A Reflected Sundial

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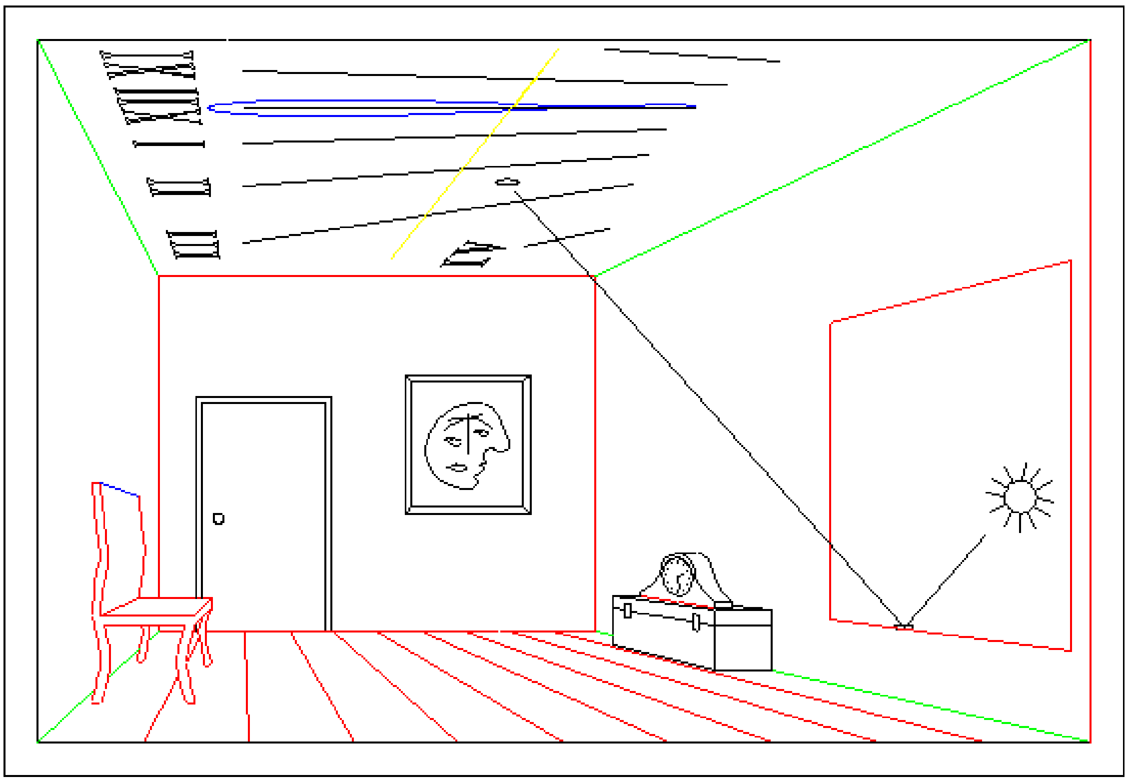
[Editor's Note: This article is excerpted from Taylor & Hendrickson's ***Beginner's Guide To The Sun****, where it appears as a project following the chapter on Scientific Development. The project formulas and directions were provided by Fred Sawyer, and the primary graphic was done by Robert Terwilliger. The project is reprinted here with the permission of Kalmbach Publishing Co. and the authors.]*



We've seen how early humans kept track of the seasons, but how did they mark the hours of the day? Some measured time by the shadow of an upright stick driven into the ground, others by a more elaborate system of shadows cast onto a surface marked with time intervals. These sundials are one of the earliest scientific instruments known. Sundials were used by the Egyptians as early as the 15th century B.C. and maintained their popularity well into A.D. 1800. The most common were known as "garden dials," many of which were richly adorned with phrases such as "I count only the hours that are serene." However, sundials have varied greatly in size, type, and layout. For example, in Jaipur, India, time was once read from the shadow cast by a stairway 36 meters long, and George Washington carried a hand-held dial that fit into his pocket.

Designs have run from the whimsical to the sublime. Sundials have been built to resemble bracelets, sextants, bird feeders, and even satellite dishes. One of the most interesting, however, is the "ceiling" or "reflected" dial. This type of sundial may have originated with Copernicus in the mid-16th century. And some say that Isaac Newton constructed a reflected dial on the ceiling of his grandmother's cottage. According to Rene Rohr, Vice-President of the British Sundial Society, the best known ceiling sundial was painted in 1673 on the walls and ceiling of a Jesuit residence in France.

Fred Sawyer and Bob Terwilliger of the North American Sundial Society have been kind enough to supply us with the details of the reflected sundial design, described below.

Materials:

A small first-surface mirror, 6 cm. square (A first-surface mirror is silvered on its face rather than its back.)

A roll of narrow masking tape and a pencil

Construction:

Begin by placing the small mirror on a window sill or another horizontal surface in a window where it will receive sunshine for a good part of the day. If the mirror is small enough, the image it reflects on the ceiling will be a circular spot of sunlight, even though the mirror itself is square.

If it is difficult to locate a mirror of that size, use a slightly larger one by covering it with a dark paper mask that contains an opening of the approximate size.

Generally speaking, the nearer the mirror is to the ceiling the better, because its reflection onto the ceiling will be seen for more of the day. If the mirror is too low, the reflected light spot will move quickly to the side and back walls of the room.

The simplest form of this experiment is to simply watch the daily motion of the reflected image of the Sun as it moves across your ceiling. In the summer when the Sun is high in the sky, the image will travel on a hyperbolic path from west to east, close to the window's wall. At the equinoxes the image follows a straight path across the ceiling. During the fall and winter the path becomes hyperbolic again, beginning at the far west corner and moving closer to the window until midday, when it turns back on a path that carries it to the east. The extremes - closest to and farthest from the windows - occur at the summer and winter solstices, respectively.

The Sun appears to move across the sky at differing rates and therefore solar days vary in length. (Our clocks reflect the average solar day throughout the year.) The Sun is sometimes a little ahead and sometimes a little behind regular clock time. To see this effect, mark the location of the reflected solar image on the ceiling at the same time each day (ignore the consequences of Daylight Savings Time), and then connect the dots. If you continue this process for a full year, the result will be an analemma, a pattern in the shape of a figure 8. This design is seen on many old globes - often in the form of a strange-looking symbol placed somewhere in the Pacific Ocean. This feature is seldom mentioned today because most of us are unaware of its special significance.

If the Sun always moved at the same rate as our clocks, the analemma would collapse into a straight line. But when the Sun falls behind the clock during their annual race, the spot falls to the west of the line, and when the Sun pulls ahead, the spot appears to the east of the line. This east-west motion combines with the Sun's seasonal north-south travel in the sky to produce a symbol in the shape of a figure 8.

Creating a reflected dial that will show "solar time" requires a little mathematics - but only simple trigonometry functions, which are available on most modern scientific calculators.

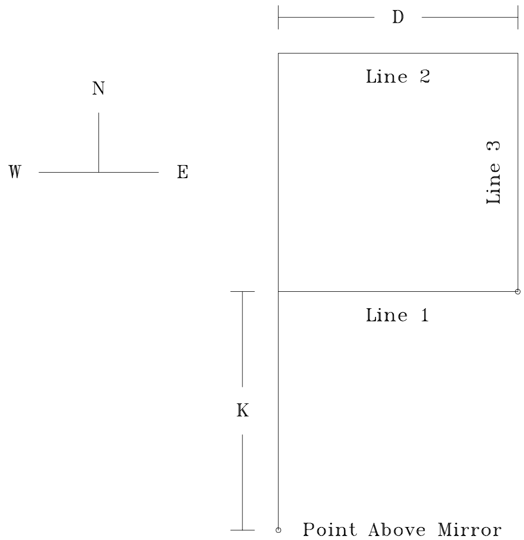
Continue construction by tracing a true north-south line on the ceiling with narrow masking tape. (This procedure works for a horizontal ceiling; a cathedral-shaped ceiling is more complicated.) Do not use a magnetic compass to establish the line, since magnetic north and true celestial north are not the same. The simplest approach is to determine the time midway between sunrise and sunset for the day the line is drawn. Such information can be obtained from a local newspaper, television weather forecast or an almanac, but be certain the time is for your location.

At the appointed time, the reflected image will be exactly due north of the mirror's location. Mark that spot and establish a tape-line on the ceiling that extends from the spot to a point directly above the mirror. This line traces your meridian - the line of longitude running through your room.

Now lay out a complete rectangle on the ceiling with masking tape, using the north-south line as the western side of the rectangle. You will use these lines to locate afternoon hour-lines. Lines for the morning hours can be determined through a similar process but with the rectangle drawn on the other side of the N-S line (that is, so that the N-S line forms its eastern boundary).

Refer to the following figure during the next steps, but bear in mind that you are looking at the drawing as if it is on the floor - and not as though it is over your head and you are looking toward the ceiling.

To find the sundial's hour-line for a particular time, say 2 P.M., proceed as follows:



Let H equal the height of the ceiling above the mirror (that is, the vertical distance between the ceiling and the [reflecting surface of] the mirror), and K equal the distance of the east-west line of masking tape (Line 1 in Figure 1) from a point directly above the mirror.

For best results, draw the rectangle so that K is small; that is, establish this end of the rectangle so it is as close to the window as possible.

Also, assign L the value of your latitude, and T the Sun's hour-angle (set the value of T at 15 degrees for each hour before or after noon; for example, 2 P.M. = 30 degrees).

Strictly speaking, this is the Sun's hour-angle for 2 P.M. local solar time. To get closer to the time our watches indicate, an additional adjustment for latitude would be required, but this does not appear in traditional sundials, nor is it something astronomers would have been particularly concerned about before the mid-19th or early 20th centuries.

Our hour-line for 2 P.M. will meet the east-west line (Line 1) at a distance P1 from the N-S line, with

P1 = tan T (K sin L + H cos L).

Of course, you will need two points to be able to draw the hour-line. If K' represents the distance from the ceiling point above the mirror to Line 2 (that is, the northern-most east-west-line of the rectangle), then the intersection of the hour-line with Line 2 occurs at distance P2 from the N-S line, with

P2 = tan T (K' sin L + H cos L).

Unfortunately, not all of the hour-lines will cross both Line 1 and Line 2, since the size of the rectangle is restricted by the confines of our ceiling. For these lines, you can locate the second point of the hour-line along Line 3 (the eastern N-S line of the rectangle).

In this case, let D represent the distance between the original N-S (west) line of the point of rectangle and Line 3. The distance P2' of the point of intersection from the southeast corner of the rectangle measured along Line 3 is determined according to

P2' = (D cot T - H cos L) / sin L - K.

(Positive values lie to the north, negative to the south.)

Once you've found two points to establish an hour-line, you can draw a straight line with tape that connects them. Extend the line in both directions (toward and away from the window) and you have another hour-line for the sundial. Continue in this way for other hour-lines.

Remember, however, that the lines will not match clock time. If you wanted them to be the same, you would require a series of figure 8's drawn on the ceiling. Instead, you have reproduced a traditional sundial, which indicates solar time. If you would like to convert a reading to clock time, try one of the following.

1. Read the material on sundials published annually in the *Old Farmer's Almanac*. This publication provides a column containing an adjustment procedure for every day of the year that gives the time - faster or slower - of the Sun compared with the clock.

2. Refer to your local newspaper or weather broadcast and determine the time exactly halfway between sunrise and sunset. The sundial will read (solar) noon at this time. The difference between solar noon and local noon can be used throughout the day to adjust for "Sun-fast" or "Sun-slow" conditions, but remember that this adjustment slowly changes from day to day.