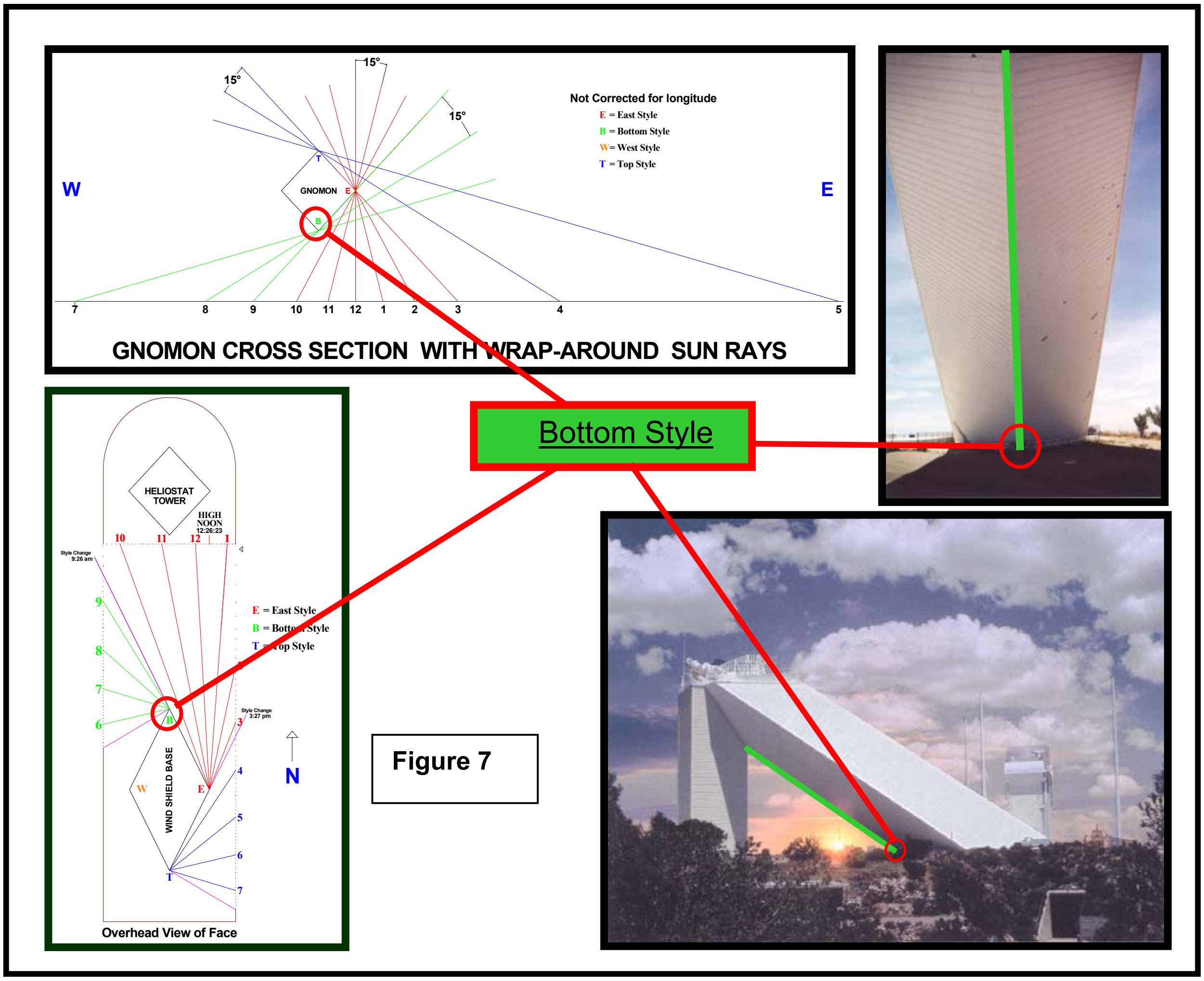

Figure 7

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.

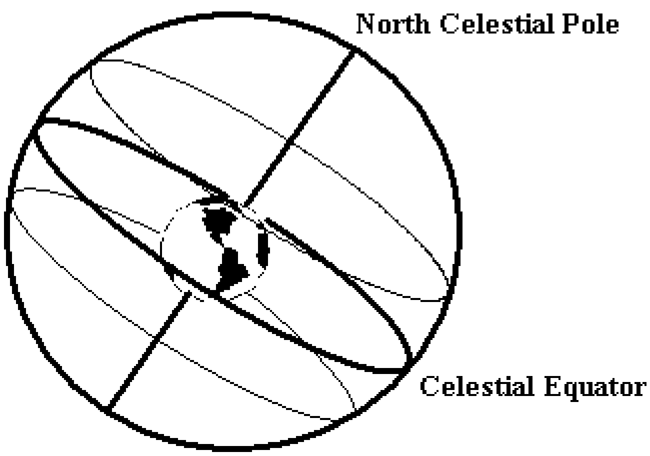

Figure 1. The Celstial Sphere

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.)

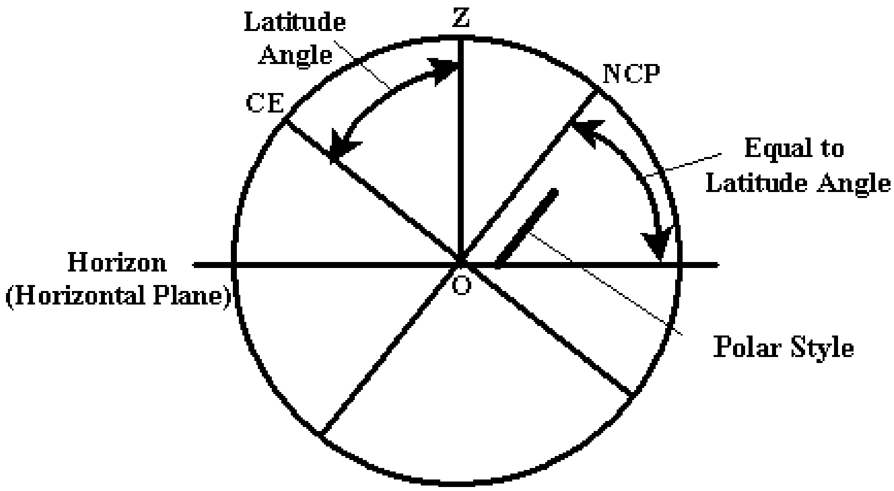

Figure 2. The Polar Style

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".

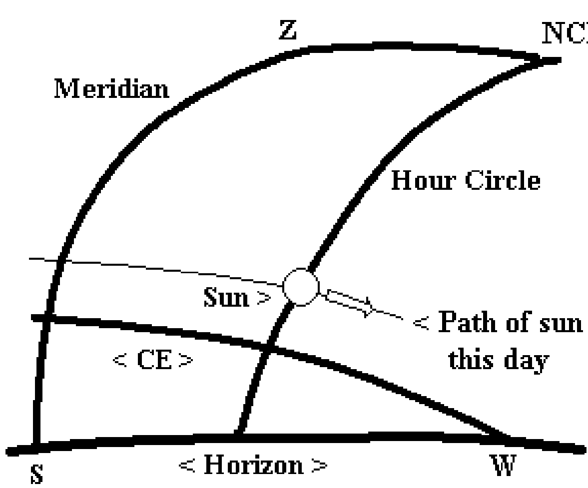

Figure 3. Hour Circle and Sky Coordinates

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.

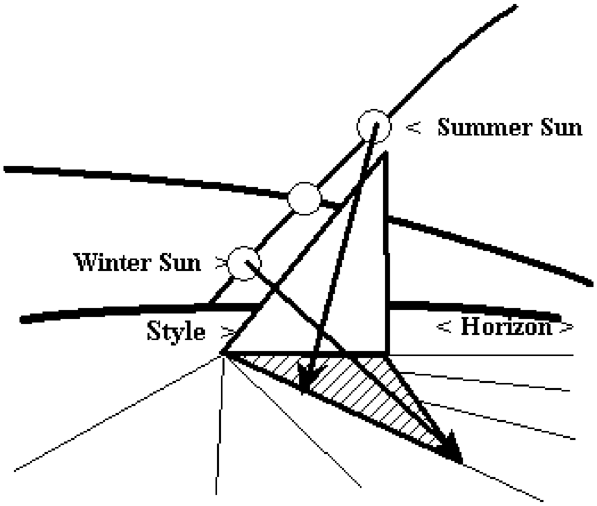

Fig. 4. A Polar Style is Always in the Same Plane as the Sun's Hour Circle

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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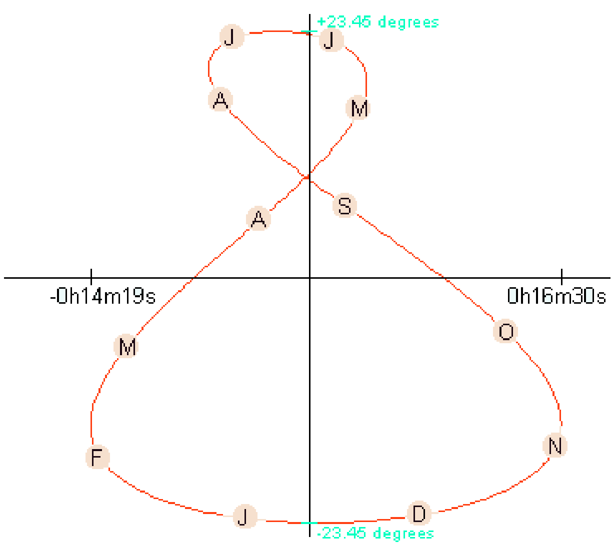
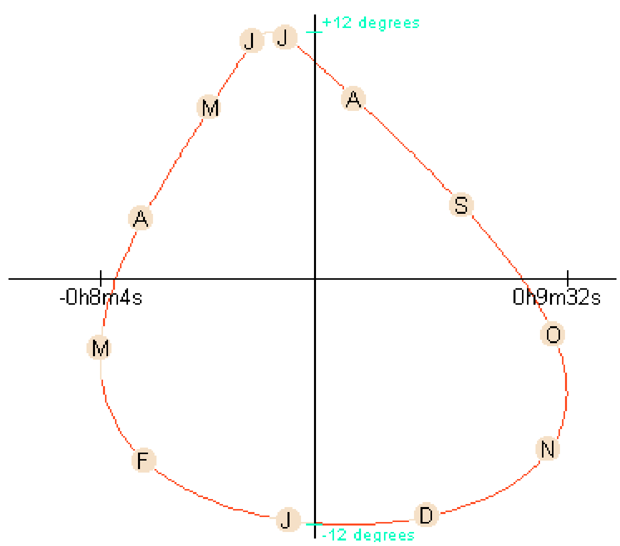
Digital Bonus: Analemma.exe (et al.)

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.