A GARDEN HELIOCHRONOMETER
(A mean-time horizontal dial)

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This article is based on a presentation that I made to the British Sundial Society at their 2012 Annual Conference in Cheltenham.

I am a physicist and since as long as I can remember I have been fascinated by sundials. I should also say that I am a newcomer to the art of sundial design and that I am not trying to teach the old hands of the BSS anything, rather I am trying to give readers an idea of the thought processes that led me to the sundial design described in this article. As the saying goes, 'There is nothing new under the sun'.

Sundials look attractive and many gardens have them for this reason alone but I have also been interested by their function; using the accurate and reliable rotation of the Earth, they can tell us the time.

I soon found out that with many garden sundials you are lucky to get the time within half an hour. Many are badly set up and inaccurate or designed for other latitudes. Occasionally I would come across what seemed to be a properly designed and accurately made dial. However, I was disappointed to find out that, even then, the time could be out by up to a quarter of an hour. It seemed to me a sad waste of the engineering effort that had clearly been put into their design

I thus came to learn about the, rather grandly titled, Equation of Time, the function that tells us how sundial (solar) time differs from clock (mean) time throughout the year. After some research, I discovered that the thing that I wanted was a heliochronometer, an instrument that measures the time accurately using the position of the sun in the sky. There are many designs of heliochronometer, many of them involving moving parts, which need to be adjusted carefully in order to determine the time. Others require the user to use tables and calculations to get the time.

I wanted to design a sundial that was accurate but looked like a normal garden sundial. After all, people seem to want sundials in their gardens even when they do not accurately tell the time. I wanted a design that was reasonably robust, easy to read, had no moving parts and did not require the any form of calculation or use of tables to get the time; in other words, a sundial that could be used and read just like a clock.

Concept

As I am sure many of you will know, if you plot the position of the sun (or its shadow) at the same clock time on different days of the year you get a figure-of-eight shape known as an analemma. This shape can then be used to determine the exact instant of 12:00 o'clock by simply noting when the sun's shadow crosses the analemma, although it is necessary to know which half of the analemma relates to the current date. Fig. 1 shows an analemma projected onto the horizontal plane, making the bottom loop (summer) much smaller than the top loop (winter).

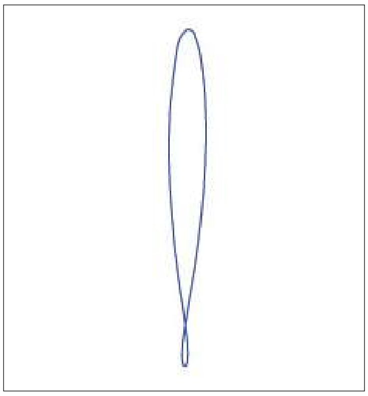


Fig. 1. A noon analemma projected onto a horizontal plane.

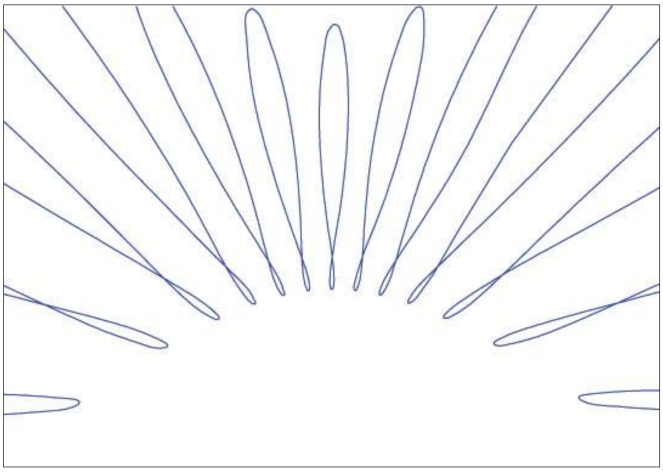


Fig. 2. Hour analemmas on a horizontal plane.

It is, of course, possible to draw an analemma for any hour (Fig. 2), and by doing this it is possible to make a sundial that will accurately tell you when each hour passes. In fact, this principle was used in the design of the sundial in Houston by John Carmichael shown in Fig. 3.

Two problems still remain, however, in producing a sundial that can tell you the time at any time of the day. First, it is necessary to know which part of the analemma applies on the day in question. Secondly, it is necessary to interpolate between the analemmas to get the time.

J. Carmichael

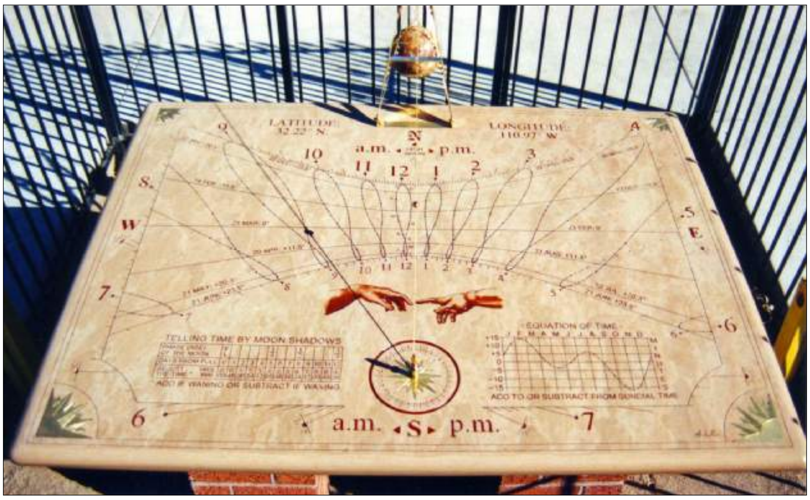
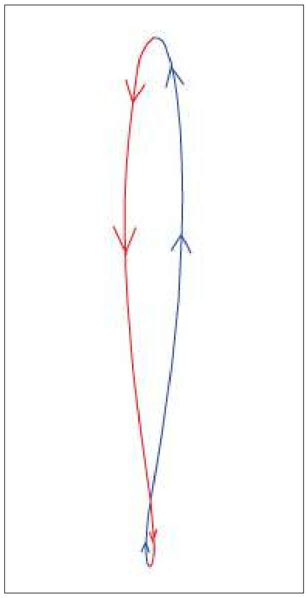


Fig. 3. Design by John Carmichael with full analemmas for each hour.

Fig. 6. Two parts of an analemma.



The problem of interpolation is reduced if analemmas are drawn every half hour, although it can be seen from Fig. 4 that that the analemmas now touch one another. To obtain a reasonable accuracy of interpolation it is necessary to draw analemmas at even closer intervals, say every ten minutes. Unfortunately, when this is done, the picture becomes hopelessly confusing, as shown in Fig. 5.

As shown in Fig. 6, each analemma consists of two parts, one which runs from the summer solstice to the winter solstice, and another which runs from the winter solstice to the summer solstice. This fact gave me the idea of just showing half of each analemma at a time. It has the advantage that the analemmas no longer cross one another and it is no longer necessary to know which is the relevant part. Provided that the right half of the analemmas are shown for the time of year, it is now possible to read the time with reasonable accuracy by interpolating between the ten-minute lines.

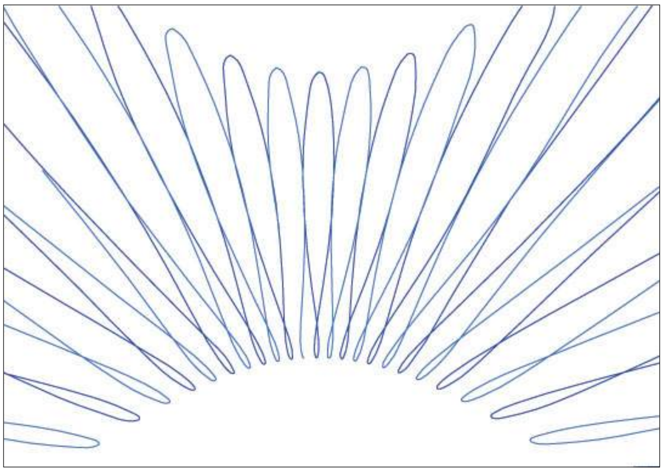


Fig. 4. Half-hour analemmas.

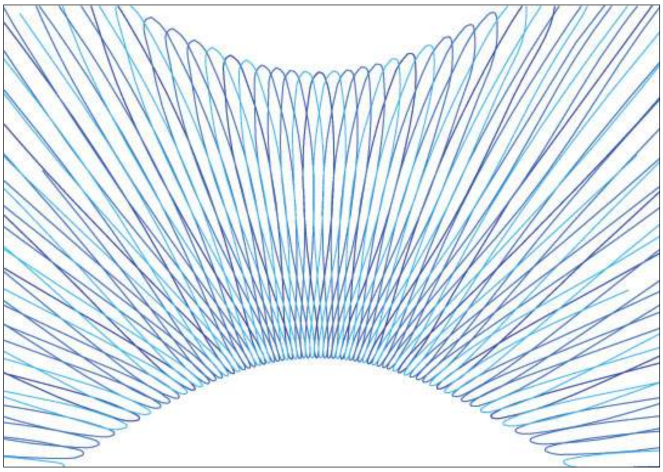


Fig. 5. Ten-minute analemmas.

Using this method (Fig. 7), two dial plates would be required, one covering the time from the summer solstice to the winter solstice (‘Autumn’) and the other covering the time from the winter solstice to the summer solstice (‘Spring’).

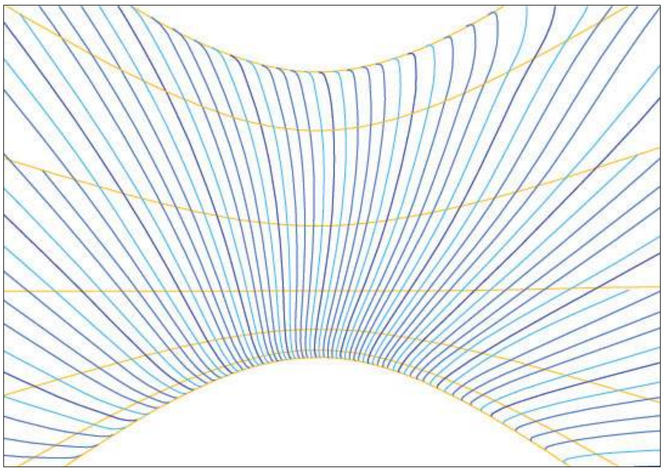


Fig. 7 ‘Autumn’ analemmas.

This idea, then, of using two dial plates, each with half analemmas on them, was to become the basis of my design for a horizontal sundial. At the time I first had this idea, which I think was in the early 2000s, I could not find any references to other designs using changeable dial plates with half analemmas. Later, I found out about the famous Dolphin equatorial dial at Greenwich, designed by Chris Daniel and sculpted by Edwin Russell back in the 1970s. In some ways it was a good thing that I did not know about this dial as this enabled me to carry on in blissful ignorance, believing that I had discovered something new.

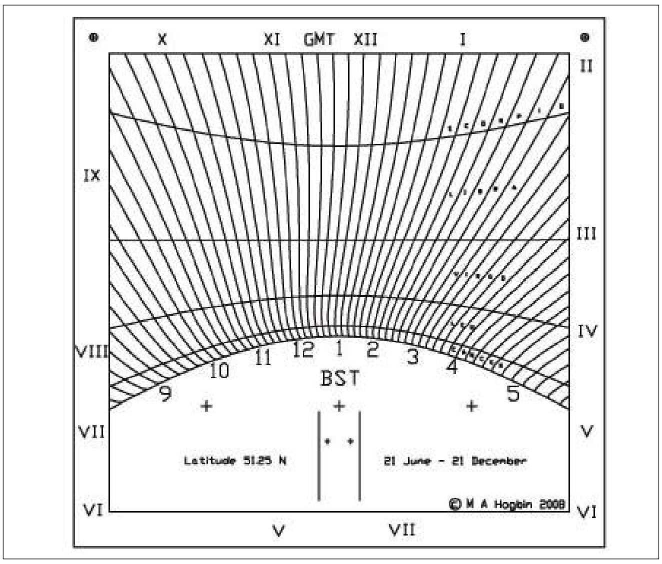


Fig. 8. The 'Autumn' side of the dial plate with markings.

Design

I decided to use a square plate for ease of manufacture and to make maximum use of the available space on my standard, square topped, plinth.

I now started on the design of a sundial based on the concept described. Two dial plates would be required, one to be used for 'Spring' and the other for 'Autumn'. It soon occurred to me that rather than having two dial plates it would be better to have the two designs on opposite sides of the same plate, which could then simply be turned over at each solstice, provided that the markings on the two sides were accurately aligned.

The design work was carried out on a PC using a standard CAD package. The half-analemma lines were produced by marking points calculated on a speadsheet from readily available ephemeris data on the design and then joining them with a smooth curve. The calculations were based on the location of my house, which happens to be yards from the Greenwich meridian and at a latitude of 51.25° N, as marked on the dial.

Some of the other features of the design are worthy of mention.

In common with many similar sundial designs, my design had date lines marked on it. I decided not to use calendar dates but to show zodiac signs for two reasons. First, leap years greatly complicate the showing of accurate dates and may have necessitated the drawing of separate plates for different years within the leap year cycle. This is not the case for the zodiac signs. Secondly, the zodiac signs are in in keeping with tradition and rather fun.

The design shows the BST hours in Arabic numerals along the inside of the summer solstice line. The GMT (UTC) hours are shown round the outside edge of the sundial in Roman numerals, giving the dial a traditional look. I did things this way because the shadow will be inside the equinox lines for most of the summer and outside the equinox lines in the winter thus making the dial automatically

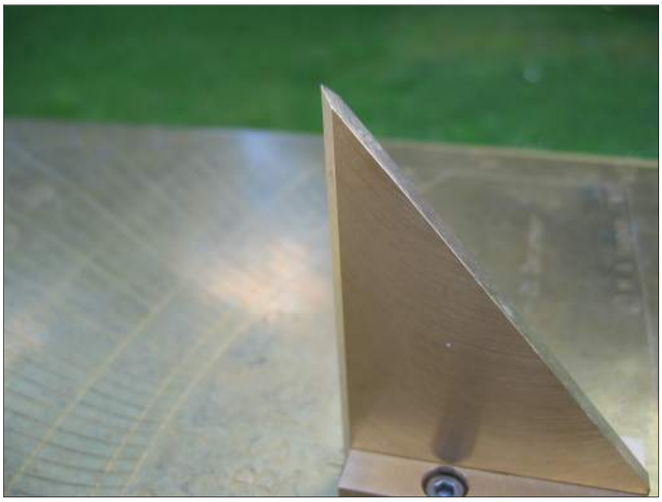


Fig. 9. The gnomon.

change when the clocks go forward and back (give or take a few weeks).

Design of the gnomon for this type of sundial is much more flexible than that for a standard horizontal dial. The only requirement is that a fixed point on the gnomon should cast an identifiable shadow on the dial plate whenever its shadow falls on the plate. A simple vertical rod with a point on it would work perfectly well. In the interests of safety and tradition, however, I decided to use a more conventional triangular gnomon, but with the northern vertical edge machined to a knife-edge thus creating a point at the top of the gnomon, which would be the reference point of the shadow for reading the time (Fig. 9). Although safer than a single point this design still presents some hazards and children need to be kept away from the dial to avoid possible injury.

The triangular design also has the advantage that, when the sun is low in sky and the tip of the shadow no longer falls on the dial plate, the shadow of the sloping edge can be used to give a rough time as in an ordinary horizontal dial.

Manufacture

To translate my CAD design into reality electrochemical etching was used. The work was carried out by Photofabrication Limited of St Neots, who were able to take my CAD drawings and etch them onto a two-sided 1 mm thick brass dial plate with a high degree of accuracy.

The base plate (Fig. 10) was a square piece of 6 mm brass plate onto which the dial plate and the gnomon were screwed. Stainless steel screws were found to be very suitable for this purpose. The base plate had screw holes in the form of circular arcs for fixing it to the pedestal whilst allowing for final adjustment.

For the manufacture of dials for sale I have considered sand casting the base.

The gnomon was machined in three parts by a local toolmaker, from brass, held together with stainless steel screws.

For commercial units I envisaged investment casting with final machining of the critical shadow-casting point.

Fig. 10. The base plate.

Setup

One unexpected benefit of this dial was the ease with which it could be set up. A standard horizontal dial must be on a level surface and carefully orientated so that the noon line points due north, with an allowance for longitude, not a particularly simple process to perform accurately.

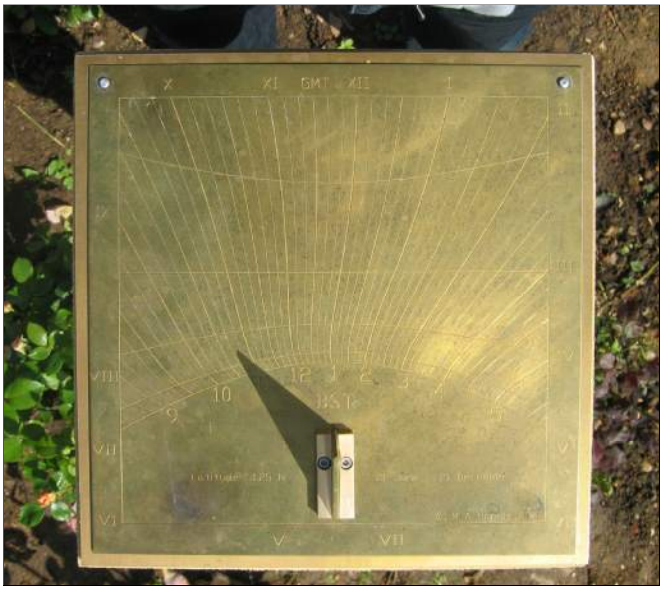


Fig. 11. The complete sundial shown from above.
Fig. 12. The time is read from the tip of the shadow.

When used in the location for which it was designed, this design, like the standard horizontal dial, requires a horizontal base but it is then simply rotated until it shows the correct time. To get the best out of the dial an accurate clock is required for this purpose. This simple method cannot be used for a standard dial, for which, in the worst case of the dial being set up at one extreme of the Equation of Time and read at the other, an error of half an hour would result.

Use

The completed dial was fixed to a standard pedestal and aligned as described above. The time is read directly from the tip of the shadow, interpolating between the ten-minute lines. In Fig. 12, the time is about 10:37.

As Figs 11 and 12 confirm, the dial achieved my objective of designing a sundial that looks similar to a standard garden horizontal dial, is easily read, and has no moving parts.

At the 2012 BSS Conference, it was suggested that the dial should be described as a horizontal mean-time dial. Whilst I do not argue with this description, I have called it a garden heliochronometer because it gives an accurate indication of the time by accounting for the Equation of Time, and it looks like a common garden sundial.

Fig. 13. The sundial on its pedestal.

Performance

Having designed and built the sundial and installed it on a plinth in my garden, I checked it at irregular intervals whenever the sun shone over a couple of years. For checking, I used my radio-controlled watch, which is accurate to the second and, rather appropriately, solar powered. The dial was usually correct to within a minute and was often within thirty seconds of the correct time.

Sources of error and limits to accuracy

In the few days about the summer solstice, when the equation of time changes rapidly and the sun is high in the sky, the accuracy was at its worst, sometimes being a couple of minutes out.

I used thicker lines on the plate to identify the hours and half-hours. This is a potential source of inaccuracy unless care is taken to use the centre of these lines as the basis for interpolation.

Fig. 14. Turning the dial plate every 6 months:

Top L: Tools required.

Top R: Removing the dial plate.

Bottom L: The gnomon removed.

Bottom R: The dial plate is turned over.

The question might be asked as to why the accuracy is limited to a minute. There are several reasons for this. Firstly, the finite size of the sun means that the shadows it casts have blurry edges – the penumbra. Some heliochronometer designs overcome this problem by have a focussing lens and using a fixed point on the sun's image to indicate the time but I wanted to keep the design simple. However, even with these refinements, it is difficult to tell the time to an accuracy of better than about 30 seconds. The position of the sun in the sky at a given time varies slightly from year to year.

Use in other locations

My dial was designed specifically for use in my own garden but I did give some thought as to what would be required to use the dial at other locations.

For small variations of longitude the well-known trick dial of rotating the dial in the horizontal plane until it shows the right time could be used. Although not mathematically correct, I suspect that the errors for this type of dial would be quite small for, say, the south-east of England. For different latitudes, I had the idea of tilting the dial but this may look a little odd. The best, but most expensive and complicated way would be to make a special dial plate for every location.

Maintenance

Twice a year, at each solstice, it is necessary to turn over the dial plate. The plate is then turned over and re-fixed (Fig. 14). The whole process takes about ten minutes. Two allen keys are required.

• The four screws holding the dial plate to the base are removed.

• The two screws securing the gnomon are removed and the dial plate is turned over.

• The gnomon and screws are then replaced. The markings on the two sides of the dial plate are sufficiently well aligned that no adjustment of the dial is required after this procedure.

The Future

As can be seen from the design, I am no artist: the design was produced from what is essentially an engineering point of view. The dial plate design looks reasonable but it would have benefited from some artistic talent.

The gnomon design provides great latitude for creativity since only one point of it, the point from which the time is read, must be fixed in space. The rest of the design could be a statue, with a raised finger, or a ship, for example, where the top of the mast is the reference point.

I would be interested in working with other sundial designers, artists, and sculptors to produce beautiful dials which actually tell you the time!

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