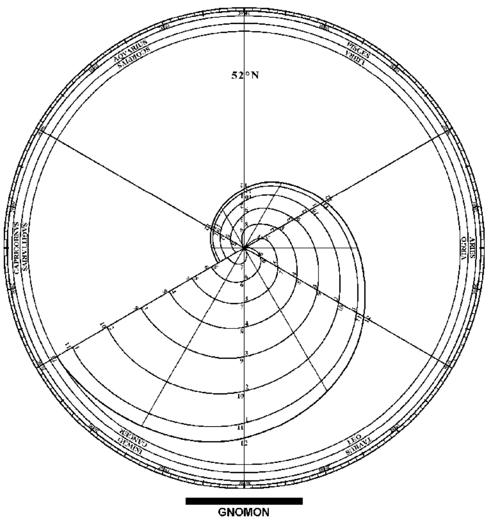
SINGLE LATITUDE ALTITUDE DIALS 1 - 6



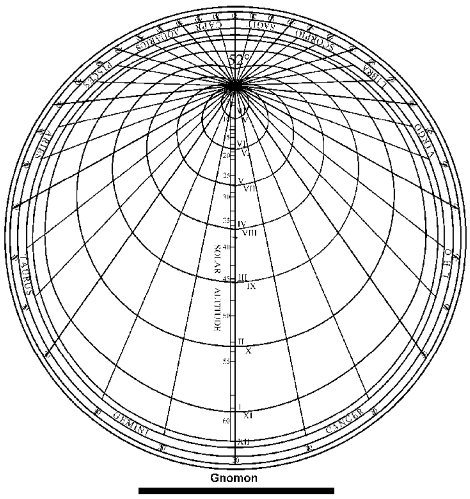
7 - Circular Plate Dial 1.tif



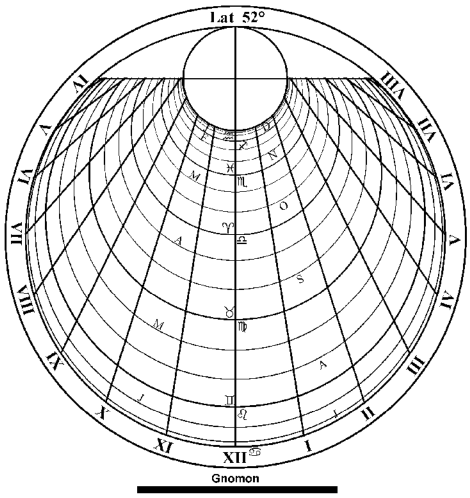
8 - Circular Plate Dial 2a .tif



8 - Circular Plate Dial 2b.tif

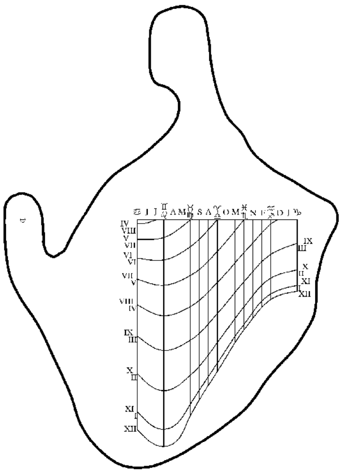


9 - Circular Plate Dial 3.tif

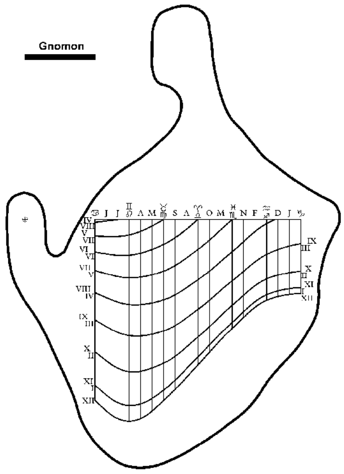


10 - Circular Plate Dial 4.tif

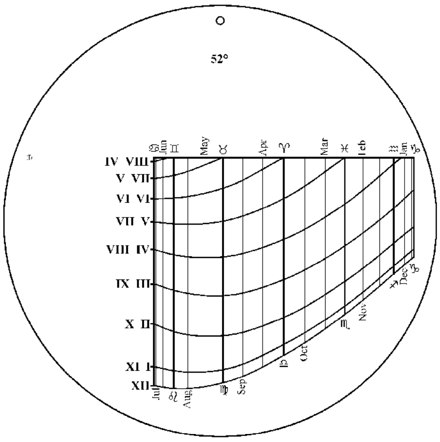
SINGLE LATITUDE ALTITUDE DIALS 7 - 10



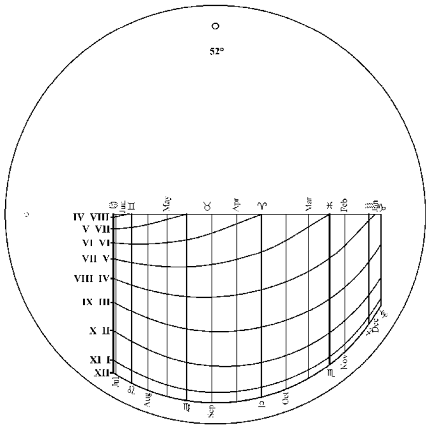
11 - Ham Dial a.tif



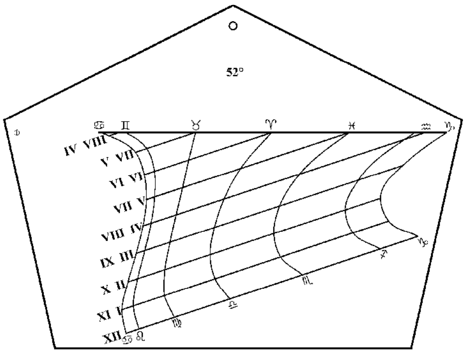
11 - Ham Dial b.tif



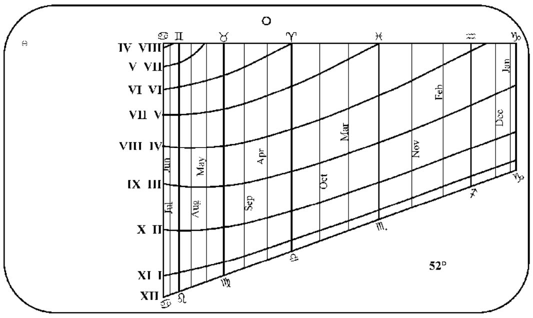
11 - Ham Dial c.tif



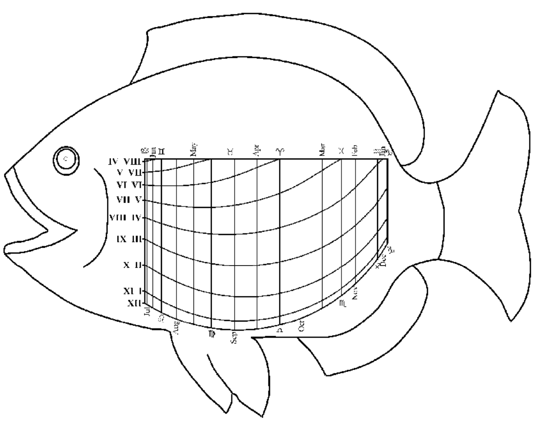
11 - Ham Dial d.tif



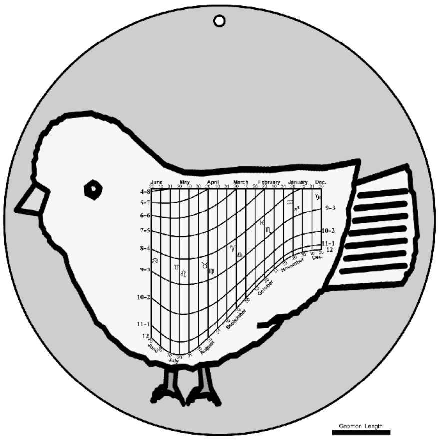
11 - Ham Dial e.tif



11 - Ham Dial f.tif

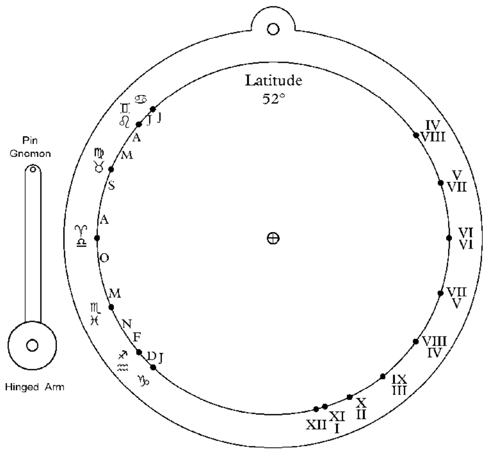


11 - Ham Dial g.tif

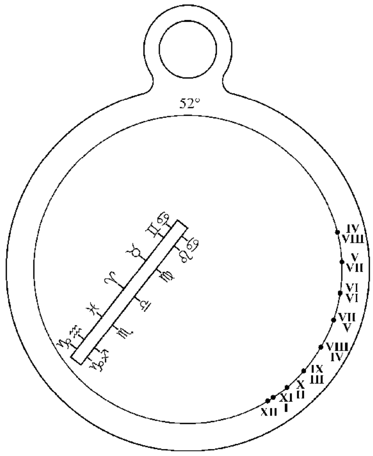


11 - Ham Dial h.tif

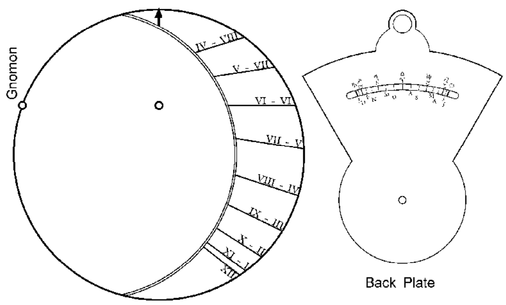
SINGLE LATITUDE ALTITUDE DIALS 11a - 11h



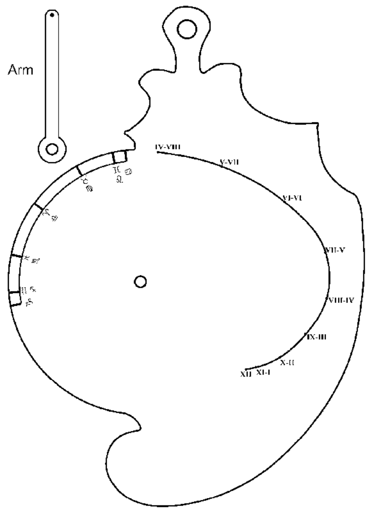
12 - Vertical Disc Dial 1.tif



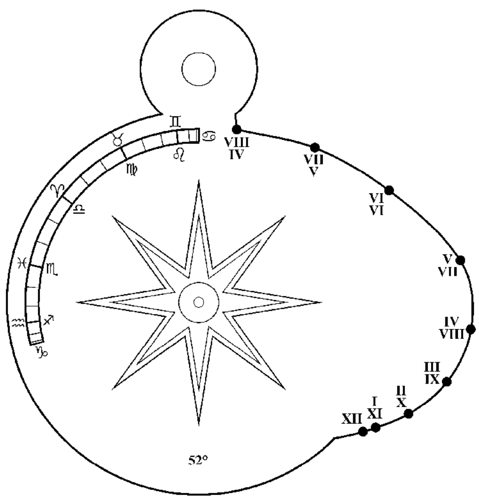
13 - Vertical Disc Dial 2.tif



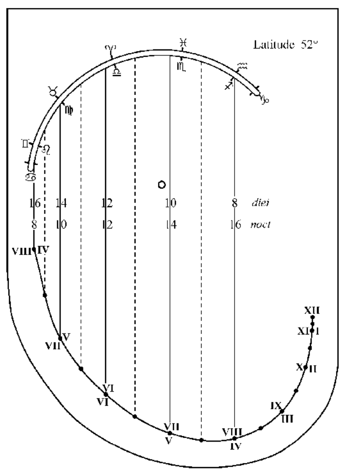
14 - Vertical Disc Dial 3.tif



15 - Vertical Disc Dial 4.tif

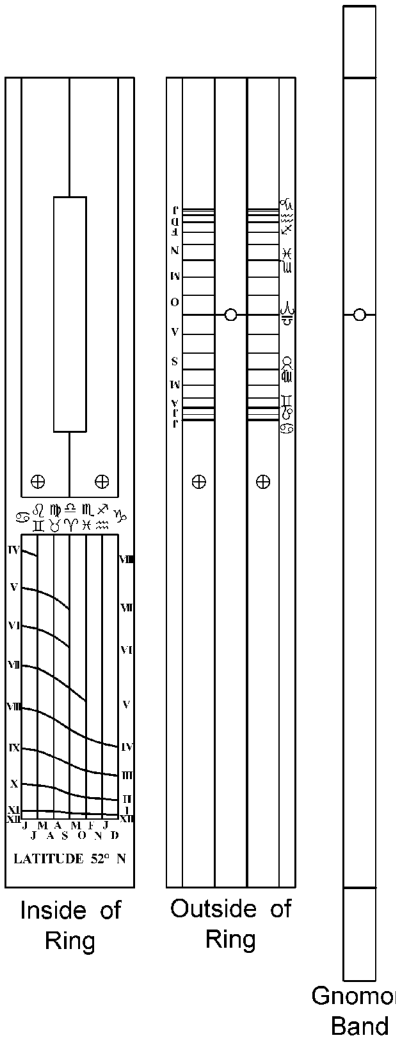


16 - Vertical Disc Dial 5.tif

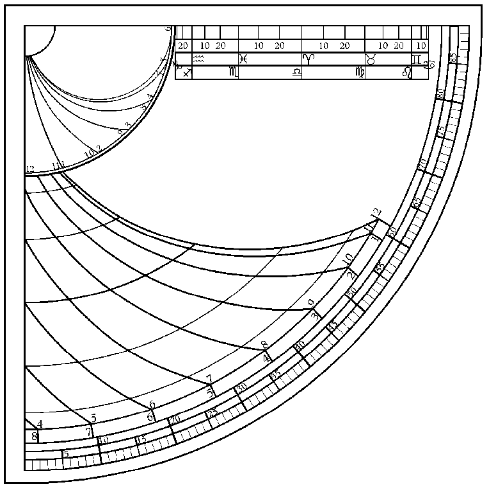


17 - Vertical Plate Dial.tif

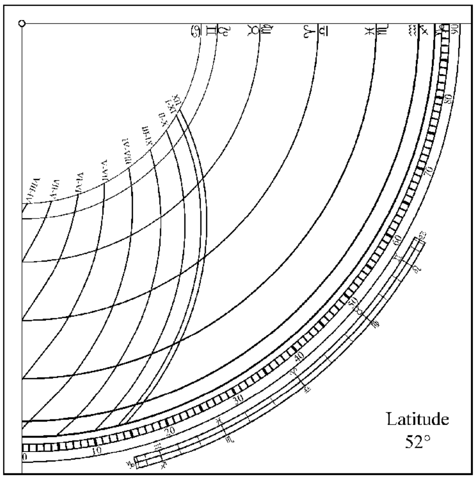
SINGLE LATITUDE ALTITUDE DIALS 12 - 17



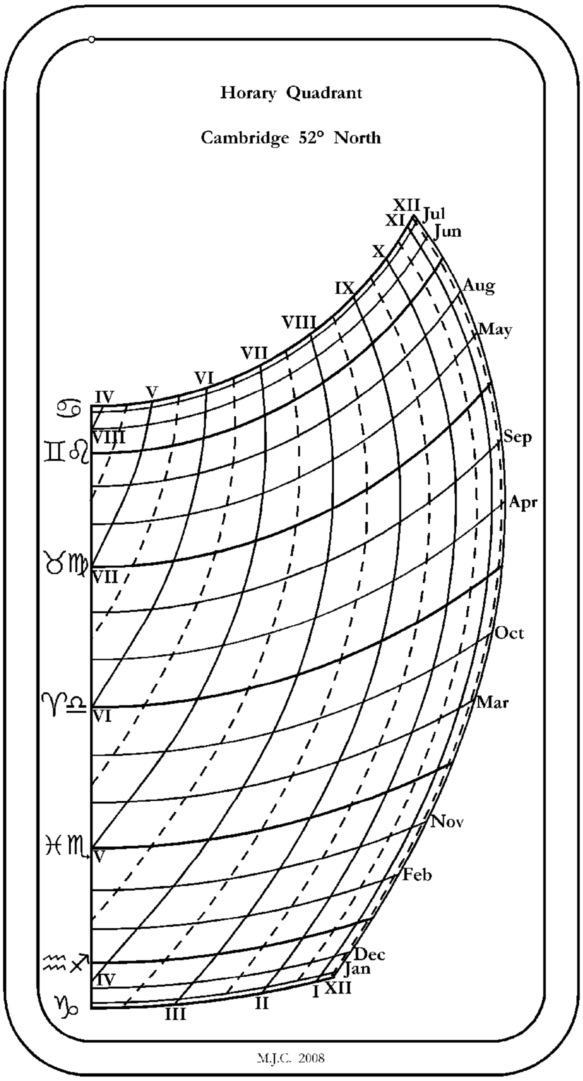
20 - Poke Dial.tif



21 - Horological Quadrant.tif

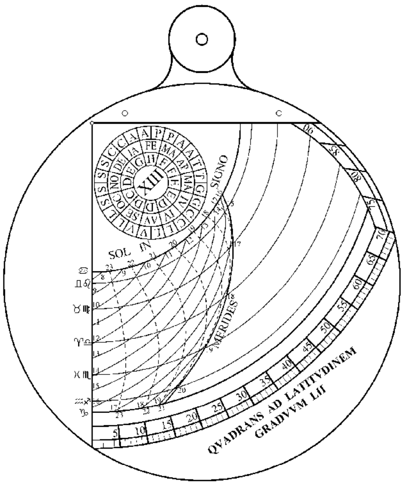


22 - Horary Quadrant a.tif

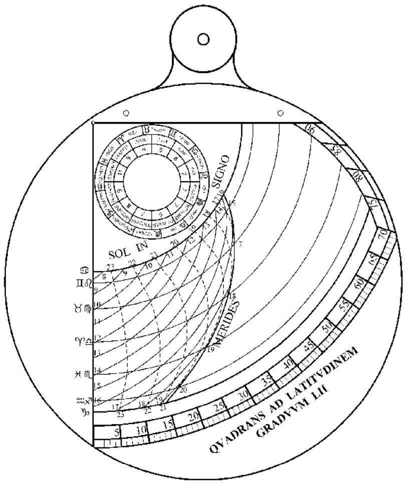


22 - Horary Quadrant b.tif

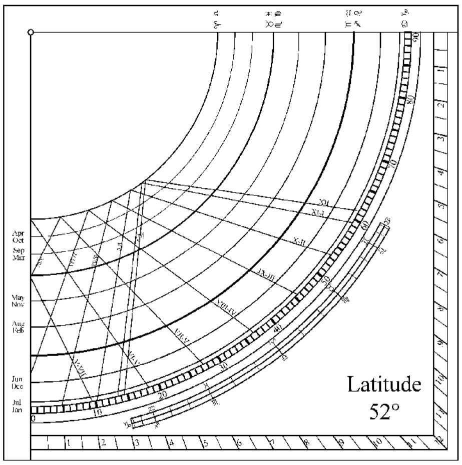
SINGLE LATITUDE ALTITUDE DIALS 20 - 22b



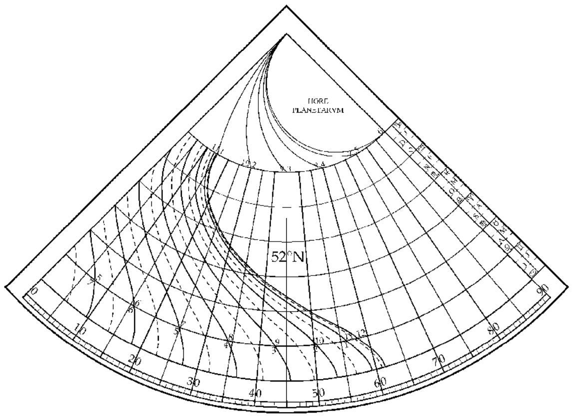
22 - Horary Quadrant c.tif



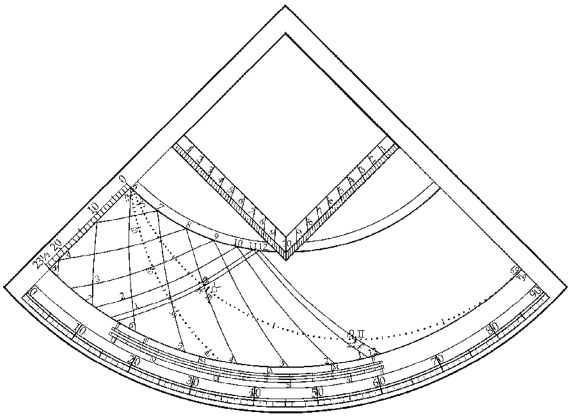
22 - Horary Quadrant d.tif



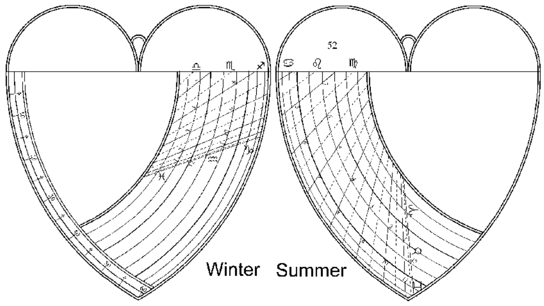
23 - Horary Quadrant.tif



24 - Horodictical Quadrant.tif

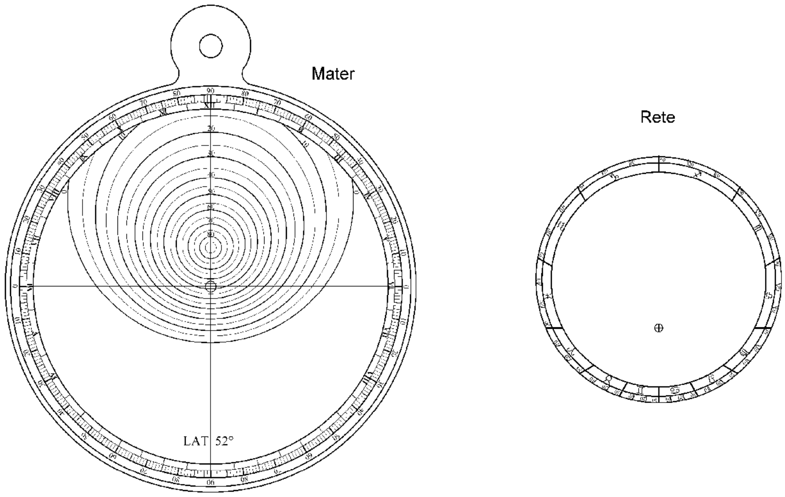


25 - Gunter's Quadrant.tif

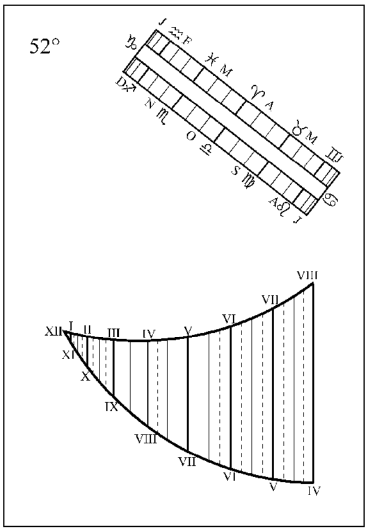


26 - Heart Quadrant.tif

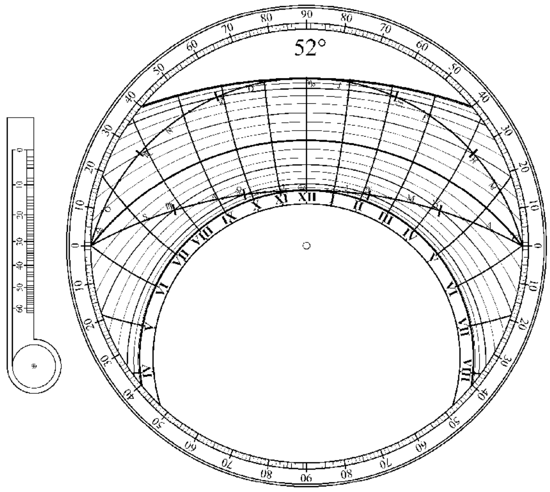
SINGLE LATITUDE ALTITUDE DIALS 22c - 26



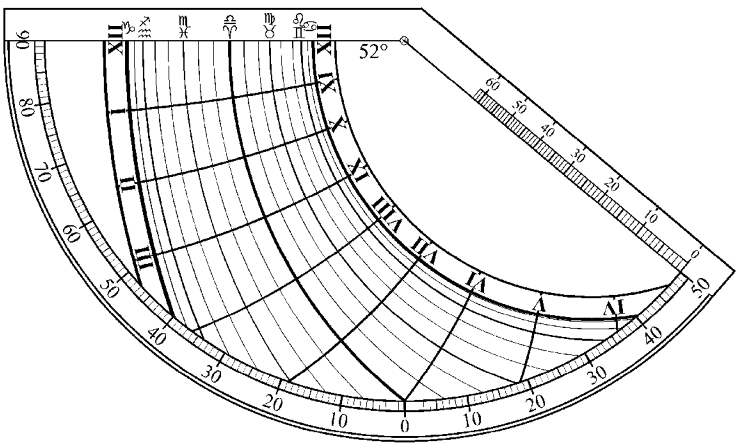
28 - Planispheric Astrolabe.tif



27 - Capucin Dial.tif

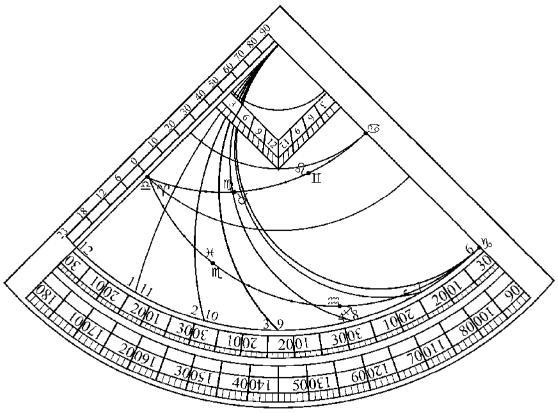


29 - Oughtred's Horizontal Instrument.tif

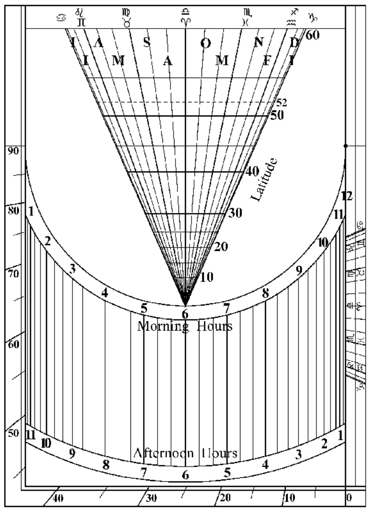


30 - Triens.tif

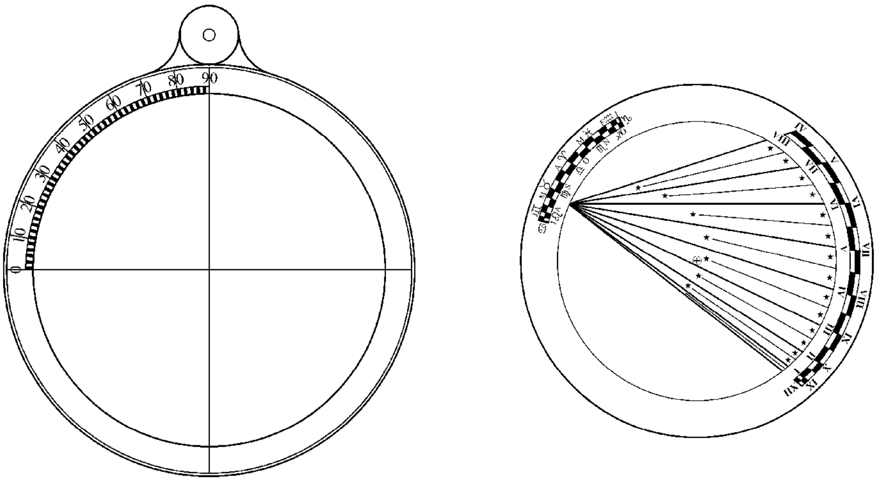
SINGLE LATITUDE ALTITUDE DIALS 27 - 30



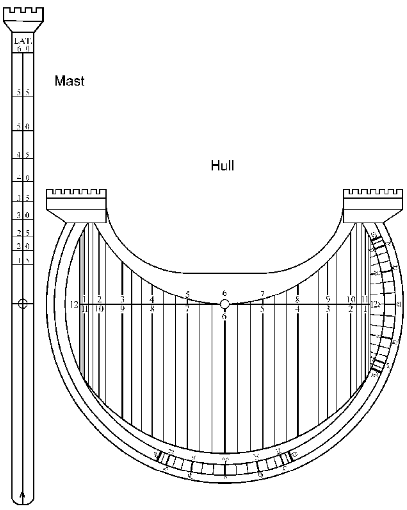
31 - Quadrans Novus.tif



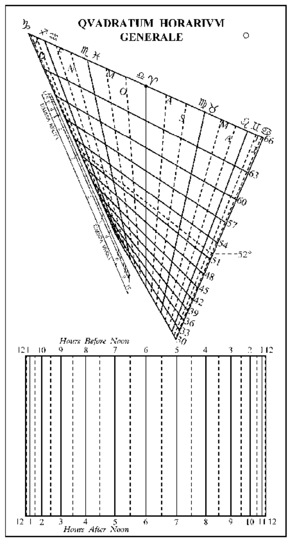
33 - Regiomontanus Dial.tif



32 - Universal Vertical Disc.tif

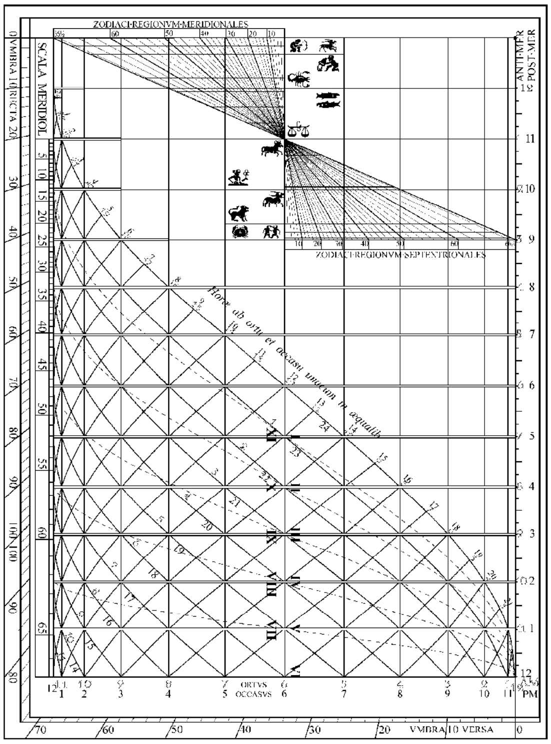


34 - Navicula.tif

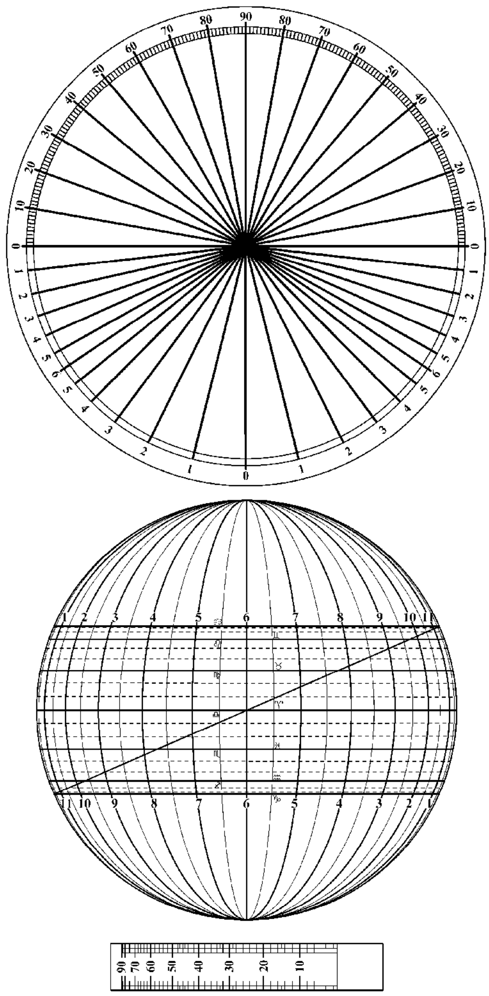


35 - Hartmann Dial.tif

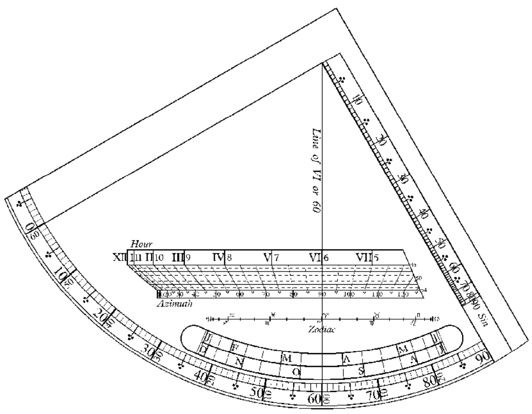
UNIVERSAL ALTITUDE DIALS 31 - 35



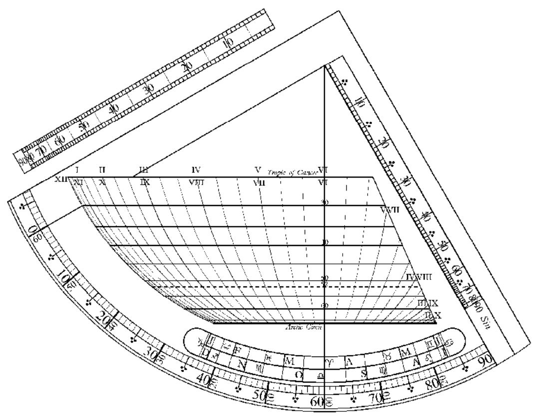
36 - Apian Horoscopium.tif



37 - Organum Ptolomaei.tif

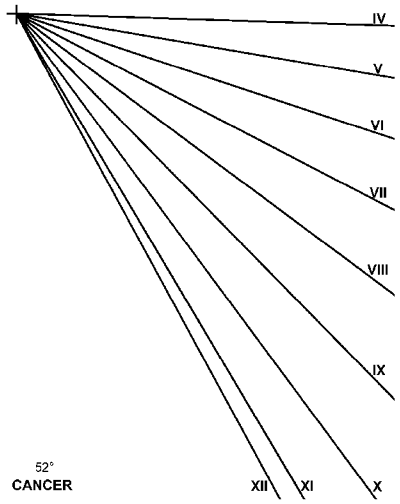


38 - Panorganon.tif

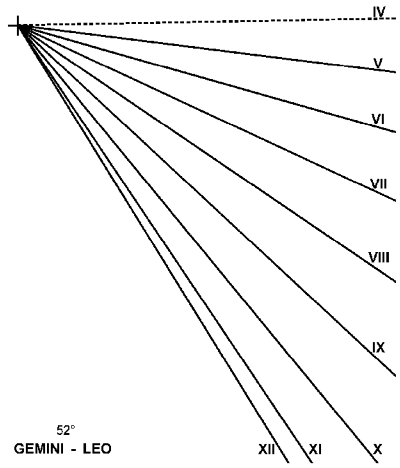


38 - Panorganon Plus.tif

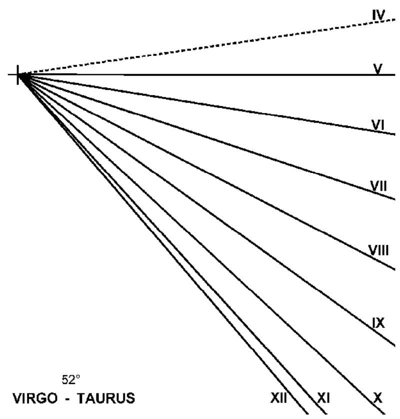
UNIVERSAL ALTITUDE DIALS 36 - 38



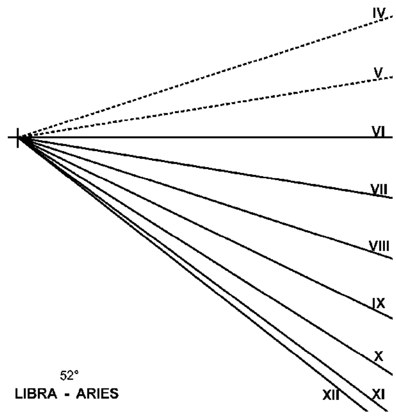
1 Cancer.tif



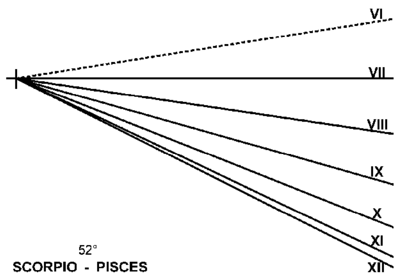
2 Gemini-Leo.tif



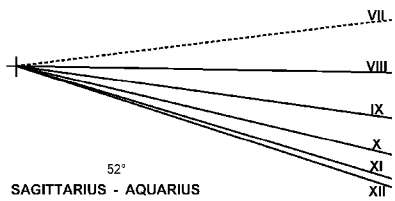
3 Virgo-Taurus.tif



4 Libra-Aries.tif

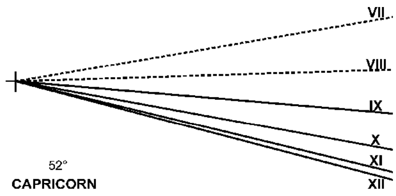


5 Scorpio-Pisces.tif

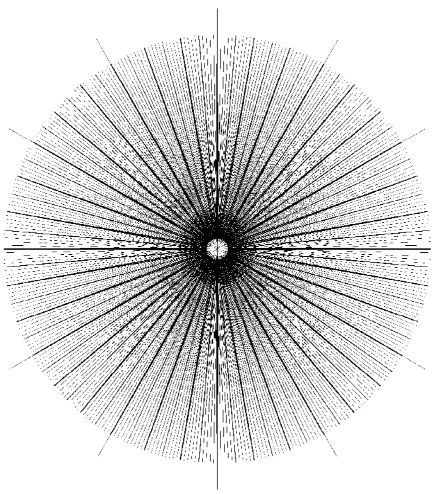


6 Sagittarius-Aquarius.tif

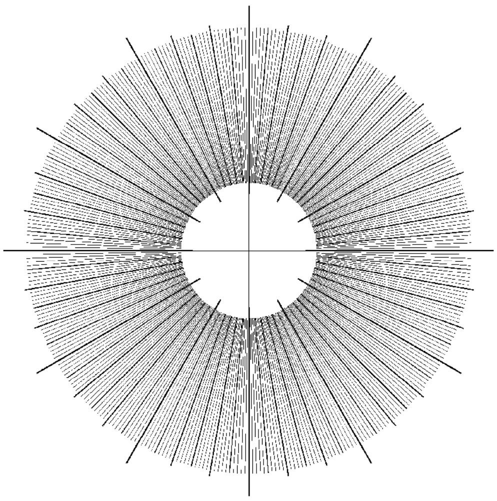
TEMPLATES A



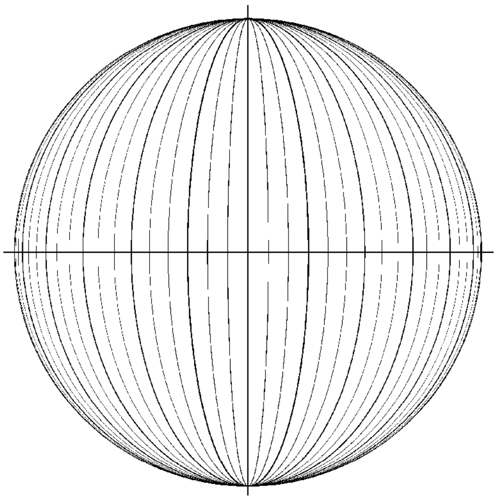
7 Capricorn.tif



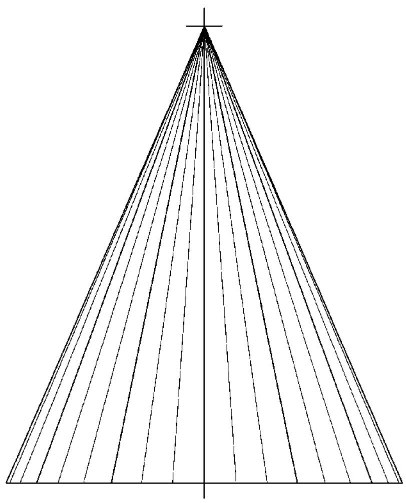
360 Degrees (Star Lines).tif



360 Degrees (Straight Lines).tif

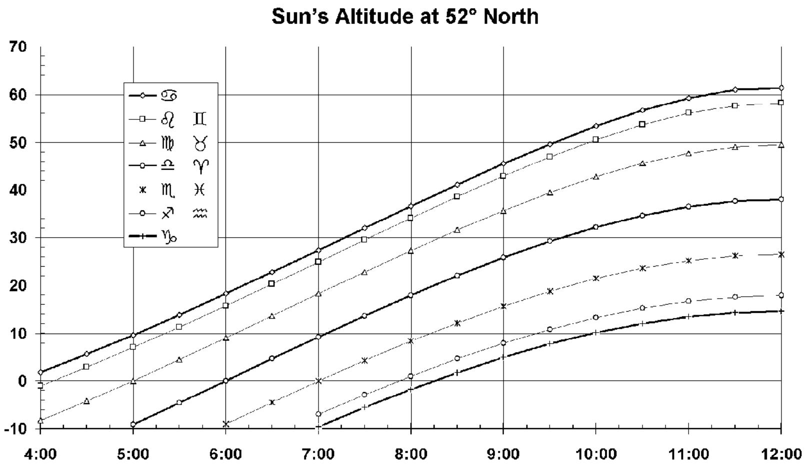


Globe.tif

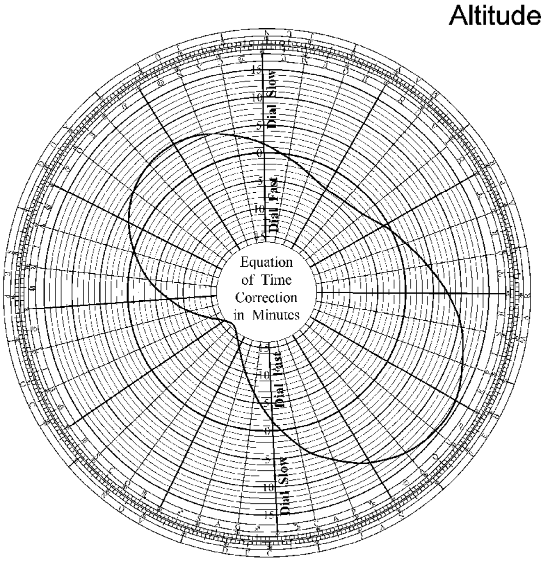


Trigon.tif

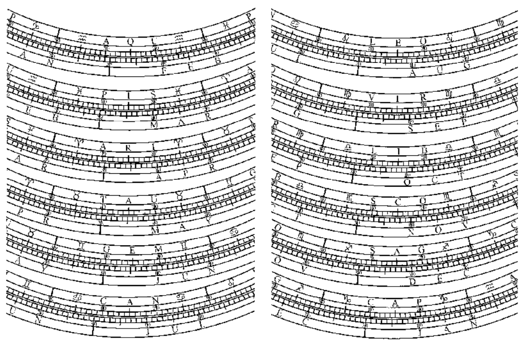
TEMPLATES B



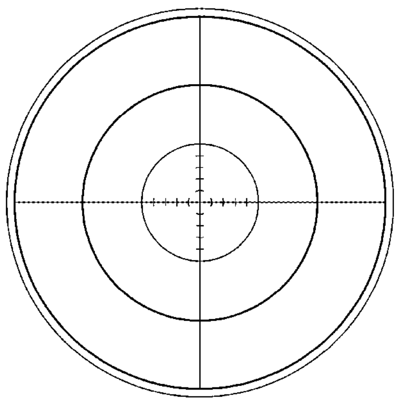
Altitude of Sun.tif



Date and EoT.tif



Date and Zodiac.tif

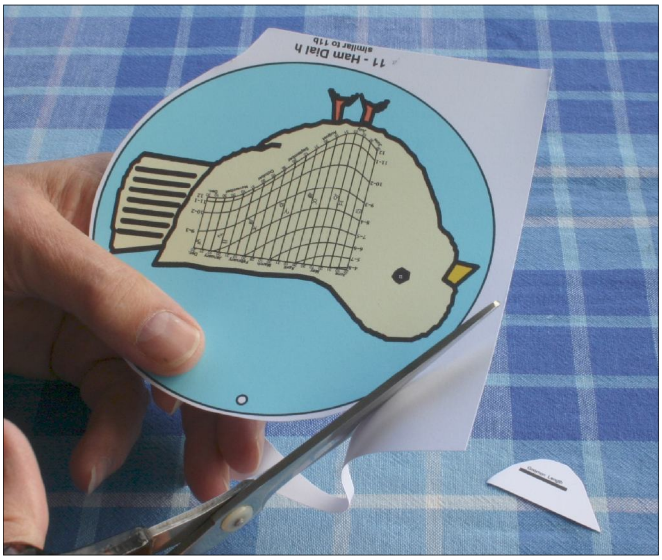


Target Sight.tif

MISCELLANEOUS

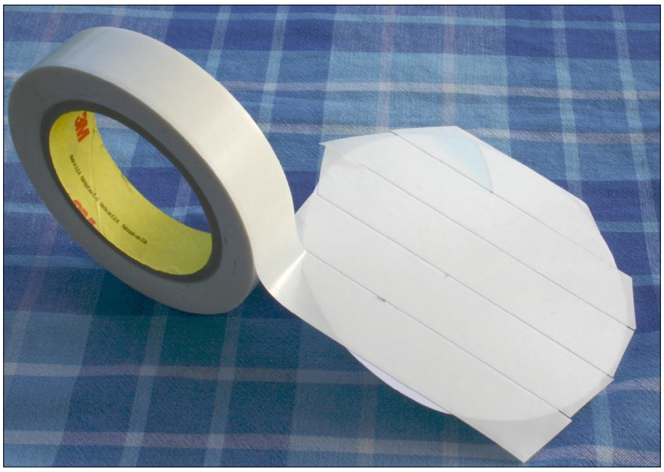
THE STEPS FOR MAKING A TYPICAL DIAL

1 Select a dial from the CD and print it at the required size on some white card of about 200 gsm.



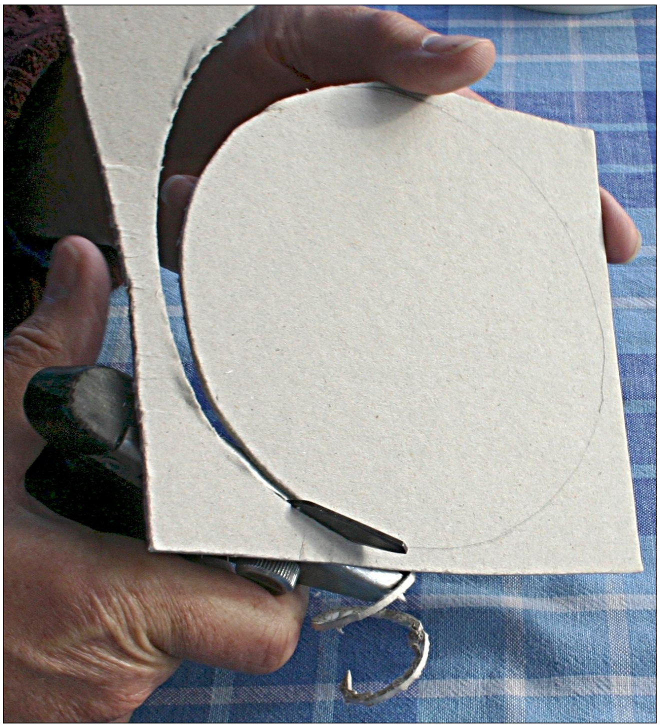
2 *Trim around the outside of the dial pattern with scissors leaving a border of about 3 mm for later trimming.*

Save the template showing the gnomon length.



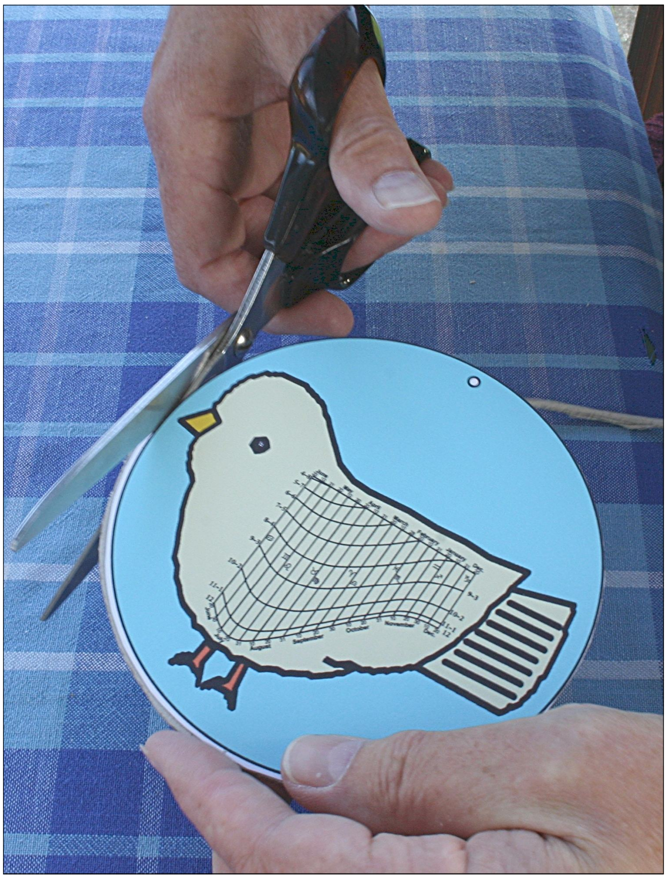
3 *Place strips of double-sided tape on the back covering all areas. Then trim again to remove all of the sticky corners so that the do not get stuck in unwanted places later.*

4 *Use some heavy card, about 3mm thick, and lay the pattern onto it. Mark its outline.*



5 *Cut carefully around the outline marked on the card using sharp scissors, sheet metal shears or, as in the picture, a sheet metal nibbling tool.*

6 *Remove the backing strips from the double-sided tape, position the dial pattern on the thick card and stick down firmly.*

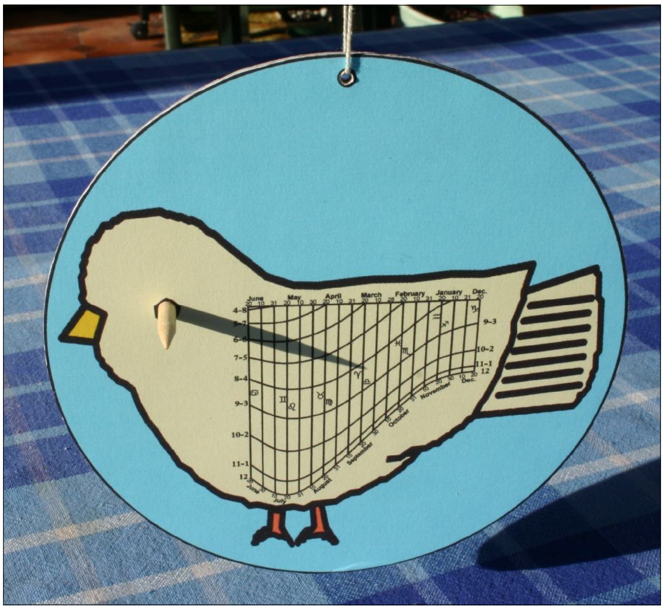


7 *Carefully trim away the remaining 2 – 3 mm of card with sharp scissors leaving a cleanly finished edge.*

8 *Drill the holes in the card, starting with a small pilot drill, then with the dial face down supported by a block of wood, drill the holes to the final size. If necessary, trim the holes with a round needle file.*

9 *Using the template saved when cutting the outline, make a gnomon from a wooden meat skewer or cocktail stick. If a lathe is available, turn it down to a shoulder where it fits into the card and fashion a point at the other end.*

10 *Fit the gnomon to the dial and add a suspension cord or a shackle.*



11 *Finally, hang up the dial in the Sun and check that it works correctly.*

Here it is reading 3:50pm on September 22.

ACKNOWLEDGMENTS

I would like to thank the following people who have allowed me to use their dials for illustration or who have assisted providing other information for my research:

Peter Kalchthaler of the Augustinermuseum, Freiberg im Breizgau for the photograph of the circular plate dial 4 by Habermel.

Trevor Philip & Sons Ltd for the illustrations of the navicula and the quadrans novus.

John Davis, Claus Jensen, Frank King, David Scott and Gerard Turner.

Particular thanks go to the various collectors who have let me photograph their dials, or who have supplied photographs but have asked to remain anonymous.

INDEX

The British Sundial Society

Patron: The Hon Sir Mark Lennox-Boyd
President: Sir Francis Graham-Smith FRS
Chairman: Christopher St J H Daniel

The Society was formed in 1989 and is a thriving and friendly society of some 500 members. Our objects are to advance the education of the public in the art and science of gnomonics and the knowledge of all types of sundial; to catalogue and advise on the restoration of the sundials that still exist in the British Isles, and to research their history. We organise meetings and conferences and publish four 48-page journals each year. For more information, or if you have a general query about sundials, write to the Secretary at 4, New Wokingham Road, Crowthorne, Berks, RG45 7NR
www.sundialsoc.org.uk