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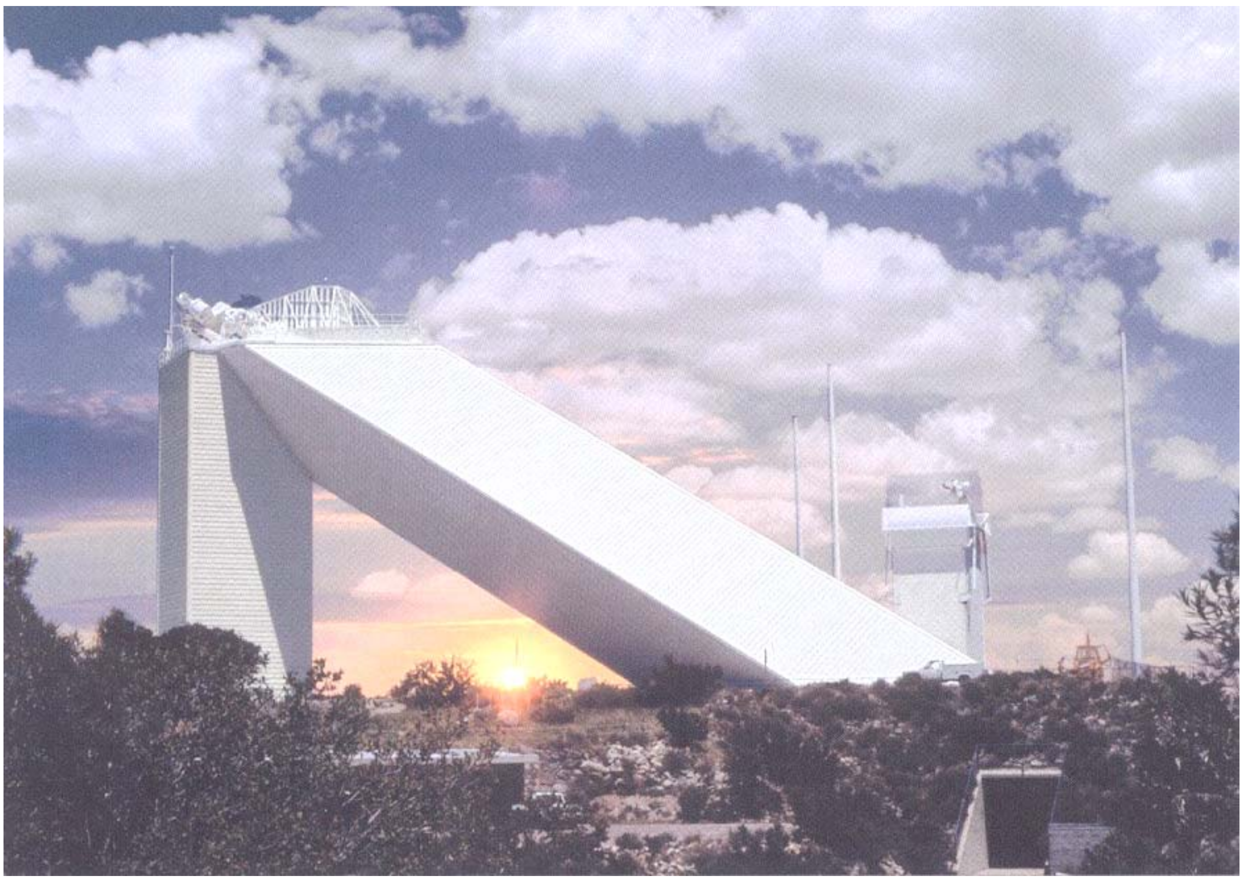
The Compendium*

Journal of the North American Sundial Society



West View of the McMath-Pierce Solar Telescope / Sundial

The sun, when it appears, making proclamation as it goes forth, is a marvelous instrument….

- Ecclesiasticus 43:2

* *Compendium... "giving the sense and substance of the topic within small compass." In dialing, a compendium is a single instrument incorporating a variety of dial types and ancillary tools.*

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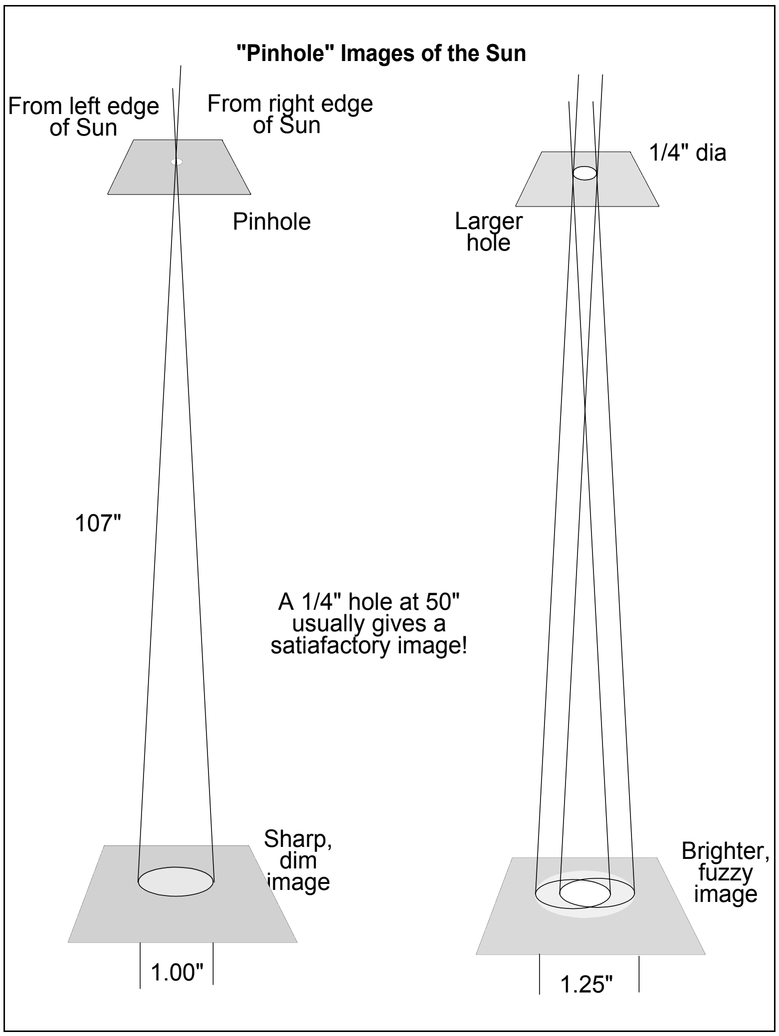
Pinholes and Shadow Sharpeners

William Walton (Plymouth MA)

Introduction

After repeated e-mail messages on the Sundial Mailing List, Mac Oglesby wrote to several of us asking for an article that would clarify what was meant by a "shadow sharpener," (how can you sharpen a non-material entity like a shadow?), and describe some experiments that would show what was possible in reading the position of a shadow more precisely. This article is my response to that request.

I want to thank all of the Sundial Mailing List contributors who shared their insights on pinholes and shadow sharpeners. Among those were Roger Bailey, Art Carlson, John Carmichael, Gianni Ferrari, Bill Gottesman, and Pete Swanstrom.



I divide the topic into two main parts. First, "Pinholes" which can be used to locate more precisely the geometric center of certain shadows, and "Shadow Sharpeners" which, in spite of the conceptual difficulty with the term, really do make the center of a diffuse shadow more sharply defined.

Pinholes

"Pinholes," in our use, may vary from "darning needle holes" to "knitting needle holes," but are used here to make it possible to find very precisely the geometric center of a penumbral shadow.

A Pinhole Image of the Sun

On the left in the diagram we see a pinhole image of the Sun. A beam from the left hand edge of the Sun travels straight through the pinhole and make the right edge of the image. A beam from the right edge of the Sun makes the left edge. Between the right and left edges, beams from the remainder of the Sun fill in the image.

The image is sharp but dim because so little light can come through the small pinhole. Since the angular width of the Sun is 32 minutes, the resulting diameter of the Sun's image is 1/107th the distance from the hole to the screen

On the right we have a larger hole, say ¼ inch in diameter. Now the bright area on the bottom screen is made up of overlapping images of the Sun. In theory, it will consist of a central bright area ¾ inch in diameter surrounded by a fuzzy edge ¼ inch wide. In practice, the fuzzy edge is much narrower due to the logarithmic sensitivity of the eye to light. This results in sharper perceived image than depicted in the

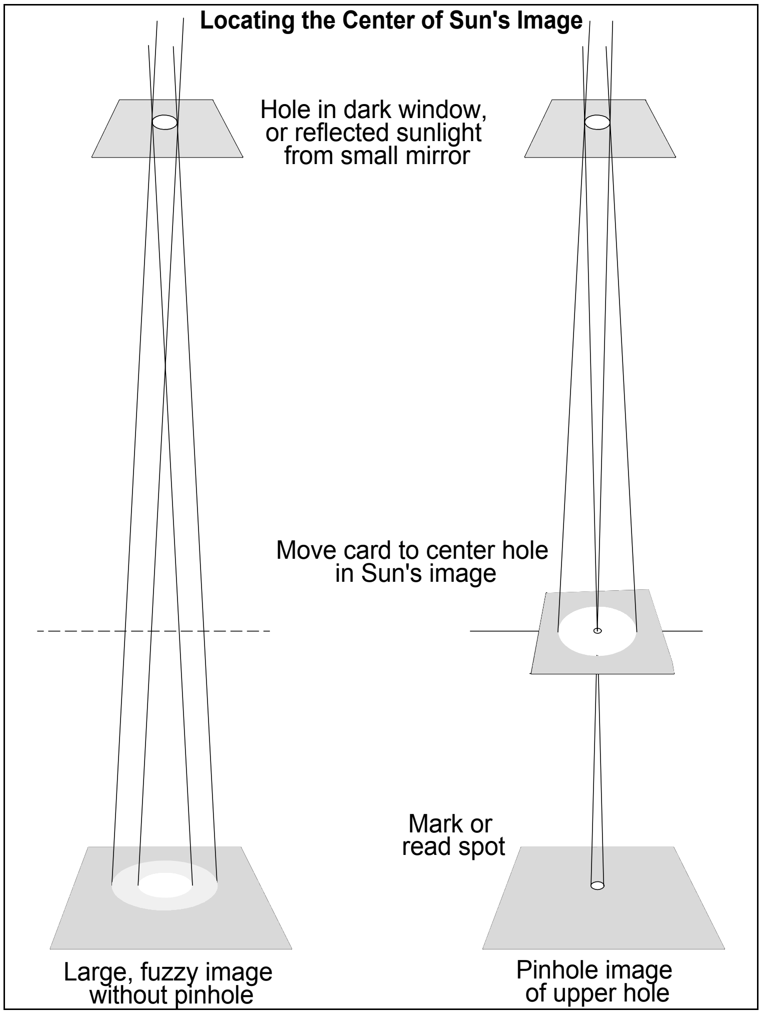


diagram. Experience shows that a ½ inch hole at 107 inches, or a ¼ inch one at 50 inches gives a satisfactory sharp, bright image of the Sun.

Locating The Center of the Sun's Image

Pinhole images of the Sun are found in noon marks, meridians in cathedrals, and reflected ceiling dials. [slide] Often it is difficult to find the center of the large, fuzzy spot of light on a sloping surface. The diagram on the right shows a remedy for this situation. Take a small card and punch a secondary pinhole in it (1/16th to 1/8th inch diameter usually works well). Hold this card, with the hole centered in the Sun's image, a few inches above the surface. The narrow shaft of light that passes through forms a pinhole image of the upper hole in the center of the original beam. Subjective judgment is still required to center the hole in the Sun's image, but since this image may be made circular by holding the card perpendicular to the beam the eye can do a surprisingly good job of finding its center.

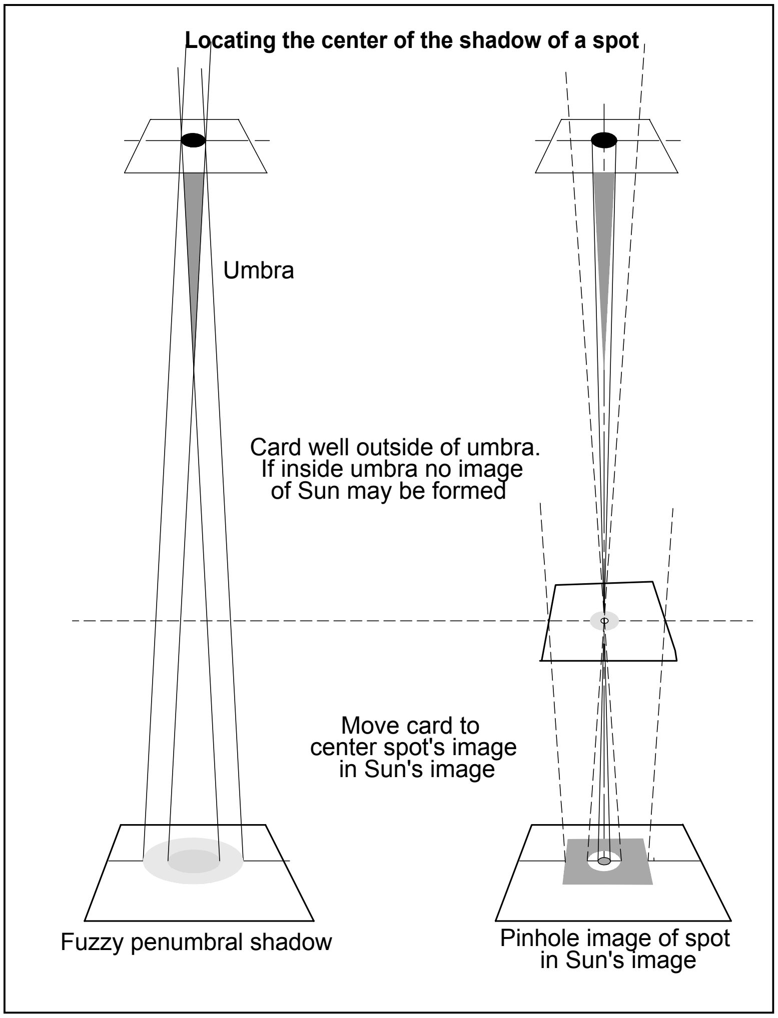
Locating the Center of the Shadow of an Opaque Spot

The diagram shows on the left an opaque spot with its umbra and penumbra in the light from the Sun. A card held just inside the tip of the umbra will show a dark spot surrounded by a gradually fading penumbra. This shadow may be sharpened by use of a special mask known as a "shadow sharpener" and discussed later in this paper.

To achieve greater angular resolution it is often desired to locate the scale on which the shadow falls beyond the tip of the umbra. On the right, the diagram shows a card with pinhole placed in the penumbra of the shadow. Here the card forms a pinhole image of the sun with the image of the spot superimposed upon it. The card with pinhole may be moved about until the image of the spot is centered in the image of the sun. At this point the image of the spot marks the center of the shadow of the opaque spot. Here the advantages of this method are real. The greater angular resolution of a distant scale may be taken advantage of, the image of the spot would not be visible at all without the card with pinhole, and the small image of the spot may be centered very precisely in the small image of the Sun.

Locating the Center of the Shadow of an Opaque Band

Here the opaque band may be the wire, rod, or pipe used as a gnomon for an equatorial dial. When the scale is near the tip of the umbra or well within the umbra, a broad to narrow dark shadow may be formed. The edge of the broad shadow may be read, but see the next section for precautions in reading



the edge of a shadow. If the narrow shadow at the tip of the umbra is used, a "shadow sharpener," discussed later, may be used.

Again, to achieve greater angular resolution it is often desired to locate the scale on which the shadow falls beyond the tip of the umbra. On the left we see the dim, fuzzy penumbra of the band. On the right, the diagram shows a card with pinhole placed in the penumbra of the shadow. Here the card forms a pinhole image of the sun with the image of the band, as a sharp line, superimposed upon it. The card with pinhole may be moved about until the line is bisects the image of the sun. At this point the line marks the center of the shadow of the opaque band. Again, the advantages of this method are real. The greater angular resolution of a distant scale may be taken advantage of, the image of the band would not be visible at all without the card with pinhole, and the small image of the band may be centered very precisely in the small image of the Sun.

Locating the Geometric Center of the Shadow of an Edge

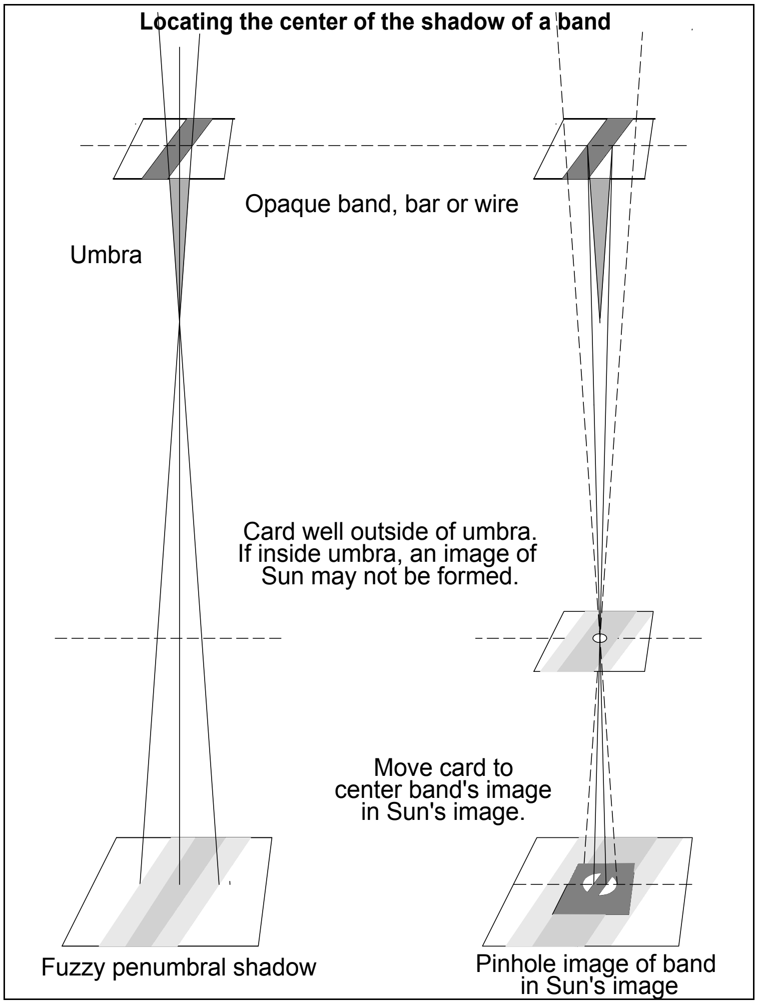
The diagram on the left shows the penumbra formed by the shadow of an edge. The umbra would be the dark area to the right of the fuzzy penumbra. The center of the geometric shadow of the edge is in this penumbra.

The diagram on the left shows how to precisely locate the center of this penumbra using a card with a pinhole in it. The pinhole forms an image of the Sun with an image of the edge superimposed upon it. The pinhole is moved in and out of the penumbra until the image of the sun appears as a half-circle. At this point the diameter of the half-circle marks the geometric center of the shadow of the edge.

Logic would tell us that at the geometric edge of the shadow the illumination would be midway between the illumination of the un-shadowed card and the illumination of the deep shadow. Experience shows that this is not what the eye perceives. The eye sensitivity to light is non-linear and varies approximately with the logarithm of the illumination. This throws the perceived mid-shadow toward the umbra, making the fuzzy edge of the shadow appear much narrower than shown in the diagram. The perceived edge of the shadow might appear to be moved roughly ¼ the width of the penumbra away from the geometric center of the shadow. Since the angular width of the penumbra is the same as the angular width of the Sun, which is one-half a degree of arc or two minutes of time, the error in reading the shadow of an edge might be approximately one-quarter of two minutes, or 30 seconds of time.

Shadow Sharpeners

Shadow Sharpeners really exist, and are used to make more narrow the somewhat diffuse shadow of a small object.



<u>Shadow Sharpener for an Opaque Spot</u>

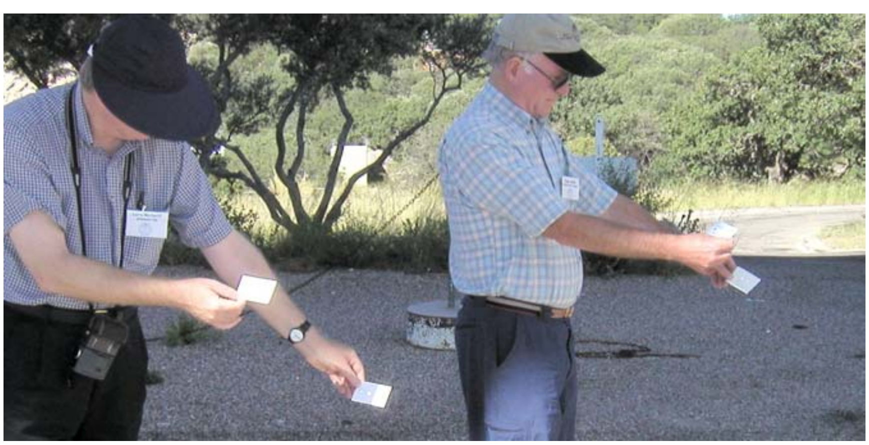
After a series of experiments to determine the best configuration for an alidade to be used in a helio-chronometer, John Carmichael (4/11/00) found that a 1/8 inch bead surrounded by a ¼ inch hole in opaque material provided a sharper shadow on a scale 18 inches away than the 1/8 inch bead did alone. The following diagram by Bill Gottesman explains how this so-called shadow sharpener works to provide a more narrowed central dark shadow.

<u>Shadow Sharpeners for an Opaque Band and "Cross Hairs"</u>

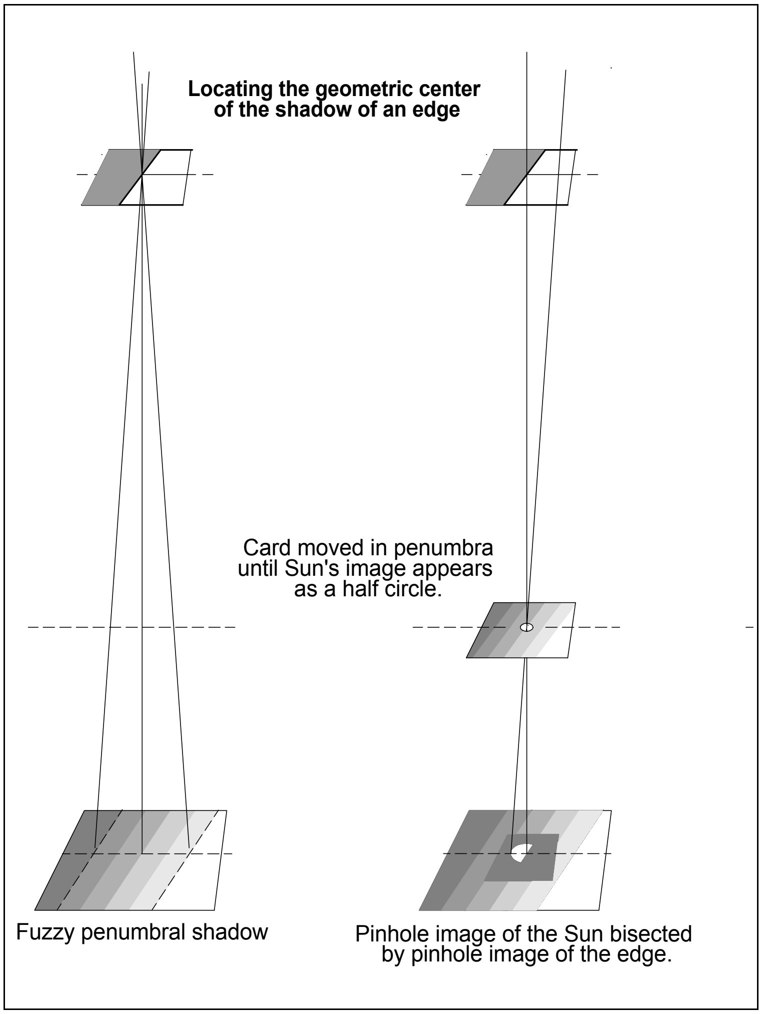
The idea for a shadow sharpener for a spot can be extended to a band or even to "cross hairs" as the following diagram and slides show.

<u>Conclusion</u>

I have shown that a card with a "pinhole" in it may be used to find the geometric center of a penumbral shadow cast by an opaque spot, band or edge at a relatively great distance from the shadow-casting object. A complementary technique may be used to find the center of an image of the sun, but is more subject to errors of judgment. These methods are applied to a sundial by the use of a hand-held card, and so are note useful for the casual observer. It should be possible to develop an equatorial dial with a fixed pinhole (or narrow slit) at noon (or any other time or times) that would enable the set time to be read with a precision of a few seconds. Perhaps a series of diagonal slits could be used to read the dial at any arbitrary time.



Experimenting with shadow sharpeners at Kitt Peak during the NASS Tucson conference.



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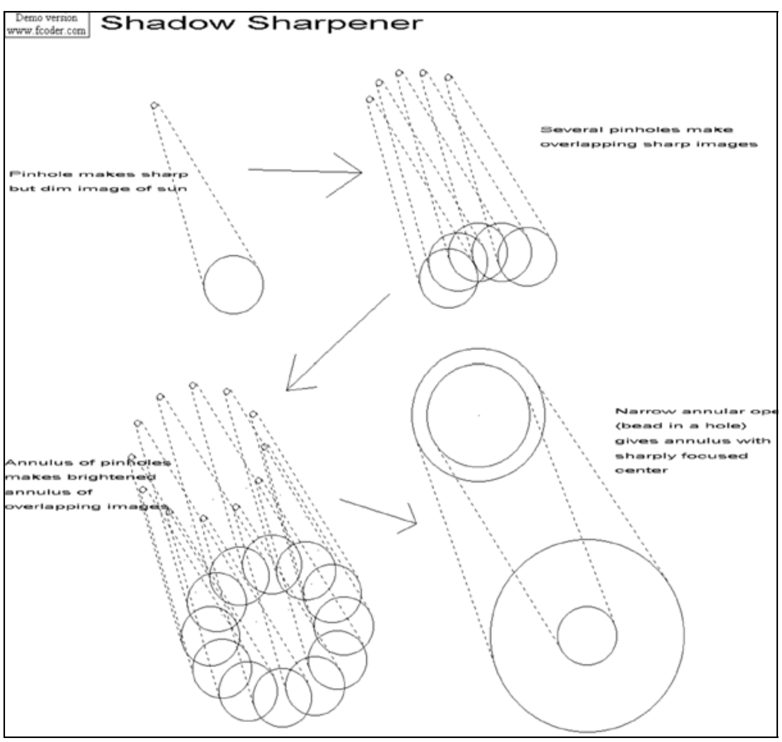


The Shadow Sharpener

Gianni Ferrari (Modena, Italy)

A Shadow Sharpener is a tool that helps us see the separation line between the shadow and the penumbra produced by a distant object illuminated by the Sun. A tool, in other words, that allows us to mark with good approximation where the "geometric" or "theoretical" shadow of a distant sunlit object finishes - the place where the line between light and shadow would be if the Sun were a point source of light.

A shadow sharpener can be made in different ways, including devices with complex optical systems, but the simplest and most ancient sharpeners are based on the projection, made with a simple little hole, of the image of the disk of the Sun and of the object that casts the shadow [1]. Devices of this type were probably used by the Chinese astronomers many centuries ago, and certainly by the Indian astronomers at the beginning of 1700's to find the edge of the gnomon's shadow in the great equatorial sundial of Jaipur in India.

The device is very simple, consisting of a piece of opaque material containing a little circular hole having a diameter from about 1/2 mm to 2 mm. A simple and practical shadow sharpener may be made by using a large needle or a nail to punch a hole in a playing card or rectangular bit of metal cut from a "tin" can.

If we place a shadow sharpener in such a way that its plane is perpendicular to the rays of the Sun, the hole produces a picture of the Sun's disk on an image-receiving screen (Fig. 1).

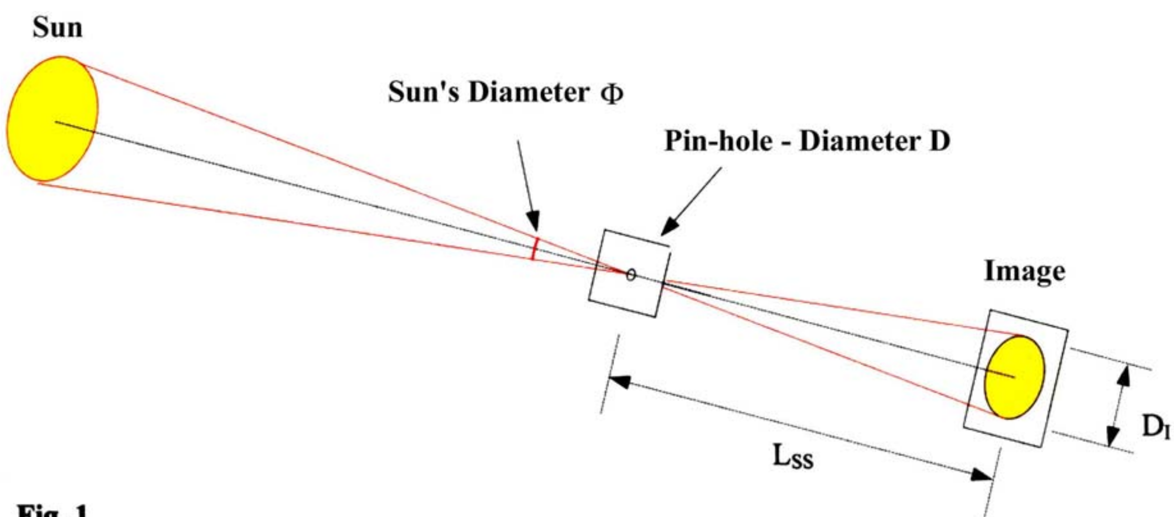


Fig. 1

Then if we call L_{SS} the distance between the hole and the screen image, D the diameter of the hole and Φ the angular diameter of the Sun in radians, the value D_I of the diameter of the image is given by $D_I = L_{SS} \cdot \Phi_{rad} \cong \frac{L_{SS}}{107}$ in which $\Phi_{rad} \cong \frac{32}{60} \cdot \frac{\pi}{180} \cong \frac{1}{107}$.

[1] A hole of this type is called pin-hole in Anglo-Saxons countries and "stenopeic hole" in Latin countries and in optics. The term stenopeic derives from the Greek word "steinôpos", formed by the two words "stenos" + "opê" that, translated literally, mean "narrow" and "opening, hole" (two words that have the same root are e.g. "stenosis" and "operculum) and therefore "stenopeic hole" means literally "hole with a small opening" or also "hole of small diameter".

A simple mnemonic rule: the diameter of the Sun's image increases 1cm for every meter of the distance L_{SS} . The distance L_{SS} is often called the length of the shadow sharpener.

If the diameter D of the hole were close to zero, the image produced would be a very dim perfect copy of the projected object. Since the hole has finite dimensions we may assume that every point of its surface produces a projection of this type. We will get the resultant image by adding these innumerable elementary images. For this reason the image is always "defocused" and surrounded by a zone of uncertainty, or fuzziness, as wide as the hole diameter D.

If our light source is the Sun, and if we want the image to be sharp enough, it is necessary that that D_I, which is approximately equal to $L_{SS}/107$, be much greater than D, and therefore, that the shadow sharpener length L_{SS} is much greater than 107 times D. For most applications it suffices that D is approximately in the range of 1/400 to 1/300 of L_{SS}. Thus, $L_{SS}/400 < D < L_{SS}/300$.

Let us now suppose there is a blocking element with a straight edge set between the Sun and the shadow sharpener at a definite distance from it. This element can be a thread or a cable, the upper edge of a wall, the edge of a roof, the edge of a tilted gnomon, the style of a very large sundial, etc. Because of the apparent diameter of the Sun, between the blocking element's shadow and the zone in full light there is a zone of penumbra whose width is $L_R \cdot \Phi_{rad}$, where L_R is the distance between the blocking element and the shaded plane. (Fig. 2)

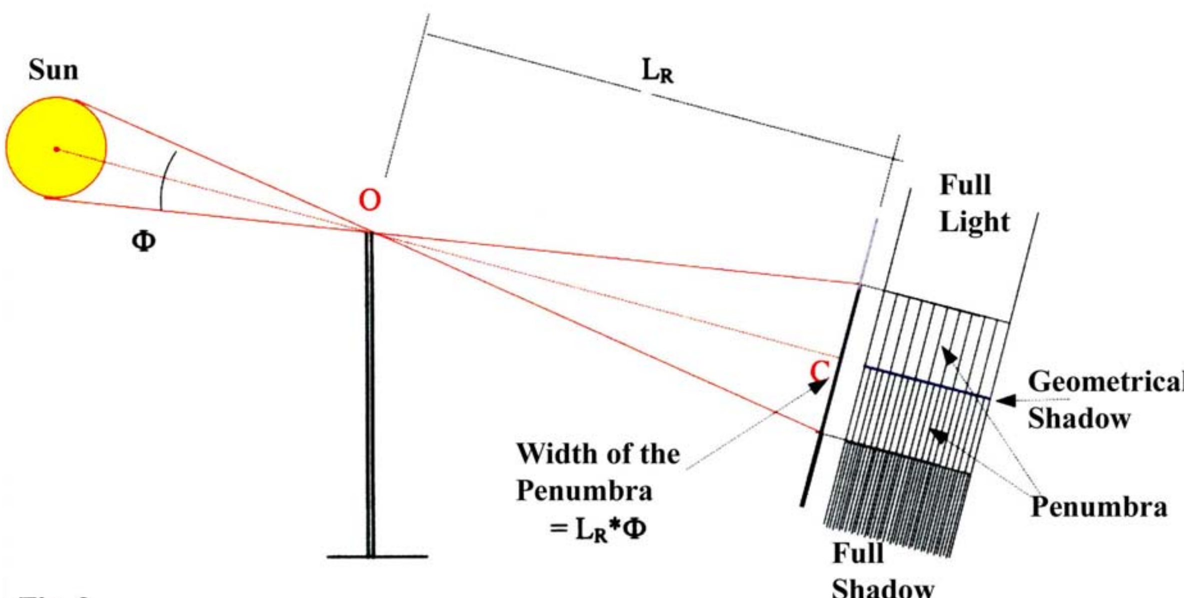


Fig. 2

If a shadow sharpener is placed to intercept the edge of the blocking element's shadow, and if the distance L_R is large in comparison to L_{SS}, then the hole produces both the image of the outline of the blocking element and that of the partially covered solar disk. (Fig. 3)

Holding the shadow sharpener in one's hand and moving it from the full light toward the full shaded zone, we see first the Sun's disk completely illuminated, then, as the hole enter the penumbra, the image of the Sun's disk that slowly becomes obscured. (Fig. 4)

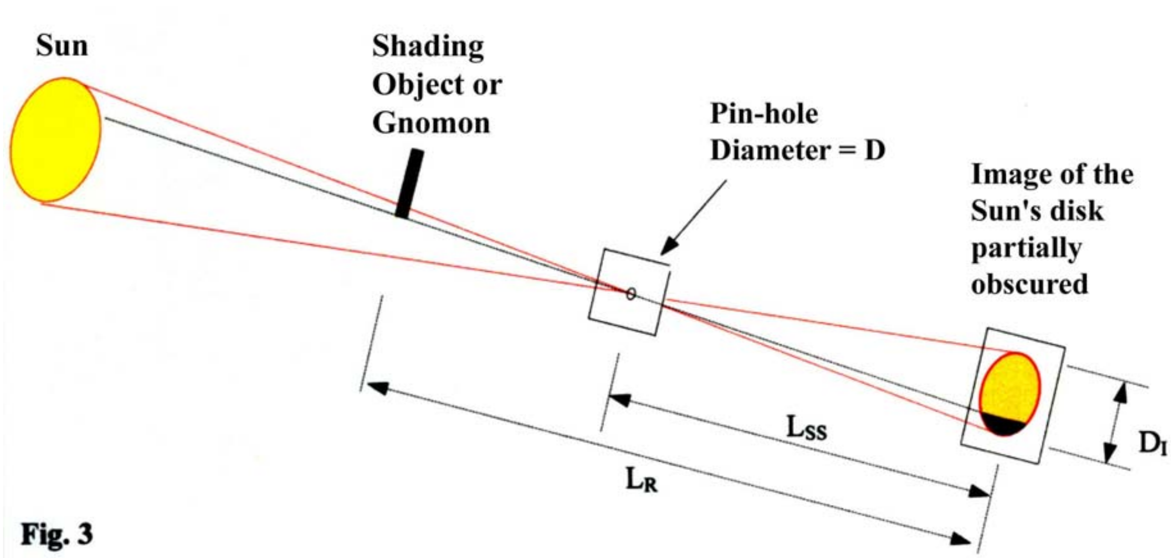


Fig. 3

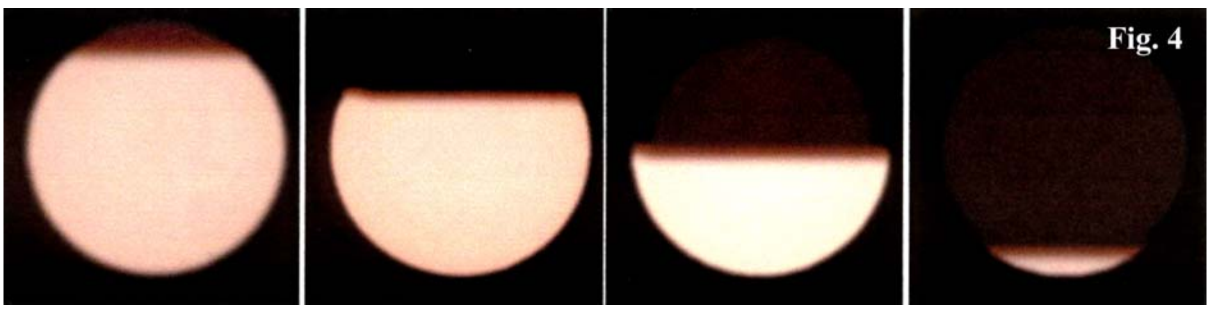


Fig. 4

When the Sun's disk appears exactly halved (3rd frame of fig. 4) the separation line between shadow and light coincides exactly with the line of the geometric shadow of the blocking element at the instant of the observation. This is because, by definition, the geometric shadow is what would have been produced by the Sun if its diameter were zero, and all of its light came from its center.

<u>The search for the geometric shadow</u>

The search for the geometric shadow of a linear element, particularly of the edge of a gnomon, is perhaps the main application of the shadow sharpener:

- either to verify the exactness of the hour lines of a sundial already drawn; i.e. to see if existing hour lines are properly located,

- or to find where the hour lines need to be located

In the first case we have to hold the shadow sharpener in such a way as to project the Sun's image, exactly half blocked by the gnomon, onto one of the lines (for example the hour line H) and to note the time. This is the exact instant at which our sundial says it is the hour H.

In the second case we move the shadow sharpener slowly and carefully, trying to keep the image of the Sun's disk continually halved while time passes, and then to mark on the plane the separation line between shadow and light exactly at the hour H.

The length L_{SS} of the shadow sharpener is limited by two different requirements:

- to be able to see comfortably and to tell with sufficient accuracy when the Sun's disk is exactly halved, it is necessary that image diameter D_I be 10 mm or more;

- to get an image of the element that casts shadow sharp enough (that is only slightly defocused), the length L_{SS} must be only a fraction of the distance L_R between the element and the screen (Fig. 3)

Several tests by some dialists have found that the length L_{SS} should be between about 70 cm and 150 cm. These values require a distance L_R of about 3m to 5m between the blocking element/gnomon and screen, and give an image of the Sun of 7 to 14 mm. Therefore a shadow sharpener cannot be used for making readings with sundials of usual dimensions, in which the distance between the gnomon and the plane is always a lot less than 2 or 3 m. L_{SS} would then have a length less then around 40 cm, giving a solar image of about 4 mm, not very useful in practice.

Errors - Accuracy of the measures.

Even if a shadow sharpener allows us to find with good approximation the line of the geometrical shadow of a gnomon at a given instant, it is also a source of errors and does not allow us to reach such an extreme accuracy as some think. The errors can be different and I list only the most important.

1. The image produced by a pin-hole is always surrounded by a strip of uncertainty (defocusing or fuzziness) that has the width of the maximum dimensions of the hole. This zone produces a reduction in the quality of the image with resulting difficulty in the search for the center line of the disk

2. The dimension of the hole of a sharpener cannot be reduced beyond a fixed limit, either because the image loses sharpness due to the diffraction of the light, or because the image becomes too dim. The examination of this image becomes very difficult if it is only a little brighter than the surrounding zone. Many tests show that it is not useful to decrease the hole diameter under 0.7 - 1 mm

3. If the hole of the shadow sharpener has irregular edges, it produces a defocused zone as wide as the maximum diameter of the teeth. Likewise if the hole is not perfectly circular the defocused zone is, in some points, as wide as the maximum dimension of the hole (Fig. 5). It is for this reason, in addition to construction convenience, that the hole is always made circular. From the theoretical point of view its shape doesn't have any importance

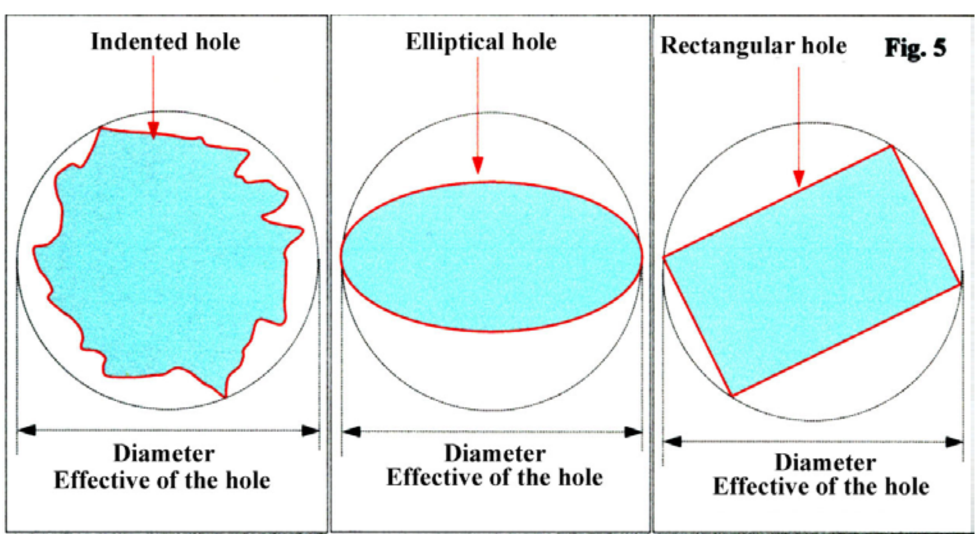
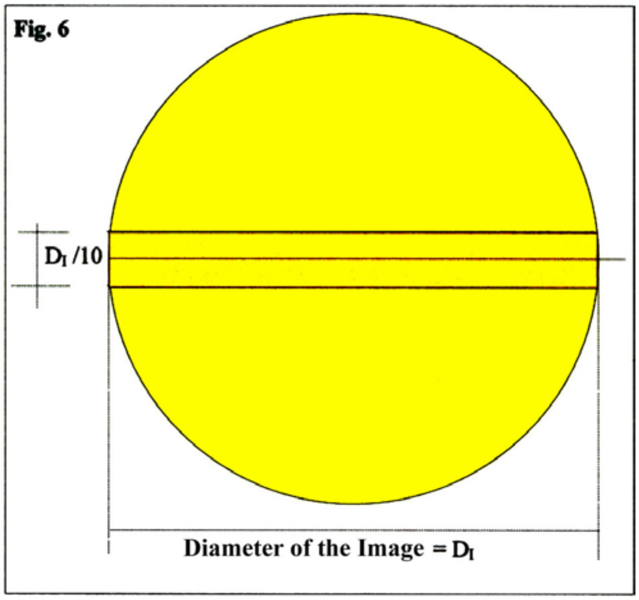


Fig. 5

4. To find with accuracy the instant at which the shadow of the element-gnomon halves the Sun's disk, it would be useful to have an image as large as possible and therefore it would be good to increase the length L_{SS} of the shadow sharpener. However as L_{SS} increases, it becomes more difficult to have a motionless image, and the image becomes dimmer (see item 2 above). Since the distance L_R between the element-gnomon and the plane has to be at least 5 - 8 times the distance L_{SS} (Fig. 3), L_{SS} cannot have very large values. If the ratio L_R / L_{SS} decreases, the defocusing of the image of the gnomon increases.

Fig. 6



5. In any case, the search for the instant at which the image of the solar disk is halved is not easy. Also supposing an uncertainty of 1/10 of the diameter (Fig. 6), in my opinion optimistic, the error at the instant would be $\pm \frac{1}{20} \cdot 2\,\text{min} = \pm 6\,\text{sec}$, where 2 minutes is the time needed by the Sun to cover a distance equal to its diameter[2]

Due to the reasons listed I do not believe that the total error, using a shadow sharpener with a pin-hole, at the instant in which the image of the Sun is halved, that is, at the instant in which the geometric shadow passes across a given point of the plane, can be less than ± 8 to 10 seconds.

<u>Some curiosities</u>

Besides the uses described, a pin-hole or a shadow sharpener allows us, for instance, to see on the ground the shadow of a wire or to see on a wall the shadows of tree leaves and branches, interspersed with spots of light. It is enough to put the hole at a distance from the wall, in the zone of shadow, and to move it slowly and with some patience. (Fig. 7)

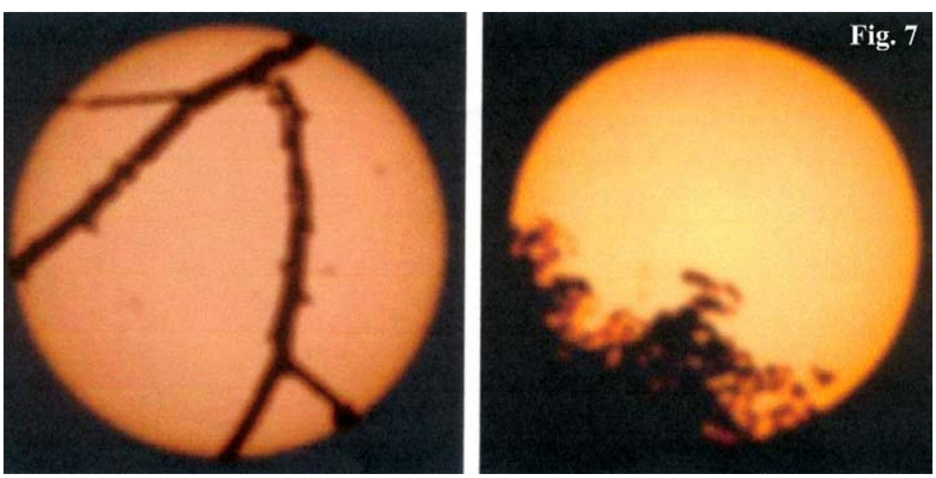


Fig. 7

[2] Since 1° of hour angle correspond exactly to 4 minutes of time, and the mean diameter of the Sun is around 31 ', it will take $\cong \frac{31}{60} \cdot 4\,\text{min} = 124\,\text{sec}$.

If you have ever stood beneath a tree during a partial eclipse of the Sun, you surely noticed the myriad of tiny crescent images of the partially blocked Sun, formed as sunlight filtered through the leaves. One tree, but a hundred or more shadow sharpeners.

A very simple shadow sharpener can be made by forming a hole with the fingers of the hands. For instance the fingertips of thumb and index of both hands can be joined and then moved nearer. In a different way, we may first close one hand and then lift the index finger, keeping it folded. Between it and the middle finger we obtain a small hole suitable to be used as a simple shadow sharpener.

Since a shadow sharpener allows us to “see” the profile of an obstacle against the background of the disk of the Sun, it cannot be used in pin-hole sundials, that is in the great sundials built in closed rooms or churches in which a little hole projects the image of the Sun. In these sundials a shadow sharpener would give only a small image of the hole without furnishing the image of the Sun’s disk. If we could put our eye in the place of the hole of the sharpener we would see in fact only the hole of the sundial completely illuminated by the Sun, whose disk, if it were not partially covered, would appear much greater than the hole itself.

Different methods

An optical shadow sharpener can be made simply by projecting the image of the Sun with common binoculars. The image in this case is magnified and very clean and precise. With this "apparatus" we must use a stand or tripod that holds the binoculars steady and eliminates the inevitable trembling of our hands.

A different system to get the same results as a shadow sharpener, proposed by different members of the Sundial List in 1999, would be to put our eye “behind” or “on” the hour line or “behind” the plane of the sundial, and from this point to look toward the Sun. If we could do this we would see, if our eye were “behind” an illuminated zone, the full disk of the Sun moving slowly toward the outline of the gnomon, and finally, completely darkened, or covered, by it - exactly as happens with a shadow sharpener, except with a sharpener the image will seem left to right reversed. For putting our eye “on” the hour line it is enough to lean a small mirror on it and to look for the reflected image of the Sun, as William Maddux proposed for the first time on 16 May 1999. At the beginning this may take some patience.

Obviously it is necessary to diminish the brightness of the Sun using a welding glass or a pair of "eclipse glasses" or a solar filter in mylar or two or more layers of blackened photographic film (not exposed and developed). WARNING!! You must NEVER look at the Sun, or its reflection, without adequate eye protection.

Bibliography

Sundial Mailing List - Messages exchanged in 1999, 2000, 2001, and 2002. See the Sundial Mailing List archives at: http://groups.yahoo.com/group/sundial/messages or http://www.astroarchive.com

My heartfelt thanks to Mac Oglesby, who has helped me with the translation into English and has corrected, with a lot of patience, my numerous mistakes

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[Editor’s Note: The next issue of *The Compendium* will include another article by Gianni Ferrari on a closely related subject: *The Shadow and Penumbra of a Rectilinear Element*.]

Sundial Face Marking Technique for the McMath-Pierce Solar Telescope

John Carmichael (Tucson AZ)

While preparing the bus tour for the NASS conference, I visited the huge observatory complex at Kitt Peak Arizona near Tucson. When I saw the sundial-like polar axis construction of the famous McMath Pierce Solar Telescope I studied the possibility of converting it into a huge horizontal sundial. This sundial would be unique because it would have a gnomon with multiple styles. After studying and measuring the building and site, I wrote a formal proposal to create a demonstration sundial. In May of this year, The National Optical Astronomy Observatory quickly accepted it. And from June 19 to June 21, a team of 5 volunteers helped me to mark the time points and seasonal markers of the demonstration sundial using the shadow of the solar telescope's angled polar axis structure (the light tube). We located the position of the marks using the very precise "Time & Shadow" method that employed the fuzzy edge (the penumbra) of the shadow, a shadow sharpener, an image projection screen, a precision radio clock and the Equation of Time Conversion. We marked the points on the chip & seal asphalt surface with 2 inch flat-head roofing nails with bright orange 1" washers. This is the procedure we used:

June 19 After checking into the cozy cabins provided by Kitt Peak, three of us (John Carmichael, Bob Hough and Cristina McVie) arrived on site at 4:00pm and we laid out the west, north and east borders of the rectangular shaped sundial using bright orange surveyor's string. We wanted all three border timelines to be in place so that we could begin practice markings at sunrise the next day. Using the south corner of the Heliostat Tower as our reference point and the border locations desired by Kitt Peak, we determined the position of the perimeter time markings. (This rectangular dial face has markings on the west, north and east sides and we will refer to them that way). We put nails a little beyond the corners and at the sunrise and sunset points on the perimeter timelines then we stretched surveyor's string between the nails and swept the excess pea gravel away with a push broom from underneath the string to expose the smoother black asphalt below. A smooth surface would allow the head nails to be driven in completely. The DeltaCad original sundial drawing I did for the proposal served as a useful guide, but we had to relocate the east timeline several feet to the west because of a chain link fence that was in the way. We noted the shadow at sunset so that we knew how long to make the east timeline.

June 20 Jun 20 was our practice day when we refined our techniques and did some experiments. Having this extra day proved to be a very wise decision! We were on site at 5:00am before our estimated sunrise at 5:22:47am. We placed all our equipment on the south end of the west timeline string where we estimated the sunrise shadow would be so that we would be ready when the sun rose. There was almost no horizon pollution to the northeast and using eclipse glasses, we observed the ½ solar disk rise above the distant mountains at 5:21:10am. The telescope's shadow appeared and we marked this point as the summer solstice sunrise time point. Then began the grueling schedule of marking time points every 5 minutes and all the other seasonal markers, style shift marks, and the High Noon mark. We worked in alternating shifts that we all agreed upon until sunset at 7:24pm. (Theoretical sunset time was 7:31, but a little horizon pollution made it happen at 7:24pm) There were 182 time points, six seasonal points, two style change points and one high noon point for a total of 191 points. We only missed two points during the day which we later marked using guesstimation and a ruler.

We used a pre-calculated Sundial Time / Mountain Standard Time List provided by Bob Hough that converts sundial time to watch time for June 20 so that we would avoid math errors by doing The Equation of Time corrections in our heads. For maximum precision, Bob had calculated the exact Equation of Time values for each and every point on the sundial! For easy reference, we had this printed time conversion chart and a drawing of the sundial face attached to a clipboard that we moved around with us. This list was indispensable.

To mark the timeline points, somebody had to watch the radio clock at all times. Another person held the 2 mm pinhole shadow sharpener at least 1 meter above the ground in the shadow's penumbra region so that the 1/2 solar disk image was centered on the string. This was somewhat difficult and required some practice, especially since we were battling 50 mile per hour winds for most of the day and it was hard to hold the sharpener still. The winds were so strong that we had to weight all our equipment down with rocks!

Because the asphalt was dark and uneven and made the image difficult to see, we placed a 1/8 inch thick, 18 inch long and 3 inch wide strip of beige flat particle board underneath the orange string to serve as the pinhole image projection screen and we slid it along the line as the shadow's penumbra moved. The clock person gave us 1 minute warnings so that we could get ready, then, counting down the seconds, at the correct radio clock time indicated on the Sundial/Watch Time list, the image location was noted, the screen removed and the nail person drove a nail into the asphalt at that point next to the string. We nailed small flat metal waterproof numerals and letters (Like the little metal ones you see on mailboxes) on the Hour, High Noon, style changes and seasonal points; and we marked the 15, 30 and 45-minute points with paper tags. Underneath the nail heads we placed bright orange washers for greater visibility.

We had a major problem after 12:50pm. This point is at the northeast corner of the sundial face. Shadow velocity increases dramatically after 12:50 because of the changing geometry of the borderlines. It was moving so fast (about 2 cm/second) that the person holding the shadow sharpener couldn't keep up and we missed a couple of points. Knowing this would happen again the next day, we were prepared for it so we wouldn't make the same mistake again. We also noted some rocks that were in the way on our late afternoon points so we had to shift the entire east timeline 23 cms to the east.

After sunset we were completely exhausted and went to bed early!

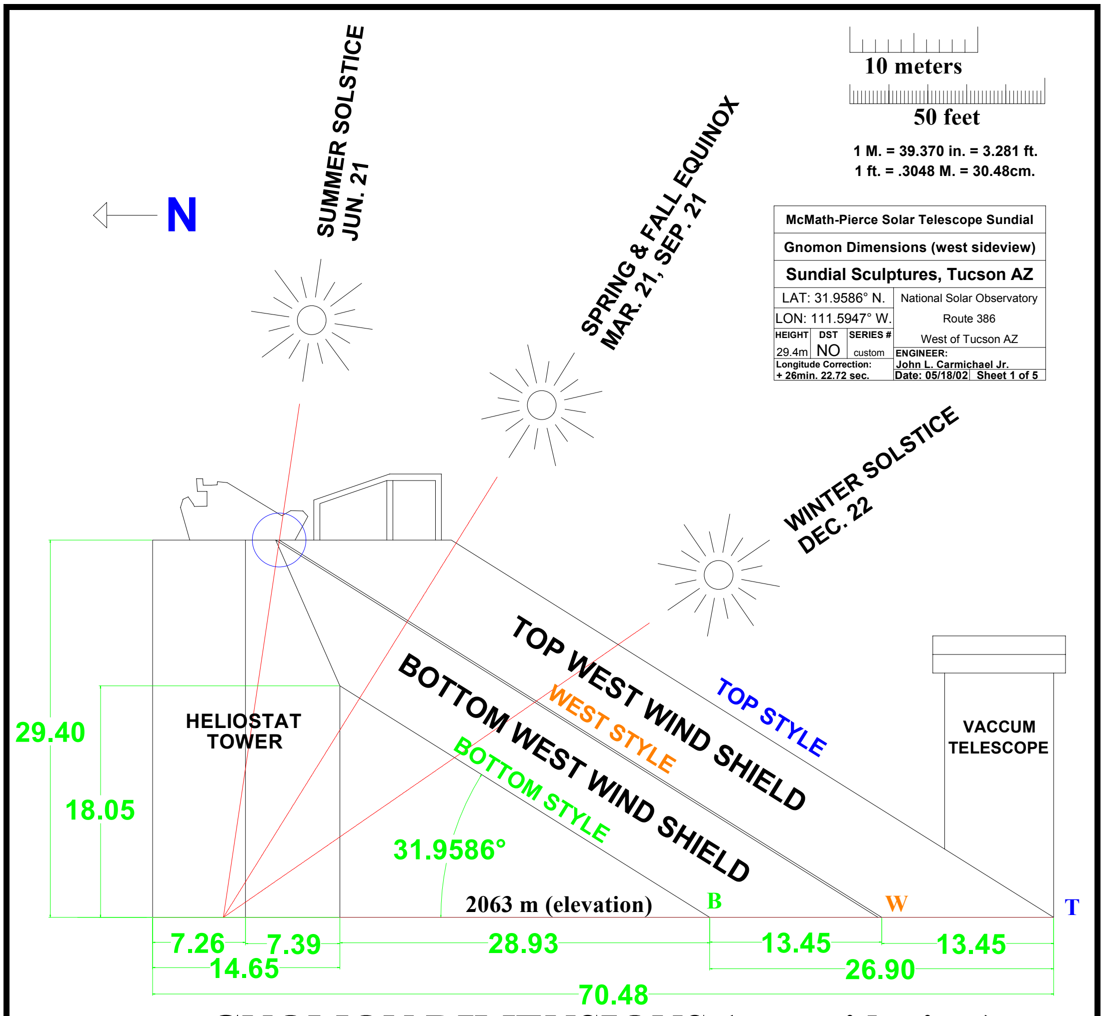
<u>June 21 (Summer Solstice)</u> With two new additional volunteers on site (Tom Maza and Mark Klingensmith), we repeated the marking procedures we perfected the day before. The extra help proved to be invaluable since there were constant distractions from visitors asking questions, and with extra people, we could take more rest and food breaks. Volunteer movie photographers Rich Richey (a docent tour guide at Kitt Peak) and Tom Maza filmed close-ups of the marking technique and a movie of the morning style shift. Unfortunately, we were unable to film a time-lapse movie because we didn't have enough time or the equipment to do it. But we also took still shots with a 35 mm camera.

In case these temporary markers are removed for some reason, and we need to reconstruct them in the future, after we marked the points, we placed a 100 ft. measuring tape along each time line and we wrote down the exact distance each point was from a corner point. With this information I can make a new DeltaCad drawing of the dial face as it actually is. And these points may help in the construction of a permanent sundial. When finished, I looked at the dial face from a distance and saw that I couldn't read any marker points because they were so small. To read the markers, you had to be near them. It was immediately apparent that the sundial lacked a sculptural presence. So, we placed rocks next to each point. We placed Big rocks next to the hour and seasonal points, medium size rocks next to the ½ hour points, and little rocks on the 5 minute points. These crude markings helped immensely to visualize the sundial and allow the user to read it from a great distance.

At sunset, we marked the last point and toasted to celebrate the finished sundial.

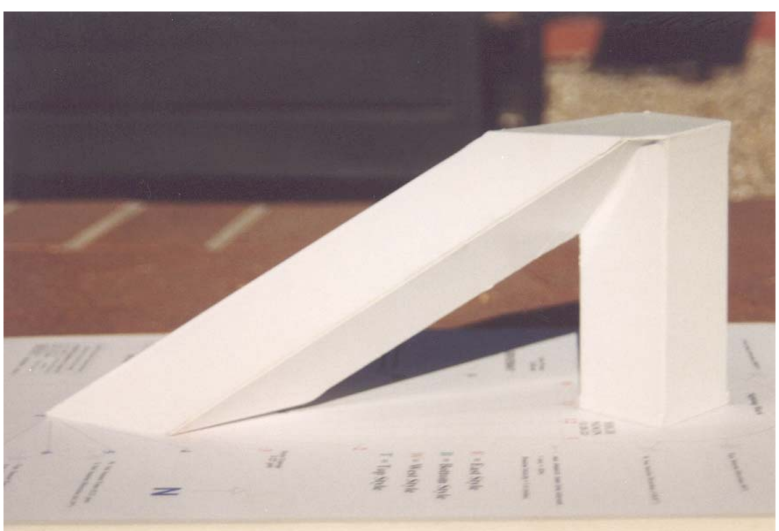
<u>The Future</u> Hopefully, the demonstration sundial will create interest and funding for a much nicer permanent sundial in the near future and that our experiences will help other dialists who wish to use the Time Method to mark future monumental sundials. We hope to monitor the demonstration dial at different dates to check its accuracy.

<u>Note on Precision</u> If we did our marking correctly, the biggest factor affecting precision will be the straightness of the styles. I suppose this could be checked exactly by using a laser, but lacking one, all we could use was our eyes. By placing one eye at the base of a style, we could look straight up the edge of the styles. We did see very slight undulations in the styles, but we guesstimated that they were only between 1 and 3 inches, a very small amount if you consider the enormous size of the sundial. These could only affect the precision of the dial by a few seconds. Time will tell!



GNOMON DIMENSIONS (west sideview)

John Carmichael, 925 E. Foothills Drive, Tucson AZ 85718 johncarmichael@mindspring.com



East view of a model of the McMath-Pierce Solar Telescope

Gnomons with Multiple Styles

John Carmichael (Tucson AZ)

My recent work adapting the giant McMath-Pierce Solar Telescope at Kitt Peak Arizona into a sundial made me realize that a sundial's gnomon can have almost any cross sectional shape, and we sundial designers are not limited to using the traditional pie-shaped, string or thin rod gnomons. Actual examples of these types of sundials are almost non-existent and we should exploit their endless design possibilities further. These dials' face markings work just like a traditional sundial, making these sundials with oddly shaped gnomons very user friendly. These sundials can be any size, and the sundial face can have any orientation: polar, equatorial, declining, reclining, uneven, etc. And best of all, they are fairly easy to design! Here is a description and drawings of gnomons with multiple styles, design instructions, and a practical example of design procedures using simplified versions of my actual telescope sundial drawings.

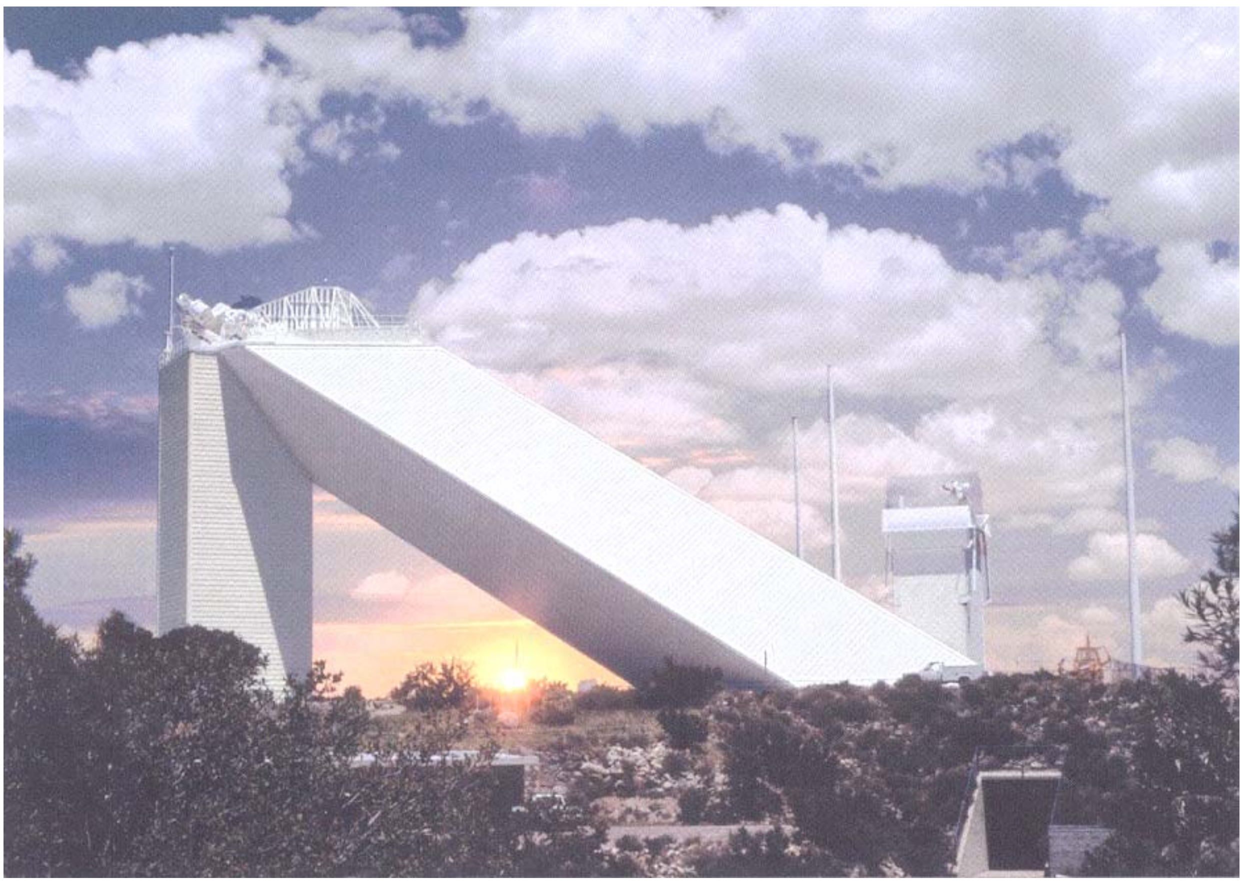


Figure 1. West View of the McMath-Pierce Solar Telescope (What is strange about this photo?)

These multi-sided gnomons lie parallel to the polar axis above the dial face just like the string or rod gnomons on typical monofilar sundials. But they are much thicker in relation to the dial face, so, to avoid large time reading errors, one must read the shadow from its edge and not its center. During the day, as the sun moves around the gnomon, different corners of the gnomon cast the edge of the shadow. So each corner of the gnomon functions as style with its own hour lines and is actually a separate sundial.

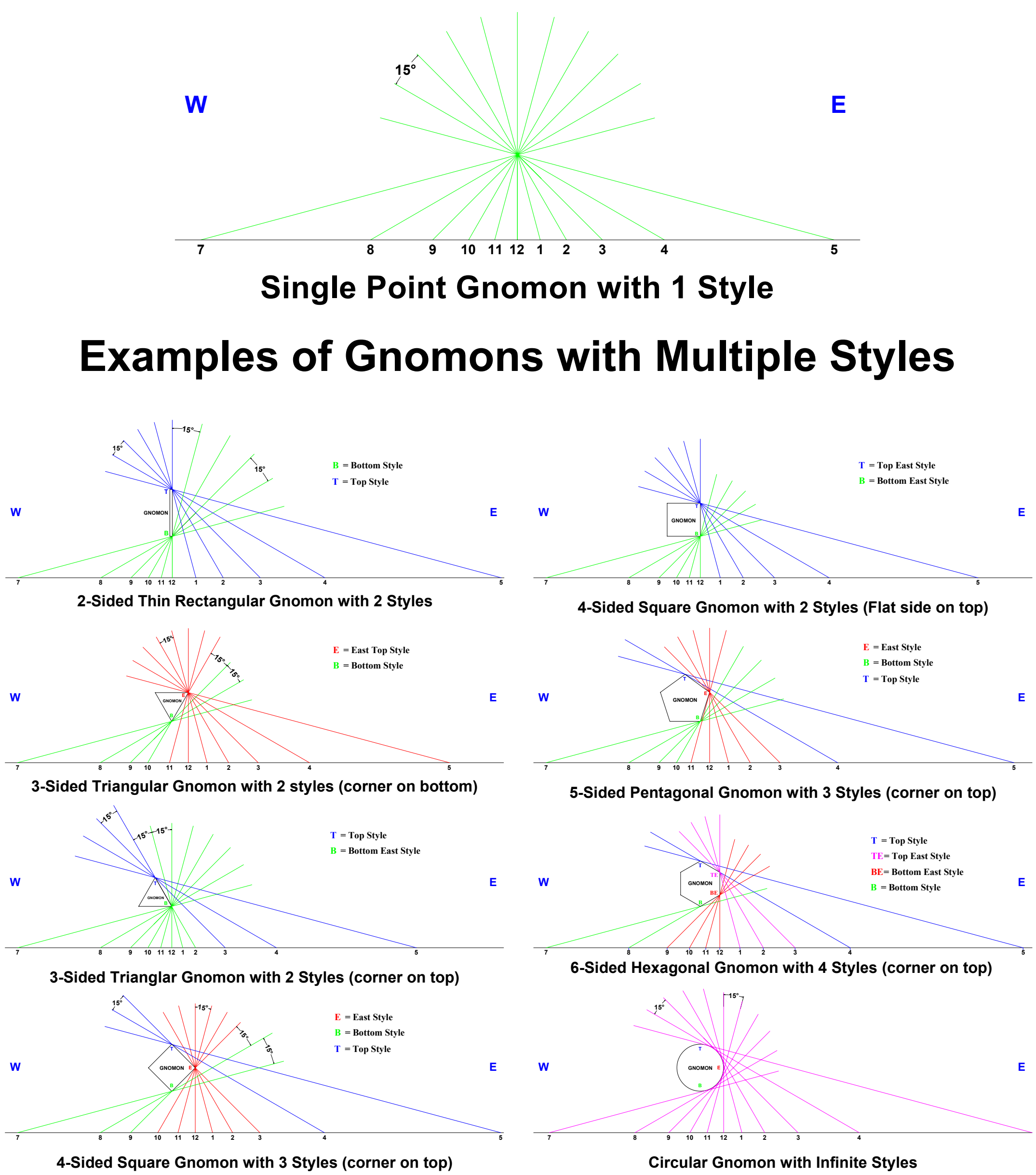
Adjacent styles work together to produce a smoothly flowing sequential timeline. Each style works for only a portion of the day because it is shaded by the gnomon's bulk at other times. The more sides there are on the gnomon, the less time each style functions. As the sun moves around the gnomon, one style becomes shaded by the next style that takes over and starts casting the shadow edge. I call this the "style shift". If a gnomon had 24 sides then one hour would pass between each style shift. You could design such a dial so that the style would shift at the top of each hour.

Figure 2

All the drawings in these examples show Apparent Solar Time in 1 hr. time intervals.
They are crossections of gnomons as viewed from the south looking towards the North Pole.

To draw gnomons with multiple styles you must first make a Reference Drawing of the hour lines.
Copy and place the appropriate hourlines from reference drawing onto the styles you are using.

Reference Drawing for Drawing Multi-styled Gnomons



After the style shift, the distance changes between the style and the face. This changes the velocity of the shadow, the width of the penumbra, and the spacing between the time points. This is a very interesting event to observe on a large monumental sundial where everything is magnified. The duration of style shift is about 80 seconds because of the apparent width of the sun's face. It takes that long for the sun's whole disk to turn the corner of the gnomon. Most observers will not even notice these subtle changes in the shadow edge unless they're paying close attention. These gnomons with what I call "wrap-around styles", can have a cross section of any polygon such as a triangle, a square, a rectangle, a hexagon, or even an oval or circle or amoeba shape!

Figure 2 shows some drawings with just a few of the possible multiple style gnomon shapes. They show a cross section of the gnomons as viewed from the south looking towards the North Celestial Pole. Some drawings show that the gnomons can have any rotational orientation. For example, you can put the corner of a triangular gnomon on the top, on the bottom or anywhere you want. Each drawing shows a gnomon with a different shape and how the hourly sunrays shine on its multiple styles. Note the Reference Drawing I used as a guide to locate the hour lines on the other drawings.

Design Instructions and an Example If you can design a traditional sundial you can design one of these. The only rule is that all the edges of the multi-sided gnomon must be parallel to the polar axis. I will use the Kitt Peak Telescope sundial as a good example of a 4-sided gnomon that uses 3 styles, but you can use the same design procedure for any polar axis gnomon with any number of multiple styles. The Kitt Peak Sundial gnomon cross section is a square with corners on the top, bottom and sides. The latitude is 32.5 degrees North and the longitude is 111.6 degrees West. The gnomon slants north by 32.5 degrees. To keep things simple in this example, we'll consider the face to be perfectly horizontal. I have drawn just the hour lines and have corrected for longitude.

First, make a drawing of a traditional horizontal sundial face that has a polar axis monofilar string

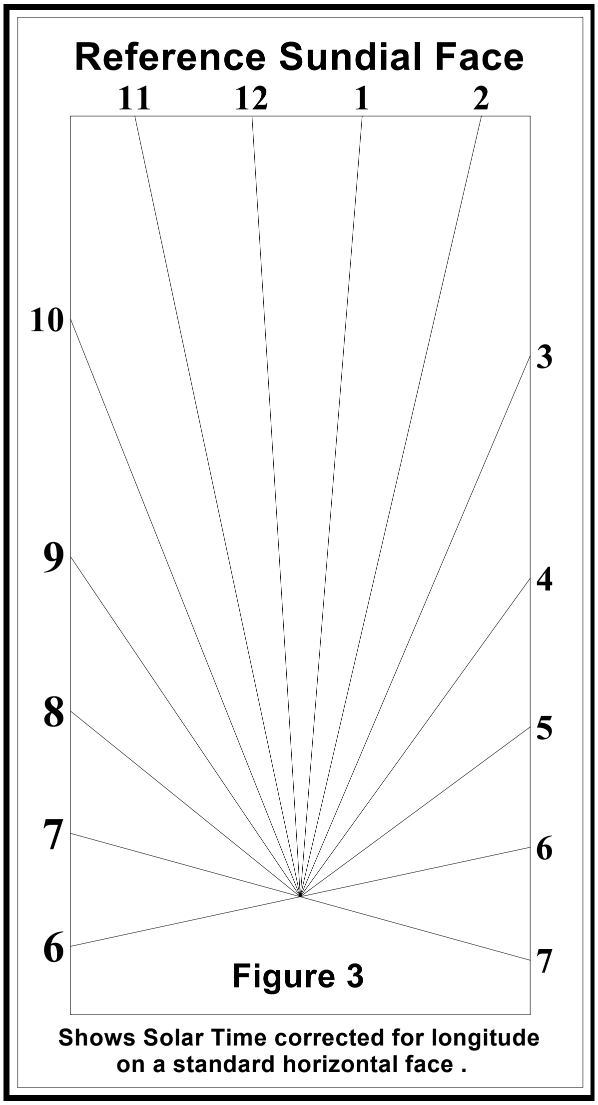


Figure 3

Shows Solar Time corrected for longitude on a standard horizontal face .

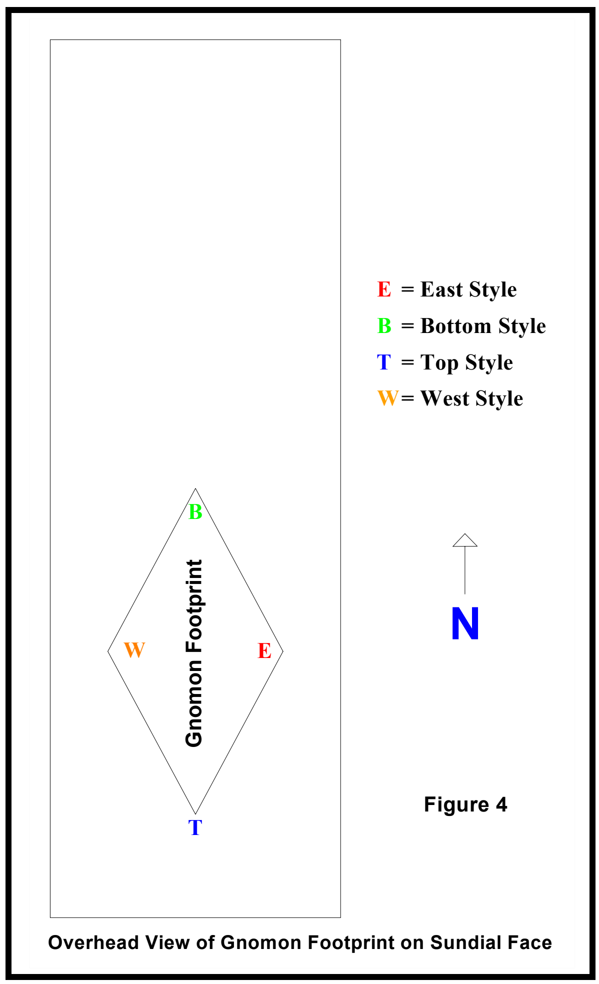
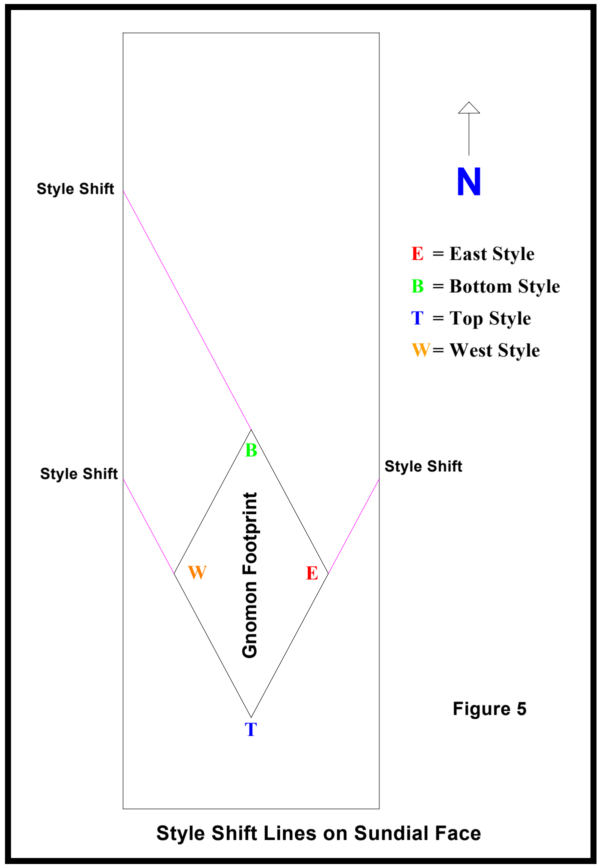


Figure 4

Overhead View of Gnomon Footprint on Sundial Face gnomon for your latitude and longitude and face orientation showing all the hour lines. Correct for longitude and DST if you like. This will be your hour line Reference Drawing that you will need to draw your sundial face (Fig 3).

Then choose the cross sectional shape and rotational orientation you want to use for your gnomon based on your artistic preferences and the face orientation that you need. Now make a new drawing of the sundial face only showing where each corner (style) on the polar axis gnomon intersects the dial face. Mark, connect and label these points. Draw the border of the sundial face. Now you have a drawing of the gnomon's "footprint" on the dial face (Fig 4). Note that the footprint of the square Kitt Peak gnomon is diamond shape. (If the Kitt Peak gnomon were round, its footprint would be an oval). Each of these points will function as the center of a separate sundial and will have its own set of hour lines. Extend the lines that connect these points out to the edge of the sundial face drawing. These



lines represent the time and location of the style shifts (Fig 5).

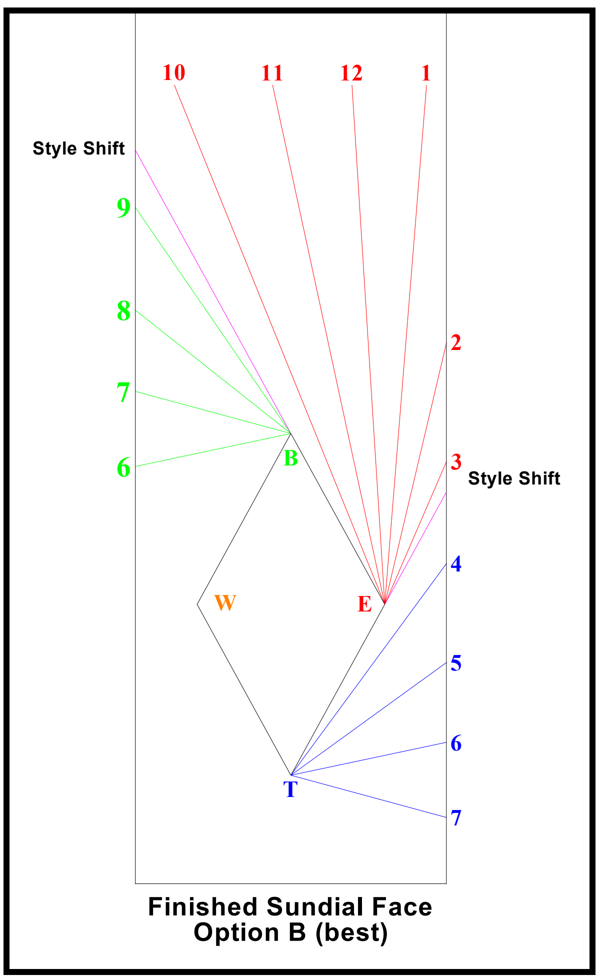


Figure 6

Now, place copies of the reference hour lines centered at each style intersection point on the face omitting those lines that are shaded by the gnomon at different times of the day. You can see which lines to use for each style by the location of the style shift lines already drawn. You now have a drawing of all possible hour lines. To cover the time period from sunrise to sunset, you'll see that you can use various combinations of styles and that you do not need to use all the styles. Choose the style combination that produces a pleasing and easy-to-read face drawing. For the Kitt Peak sundial I chose the Bottom, the East and the Top styles. Now erase all the timelines from the unused styles. In this case, I removed the unused West style lines. Your face drawing is complete (Fig 6).

Figure 7 is a collage of actual Kitt Peak photos and drawings showing the location of the bottom style as it appears on different drawings and photographs. This should help you visualize how the drawings are related.

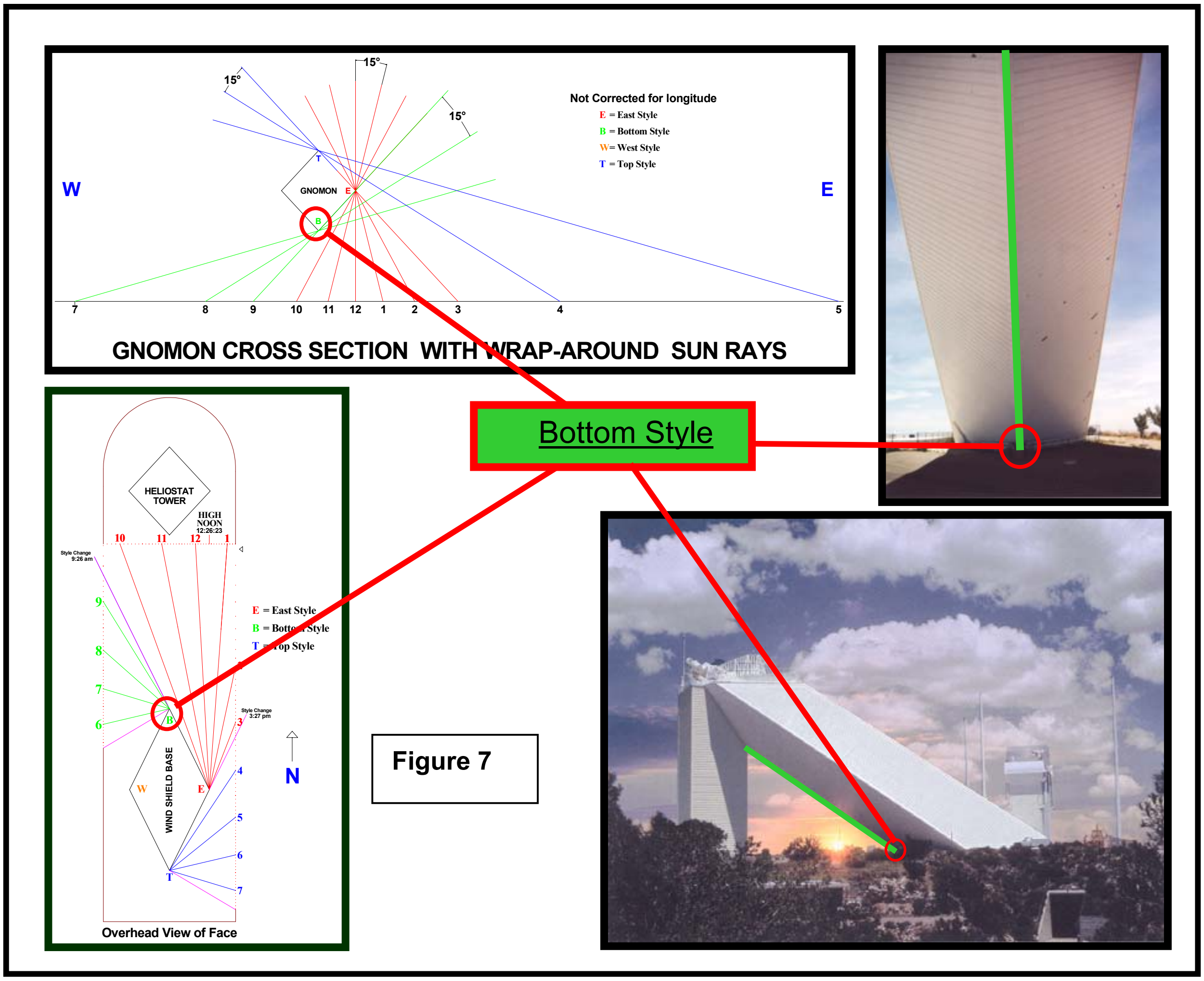


Figure 7

John L. Carmichael Jr. Sundial Sculptures, 925 E. Foothills Drive, Tucson AZ 85718
johncarmichael@mindspring.com, Website: Sundialsculptures.com
For links to the Kit Peak Solar Telescope Sundial go the NASS Links at sundials.org.

Back to Basics A column for the novice written by a novice

I continue to take another look at some familiar topics. Sometimes, understanding and insight comes with review and trying a *different* way to look at things. Here is the list for future discussions. Please look these over. If any of you has ideas on these questions, drop me a line.

March issue Things to look for -evaluating sundials. What adds dramatic interest? It has been suggested that a dialing scale can quickly check the accuracy of a dial. How?

June issue Drawing dials -simple ways to do it or how to use what is out there. What about other aids? What would you recommend?

This issue's article This is the issue for "other" topics. The question posed was, "How do you explain how a sundial works?" My answer starts with the daily motion of the sun. So, I take this opportunity to review the celestial sphere.

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The Celestial Sphere

Claude Hartman (Arroyo Grande CA)

It has been said that *a sundial is a finely crafted time instrument with only one moving part, the sun.* It works because the shadow from parts of the sundial follows the daily movement of the sun across the sky. This movement, we have learned, is a consequence of the earth's movement. Thus this shadow's record is as regular as the movement of the earth.

The Celestial Sphere

The construction of a sundial must recognize how the sun appears to move across the sky. In many ways this movement is seen as similar to the movement of a sphere surrounding us as we stand in the exact center. This sphere is called the "celestial sphere". This daily motion, up in the East and down in the West, is called “diurnal motion” and can be seen in the stars also, after all, a single motion of the earth causes it. Perhaps you have seen time exposures of stars moving along their “diurnal circles”. This takes some time because the movement is quite slow. The sun rises, sets and rises again in about 24 hours. This is a trip through 360 degrees. Thus, the rate of this movement, the “diurnal rate”, is 360 degrees per 24 hours, 15 degrees per hour or 1 degree each 4 minutes.

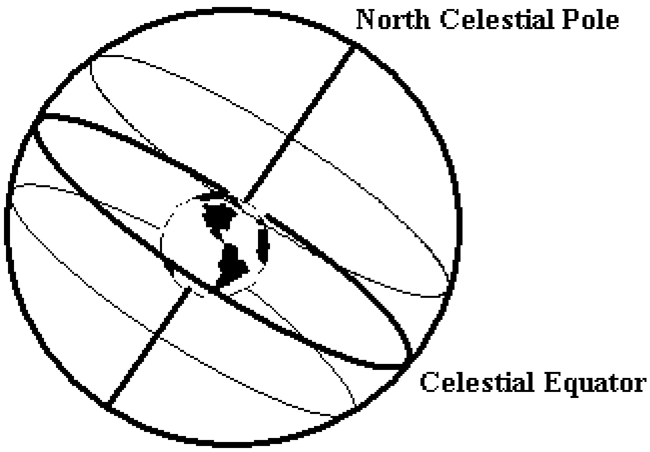

Figure 1. The Celstial Sphere

If we watch the movement of stars overhead, we will notice that there is one point in the sky that does not move. This is called the "Celestial Pole". The whole celestial sphere appears to move as though it is mounted on a pole or axis passing through the celestial poles and us. In Figure 1 the earth is shown in the center of the sphere in order to emphasize that it is the movement of the earth on its polar axis that is seen in the sky as the movement of the celestial sphere

The Polar Style

A sundial is most easily constructed if it models this movement. In order to do this, we must first make a pole that is parallel to the earth's pole. This means that it must point at the celestial pole in the sky. How do we position a pole so that it parallels the pole of rotation of the earth or the celestial sphere? You may have heard the answer often, angle it up at an angle equal to your latitude and point it due North.

In order to clarify some issues it is useful to look at a proof of that answer. In Figure 2 we are looking at an intersection of the celestial sphere with a vertical plane that passes through the north celestial pole, NCP. We, as the observer, are at the exact center, O. Directly overhead is our zenith, Z. The line ZO in the diagram is our vertical and must be perpendicular to the horizon. Our latitude is the angle from the celestial equator, CE, up to our zenith. Another right angle is between the NCP and CE. Now note that the little angle, Z-O-NCP complements both the right angles between the NCP and the CE as well as between Z and the horizon. That must mean the angle of the NCP above the horizon is equal to our latitude angle. A pole angled up from the horizon at an angle equal to our latitude must point at the celestial pole and be parallel to the earth's pole. Such a pole used as the shadow pointer of a sundial is called a "polar style". (The polar style shown in Figure 2 is shown displaced from the position of observation, O, for clarity.)

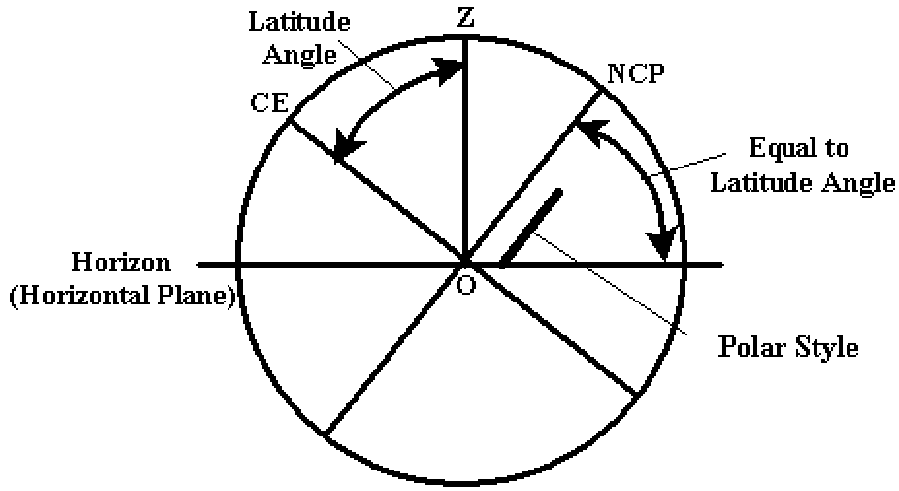

Figure 2. The Polar Style

Solar Declination

Unlike the stars, the position of the sun relative to the celestial equator is not fixed. It appears to move north and south during the year and is one of the principal reasons for changes in seasons. This is a consequence of seeing the sun from the earth among the stars. As we move about the sun, we see it in front of different groups of stars. However, the spin axis of the earth, the polar axis, is tipped with respect to the plane of our orbit. As we move about the sun, the polar axis keeps pointing at the same star. The consequence of this is that the equator sometimes appears above the sun and sometimes below. The position of an object is measured as an angle from the celestial equator called "declination". The maximum declination of the sun is about 23.44 degrees north (+) or south (-).

Unfortunately, the same name is used in sundial construction to describe how a surface differs, or declines, from facing South. For this reason we usually say "Solar declination" when talking about the position of the sun relative to the celestial equator.

The seasonal movement of the sun is eastward along the celestial equator relative to the stars. Keeping track of this allows determining seasons and the important events of the year. For this reason, the annual path of the sun among the stars was outlined by twelve constellations called the "Zodiac". Each constellation of the zodiac has a symbol. We often see these pictured on celestial spheres as a band of figures or symbols inclined by the 23.44 degrees to the celestial equator.

When the sun crosses the equator nearly equal daylight and night times are achieved. For this reason those positions are called an "equinox" (equal nights). At the extremes we have a "solstice". This name probably comes from observing the rising (or setting) sun along the horizon. During the year the rising or setting points can be seen to move as the declination changes. Toward a maximum this movement slows and at the maximum the sun appears to "stand" in the same place. The term "Solstice" means, "sun stands".

The symbols for the zodiac constellations (or "signs") in which the sun used to appear are still used for these positions or events. A third movement of the earth causes the position of the NCP to move among the stars. This in turn moves the position of the CE and all the coordinates related to it to change very slowly (360 degrees in about 26,000 years). Although slow, the difference has now moved the equinox more than two signs of the zodiac! It is odd that most Astrologers, aware of this difference, refer to “sun signs” as though the position among the stars has no meaning.

On the celestial sphere we often picture the northern and southern limits of solar declination as separate diurnal circles. See Figure 1. These are often referred to as the "tropics" coming from the word "tropo" referring to a line or limit.

This long discussion may help explain why we often see zodiacal signs instead of months on sundials. In addition, we often see two signs for the same declination lines!

Hour Circles and Hour Angles

Many ways of measuring the position of objects on the celestial sphere could be used. Any of these use only two measurements or coordinates. This is because the distance from the center of the sphere to any object is so great it can be ignored for many observations. All measurements on the sphere are really angles. A coordinate system then has a fundamental circle for measuring around the sphere and angles above or below this circle.

In the equatorial set of coordinates, the fundamental circle is the celestial equator, half way between the celestial poles. We have seen how the angle above or below this equator is an angle called declination. The other coordinate would be the angle around the equator. Astronomers have long used such a measurement for positions. The easiest way to make such a measurement was to note the time some point crossed your meridian. Remember that an observer's meridian is a vertical plane that divides his sky. The intersection of this plane on the celestial sphere can be seen as a line that rises due south passes through your zenith, through the NCP and then down through the north point on the horizon.

Now, to measure around the equator it is only necessary to *time* the crossing of the meridian. First note the time of the crossing of a reference point. The position of the spring equinox was used. Then note the time of crossing of the object of interest. This gives a position for the object around the celestial equator from the spring equinox. Lines that all have the same measurement would run through the celestial poles and perpendicular to the celestial equator. They look like the longitude lines that are shown on the earth's globe. Because of the way they are measured they have been called lines of "right ascension". This is because, as seen in the Northern Hemisphere while looking South, an object moves to the right (westward) and ascends to the meridian.

The position of the sun is often measured in a similar way, relative to the meridian. We time the crossing, most conveniently with a sundial! The position of the sun in the sky, the two coordinates, can be thought of as angle above or below the celestial equator and some time line around it called an "hour circle". (The intersection of a sphere and any plane passing through it is a circle.) I like to think of these hour circles as being fixed in the sky and the sun passing through them. In order to convert these timings into angles, we use the diurnal rate of 15 degrees per hour to get the "hour angle".

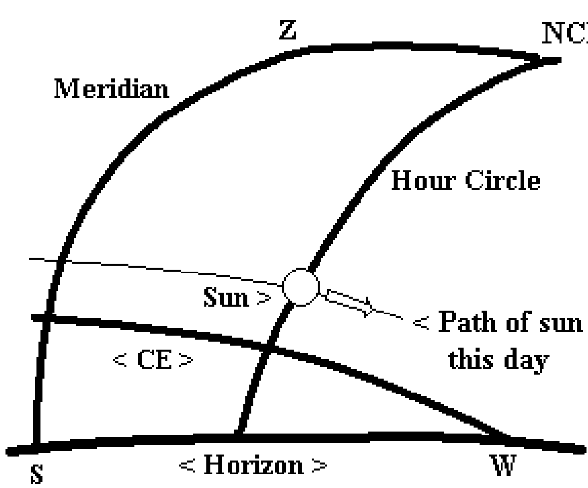

Figure 3. Hour Circle and Sky Coordinates

Why Polar Pointing Styles Work

All of this discussion of the celestial sphere can be put to work in order to understand many properties of sundials. For example, one of the problems with many designs is getting them to work all year long. This is really the problem of following the changing declination of the sun. Imagine looking at the sun in the afternoon. If we could see the coordinates of the celestial sphere it would look like Figure 3. However, in order to avoid a lot of clutter, only a few lines are shown.

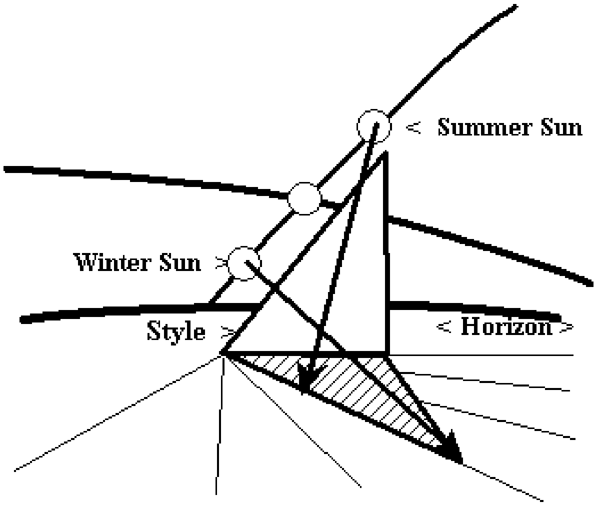

Fig. 4. A Polar Style is Always in the Same Plane as the Sun's Hour Circle

Consider the same time of day during the year. The change in declination of the sun moves it along some hour circle. In the summer it is higher in the sky than in the winter but for the same time of day, on the same hour circle. This is at an angle to the horizon that is not perpendicular except for noon. Now, look at this over a polar stye as in Figure 4. The annual motion of the sun would be seen to move right along this edge! Hence the shadow line for that hour would be the same at all times of the year. (The hour circles are circles that pass through both celestial poles; consequently, the polar axis must lie in this plane and so will a polar pointing style. Thus the hour circle, style, and lines of sunlight from the sun on that hour circle are still all in the same plane.)

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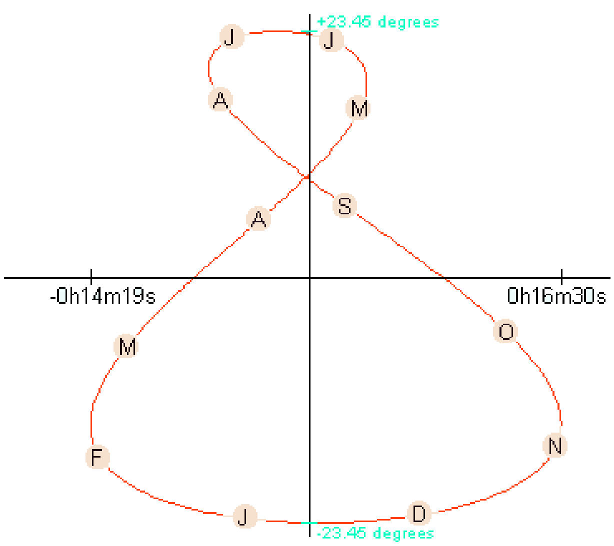
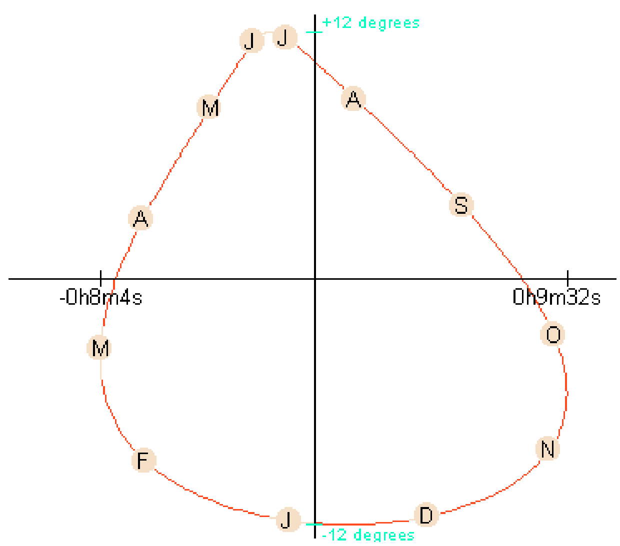
Digital Bonus: Analemma.exe (et al.)

Ever wonder what gives the analemma its distinctive shape? Care to know how each parameter affects the curve? How each affects the equation of time? Try analemma.exe, included with the digital edition of *The Compendium*. This program by Bob Urschel can also be found on the Internet at his excellent site www.analemma.com. The program allows you to set a variety of values for the earth's inclination and eccentricity of orbit, and the month of the vernal equinox – then with the click of a button, the resulting analemma or equation of time is drawn. We have shown here the standard analemma and the one that would result from a tilt in the earth's orbit of only 12º.





This issue of *The Compendium* also includes the full set of patent papers for Michael Eble's solar horoscope of 1863, and a revised copy (version 1.3) of the Reduce program produced for the December 1994 issue. This revision fixes a minor bug that has recently cropped up. For details on the use of this program, see *The Compendium*, Volume 1, Issue 4, (Dec. 1994). Also included are a new version of Helmut Sonderegger's Sonne.exe program (v.1.6.4) for drawing a variety of dial types and Analemma22.xls (v. 2.2), a corrected form of the spreadsheet sent with the June issue.

The First Analemmatic Sundial In Iran

Mohammad Bagheri (Tehran, Iran)

Iran has a long and rich tradition in many branches of astronomy, including gnomonics. Until a few decades ago, sundials were used in mosques and *madrasas* (traditional religious schools) to show the times of the day, especially to determine the times of the five daily ritual prayers. Nowadays in Iran, there is a noticeable interest in astronomy, both on academic and amateur levels. Some modern sundials have been constructed in educational and religious centers. For a short report on “Sundials in Iran”, see *The Compendium*, Dec 1998, 5(4):24-25.

The first analemmatic sundial or Iran has been constructed in a beautiful park named Būstān-e Mellat (lit., National Park) in the city of Rasht, center of the green province of Gīlān (37º16’N 49º 36’E) situated on the southern coast of the Caspian Sea. Gīlān is the birthplace of Kūshyār ibn Labbān, the Iranian astronomer who flourished around 1000 AD (see *Dictionary of Scientific Biography*, 1981, 7:531-533.)

The calculations and design of this analemmatic sundial were carried out by Mohammad Bagheri, an Iranian member of NASS. The construction of the sundial was encouraged by Thāqeb Astronomical Society of Gīlān and supported by the municipality and the city council of Rasht. Rasht, being surrounded by the Caspian and the Alburz mountain range, has mostly cloudy and rainy weather. However, on March 2, 2002, when the inauguration ceremony was being held in the presence of the official and academic authorities of the province and scores of astronomy enthusiasts, the sky was clear and the sun was shining. So, the curious participants in the gathering could check how the sundial works. There was also an exhibition of photos of different types of sundials from all over the world in the Park in a building that is the seat of the astronomical society.

There is a plan to construct several sundials of different types in this park in order to make it a scientific tourist attraction. We also plan to make Thāqeb Astronomical Society of Gīlān the main center for research and activity in gnomonics. We appeal hereby to all dialists and related institutions (observatories, planetariums, astronomical societies, sundial societies, etc.) to contribute to these goals by kindly sending their ideas, designs and sundial kits through the address mentioned below.

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[Friday 27 September 2002 was the first day of establishment and formal activity of a "Sundial Group" as a working branch of the Thāqeb Astronomical Society in Rasht. The seat of the Society is in a newly built beautiful park, which is planned to become a "Sundial Park". At present there is an analemmatic sundial in this park that attracts many visitors. The members of the Sundial Group (mostly young schoolgirls) plan to study the history along with mathematical, astronomical and artistic aspects of sundials, which provide them with a concrete application of the mathematical courses, especially trigonometry. They are supposed to be in charge of designing several sundials for the cultural buildings in the whole province in future. Any comments or communications may be sent to the Sundial Group at the above address.]

Quiz Answer : Finding Longitude

Posed by Rolf Wieland Solution by Gianni Ferrari

In 1714 the British Parliament announced in the famous Longitude Act a reward of 20,000 pounds sterling for a useful method to determine the geographical longitude within a deviation of not more than half a degree (more than 55km at the equator). In today's terms, this award would be worth several millions of dollars. After long quarrels in 1773 Mr. Harrison, a clockmaker, won the prize with his five highly accurate timekeepers H1 to H5, which carried Universal Time to places far away and thus made it possible to determine the longitude by the difference from Local Time. There are also other methods involving, for example, lunar distances or Jupiter eclipses, both of which require precise positions of the celestial bodies and precise instruments not available at that time.

One day in the year 2001 I measured from my back yard at latitude φ=49° 10' 13" with a fine second-theodolite the sun's azimuth a=53°29'13" and altitude h=35°26'18". What was the date and the time of observation? Is it possible to determine from this without a timekeeper the longitude λ of my home, too?

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Solution Preface by Rolf Wieland

This quiz was a challenge even for me, the author. I learned a lot by it. Most pleasure I took in the exchange of thoughts with other dialists. With all our different programs we can calculate very exactly the sun's declination for a certain moment because it is changing comparatively little. On the other hand, a very little alteration in the declination results in a large difference in the rotation angle of the earth. Thus I am not sure whether we could determine the moment when the sun reaches the required declination with an accuracy of 1", which is necessary for a good result for finding the longitude. Not to mention the difficulties with the practical performance. All this shows that the quiz was rather an experiment in mind than a real problem of observation. René J. Vinck is quite right in his solution when he notes that this quiz is very interesting but also very theoretical. The method doesn't work in practice for finding the longitude.

The excellent solution by Gianni Ferrari follows below - not to lessen the efforts of René J. Vinck, Richard Threet, Bill Buckler, Manuel Valdés, Hal Brandmaier and my own. Gianni tackled the problem, just as I had it in mind, in a perfect manner.

Solution by Gianni Ferrari...

I've calculated :
1. The Refraction (Bennett-Samudson's formulas) R = 1.3957'

2. The true height of the Sun h = h_apparent - R = 35° 24 ' 54"

3. Calling φ the Latitude, with the formulas

$$\sin(\delta) = \sin(h)\cdot\sin(\varphi) - \cos(h)\cdot\cos(\varphi)\cdot\cos(Az)$$

$$\sin(\omega) = \frac{\cos(h)\cdot\sin(Az)}{\cos(\delta)}$$

I've found the values of the Sun's Declination δ = 6° 58' 29.7" and of the Sun's hour angle ω = 41° 17' 31.1" corresponding to Local Apparent Time 14h 45m 10s.

4. There are two instants in the year in which the declination has the found value: Apr 7th 2001 at 13h 10m 56s and Sep 4th 2001 at 16h 57m 35s Greenwich Local Apparent Time. For this reason there are also two places on the Earth.

5. Making the differences between the times I've found the value of the longitudes of the two places. Exactly:

Longitude 23° 33 ' 31" East
Instant of the observation 15h 13m 01s Local Mean Time (TZ=-2h)

Longitude 33° 06 ' 15" West
Instant of the observation 14h 56m 30s Local Mean Time (TZ=+2)

With a very accurate program, I have checked the results : the program has confirmed the values found with a maximum error of 1" - 3".

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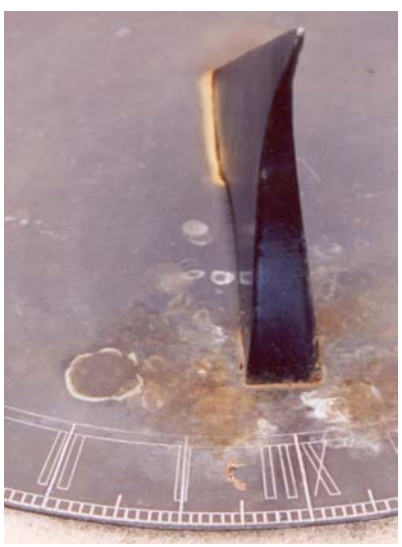
Sightings . . . Old and New in Augusta, Georgia

Steven R. Woodbury (Springfield VA)

Augusta, Georgia, is located on the fall line of the Savannah River, and was an industrial center even before the Civil War. Augusta State University has a brass horizontal sundial dating back to 1870 when the site was a U.S. Arsenal. The Riverwalk, along the river levee downtown, features a modern analemmatic dial.



The Arsenal Dial is bronze, with an iron knife-edge gnomon. It is circular, 22 inches across, and mounted on a rather plain concrete pedestal. The time marks (hour, half-hour, five-minute) are clear and unornamented. Very faint, but visible in the right light, are inscriptions apparently hammered with letter punches (they are not engraved). In large ornate letters: "AUGUSTA ARSENAL GA." In smaller letters "[???] by B. Lt. Col D.W. ORDNANCE" ; "Latitude 33^{o} 27' "; and "NUX YN EPXETAI". This latter is translated, in an old undated newspaper clipping, as "Night comes upon the earth" or more freely, "It is later than you think". The Augusta Arsenal was established in 1816 at a site along the Savannah River. It was removed to an upland site in 1827, after the garrison was wiped out in 1819 by 'black fever.' The arsenal continued at the site until 1955; the property is now the site of Augusta State University.

The Riverwalk is an attractive urban redevelopment effort, providing an attractive walkway along the river, and a cluster of museums, hotels, and attractions downtown. It includes a fine analemmatic dial, elegantly carved in granite, and embedded in the brick walkway. The dial tells daylight savings time, and includes a longitude correction.

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Eble's Horoscope

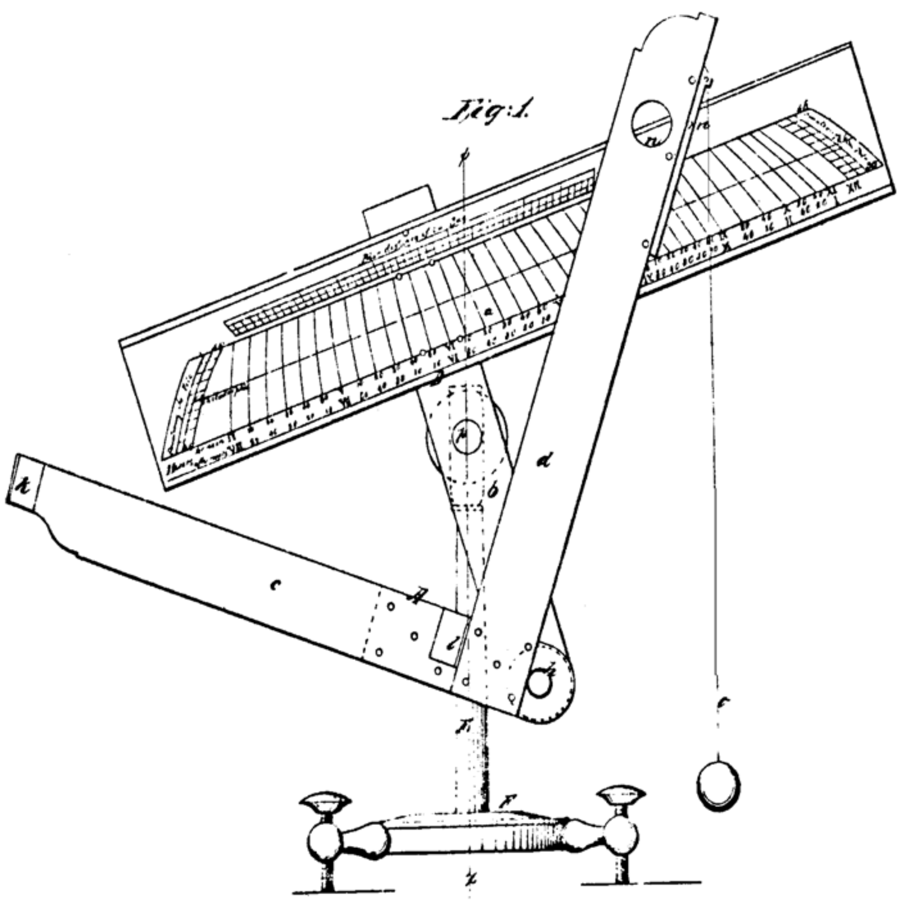
Fred Sawyer (Glastonbury CT)

Abstract: This paper discusses a 19th century horoscope invented by Michael Eble; it explains the operation of the device and presents an analysis of the theory underlying it. It will be shown that the horoscope is a universal altitude sundial using an interesting graphical algorithm.

In examining the history of sundials - at least the recent history - there is a middle ground between the geometrical constructions and trigonometric proofs of the scholarly book and the pleasant but time-consuming search through the countryside for surviving dials. One example of this middle ground is the Patent Office, for here one finds detailed drawings and descriptions of new approaches to the art of dialing, often as conceived not by the mathematical expert but by the practical artificer interested in introducing some new wrinkle to an age-old device.

In the United States, approximately 232 patents have been issued over the last century and a half for inventions relating to sundials. A review of the patent submissions shows that the examiners (and inventors) often were not familiar with the types of dials already in the public domain; in fact, a case can probably be made that they were not always familiar even with earlier patents issued in the same area. Nonetheless, a perusal of the patent papers can prove interesting and will sometimes surface designs worthy of note.

On September 8, 1863, U.S. Patent # 39,860 was issued for a solar horoscope. The inventor was Michael Eble, of Ellwangen in the Kingdom of Württemberg (now a region in the southwest of



Eble's Horoscope

Germany). Despite the astrological connotation of the term `horoscope', its etymological roots `ora' + `skopus' simply denote an hour or time observer. Eble's invention, which is pictured here, conforms to this latter sense of the term and is actually an interesting form of sundial.

Construction

The construction is as shown in the illustration above. Two flat strips of wood or metal are joined in a T shape and secured to a pivot on some appropriate stand. The pivot has a screw and nut arrangement allowing the user to lock the scale boards in any desired position, *i.e.* tilted at any angle from the vertical. The horizontal strip carries scales marked with latitudes, hours and solar declinations as shown in Fig. 1.

The declination scale along the top simply allows the user to tilt the scale board around the pivot so that its angle from the vertical equals the sun's declination. The scale therefore is simply an angle measure with the low end of the vertical strip as the vertex.

Now using this vertex as the origin of our measurements, the latitude scales are drawn as horizontal lines at a distance equal to sin L (where L is the latitude and the unit of measurement is some arbitrary value). Latitude lines can be seen in Fig. 1. The latitude line in Fig. 2 is nr, at a distance mp = sin L from the origin m. The entire scale board is shown here tilted from the vertical at an angle D equal to the solar declination.

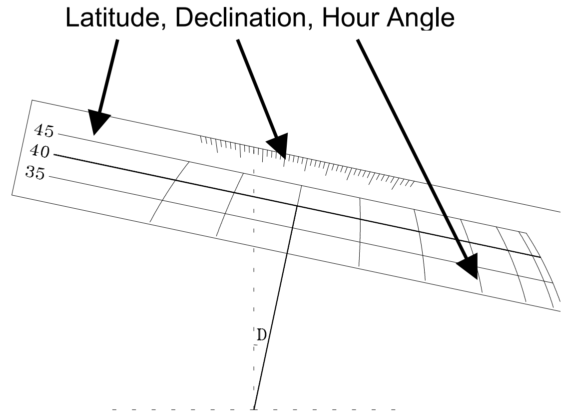


Figure 1. *The orientation of the scale here differs from that in the above illustration because here we are showing the scale set for a positive solar declination, and the above illustration shows a negative declination.*

Now using this vertex as the origin of our measurements, the latitude scales are drawn as horizontal lines at a distance equal to sin L (where L is the latitude and the unit of measurement is some arbitrary value). Latitude lines can be seen in Fig. 1. The latitude line in Fig. 2 is nr, at a distance mp = sin L from the origin m. The entire scale board is shown here tilted from the vertical at an angle D equal to the solar declination.

Finally, hours are marked by drawing a set of

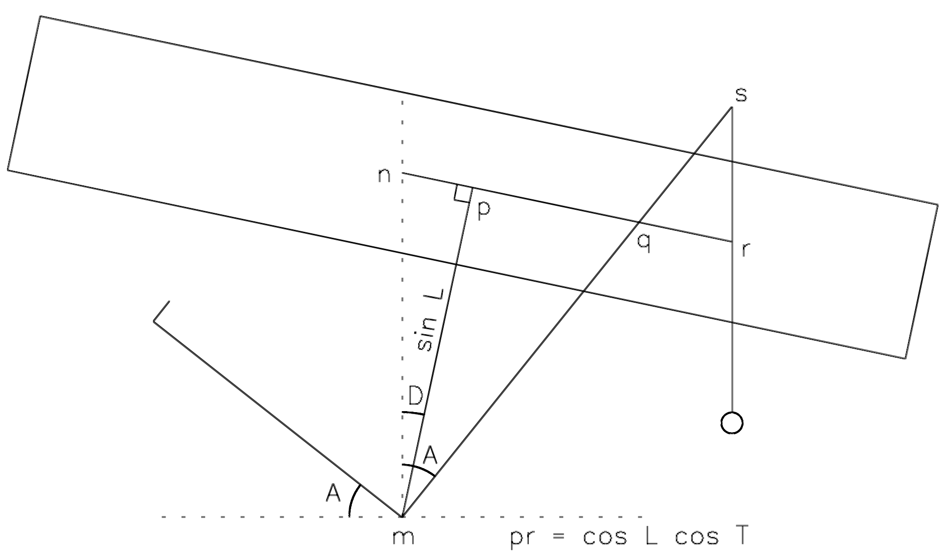


Figure 2.

curves so that the hour curve for T intersects the latitude line for L at r, with the distance pr = cos L cos T.

To finish the construction, an L-shaped index must be added. In Fig. 2, this index rises to the left from point m at an angle equal to the sun's altitude. Two vanes or small brass plates are attached to either end of this arm of the index; the front vane has a small hole so that the horoscope can be arranged to have the sun shine through the hole and onto a target point on the back vane.

The right arm of this L-shaped index is ms in Fig. 2; it has a length equal to 1 (*i.e.* equal to whatever unit measure we have chosen).

The index is joined to the horoscope at point m in such a way that it can rotate in the vertical plane as it is pointed towards the sun. Note that it must be mounted so that the point s lies on the line through m and perpendicular to the sun ray located by the left arm of the index.

Now let a plumb line fall from the s point so that its intersection with the latitude lines and hour curves can be seen.

Use

Begin by tilting the scale board from the vertical at an angle equal to the sun's declination for the current date. Place the device on a horizontal surface and turn it so that the index arm with vanes is pointed at the sun; rotate the L-shaped index about the point m as necessary to have a spot of light shine through the front vane and onto the center of the back vane. In this way, the front arm of the index is raised above the horizon at an angle equal to the sun's altitude. To read the time of day (before or after noon), note the intersection of the plumb line and the line corresponding to the latitude of the dial's location. Where this intersection falls amid the hour curves indicates the current time.

Justification

Referring to Fig. 2, note that the scale board is tilted from the vertical at angle D equal to the solar declination. The latitude line nr is at a distance mp = sin L from point m. We therefore have:

$$np = \sin L \tan D \qquad pq = \sin L \tan(A - D)$$
$$mq = \sin L / \cos(A - D)$$

Since mn and sr are parallel, giving us similar triangles mnq and srq, and ms = 1, we have nr = nq/mq, so:

$$nr = nq / mq = \frac{\sin L(\tan(A-D) + \tan D}{\sin L / \cos(A-D)}$$
$$= \sin(A-D) + \tan D \cos(A-D)$$
$$= \sin A / \cos D$$

We use this result with the expression above for np to find pr:

$$pr = nr - np = (\sin A - \sin L \sin D) / \cos D$$

Since we know from the construction of the hour scale that $pr = \cos L \cos T$, we can set these two expressions equal to each other and solve for A to obtain:

$$\sin A = \sin L \sin D + \cos L \cos D \cos T \text{ ,}$$

which is the standard equation relating latitude and solar altitude, declination and hour angle. So, if the horoscope is arranged so that the angles L, A and D respectively equal the latitude and the sun's altitude and declination, then T is in fact the sun's hour angle, and the horoscope operates as a universal altitude sundial.

Final note

In closing, note that the justification of this horoscope would work as just well if the latitude and declination angles were switched everywhere in the proof – one for the other. If we were to do this, the resulting device would simply be the universal Rojas astrolabe popularized in the 16th century by Juan de Rojas. This astrolabe also determines time from the altitude of the sun and is based on an orthographic projection of the sky onto the meridian plane.

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From The Rojas Astrolabe To Four Universal Altitude Dials

Yvon Massé (Pontoise, France)

Translation by Bethanie L. Sawyer

SUMMARY: The Rojas astrolabe is an instrument of calculation which implements the graphic layout of the analemma used since antiquity. The instrument, or analemma, represents the orthogonal projection of the celestial sphere on the plane of the meridian and allows the resolution of the problems of spherical astronomy, in particular, of obtaining the height of the sun, given its hour angle. Inversely, the sight vanes can be adapted on the regula of the astrolabe in order to read the height of the sun and then obtain the actual hour of observation. A different orientation of the layout of the astrolabe associated with the use of the original alidade, presented in this article, will permit the direct reading of the hour and thus the realization of a universal altitude dial. The examination of the necessary elements alone for the reading of the hour will yield another type of dial using a regula graduated by hour to move according to the seasons. Finally, the analysis of the equation which gives the height of the sun will furnish an immediate short-cut for obtaining from the two preceding dials two new altitude dials.

Let us recall in a few lines the principle and use of Rojas' astrolabe. We can see in figure 1 the instrument reduced to the layout, which interests us for gnomonics. Its graduation involves parallel lines, which correspond to the declinations of the sun and portions of ellipses for the hour angles. Thus for one given hour and date the position of the sun is determined at the intersection of these curves.

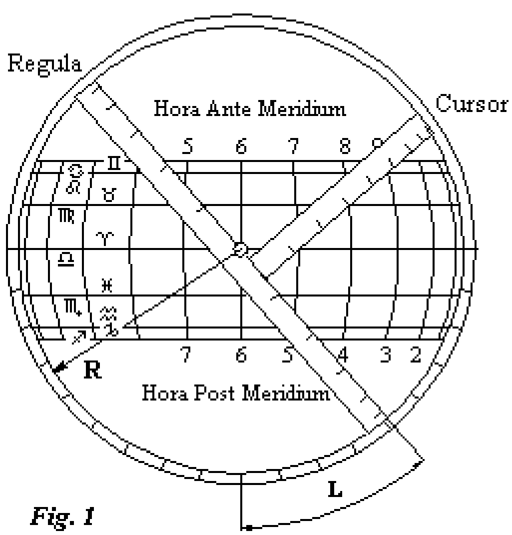

Fig. 1

The regula permits, by rotation around its fixed point at the center of the astrolabe, its adjustment for the latitude of the place of observation. The cursor, guided along the regula, gives the height of the sun by its intersection with the declination line and graduated hour curve. We see thus in figure 1 that at the latitude 41° North, at 4 solar hours after noon, when the sun enters into Taurus, that it is situated at 30° above the horizon (cursor markings are given for 10° intervals).

Let R be the radius of reference of the astrolabe, L the latitude of the location, D the declination of the sun, Ah its hour angle and H its height or altitude. The astrolabe solves in this case the relation of the height of the sun:

$$\sin H = \sin L \sin D + \cos L \cos D \cos Ah$$

The factors sin L and cos L correspond to the rotation of the mark "regula" in relation to the mark "astrolabe". The H-point of the cursor is situated at R sin H along the graduated edge of the regula. This distance can be shown directly from the reading of the height of the sun using the alidade of figure 2.

The vanes involve an arm articulated around point O. A coarse thread is suspended at point Q and the line of sight PP' is perpendicular to the straight line OQ. The distance of the thread to point O is therefore OQ sin H. Note that the result has an orientation: in effect if it is sight-vane P which is directed toward the sun, then the thread passes to the other side of point O and we can consider therefore that its distance from O is negative. Taking OQ = R, the taut thread shows then all the positions that the graduation H of the cursor can take, moving on the regula, held vertical. Orienting the astrolabe in this way, we obtain directly the instrument of figure 3 which is a universal altitude dial, which we will call dial 1.

Its directions for use are very simple:

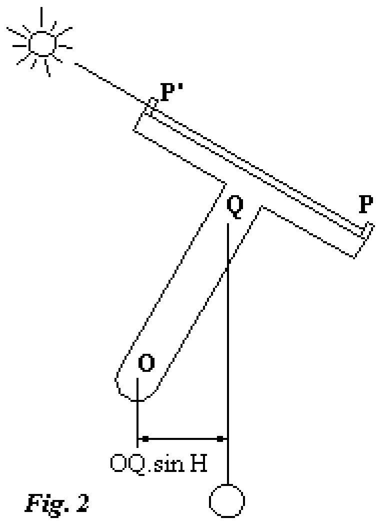

Fig. 2

Adjust the dial for the latitude L of the location by turning the table in front of index I in the direction of the figure for the northern hemisphere and in the inverse direction for the southern hemisphere. The dial is then suspended from the hole S and the alidade, well-balanced by the counterweight C, is oriented in the direction of the sun, as shown by the arrow. We then read the hour at the intersection of the taut thread and the line of declination of the day of observation. On the figure, we can see for a height of 30°, at the latitude 41° North and when the sun enters into Taurus, that it is the 8th hour of the morning or the 4th hour of the afternoon.

Let us note that, for a given day, the reading of the hour will take place on one unique segment of the line. Let us isolate this segment and describe its position and those of its graduations. In figure 4 we can see the angles L, D, and H as well as the ray R which define entirely the functional geometry of the dial. The segment has a length of 2R cos D and is R sin D in distance from the center O of the dial. Finally the graduation of the hourly angle Ah is situated at a distance R cos D cos Ah from the center of the segment.

If, for each declination D of the sun, we make a scale change of factor 1/cos D the system is still functional. The interesting point here is that the segment now has a constant length and a graduation and it can be replaced by a regula of length 2R to move according to the declination of the sun. It must then be at a distance of R tan D from the center of the dial. The distance of the point of suspension of the thread must also be moved to R/cos D.

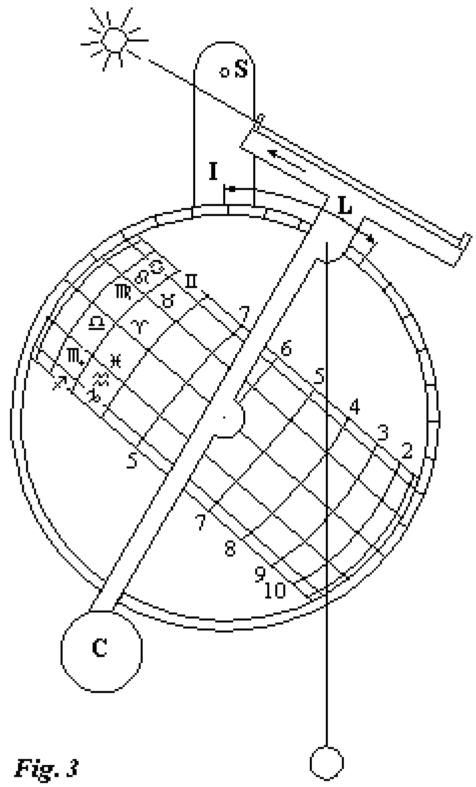

Fig. 3

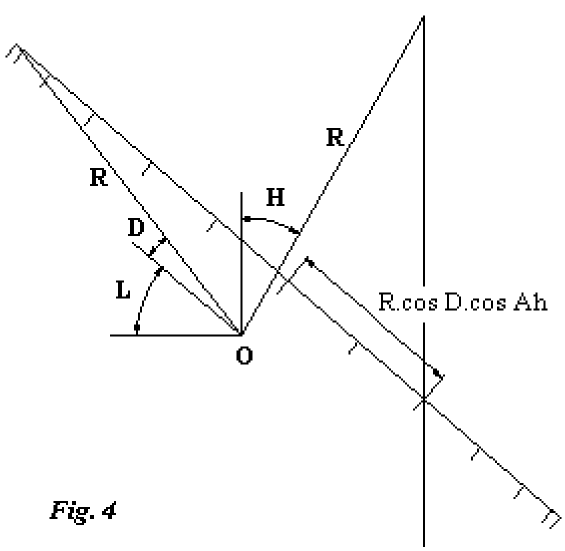

Fig. 4

We can now imagine the dial in figure 5 which we will call dial 2.

Directions for its use follow:

Move the regula T, guided by the two grooves G and G', to the declination of the sun on the day of observation. By turning the alidade, approach the point of suspension of the thread from the edge of the regula. Loosen the screw M and, by sliding the point of suspension the length of the arm, adjust it so that it just touches the edge of the regula, then retighten the screw. Proceed in the same manner with the counterweight. Turn the table/regula ensemble in front of index I to set the dial to the latitude of the location. If the regula is of a considerable weight and is liable to unbalance the dial, suspend this and use the thread as an index after having turned the alidade until the thread

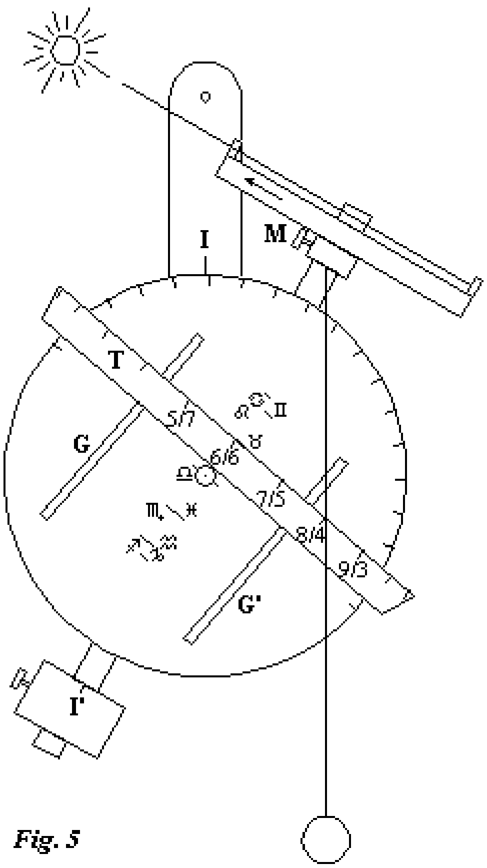

Fig. 5

passes in front of the mark I' of the counterweight. Direct the sight vanes into the alignment of the sun taking into account the arrow and read the hour indicated by the thread on the regula.

Let us rewrite the formula giving the height of the sun and examine it closely.

sin H = sin L sin D + cos L cos D cos Ah

We can note that the angles L and D are used at the same time (*i.e.* in the same algebraic terms) and with the same trigonometric functions. We reach therefore the same result if we use the declination of the sun for the latitude and inversely the latitude for the declination of the sun. It is this transformation, which permits us to pass from the universal dial of Regiomontanus to that of Apian. It allows us to obtain directly from dial 1 the dial in figure six, which we will call dial 3.

Its method of use is similar to that of dial 1, the difference being that we must invert the latitude and the declination. So it is the declination of the sun on the day of observation that must be set before index I and the reading of the hour occurs on the segment corresponding to the latitude of the location.

In the same manner we can get from dial 2 the dial in figure 7, which was described in the supplement of the *Encyclopédie* by Diderot and d'Alembert. To configure it to the latitude of the place it is necessary to slide the regula BD to bring it about to face the corresponding graduation as well as the point of suspension of the thread on the arm AF.

For its use here is what we can read in the encyclopedia about a simplification of this dial:

To find the hour by this instrument, place the ruler AF on the sign and on the degree of the ecliptic where the sun is the day of observation; turn the sector so that the ruler which stays always on the degree of the ecliptic where it was put, is perpendicular to the horizon and in the position AON, or that the thread IK passes by the center A; then, without moving the sector, turn the ruler until the sight vanes are directed to the center of the sun; the thread IK will indicate what hour it is.

Let us note that, just as is the case with the universal dials of Regiomontanus and Apian, this dial is not graduated for latitudes in the southern hemisphere. The reason for this is to simplify most of the graduations. In exchange its use in the southern hemisphere requires an inversion, whether it be of the scale of signs or the direction of aim of the sight vanes and the morning hours with those of the afternoon.

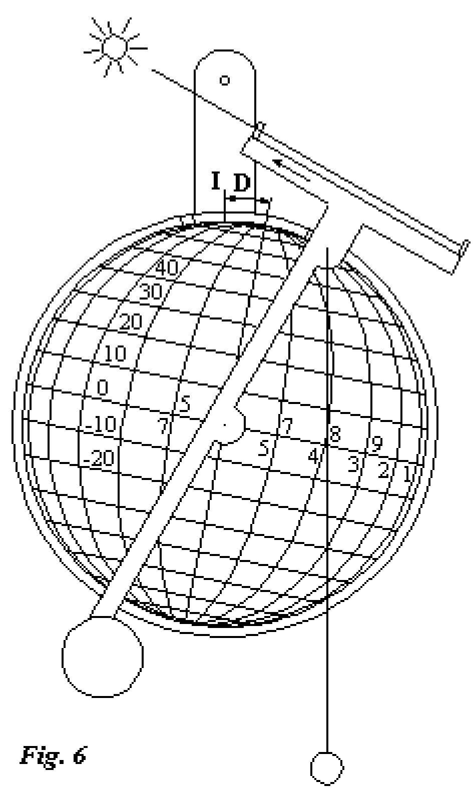

Fig. 6

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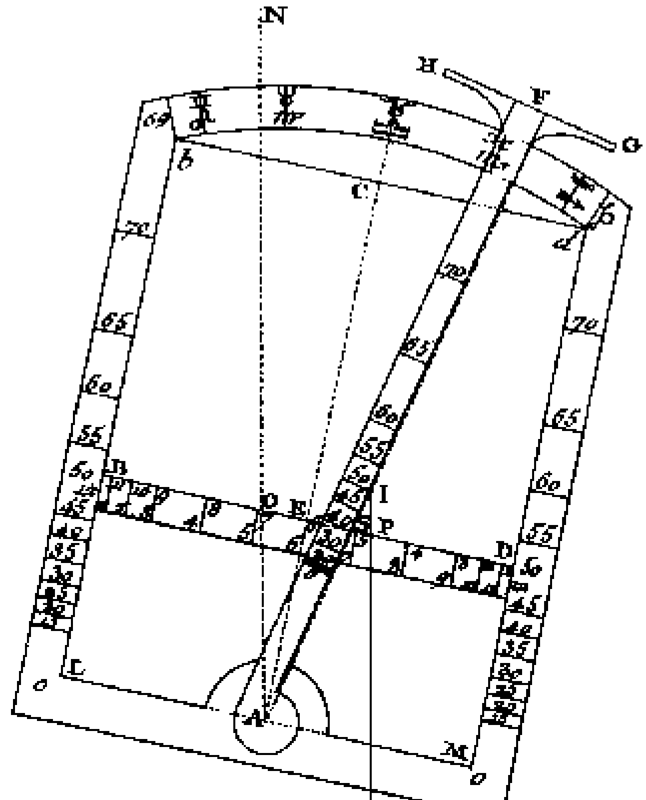
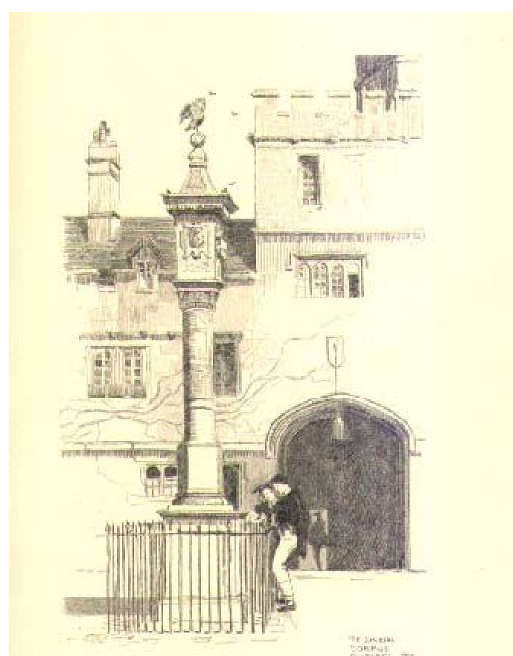


Fig. 7

Quiz: Winston's Window

Rolf Wieland (Satteldorf, Germany)

As a young student, my friend Winston lived in Würzburg at longitude λ=10°E and latitude φ=50°N in a garret apartment beneath a steep roof with only a small dormer window. He never got up early in the morning, so it was lucky that the sun shone fully through the window in the roof at 9:00 Central European Time. My friend allowed that this happened all year around, in winter as well as in summer, at nearly the same time with only little differences of about a quarter of an hour maximum when the sun was shining at all. How was it possible that the time of the sun's full illumination of the window did not vary much in the course of the year, and what was the direction of the window?



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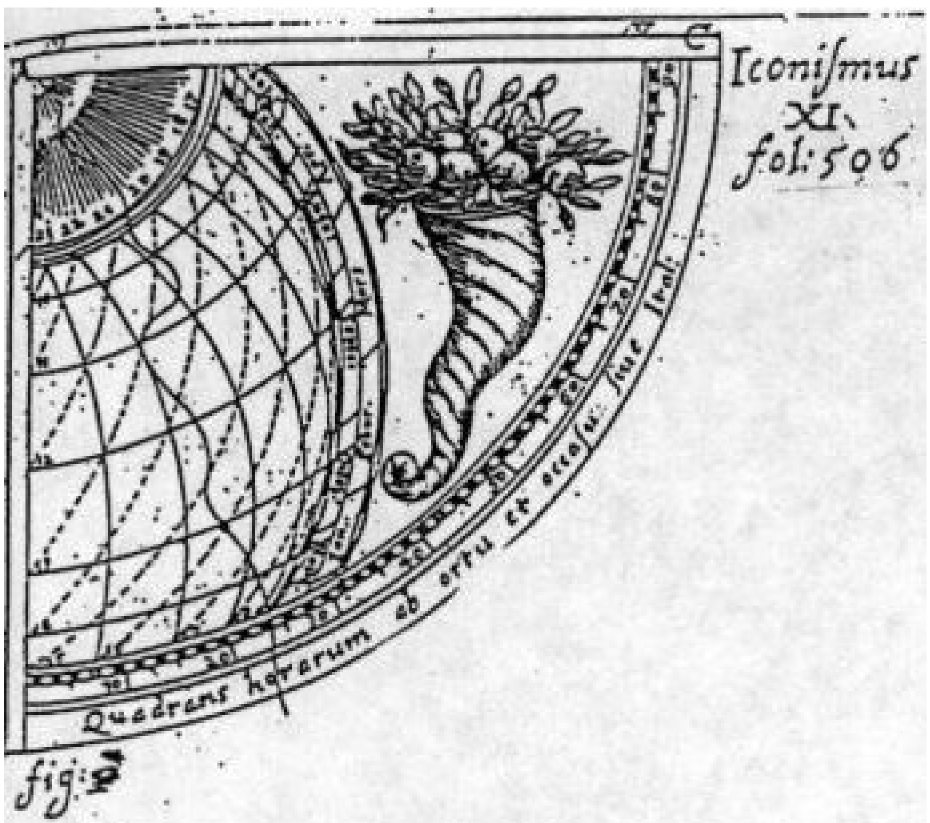
Letters, Notes, Email, Internet….

From Fer J. de Vries ferdv@iae.nl

In 1998 we wrote in the September issue of *The Compendium* about Card Dials with Italian Hours. In graphic 4 of that article an old card dial is shown. The only one we could find. Because only numerals for Italian hours could be read, we wrote that we weren't aware of such a dial for Babylonian hours. However it is possible to use the card for Babylonian hours as well. We also did that in our graphics, using the same lines for both the time systems.

But now I have a picture of such a dial in which it is noted that it may be used for both time systems, although I only see the numerals for the Italian hours. I found this picture in the Italian gnomonic dictionary by Nicola Severino as fig.19 and I attach the appropriate part of that picture.

From A. Kircher, Ars Magna Lucis et Umbrae, fol. 506, liber VI



The dictionary is at http://www.gnomonica.it/diziona.html. In the text around is written: Quadrans horarum ab ortu et occasu.... Well, our call "We would be pleased to learn of any such" is answered now.

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I want to make a suggestion to the Compendium Editor: It is a common mistake in the articles in *The Compendium* to refer to Winter Solstice and Summer Solstice. That is OK for the North Hemisphere; for instance, in the article of Art Kaufman, "*A Physics Experiment, etc.*" Fig.4. At Machu Picchu in December they are in Summer Solstice. I think it is better to refer to Boreal or Septentrional Solstice, and Austral Solstice. Or, if you prefer, more simply, North Solstice and South Solstice. Also on the ecliptic, the Vernal Equinox would be better called the Ascending Equinox. I leave this suggestion for your consideration. All this for the Globalization of Astronomy.

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In searching for a website that gives you latitude and longitude coordinates from a street address or zipcode, I really started to worry when I found that all of the major map making websites do not offer this service anymore…. Finally, I found: maporama.com. It gives latitude and longitude in both decimal form and degrees:min:sec. It works for anyplace in the world. And it's very user friendly.

Robert Hough shadow_master@comcast.net

[T]hanks to John for sharing the Maporama web site and to Patrick Powers for contributing the Multimap web site. I have been trying both of them and have found that Maporama offers the coordinate in both the d/m/s and decimal notations while Multimap offers only d/m/s, but that is a small difference. The big difference is the Multimap is much better in locating small streets and exact locations and showing the street details. I am currently working on dials for people that live on short streets in Germany, Scotland and the US and Multimap has been able to find them all right down to the street block, while Maporama in most cases could only discriminate to the town level and in some cases couldn't even find the town. For my own address on a one-block long street, Maporama can't find it, while Multimap pin points it exactly even though it doesn't show my street on the map background, it does show the exact location in relation to nearby streets. www.multimap.com maporama.com

Fred Sawyer fwsawyer@aya.yale.edu To Bruce Stephenson of the Adler Planetarium

Now that the Tucson NASS conference is finished, I've already begun working on talks I am planning to give at next year's gathering. While doing research for one of the talks, I came across some material which may or may not be new information on one of the dials in the Adler's collection. I'm thinking of the magnetic azimuth dial from Dieppe – identified only as such on page 20 of S. Lloyd's _Ivory Diptych Sundials 1570-1750_. Lloyd provides a translation of a brief instruction manual found in the case accompanyng the dial; the manual is by an unidentified "N.C." _Usage de l'Orloge ou Cadran Azimuttal ensemble, de l'Equinoctial ou Cadran Universel, avec celui de la Lune_, by N.C., Estienne & Pierre Acher, Dieppe, 1653. This manual appears to be a set of instructions that was copied by different dial makers for use with the dial type generally known today as a Bloud dial, closely associated with the Dieppe sundial trade. It's not clear who the original author was. On pp.49-50 of Apel & Pytel's _L'Ombre Domestiquée_ there is a reproduction of the title page of essentially the same manual (circa 1667) with Gabriel Blou(d) listed as author. Apel & Pytel also excerpt a portion of the manual – making some comparison with the Adler's version fairly easy. Blou(d), Gabriel, _Usage de l'Horloge ou Quadran Azimutal, ensemble de l'Equinoctial ou Cadran Universel, avec celuy de la Lune_, Dieppe, ca. 1667. Finally, I found that the 1680 pamphlet by Peter Aubri, printed in Dieppe by the same printer (Pyter Acher) as the N.C. manual, is also essentially an English version of the same material (for the first section dealing with the magnetic azimuth dial itself). Aubri, John, _The use of the horloge or dyall azimutall: with that of the equinoctiall or universall dyall and that of the moone_, Pyter Acher, Dieppe, 1680. Wing attributed this pamphlet to Aubri because the title page carries the phrase "Are to bee sould att John Aubri att the Snuf box in the gratt street in Deepe".

If we assume that the manual is attributed to the dialist who made the dial that it accompanies, then the Adler's dial was the product of a cadranier Dieppois with the initials N.C. Apel & Pytel provide an extract (p.25) of the Registres du Tabellionage for 28 Jan 1662 (8-9 years after the date of your manual), dealing with the terms of a price support agreement entered into by the cadraniers. Prominent in the list of names – in fact one of two cadraniers charged with overseeing the agreement – is Nicolas Crucefix, or N.C.

If you have not otherwise attributed this dial to a maker, I would think this provides at least an indication that it may be the work of Nicolas Crucefix.

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Having returned from the NASS conference in Tucson and having been dazzled by the beauty and techniques John demonstrated for working with sandstone, I am energized to attempt something similar using locally available materials. My neighborhood stone supply place sells slate and white/black/green marble. I know slate is very easy to work with, having made a slate dial once by simply scribing the lines and numbers with some home-made hardened steel tools and a straightedge. Marble should also be quite easy to carve, but I wonder how durable an exposed marble horizontal surface would be given acid rain and so forth. I also wonder if it would be feasible to use John's technique (diamond cutting tools with water drip) to work on granite, which is quite a bit harder. I suspect it might be feasible to carve the lines, but perhaps not to polish by hand. I wonder if John or any of the other list members have any ideas about the suitability of different types of stone.

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Typically…, many slate sundials are scratched or scribed using the technique you mention, probably because scribing is a lot easier than chiseling. Of course, a scribed sundial face has carvings that are more shallow and less prominent than a chiseled face. Over many years a scribed sundial will lose its markings faster than a chiseled one. Marble and other sandstones can be scribed or chiseled easier than slate because they are softer stones. If you want to see how well marble, slate and granite weather, visit your local cemetery and look at the dates on the headstones. You can really see the effects of weathering, especially in Europe where the cemeteries are older. You'd be surprised to see how poorly granite weathers. Marble weathering can be severe in acid rain areas and areas that freeze. Slate seems to be the most durable of all. Its pores are so small that water can't seep in. Cutting with diamond burrs works very well on marble, limestone, sandstone, and flagstone. It works on granite, but is more difficult to cut. I haven't tried it on slate because there is none available here. If you could send me a tiny sample of slate, I'll try it… I received the slate sample you sent and did some cutting and engraving experiments using my diamond burrs and disks. They work great on slate!!! When cutting, I can feel that it is a harder stone than sandstone or marble because I have to press harder on the handpiece, but it is not as hard to work as granite. And we keep learning.

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The Arizona Daily Star reporter who met with the NASS tour group came to my studio on Monday with a photographer to finish up his interviews. Today his 1/2 page article appeared in the newspaper. He has several quotes from Fred Sawyer and also lists all the sundials we saw on our tour. And there are two good photographs. You can see the article at: www.azstarnet.com/star/wed/21030FHMAIN.html

Anselmo Perez Serrada

This is a hint for teachers and those who want to make an analemmatic sundial in their gardens. You do not need to draw the whole ellipse, just the hour marks, and for that purpose the method of the evolute works better. Suppose you have calculated the major (a) and minor (b) semiaxis of the ellipse for your latitude. Then proceed as follows:

1. Take a thin wooden lath or a curtain bar (even a string could do, if you don't have anything else) as long as the major semiaxis (a).

2. Place a mark on it at a distance b from one of its tips. Then the bar has two arms, so to say: the long one whose length is b and the short one whose length is a - b. Right?

3. OK. Now place marks on the major axis at the following distances:

$$D_i = b \cdot \sin(HourAngle_i) = a \cdot \sin(Latitude) \cdot \sin(HourAngle_i)$$

where the Hour Angles are 0º at noon, negative in the mornings and positive in the evenings. (It is also very easy to make a graphical construction to determine these dots).

4. Nearly finished. Then we just have to place the mark into the bar on one of these dots, rotate the bar so that the closest tip (i.e., the one at distance a - b) just touches the short axis. Then the other tip lies in the corresponding hour mark.

5. Repeat the latter step for every hour angle and that is it!

<u>Images of Sebastian Münster, author of the first modern book on dialing</u>