

# SUNDIALS FOR BAY COUNTY

By Dick Suiter

## THE DESIGN OF THE HORIZONTAL DIAL

In ancient days, the concept of "measurement" was rarely important. However, counting of whole numbers has existed since the old stone age. With the onset of agriculture, this was extended to comparing two weights on an equal-arm balance, allowing traders to weigh grain or whatever else was required. The cubit, being the distance spanned from an elbow to the tips of the fingers (about 18 inches) was employed as a rough-and-ready measurement of length. When more accuracy was needed, recourse could be had to length standards marked on boards or metal rods and held at the local king's palace or, more likely, the temple. Literacy and some degree of education were required, so the natural custodians of measurement standards were the literate clerics, once writing was invented.

Time, on the other hand, was coarsely measured, if at all. Years and months were measured first, because they were approximately divided into integers. But even here difficulties were encountered, simply because they did not divide up evenly. Somewhere around 29 days was an apparent month, a year wasn't an even number of months, and the length of a year was not accurately known at first. The day was broken up into rough quarters by sun altitude, if at all.

Perhaps the Babylonians, with their easily-divisible base-12 or base-60 number system, were the first to divide the day up into 12 hours of night and 12 hours of day. In the case of a tropical sun, one can easily divide the angle the sun is above the horizon into about 6 fist-and-a-thumb jumps of 15 degrees in an outstretched arm until you get to zenith. In the case of non-tropical sun, it is more complicated.

I don't know how it happened, but I could well imagine a clever young temple acolyte having the top of a hill pounded flat and erecting a high sharp pole as a shadowing device. On the first day he marks the shadow of the sharp point at each hour as estimated with a 15-degree sighting stick, and he thinks he is done. It works great for about a week, but slowly gets out of alignment as the sun drifts northward or southward in its seasonal variation. The shadow just doesn't move over the marks anymore. Next, he tries putting a set of lines radially from the base of the shadow pole, but it works no better. The hours are long, uneven, and few in the summertime days and fast and many in the wintertime. So he sits back and thinks about this. Finally, he (or a much later descendant) realizes that the axis of symmetry is not the vertical one of the shadow pole (called in sundial-speak the "gnomon"), but the rotation axis of the apparent sky going through the celestial pole. He draws lines not from the base of the pole, but from the intersection of this imagined axis with the ground and now he has Figure 1.

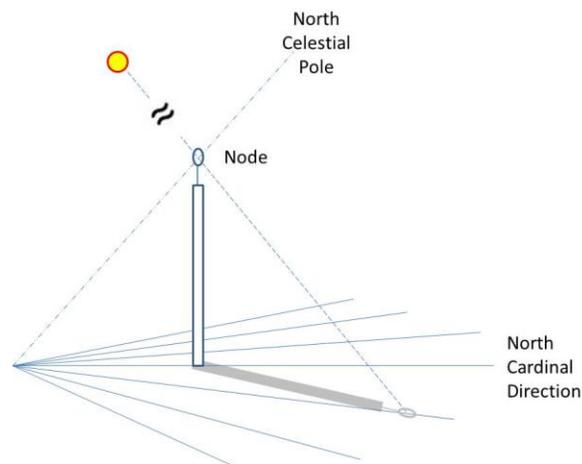


Figure 1. A single-node horizontal dial, one hour past noon.

The area the shadow of the nodus (or node) sweeps out is very large if the node is high enough, so pure nodal sundials tend to be small hemispherical devices. The way to shrink a horizontal dial down is to notice that any place along the line cast by the celestial polar line (along AB) is a valid place to slide the node, and it makes the shadow appear along the whole line BC. See Figure 2(a). The arrow denoting the business end (the upper part) of this line is called the "style," as in "stylus." The delicate edge may be stiffened by adding a support wedge to the gnomon, but it still casts the style-edge shadow along line BC. Triangle ABC denotes a sheet of light going through the sun. (For our purposes, the sun is infinitely far away.) Because the entire tilted style can be used, there isn't really a need for lines beyond the dotted arc drawn under the style. We now have all the elements of a garden horizontal sundial.

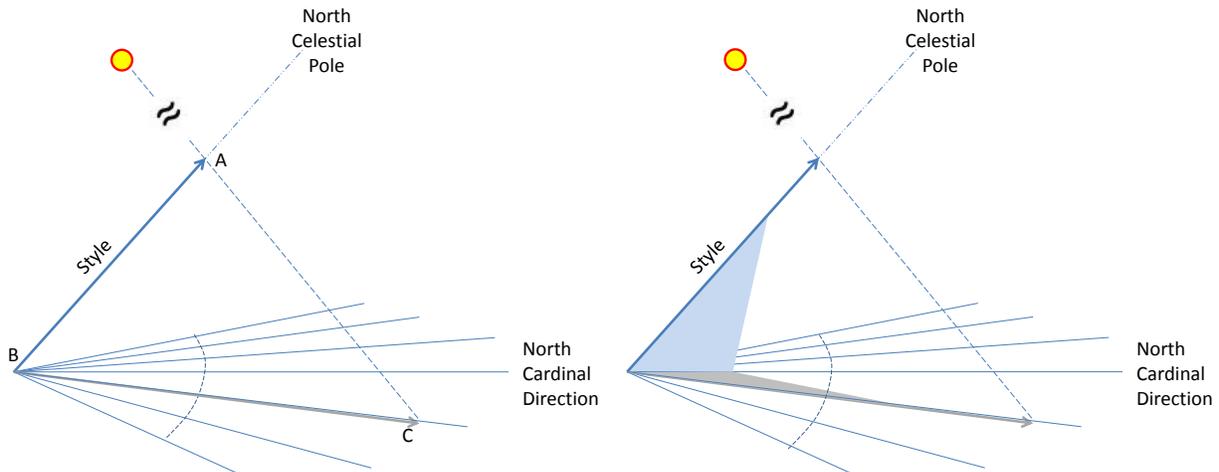


Figure 2. (a) A tilted style sundial and (b) the way most of them are stiffened.

Still, the way our supposed temple acolyte designed the hour counting was sloppy. Let's see if one could do better. Figure 3 is a notional *equatorial* sundial viewed almost from the side. It is shape like a child's top sitting on its rim. On the day of equinox a shadow with a node at the center of this imaginary circle goes on a straight line through the east cardinal direction, the edge of the circle, and the west cardinal direction. The circle can be divided up into 15 degree hour lines using simple geometric methods. We know that people could identify the cardinal directions by 2500 BCE, because the Great Pyramid was aligned to these angles within 4 minutes of arc (little more than eye resolution). Therefore, he could measure the diameter of the disk,  $r$ , by stretching a rope from the end of the shadow to the node. Then the dialist could lay the circle flat *on the ground*, and project the hour lines to the tangential equinox line.

Indicated are the hours of 7 AM through 5 PM (the dark line is set on 5 PM). Six AM and 6 PM are at  $\pm 90$  degrees and are projected to the horizon. These projections are not the same as the dial lines, because the dial lines go through the plate intercept, and we have shown the intercept of the pattern as it lays on the ground by a five pointed star. It is an easy matter to connect the points of the equinox line with this plate intercept. In fact, you can flip the circle to the north side and project from there. Because it would make the diagram too busy, I display only the hour line for 5 PM. Having two points of a given line is enough to completely determine the whole line, so we have correctly laid out an evenly-timed sundial as sophisticated as that made for backyards even today. This happened sometime between 1500 BCE and 1500 CE, with the capability in hand at the time of Claudius Ptolemy (c. 130 CE), if not the surviving concrete examples.

The trigonometric equations describing these processes are in the figure, but it is important to realize that *they are not necessary*. As Ron Doerfler points out in his blog entry on the analemmas of Vitruvius and Ptolemy, this was done originally without algebra, logarithms, or trigonometry (or, I might add, even decimal numbers). The old scientists didn't know everything we do, but their intelligence was of a very high order.

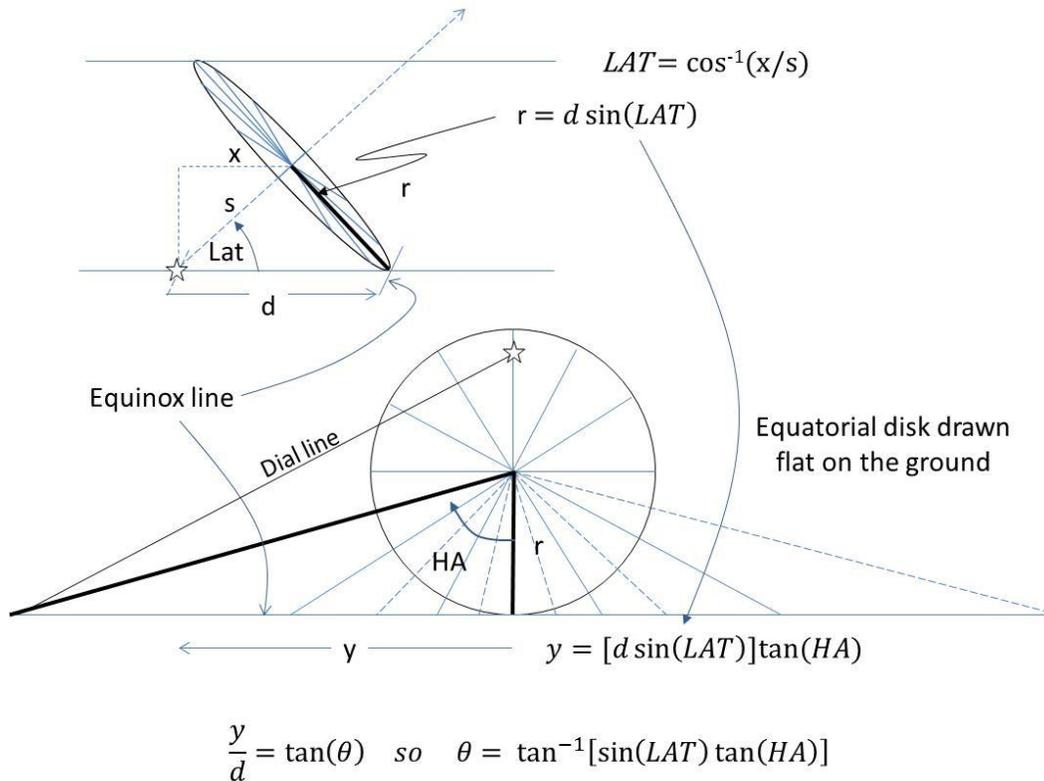


Figure 3. Evenly-spaced hours projected along an equinox line. The dial line is shown drawn for 5 pm

The expression for  $\theta$  in the bottom line of Figure 3 is conventionally zeroed at the 12 o'clock line, but for central time is slightly offset. The longitude of the Science and Discovery Center is 85.66327 deg W. The difference from 90 degrees, 4.33673 deg, means that here the sun transits at 17min 20.8sec before central mean time. You can put offset hour angles in just as well as balanced ones, and that has been done in Figure 4. Figure 4 is a printable sundial that is tuned to give a kind of zonal time at the Discovery Center's location, without the equation of time being compensated for.

### THE EQUATION OF TIME

Mean time is a little bit of a problem. In the days when clocks were horribly inaccurate, solar time was king. If it was cloudy, you were out of luck. You had to rely on water clocks or candle clocks or whatever. If it was clear, you trusted your sundial time. The problem was that mechanical clocks could be made for only one speed. Even after they were made to be accurate they kept plodding along at one speed and did not follow the variance of the earth's orbit that causes the solar time to migrate about a half hour throughout the year. They continually had to be reset for noon passage to get the local solar time right.

And why not? The local solar time is *precisely tuned for your longitude*. It can be maintained by having an accurate large tower clock that rings out the hours and is frequently adjusted for meridian passage of the sun. If people wanted a timekeeper in their own homes, they just reset their home clock to tower chimes once every week or so, or they had a sundial in their garden. A feature of old clock faces was that the covering glass swung back to allow frequent resetting, because people wanted to be able to easily change them. Temperature-compensated pendulum clocks were eventually made, but they were rare and they ironically came with an equation of time label so people could calculate back to "real" solar time.

Then came the ability to move between cities quickly enough to notice the east-west variation of local times. About at the same era came an increase in the accuracy of portable timepieces. Train companies had to maintain synchronized schedules over a large area, else their trains might collide. Enter Railroad Time, or the first paradigm shift where people began to follow zoned mean time. Now clock time became "real."

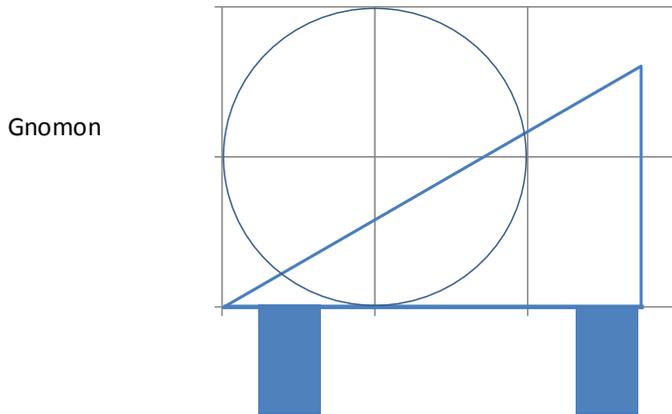
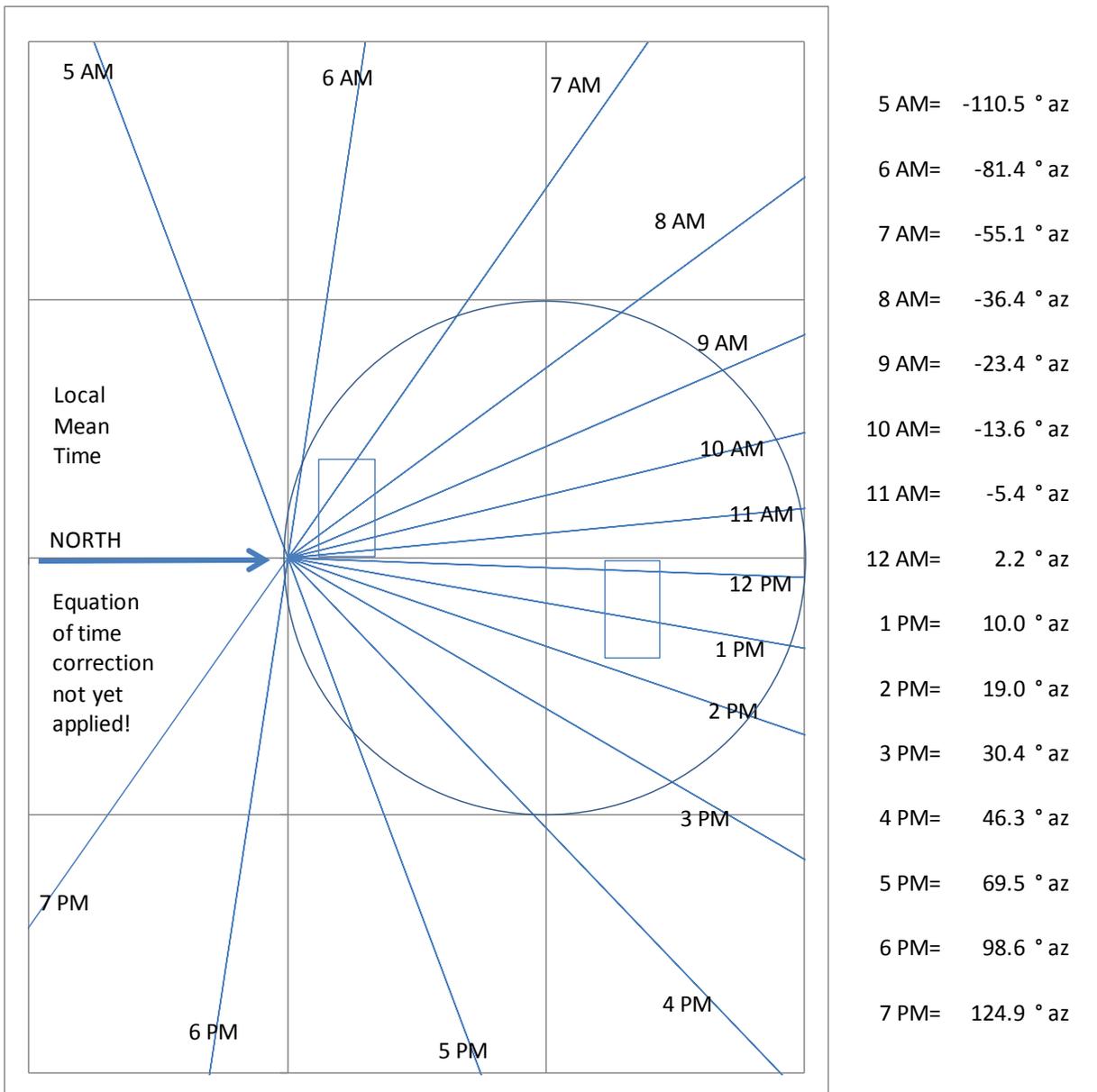


Figure 4. Printable sundial for Science & Discovery Center, Panama City FL. EOT correction is blue line of Fig 5.

The burden of the equation of time correction had been shifted to the sundial. Suddenly, the sundials have become inaccurate and equation of time must be added or subtracted from them.

What does the equation of time look like? The "equation" itself is kind of complicated and unilluminating, but the graph of Figure 5 tells it all. The lower (red) curve is for the usual type of dial where 12 noon is on the north-south line. The upper (blue) curve is for the Figure 4 type, where the mean time shift is already added or subtracted out. The red curve depends on the location. The blue curve depends only on the earth's orbit at the center of the time zone, and does not change from place to place. It seems to be comprised of two sine waves, with one having about twice the frequency of the other. We see that the shadow goes from about 3 minutes fast to 34 minutes fast (red curve) at the Science and Discovery center for the 12 o'clock line pointed North.

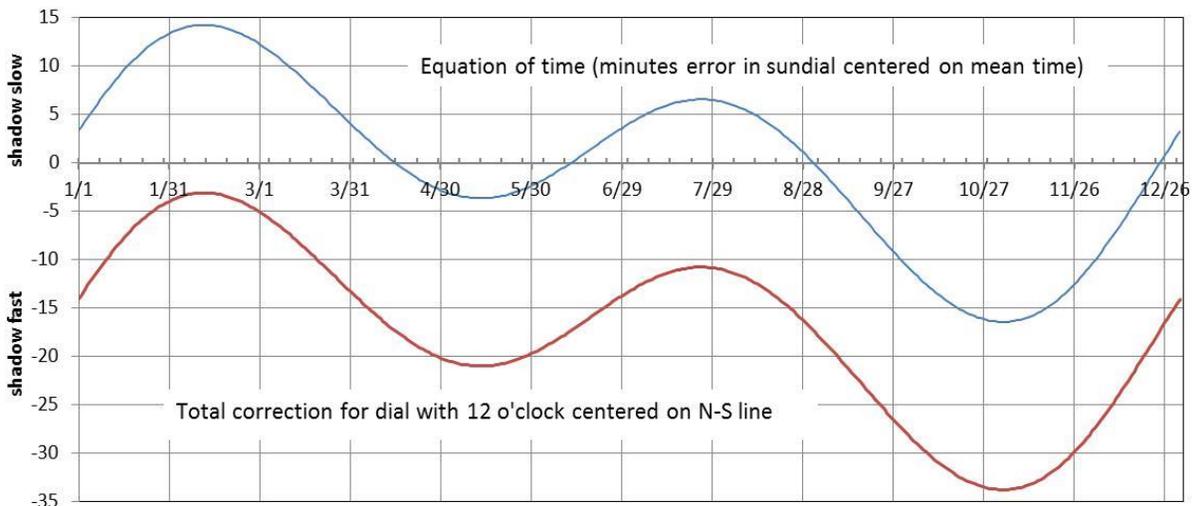


Figure 5. Top (blue) curve . Equation of time (EOT = local mean – apparent time). Please note sign convention here. Bottom (red) curve. Correction with mean time shift included for the Science and Discovery center.

If you rotate the hour angle so that it is permanently "late" (as in Figure 4), you can read the time from about 14 minutes slow in February to about 17 minutes fast in November (blue curve). It is not balanced because the higher frequency curve does not line up with the low frequency curve.

The equation of time chart presents us with a conundrum. We can leave it uncorrected with an east-west balanced sundial, accompanying it with a plaque or monoment of the graph, and hope that sundial users will have the sense to subtract the correct number of minutes (red curve) to derive the clock time. Or perhaps we can shift by the P.C. average 17.34 minutes, and accompany it with the blue curve. That way, sophisticated users can use the EOT curve to derive the clock time. Less sophisticated users who don't use the curve will spend much of the year within plus or minus 5 to 10 minutes even if they ignore the chart. Fig. 4 is of the latter type, though I admit that sundials without east-west symmetry are a bit more confusing and a timepiece accurate to only about 10 minutes is hardly inspiring. If it is read with the aid of the time correction chart, properly made sundials are routinely accurate to within 2 minutes or so.

## SUNDIAL SOFTWARE

Figure 4 was prepared with an Excel spreadsheet and the formula for  $\theta$  in Figure 3. But you might guess that more specialized software has been written, and you would be correct. One such software is the program *ShadowsPro* by François Blateyron (source at end). It is available in a freeware version that is perfectly adequate for the preparation of ordinary horizontal dials. *ShadowsPro*'s more obscure capabilities are found in mid-level and high-level (paid) versions. Figure 6 shows one output.

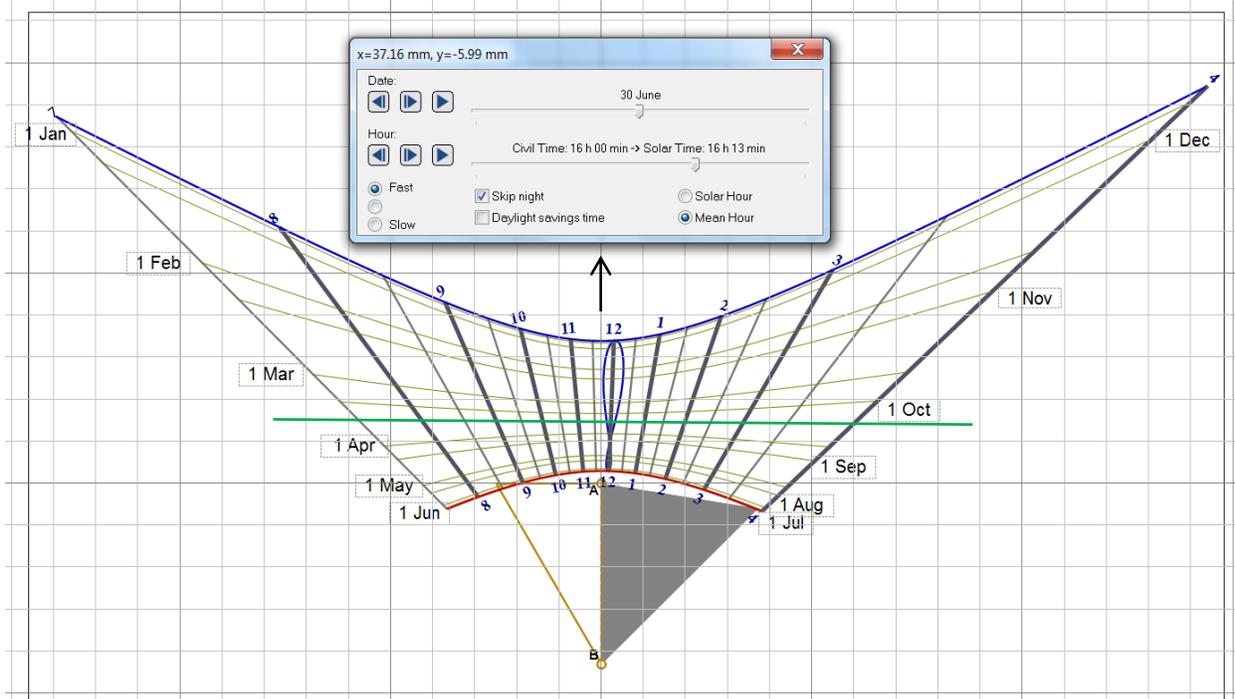


Figure 6. Time-zone corrected horizontal dial with day-of-year readout. Equation-of-time is shown for 12 noon, but is true of any time. Green line is rough position of straight equinox line of Fig. 3

A bit of interpretation will illuminate this busy diagram. To avoid a huge area being covered, this nodal dial only covers times between 7 am and 4 pm, although it could cover more time if we were to draw the lines all the way to the center B, as inside the dotted line of Figure 2. This is a day-of-year sundial, with the tip of the style's shadow pointing out the day, assuming you know approximately which season it is in. The gnomon is between A and B. The tan triangle is the gnomon's shape if we were to lay it flat on the ground. The gray triangle is the shadow with the time indicated at 3:57 zone-corrected dial time on June 30. If each square were 1 inch, this dial would have a 2.5-inch high gnomon and cover 29 by 14 inches.

Reading the blue curve correction of Figure 5, we realize that this is 4:00 central standard time, which is the civil time in the inset. The inset also gives the true solar time as 4:13 pm, but that is measured from a 12-noon line pointed to the north (the red curve gives the eq. of time is 13 minutes ahead in Figure 5).

The day-of-year is poorly estimated for days around the solstices, since the shadow has such a long hang time, especially in the summer. In middle months, it is wonderfully precise, because the tip shadow is flying in the declination direction. The two solstice lines are seen to be oppositely directed hyperbolas. The curve flattens to about the position of the green line on the days of the equinoxes. As mentioned before, these are the only days the tip of the shadow follows a straight line.

## ANALEMMATIC DIALS

Sundials possess one disadvantage. The gnomons eventually get damaged or stolen, "traveling" somewhat like the similarly-named garden gnome of the movie *Amelie* or the Travelocity commercials. There is one near the William Oxley Thompson Library at the Ohio State University campus in Columbus Ohio (see reference) that was made in 1905, and has been without gnomon most of the intervening 111 years. It is too bad because it was a really accurate equatorial-type that had the equation of time correction scribed-in at each hour. Incidentally, when it was installed it was thought to be exactly at latitude 40 degrees north, but the latitude line has crept a few hundred feet away with more accurate surveying methods.

There is a type of monumental sundial that dispenses with the gnomon and replaces it with a person standing above a mark on the pavement. Thus, users carry the gnomon with them and it cannot be stolen. This vertical-gnomon dial is not the usual type because each "walking" gnomon has a different height, and hence different center point at B. It turns out that the height of the gnomon makes no difference if one slides its position along a linear track that looks similar to the analemma collapsed to a one-dimensional structure (it is not a projection of the analemma, really). The dial shadow is read where it crosses an ellipse. See Figure 7 for one calculated for Panama City, FL. The central line is an annual chart telling you where the gnomon/style goes. For example, if you want to set the style on the summer solstice, you go all the way to the red ball at the top, just below the astrological symbol for Cancer (i.e., the tropic of Cancer). Conversely, winter solstice is the tiny blue circle at the bottom, above the symbol for Capricorn. The symbol 1-III stands for 1 Mar, and 1-IV stands for 1 Apr. March 21, the equinox, is about 2/3 of the distance between them along the straight line connecting 6 am and 6 pm.

If you are using your body as the style/gnomon, you have to stand with the center of your feet above this point. The center point for most people is between the arches of the feet. It is more accurate if you face in the direction of your shadow, holding the center line between your feet. If your shadow isn't long enough, hold your arms above your head with the palms flat together. If your shadow is much too long, you can often use the gap between your legs as an inverted gnomon.

So where does the "analemmatic" come in if Z is not the same as the declination of the sun? In this case we are expected to use the term *analemma* in its more generic meaning. That is, any graphical construct acting as an astronomical computer. All sundials are in this sense "analemmatic" but this one compresses a great deal of analog computation in its construction, and so perhaps deserves the prize.

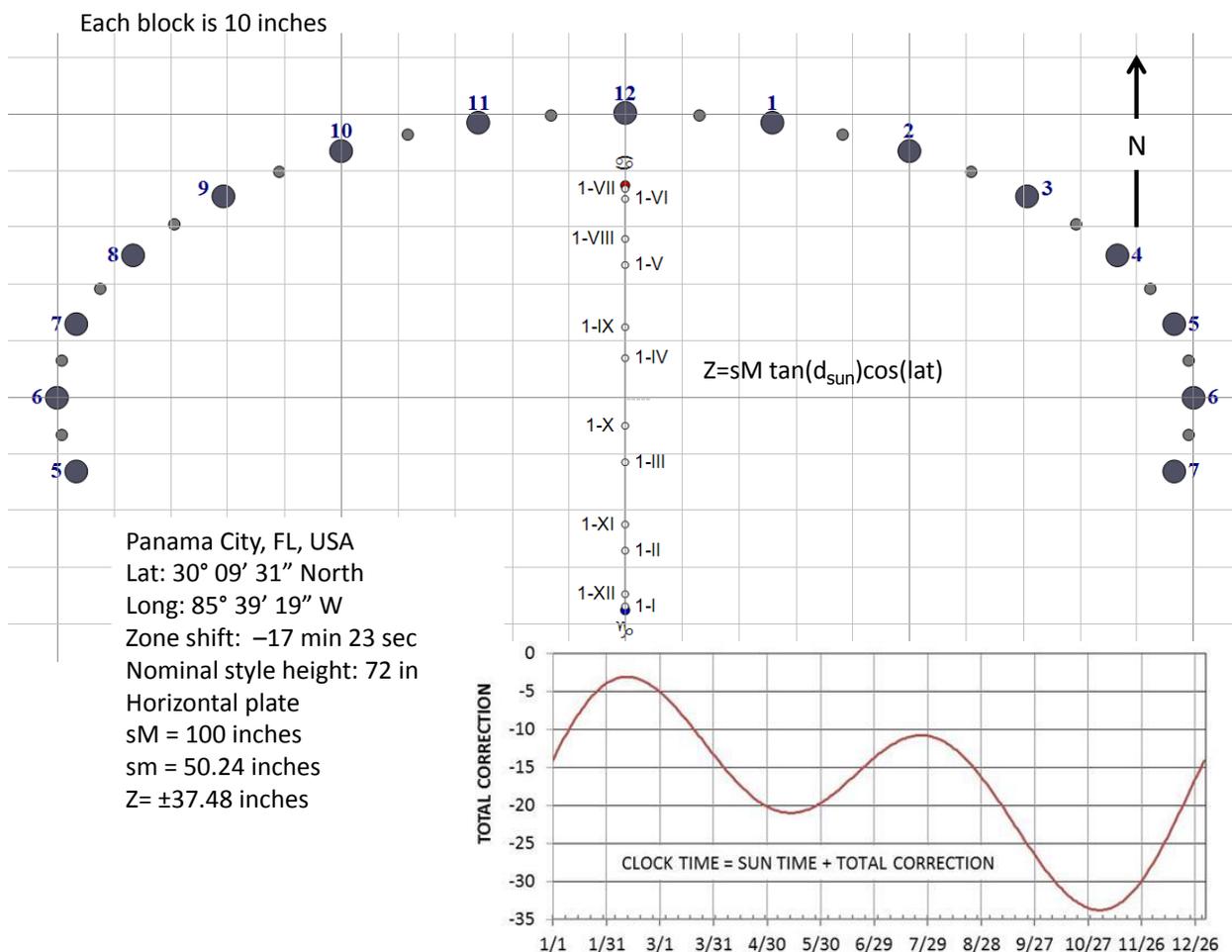


Figure 7. An analemmatic dial centered on solar time with Panama City time correction indicated.

It and the sun's rays are, in fact, a complicated 3-D nomogram. Prior to the advent of calculators, nomograms were a lot more common for repetitive calculations. Incidentally, the other formulas you need are:

$$sm = sM \sin(\text{lat}) , \quad \tan(\theta) = \frac{\tan(HA)}{\tan(\text{lat})} ,$$

where  $\theta$  is the angle to the middle, HA is the hour angle. The total time correction is  $-(\Delta\text{Long}-\text{EOT})$ . For downtown Panama City,  $-\Delta\text{Long} = -(90-85.65528)/15 = -0.28965$  hours, meaning the dial is 17 minutes 23 seconds fast from the zone shift alone. For Panama City, the total correction is conveniently always negative.

In Figure 8, I took a little model of this dial outside, set a chess bishop with a pointy symmetric knob on top of the approximate position of the day 9/10/16 (or 1/3<sup>rd</sup> the way between 1-IX and 1-X), aligned it N-S, leveled it, and read off the time as 4:27 pm solar time. (The white line has been painted on in PowerPoint to make the middle of the shadow easier to see. Estimated time is  $4+(30 \text{ min} \times 9/10) = 4:27$ ) By using the time correction chart and the 1 hour correction for daylight time, I was able to calculate the clock time within a minute. This relies somewhat on luck, but I don't think my earlier claim of accuracy to within 2 minutes of a properly aligned and used sundial is completely unreasonable.

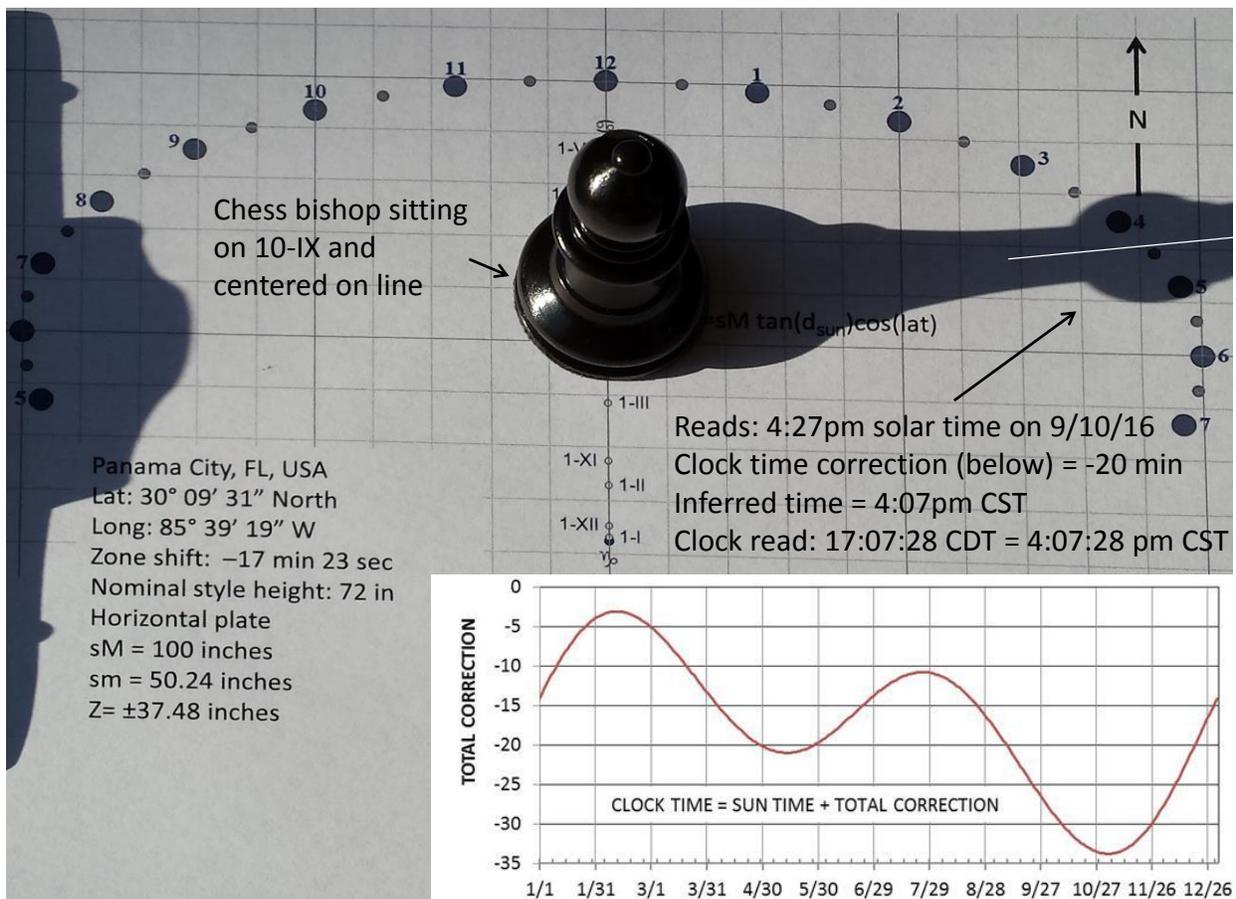


Figure 8. A miniature model of an analemmatic dial seems to work. Quartz clock set within 24 hrs by WWV.

There is a nice example of an analemmatic dial at Northwest Florida State College in a small courtyard in the campus at Niceville. The semi-major axis of this sundial is about 10 feet (20 feet total width). It is made of an array of artistic colored tiles, which is described at the Niceville link in the references. In Figure 9, you can see the user lining up with the North line, but the user has not yet turned to face her shadow. Facing one's shadow is best to minimize forward-backward leaning errors, but stay on the line. For really accurate reading, a vertical surveying pole is used as a gnomon.



Left pic: © 2010 Northwest Florida State College, used with permission

Figure 9. (Inset)"Owl's head" shape of analematic dial of NWFSC in Niceville FL. (Photos) Dial in use. Assuming an autumn time, it was about 2:30 solar time on Oct 17; 2:00 CST, or 3:00 CDT. My shadow on 1/21/17. LST about 12:35 – 0:02:56 min [correction from college handout]= 12:32 compares to recorded cell time of 12:33:25

The analematic dial in Figure 7 is suggested as a project for supervised youngsters using sidewalk chalk and the 100-inch semi-major axis design indicated in the same figure (I chose this scaling because the height of the pre-teen kid is a little smaller than college students). I would recommend it for the Science and Discovery Center if I could think of a level and sunny place to put it. More permanent installations could be done with rectangular bricks set on edges for the central line and circular pavers set even with the ground for the ellipse. The Fig. 7 dial can be used and scaled anywhere in northwest Florida, but the time correction is tuned for the longitude of Panama City. For more info about the calculation, see the sourceforge entry in the References. To derive a 12 noon=North dial, you just tell a fib to the online app and claim you are at 30.2 latitude and -90 degrees longitude. Then you use the total time correction appearing in Figure 7. Or you can go with the skewed one like the app generates, but you need to use the centered equation of time (blue line instead of red line in Fig 5).

Figure 10 is the Fig. 7 central slide line for the Panama City annalematic in Figure 8, expanded and set on its side. The table at right is the location in inches of the little beginning-of-month circles, calculated from the Z expression in Fig 7. Declination was calculated from pg. 485 of the *Explanatory Supplement* in the references. The zero point is the 6 o'clock crossing line. It can be seen to slide plus or minus a little over a yard in this 100-inch semimajor axis ellipse.

### SOME SUNDIALS IN BAY COUNTY

I know of at least three large sundials in Bay County. Unfortunately, two of these are not always available to the public. One is on interior elementary school grounds and the other in a gated community. The other is at the recently reconditioned downtown marina, and was moved from the place where it was set down by the builders. This is by no means a comprehensive list. I just heard about them.

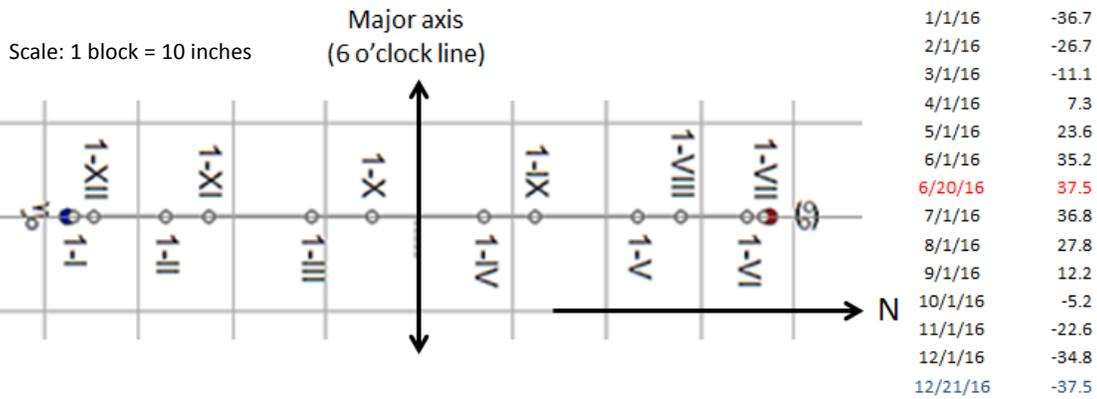


Figure 10. Details on the yearly vertical gnomon track of Panama City FL (100-in sMA) with table of offsets (inches).

1) At Lucille Moore Elementary school there is a large courtyard sundial. It seems to be a longitude-corrected because of the tilt (or the tilt could be caused by distortion in the imaging lens). Figure 11 shows that it is about 10 feet in diameter. I can't tell from the Google aerial photo below whether the red arrow is comprised of pavers or just red paint. It, like many sundials, is being crept up on by surrounding trees. The prettiest places to put sundials don't always keep the shade out. [The only reason there is no recent effort made to replace the gnomon at Ohio State's dial is because the dial has become mostly shaded.] If you can't achieve altitude, the best location for sundials are immediately north-center of wide, low, buildings or a street, both in big paved areas that cannot ever support trees. No prettiness in this instruction, but good sundial long-term survivability. There are no lines on this dial photo, but that may be just low resolution. From the inset (Figure 4 on its side), the numbers around the outside seem to be spaced wrong. It could be my imagination, but this sundial seems to be only decorative. (It also seems to be matched by an identical courtyard pattern at Patronis Elementary.)

2) The Wild Heron roundabout dial (Figure 12). This dial, whose primary function is being a sculpture and only secondarily is a sundial, seems to have a nodal-type gnomon (recall this means that the indicator is not the blade of a style but a single point). That point in this case seems to be the tip of the beak of the highest heron. By moving the triangle to along the dotted curve, I was speculating that the artists were trying for an "average position" more-or-less accurate style, but the sculpture is just too wide to use in this manner and besides it wiggles too much around the proper position. It was originally installed with hour monuments approximately on the equinox line (follow the red line down), which would be good only for a brief time of the year, but is currently not even laid out as a sundial. Nevertheless, I'm sure you'll agree it is doing a fine job just as a giant sculpture.

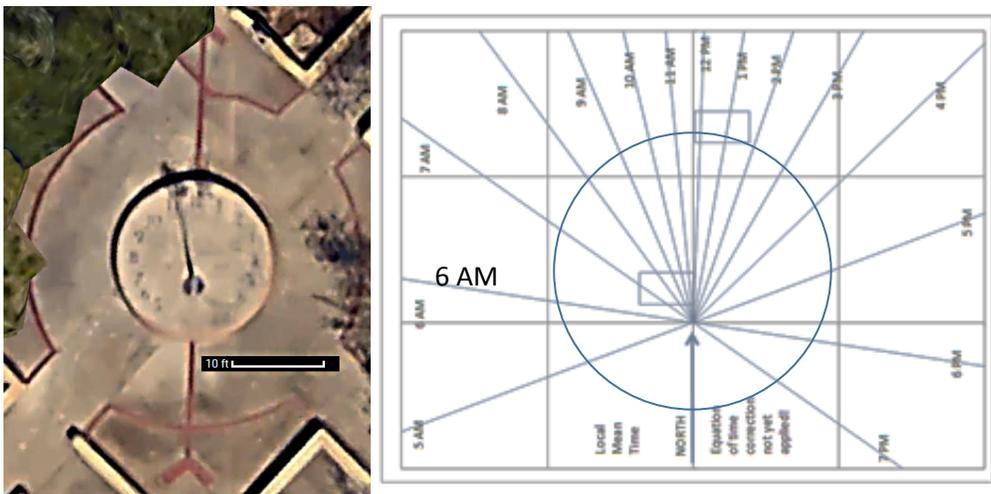


Figure 11. Horizontal dial in interior courtyard at Lucille Moore school [from Google Maps]. At right is correct configuration for a horizontal dial with a polar style. Note too even spacing at edge of circle.



Figure 12. The Wild Heron gated community roundabout centerpiece sculpture with various angles shown.  
[photo and annotation by author]

There is some talk about resurrecting the Wild Heron sculpture's function as a sundial, but its sheer size may preclude this. The nodus is 100 inches above the concrete pedestal and even the limited hours of the bat-winged plate of Figure 6 would have a width of 50 feet. It is huge.

3) The downtown Panama City Marina used to have a sundial donated by Navy personnel in 1963. Then the Marina streets were moved and the sundial disappeared. After some time, it reappeared. It is a classic horizontal centered-on-zone type (blue EOT correction curve) with a robust, wide gnomon. To think of the way a wide gnomon works, imagine it as two slightly offset dials, with one edge of the style being for AM times and the other edge being for PM. This implies a little jog in the lines that are continued onto the other side (usually 5, 6 and 7). The maker chose deliberately to neglect the jogs because the shadow sometimes switches shadowing edges with the sun that low. The point at which the lines are drawn meet curls around the blunt low end of the gnomon. It is shown in Figure 13.

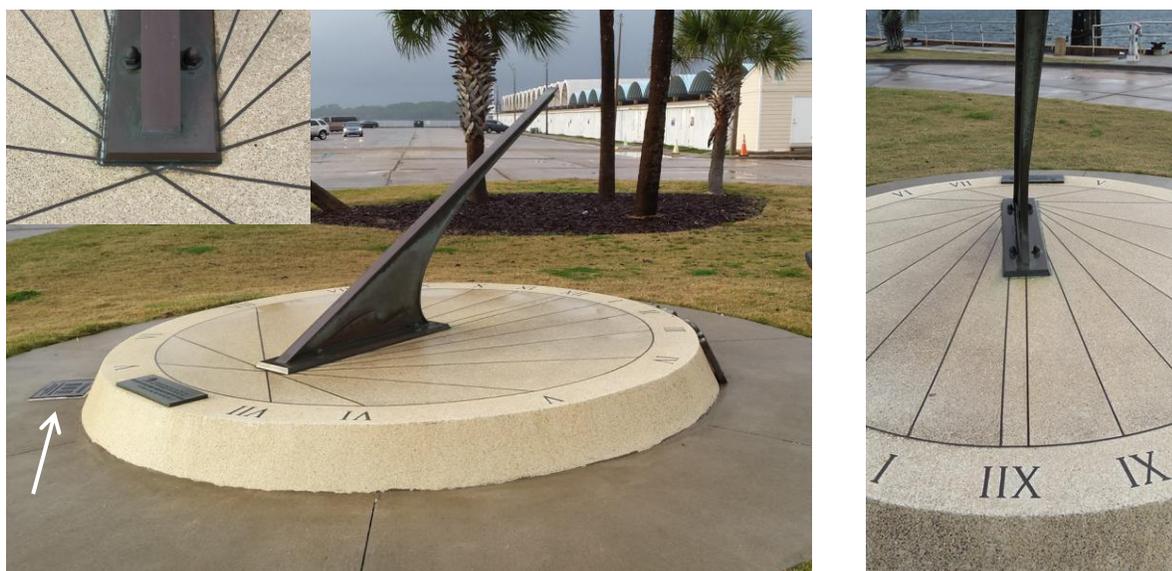
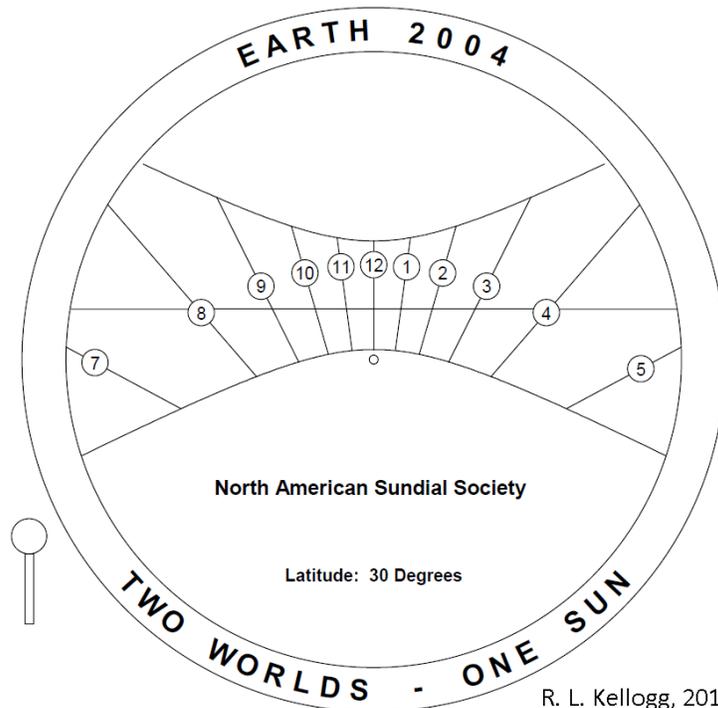
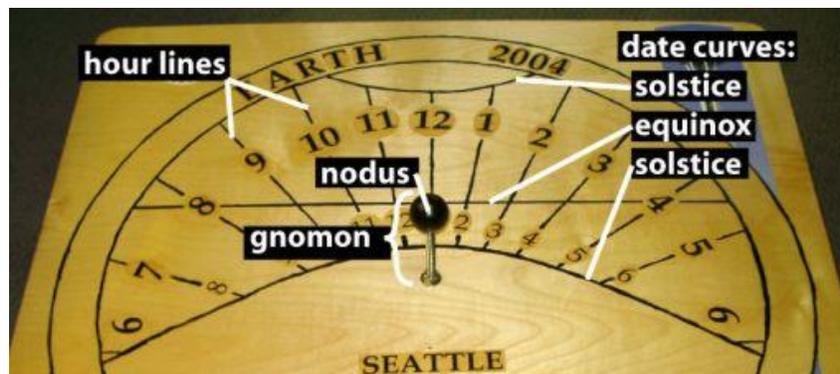


Figure 13. Marina sundial, showing split and zonal offset (white arrow points out equation-of-time plaque).  
Yes, this sideshifted gnomon is mounted correctly. The two edges are offset as in Fig 4.

In a brief moment of sunlight among the above photographs (not shown), it displayed about an 8.5 minute error, even calculated with its correction curve. It is my belief that in moving this (very heavy) dial, it was not set down with as good a north alignment as it must have had originally, or perhaps it was not leveled accurately. It is close, but it is no longer a reliable timepiece.

#### OLD JUNIOR MUSEUM PARTICIPATION IN EARTH DIAL 2004 PROJECT

Before he moved to the Washington DC area, ASBC member Tom Rackers participated in the Planetary Society's Earth Dial Project (see reference below) as a volunteer for the Junior Museum (the old name for the Science and Discovery Center). Somewhere on the Junior Museum property (the roof perhaps), he set up a webcam looking at a variant of the sundial below. (I don't have a photo of the one for Panama City.) The node is only a little more than 3 inches high, and the whole sundial is a few feet across. I remember all of these sites everywhere in the world having simultaneous views of their dials continuously streamed to the web. Half of the world was in darkness, of course. Some were under clouds, and the rest displayed local solar times. I don't recall how long he kept it going, but it was for a long time. I bet the dial is still around here somewhere, although Tom says the closed-cell styrofoam of which it was made eventually began to absorb water and get soggy. (It was not made of coated wood like that in Fig 14.)



R. L. Kellogg, 2013

Figure 14. Seattle example from Planetary Society Earth Dial website and a 2013 pattern that must have been close to what Tom Rackers computed for P.C. The 8 cm high spherical nodus (perpendicular to the dot) has the advantage of projecting a centered elliptical shadow at all hours, kind of like the chess piece in the earlier photo.

## SEASIDE/WATERCOLOR DIAL AT NATCHEZ PARK

There is a monument dial near Bay County between Seaside and Watercolor (Hwy 30A). This sundial is shown in Figure 15. It is a classic horizontal dial which reads local sun time (the "red" correction curve). It is really two dials in one. It has a long style that points shadows markers out near a hedge (see red arrow marking one such line below). Plus, it has a smaller plate that only requires the tip end of the style.



Figure 15. Upper two: Natchez Park sundial between Seaside and Watercolor. Bottom: How to get there.

I was there when it was sprinkling rain, so I did not see the sun coverage, but I saw that the small part of this dial is in danger of being overshadowed by trees. The whole dial probably doesn't work far into the evening because of the hedge and the surrounding woods. The trees are not yet very high, but they are growing, especially on the east and south. The dial plate has the hours bunched up near noon, and that is one indicator that it was properly designed. Too bad such a great dial will be so soon in the shade.

The hardest part is finding this dial. There is a parking lot for beach access off a currently unmarked road called Western Lake Drive. Park in this lot (if you can find it) and follow the yellow line past the public rest rooms. Then, you either go by the dotted path behind the houses, or you go down Natchez St. until you see a narrow pathway between two houses enclosed by white picket fences on both sides of the path about 4 feet apart. Go down this pathway past the little step-pyramid structure and you will see the secret garden entrance beyond. Because both paths seem to be outside of people's lawns, I believe this is public access, but it is the oddest and least-marked park amenity I've ever seen. Too bad, because it is beautiful.

## ERROR IN SUNDIALS

There is a possible problem when reading the edge of a distant shadow. That problem is the blur caused by the finite extent of the sun. The sun occupies approximately a 1/2-degree angle (about 2 minutes extent) in the sky and the eye must choose an edge to the shadow. If the sky is a bright clear blue, the edge may show at a different place than the eye selects it for a hazy day. You can use aids, such as the nearby postcard for the shadow shown below to push the error down to about 12 seconds, but even these tricks display systematic errors under haze.

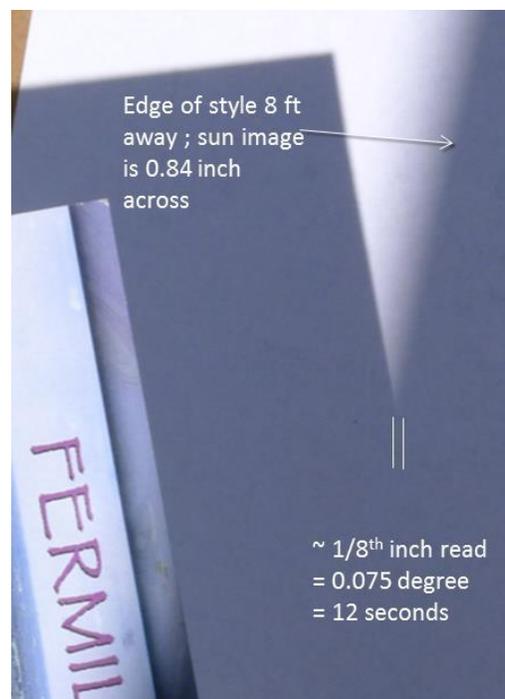


Figure 16. Fuzziness limits the accuracy of the reading, but you can use tricks like the one above.

You can also use two-side gnomons or wire styles to split the side of the shadow like I split the chess piece's shadow, but this will only work until the shadow is imperceptible. You can't find the shadow of a thin wire line if you're too far away. Another technique might be the perforated nodus casting a pinhole image (or better, a tiny mirror on the windowsill, projecting a pinhole image of the sun on your ceiling). Even so, I bet it is difficult to read this dial to much better than 1/20<sup>th</sup> of the sun's diameter, or 120s/20 = 6 seconds. In Florida, a windowsill mirror is often shadowed by eaves in the summertime.

There is another error due to refraction. As the sun sets in the sky, its position is shifted by the thin wedge of air it is looking through. When the sun appears right on the horizon, its true altitude is  $-0.57$  degrees. As it is viewed at higher and higher altitude, this effect goes away. Figure 17 is a kind of busy graph explaining this effect at 20 degrees C, 1013 millibars, and at the latitude of Panama City.

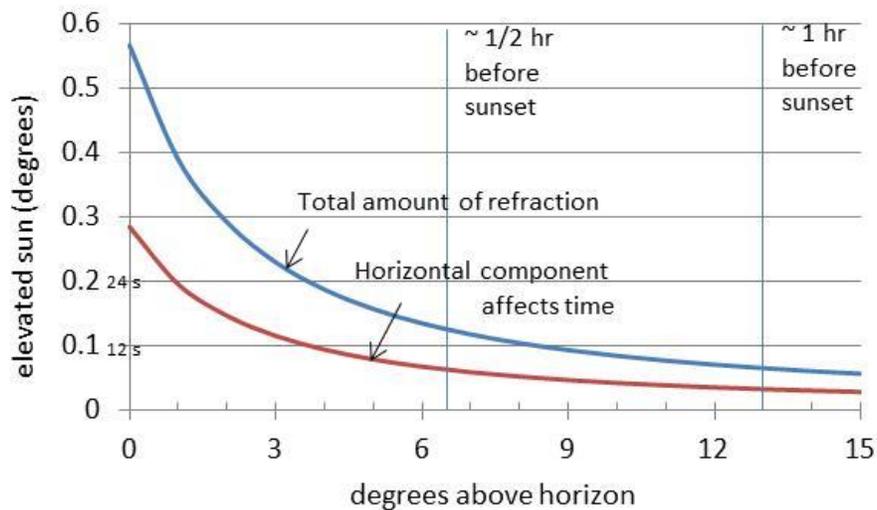


Figure 17. Chart of effect of refraction on low Sun angles. Approximation appearing on pg 144 of Seidelmann.

The total effect of refraction is to shift the appearance of the sun in the sky. But only the error in azimuthal position (red curve) has any effect on mistakes in sundial time. The diagram shows that the sun should be below 20 minutes to sunset for an equal size error to that appearing in Figure 16 (12 seconds) to become apparent. It is not a strong effect.

## CONCLUSIONS

A lot of people point to Newton's laws as the first successful application of scientific principles because of the astounding precision in predicting planetary positions that was achieved. I would argue that astronomers had an earlier mild success with sundials. Think of what they accomplished. They took a moving and (then) unexplained sun position and derived a method of keeping time with it accurate to a couple of minutes. This was done with only a straightedge and radius cord. The sundials I have shown here are only the simplest of the type. There are vertical dials, declined, inclined, transit markers, and reflection dials. Noon dials, armillary-sphere dials, hemispherical dials, equation-of-time corrected dials, cylindrical shepherd's dials, polar dials, and diptych portable dials. Many were invented before advanced mathematics became available. We can also drift a little away from the the Sun and mention astrolabes and nocturnals, timepieces meant to be used for farther-away stars.

At the same time, sundials have become a joke. People have become accustomed to setting up those decorative, fake-green patina, pot-metal dishes in their lawn that have not been even calculated for their latitude or for *any* latitude. (Not all are even made with the style pointed the correct way!) See Figure 18, which depicts a sundial I once received as a gift. It is an adjustable inclination dial, which is the proper way to use a generic dial calculated for one latitude at another latitude. It should be calculated as a flat horizontal dial for 40 degrees latitude (this is the setting on the base that holds the dial flat). However, as can be seen by the accompanying diagram, it is not correct. This is most easily seen by looking at the intercepts on the circle of 8 and 9 o'clock, which are balanced around the red line on the dial, but are offset on the diagram. By fishing for this 8 - 9 balance around the red line, I guessed the casting mold was likely copied from a dial at the latitude of Paris, at about 49 degrees. This is plausible because the French love sundials, and have made many of them.

Even with a good sundial, users inevitably attempt to read them in total ignorance of the equation of time and the offset from the center of the time zone. They conclude that their dials possess little or no accuracy. That is unfortunate. As the PDF flyer about the Northwest Florida State College sundial said, it is we and our plodding fixed-rate clocks that are keeping incorrect local time.

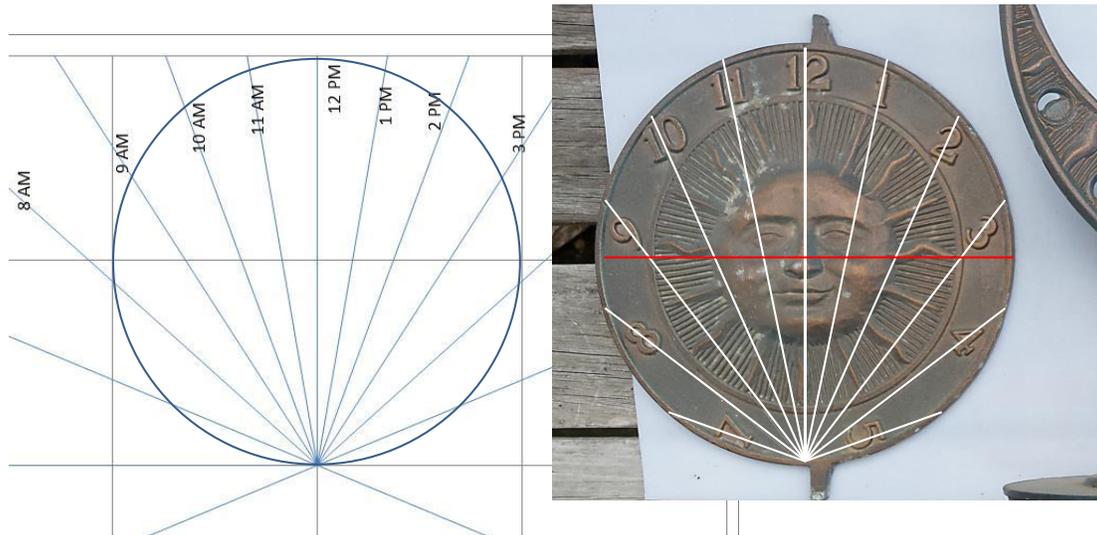


Figure 18. Cheap, incorrectly calculated garden dial with theoretical 40-degree calculation at left. White lines are drawn on the figure to emphasize inscribed lines on the casting.

## REFERENCES

*The Analemmas of Vitruvius and Ptolemy*, Ron Doerfler, [myreckonings.com/wordpress/2007/10/28/12](http://myreckonings.com/wordpress/2007/10/28/12)

*Sundials: Their Construction and Use*, by R. Newton Mayall and Margaret W. Mayall, Sky Publishing, 1938, 1974, 3<sup>rd</sup> edition 1994. Cambridge MA.

*Sundials: History, Theory, and Practice*, René R. J. Rohr, 1965 Gauthier-Villars, Reprinted by Dover Publications, New York, 1996.

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

*Explanatory Supplement to the Astronomical Almanac*, ed. by P. Kenneth Seidelmann, US Naval Observatory, Washington DC, University Science Books, Mill Valley, CA 1992. (the equation of time was derived from the expressions on page 484 and 485).

**SHADOWS PRO**, a sundial/astrolabe software application by François Blateyron, at [www.shadowspro.com](http://www.shadowspro.com), Perrouse, France (2016). The freeware version is adequate, but if you want to dig deeper, obtain one of the paid versions.

OSU dial: <http://sundials.org/index.php/component/sundials/oneDial/681>

Niceville dial: <http://sundials.org/index.php/component/sundials/oneDial/727>

Analemmatic dial calculation: <http://analemmatic.sourceforge.net/cgi-bin/sundial.pl> also in Instructables at <http://www.instructables.com/id/Large-driveaway-sidewalk-or-garden-sundial/>

Earth Dial project: <http://www.planetary.org/explore/projects/earth-dial/instructions.html>

Seaside dial: <http://www.sundials.org/index.php/component/sundials/oneDial/551>

## APPENDIX: My Favorite Sundial

Of all difficulties associated with sundials, the most obnoxious is the equation of time chart. Naturally, we can all look back nostalgically to the olden times when sundial time was the only correct time, and the clocks had to play catch up, but such times will never happen again. Is there any way we can have a more or less automatically corrected sundial?

There are a number of techniques. First of all, you can have a bowling-pin analemma-shaped gnomon in an armillary-sphere type of equatorial dial. Then you have to know whether it is only the first half or the second half of the year, so you'll read the correct side of the shadow. Second, you can have an S-shaped gnomon for ascending sun, which is changed out for the opposite S during descending sun, again in an armillary or half-armillary. Are there any flat ones?

Well, we have already seen how an existing sundial may be modified by replacing the mark by an analemma. Such a move tends to make the plate too busy, particularly at the summer solstice end. So, we balance the plate by pointing it away from the horizon, toward the celestial pole. This would be the same as a horizontal plate as used at the equator. Then we divide the marks into two half-analemmas, each applying to half of the year. The result is in Figure A-1.

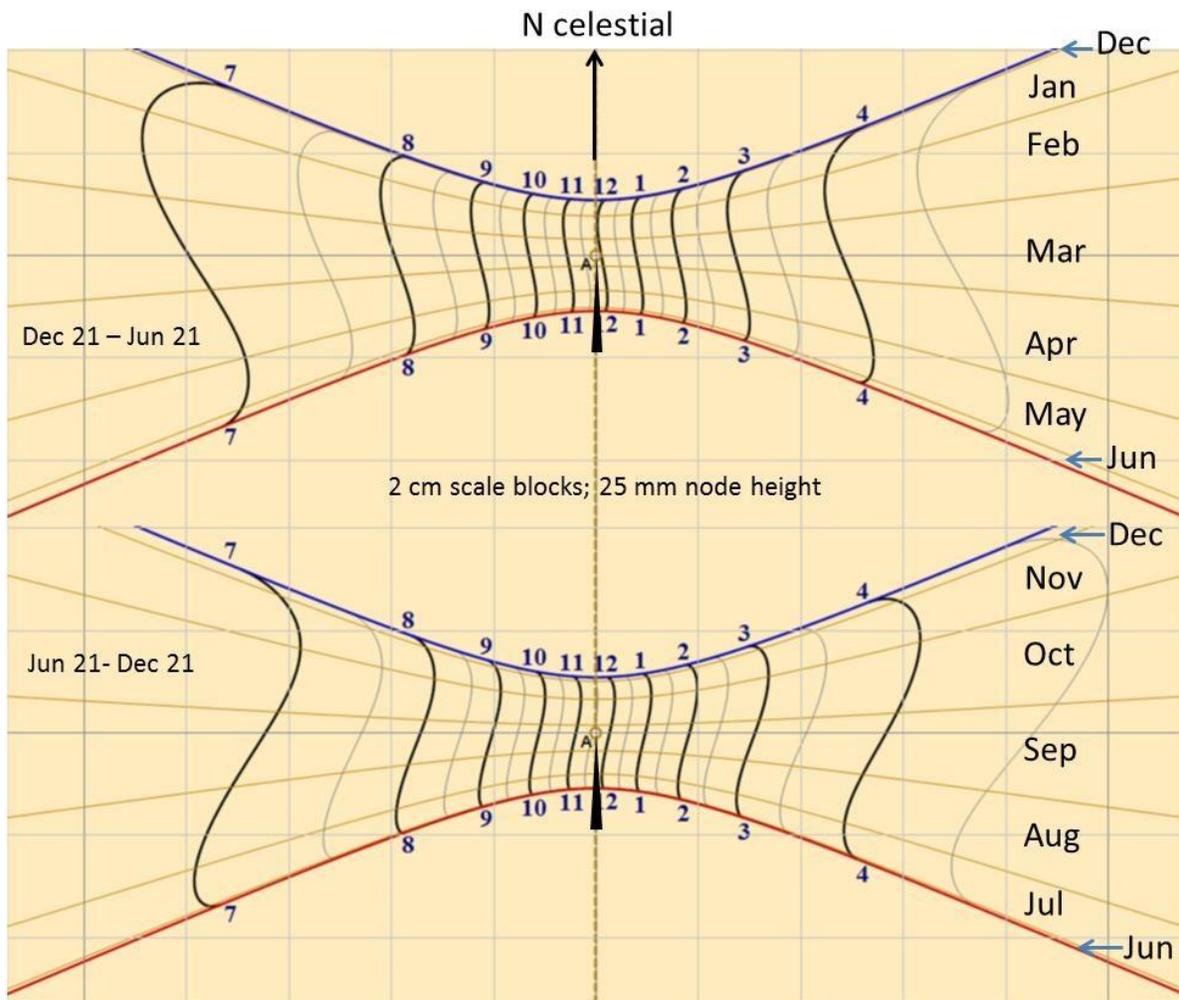


Figure A-1. The polar sundial, analemma corrected.

There is an example sundial made of this type at the old National Bureau of Standards (now NIST) at Gaithersburg, MD. Called the Briggs Commemorative Sundial, it would read in the manner indicated in Figure A-1, although not with an aperture nodus, but with a miniature pylon. Only half the sundial is modeled in Figure A-2.

I'm sure you'll agree that once you have constructed and aligned such a dial, using it would be a pleasure. The problem is constructing it. Having all those curvy lines that need to be precisely chased in a piece of metal, and then tilting it up and aligning it is very difficult to do. You almost need to be a professional engraver.

Indeed, the Briggs dial was constructed by R. Newton Mayall himself, who wrote one of the books in the bibliography. He discussed chasing and planing off the engraving-tool marks at length. With modern printers and materials, you may be able to get by with acrylic plastic over printer paper. There is an example on the sundials.org site of such a dial at Atlantic Beach, FL. I bet the usual deterioration of plastic materials makes this dial subject to frequent replacement, however.

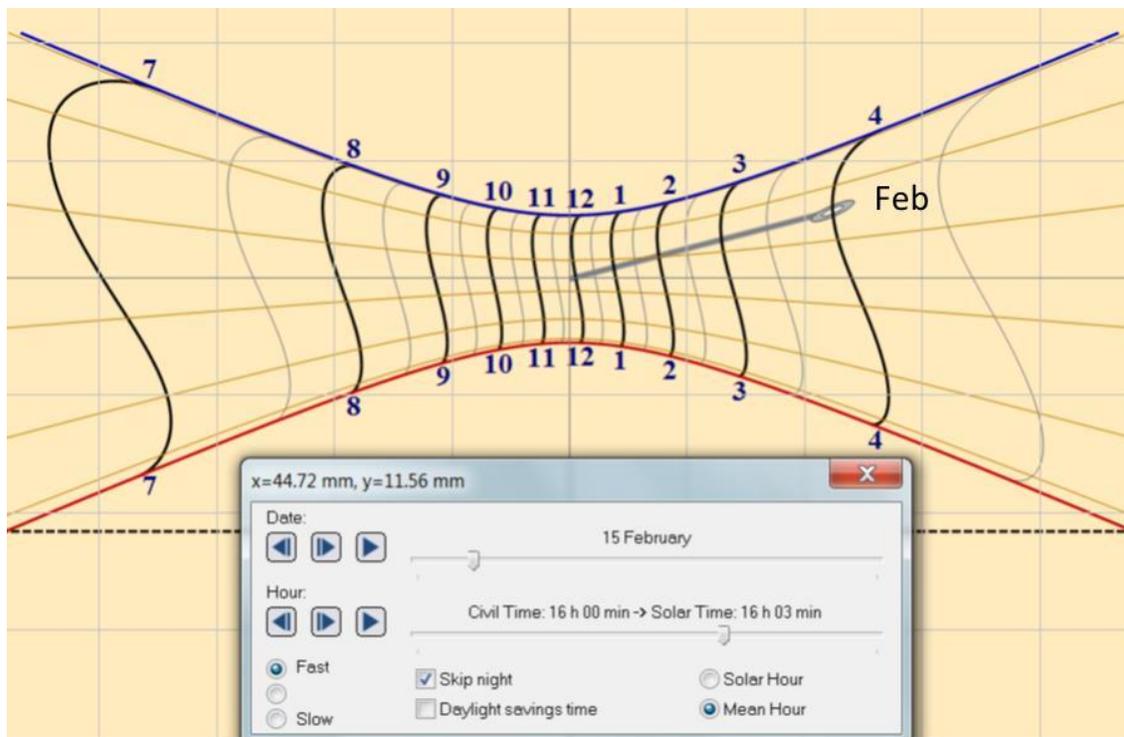


Figure A-2. The simple manner that the polar analemma-corrected dial would read off 4:00 pm clock time on 15 Feb. (modeled by Shadows Pro)

## REFERENCES

NIST Briggs dial: <http://www.sundials.org/index.php/component/sundials/oneDial/51>

*Sundials: Their Construction and Use*, by R. Newton Mayall and Margaret W. Mayall, Sky Publishing, 1938, 1974, 3<sup>rd</sup> edition, **pg. 49**, 1994. Cambridge MA.

Atlantic Beach FL: <http://www.sundials.org/index.php/component/sundials/oneDial/732>