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CONTENTS

Sundials For Starters: Time for Another Solar Eclipse for North America — 1
Robert L. Kellogg

Horizontal Sidereal Time and Standard Time Sundials — 9
Sven De Rijcke

It’s Bifilar Sundial Time! — 19
Gian Casalegno

On Lunar Volvelles – Part 2 — 29
Mark Montgomery

A Hybrid Peaucellier Sundial — 41
Martin Jenkins

In the Footsteps Of Hugo Michnik — 48
Maciej Lose

The Equinoctial Curve in the Bifilar Dial with a Polar Thread — 61
Fabio Savian

Interview: John Carmichael — 69
Interviewed by Steve Lelievre

Don’t forget Quadrant Arctangent! — 77
Steve Lelievre

The Tove’s Nest — 78

Digital Bonus — 78

Front cover: Gneisenaustrasse, Breslau, Germany (now Wrocław, Poland), seen in a pre-WWII postcard. Hugo Michnik lived at No. 5.

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NASS Officers

President & Editor Emeritus

Frederick W. Sawyer III
27 Ninas Way – Hampton Run
Manchester CT 06040-6388
USA
sundial.society+president
@gmail.com

Vice President

Robert L. Kellogg
10629 Rock Run Drive
Potomac MD 20854-1701
USA
sundial.society+vicepresident
@gmail.com

Secretary & Editor

Steve Lelievre
307-2211 Shelbourne Street
Victoria BC V8R 4K9
Canada
sundial.society+secretary
@gmail.com
sundial.society+editor
@gmail.com

Treasurer

Mark Montgomery
311 Water Tower Drive
Chesterton IN 46304-2654
USA
sundial.society+treasurer
@gmail.com

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SUNDIALS FOR STARTERS: TIME FOR ANOTHER SOLAR ECLIPSE FOR NORTH AMERICA

Robert L. Kellogg (Potomac, MD)

Five years ago, we had a total solar eclipse sweep across the United States, on August 21, 2017, when the weather was spectacularly clear. Last October an annular solar eclipse crossed the United States, Mexico, and South America. Now once again on April 8, 2024, we have a solar eclipse traveling across Mexico, the United States and the far eastern corner of Canada.

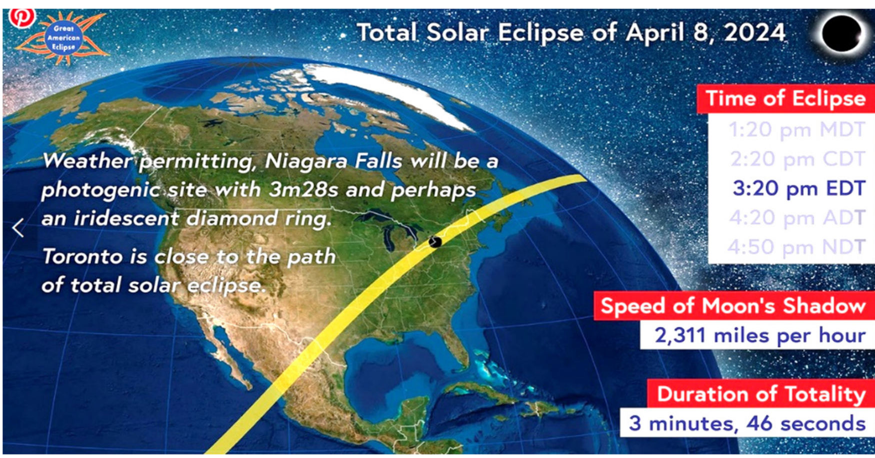

Fig. 1. Path of 2024 Total Solar Eclipse. From GreatAmericanEclipse.com

We think of the Babylonians and Assyrians as the first ancient astronomers to record lunar and solar eclipses, but the earliest solar eclipse record that can be verified appears in Chinese oracle bone inscriptions dating back to an eclipse that occurred on October 22, 2136 BCE. It seems that the royal astronomers, Hsi and Ho, during the reign of Chung-Kan, fourth emperor of the Hsia Dynasty, failed to predict this solar eclipse and perform the required protective ceremonies. They were executed on the grounds that their slackness (possibly drunkenness) put the whole kingdom in peril.

Fortunately, today’s astronomers can predict eclipses down to the second. In fact, Fred Espenak and Jean Meeus have cataloged and predicted solar eclipses from the 18th to 23rd century. But the mathematics goes back to Thales of Miletus, when according to Herodotus from his *History*,

> *... there was war between the Lydians and the Medes five years... They were still warring with equal success, when it chanced, at an encounter which happened in the sixth year, that during the battle the day turned to night. Thales of Miletus had foretold this loss of daylight to the Ionians, fixing it within the year in which the change did indeed happen. So, when the Lydians and Medes saw the day turned to night, they ceased from fighting, and both were the more zealous to make peace.*

This solar eclipse occurred on May 25, 585 BCE. How did Thales predict an eclipse would occur?

Solar and lunar eclipses occur only when the moon crosses the ecliptic near the longitude of the sun near full or new moon. The time from one new moon to the next is called the Synodic Month, with an average period of 29.530589 days. We need to make sure that the new moon (for a solar eclipse) or full moon (for a lunar eclipse) is nearly in line with the sun. This does not happen most of the time since the moon's orbit around the earth is not in the ecliptic plane but is inclined 5° to it. And to make calculations difficult, the sun and ellipsoidal earth perturb this orbit, shifting its ecliptic crossing longitude.

In other words, lunisolar perturbations cause precession of the longitude of nodes. The moon's orbital node has a western precession that completes one cycle in 18.6 years, or 242 Draconic Months. So, we need to consider both the Synodic Month and the length of the Draconic Month, and we have two periods to deal with [1]:

Synodic Month (new moon to new moon)	29.530589 days
Draconic Month (moon passing node to node)	27.212221 days

We should also consider the Anomalistic Month which is the time for the moon to travel from perigee to perigee. This governs whether we have a total or annular eclipse:

Anomalistic Month (perigee to perigee)	27.554550 days

Since the Anomalistic Month does not mesh with either the Synodic Month or Draconic Month, we can get an annular solar eclipse when the moon is at apogee (furthest away from the sun) or, for more than half the orbit nearer to perigee (closest to the earth), we can have a total solar eclipse. Fred Espenak explains on the NASA website [1]:

> *One Saros [cycle] is equal to 223 synodic months. However, 239 anomalistic months and 242 draconic months are also equal to this same period (to within a couple hours)!*

223 Synodic Months.	= 6585.3223 days	= 6585d 07h 43m
239 Anomalistic Months	= 6585.5375 days	= 6585d 12h 54m
242 Draconic Months	= 6585.3575 days	= 6585d 08h 35m

> *Any two eclipses separated by one Saros cycle share very similar geometries… Because the Saros period is not equal to a whole number of days, its biggest drawback is that subsequent eclipses are visible from different parts of the globe. The extra ⅓ day displacement means that Earth must rotate an additional ~8 hours or ~120° with each cycle. For solar eclipses, this results in the shifting of each successive eclipse path by ~120° westward. Thus, a Saros series returns to about the same geographic region every 3 saroses (54 years and 34 days).*

The triple Saros cycle is called the Exeligmos Cycle. Hence the upcoming total solar eclipse of April 8, 2024 (Saros cycle 139) will repeat 54 years later on May 11, 2078, albeit with a slightly more southern shift of the path of totality. See https://www.solar-eclipse.info/en/saros/detail/139/ for more details.

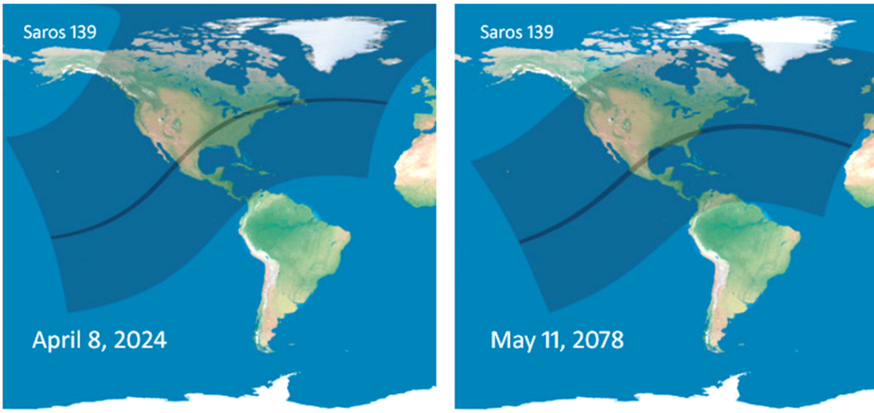

Fig. 2. Saros 139 repeating 54 years apart. From https://www.solar-eclipse.info/en/saros/detail/139/.

Other notable total solar eclipses over North America include Aug 12, 2045 (Saros 136), Mar. 30, 2052 (Saros 130), and Sep. 23, 2071 (Saros 145).

For the April 8, 2024 total eclipse, many events are planned across the US. Here are just a few of the ones listed in Reference 2:

Most international visitors to Mazatlán [Sinaloa, Mexico] — the first place to experience totality and one of the most likely to have clear skies — will stay in big hotels and resorts. However, [one] festival offers a different experience, featuring off-grid camping, yoga and DJs. It will take place April 5-9 at an ecotourism resort called Ecovillage Sembrando Vida, near the beach just south of Mazatlán. [Tickets cost $295.99].
McLane Stadium in Waco, Texas, will host an eclipse viewing event… It's being staged by the Flagstaff, Arizona-based Lowell Observatory, which hosted a huge event in Oregon in 2017, together with the City of Waco and Baylor University. The

Discovery Channel will broadcast the event live. [Tickets cost $20 for adults, $10 for children, $25 for parking].
You can join thousands of eclipse chasers for the Southern Illinois Crossroads Eclipse Festival at Southern Illinois University Carbondale's Saluki Stadium, where Mat Kaplan, ex-host and creator of Planetary Radio, will host and guide. [Tickets cost $25 for adults, $5 for children].
[In Rochester, New York] several thousand people are expected to attend a three-day event (April 6-8) at the Rochester Museum and Science Center. At the largely free event, festivities will include science speakers, music, NPR Science Friday hands-on activities, solar telescopes, food trucks and, most importantly, Rochester's famous 6-foot-wide (1.8 meters) eclipse glasses (as well as places to purchase smaller glasses).
[At ASTROLab, Mont-Mégantic Observatory, Mont-Mégantic National Park, Quebec] A total solar eclipse rarely occurs directly above a famous astronomical observatory within an International Dark Sky Reserve, but that will happen on April 8, when Mont Mégantic Observatory is eclipsed. An event for 2,500 people is planned, including an outdoor stage, a giant animation of the eclipse's progress on-screen and solar telescopes at the nearby ASTROLab museum. There will be silence during totality.

Check for a spot near you on the path of totality at nso.edu/for-public/eclipse-map-2024/ or go to greatamericaneclipse.com/april-8-2024 which has some very nice animated graphics to help explain the eclipse and to 'fly along the path' with animated maps.

Wherever you are, **never look at the sun without solar glasses**. Normal sunglasses *DO NOT* provide protection. As Dr. Jeff Kretsch of NASS and The Analemma Society notes:

The essential danger is not only visible light, but infra-red that burns the retina. You need a solar filter for both you and your telescope and binoculars if you intend to look directly at the progress of the eclipse from initial lunar occultation (first contact) to the final lunar egress (fourth contact). Not all filters are safe.

You need ISO 12312-2 certified Solar Glasses that let in only 0.00032 percent of the sun's light. For example, they are available at https://nationaleclipse.com/store.html and many other website stores.

Fig. 3. Stages of a total solar eclipse and when you need safe solar glasses. From www.greatamericaneclipse.com/phenomena.

The total duration of the eclipse takes about 90 minutes with totality occurring for several minutes (4m 28s in Texas, 3m 30s in New York) in the middle of the event. During the partial eclipse phase if you want to see the moon's disk in front of the sun, YOU NEED TO WEAR THE ISO-CERTIFIED GLASSES.

During totality, it is possible to look at the sun and use an unfiltered telescope or binoculars. BUT KEEP TRACK OF THE TIME. Even a tiny amount of sunlight emerging at the end of totality can damage your eyes.

What will you see during totality? During the 2017 solar eclipse, the sun was nearing the end of its 11-year sunspot cycle (cycle 24), and was relatively quiescent. Yet it had a wonderful, luminous corona with delicate radial 'spikes' extending out from the sun by a number of solar radii.

Fig. 4. Quiescent Sun during 2017 Solar Eclipse. Photo by R.L. Kellogg.

April's total eclipse may be completely different. The sun is ramping up solar flare and sunspot activity as part of the strong solar cycle 25.

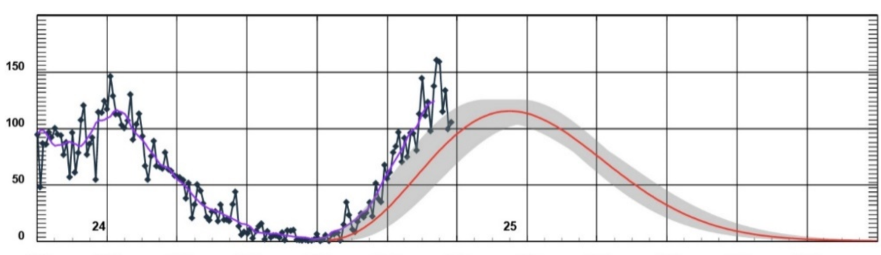

Fig. 5. Sunspot Count. Note late 2017 and the number of sunspots was about 25. At the start of 2024 the sunspot count has already been above 125 and by April 2024 could very well exceed 175. From https://www.swpc.noaa.gov/products/solar-cycle-progression

On December 14, 2023 we had an extremely strong solar flare given the category designation X2,8 (X-class denotes the most intense flares and number 1-9 the strength within the class). Without a solar eclipse, NASA's Solar Dynamic Observatory monitors a band of visible light (0.6173, 0.4500, and 0.1700 micron), helium (He II at 0.0304 micron), and highly ionized iron (Fe IX at 0.0171 micron, Fe XII at 0.0193 micron and additional excited states up to Fe XVIII at 0.0094 micron). You can check the state of the current sun at https://sdo.gsfc.nasa.gov/data/.

On April 8, 2024 during totality, you will see the sun's corona with multiple pink prominences (solar flares in profile). There may be a lot of activity! Also in the sky you'll be able to see Mercury, Venus, and Jupiter. If weather disappoints, remember that during totality it still will get very dark (the moon's shadow approaches from the west). The twilight will seem strange and birds will begin to roost. If this is your first total eclipse, just take it all in. A pair of binoculars (**with ISO certified filter** except perhaps during totality) will give an amazing sight.

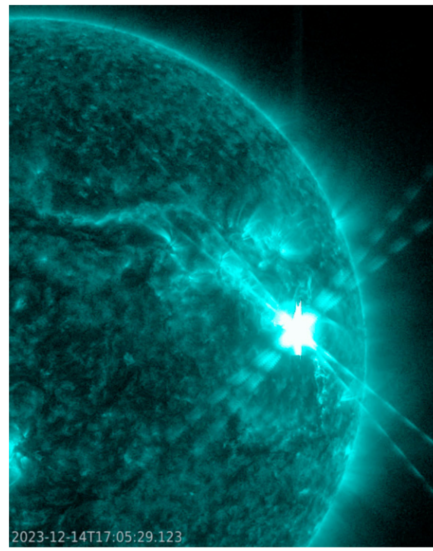

Fig. 6. Solar flare of Dec. 14, 2023 captured by NASA's Solar Dynamics Observatory (SDO) showing the flare (bright spot) in extreme ultraviolet light at 0.0131 micron.

Bob Kellogg *rkellogg@comcast.net*

References

1. Fred Espenak, "Eclipses and the Saros", https://eclipse.gsfc.nasa.gov/SEsaros/SEsaros.html accessed 1 Jan. 2024.
2. https://www.space.com/total-solar-eclipse-april-2024-viewing-events-parties-festivals accessed 1 Jan 2024.

See 'The Tove's Nest' at p.78 for information about Bill Gottesman's wonderful Solar Eclipse Sundial, updated for the 2024 eclipse.

HORIZONTAL SIDEREAL TIME AND STANDARD TIME SUNDIALS

S. De Rijcke (Gent, Belgium)

In the September 2023 issue of THE COMPENDIUM[1], a thorough discussion of Hugo Michnik's design for a sidereal-time sundial was presented. This dial makes use of the shadow of a nodus, e.g., the tip of a vertical style, projected onto the horizontal plane. Unfortunately, the shadow of a nodus runs off to infinity at sunrise and sunset, and, therefore, not all hour points can be accommodated on a sundial plate with finite dimensions. This problem can be solved by using the *direction* of the style's shadow to tell time. This is the working principle behind, for instance, the horizontal sundial, where the direction of the shadow of a style aimed towards the celestial pole is employed. Can we tinker with the horizontal sundial such that it indicates sidereal time as well as solar time?

In its common form, the horizontal sundial has a layout that is independent of date: a single set of hour points is used to indicate solar time throughout the whole year. That is unfortunate for our purposes, since solar time (tracking the hour angle $h_\odot$ of the Sun) and sidereal time Θ (tracking the hour angle of the March equinox) are related by a date-dependent rotation,

$$\Theta = h_\odot + \alpha_\odot,$$

with $\alpha_\odot$ the Sun's right ascension. Fortunately, this problem is easily overcome. We can derive the layout of a horizontal sundial by projecting an auxiliary circular equatorial sundial with radius R along the Earth's rotation axis onto the horizontal plane[2]. Using this construction, an hour mark on the equatorial sundial's edge

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[1] Fred Sawyer, Hugo Michnik's Sidereal Sundial Design, The Compendium, 30(3):36-45, Sep. 2023

[2] Denis Savoie, Sundials – Design, Construction, and Use, 2009, Springer-Praxis, p.69ff

corresponding to a Solar hour angle $h_\odot$ is projected onto the horizontal plane at a position

$$\vec{s}(h_\odot) = R\left(\sin h_\odot\,\vec{e}_{\text{east}} + \frac{\cos h_\odot}{\sin\varphi}\,\vec{e}_{\text{north}}\right).$$

Here, φ is the dial's latitude, $\vec{e}_{\text{east}}$ is a unit vector pointing east, and $\vec{e}_{\text{north}}$ is a unit vector pointing north. This coordinate system lives in the horizontal plane and its origin is anchored to the dials' shared center (see Figure 1).

We are perfectly at liberty of assembling a horizontal sundial by projecting a *different* equatorial sundial for each hour mark. In other words, we can let the radius R of the auxiliary equatorial sundial depend on time and date to produce the hour marks

$$\vec{s}(\text{date}, h_\odot) = R(\text{date}, \text{time})\left(\sin h_\odot\,\vec{e}_{\text{east}} + \frac{\cos h_\odot}{\sin\varphi}\,\vec{e}_{\text{north}}\right). \quad (1)$$

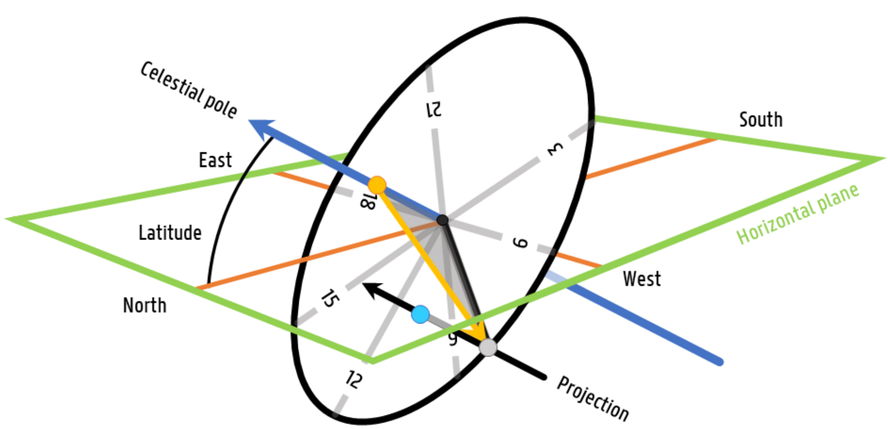

Fig. 1. The shadow of a point (yellow bullet) on the style of a circular equatorial sundial falls on the dial's edge (grey bullet). The projection of this shadow point along a direction parallel to the Earth's axis (black arrow) onto the horizontal plane (the green square) is an hour point (blue bullet) of a horizontal sundial. The centers of the equatorial and horizontal sundials coincide and lie in the horizontal plane.

Of course, this extra freedom does not make much sense for a horizontal sundial that indicates apparent Solar Time. Irrespective of what radius $R(\text{date}, \text{time})$ we use, the hour marks corresponding to a given $h_{\odot}$ always lie in the same direction. However, we can exploit the freedom to choose $R(\text{date}, \text{time})$ to construct a horizontal sundial that accurately indicates local Standard Time (ST) or local Sidereal Time (LST).

A Standard Time horizontal sundial

To construct a ST horizontal sundial, we need to predict the direction of the style's shadow, and therefore the position of the apparent Sun, for a given ST and date. The mean Sun's hour angle with respect to the local meridian, $h_{\text{M}\odot}$, is the basis for ST (see the appendix for a precise definition of these, and other, Suns). To a precision better than 1 second, Universal Time, or UT, equals the hour angle of the mean Sun with respect to the Greenwich meridian. In a time-zone ΔTZ hours away from Western European Time (WET), UT and ST are connected by the simple relation $\text{UT} = \text{ST} - \Delta\text{TZ}$. Here, ΔTZ is understood to include the Daylight-Saving Time offset, if applicable. In other words, for a dial at a location with geographical longitude λ, $\text{UT} = 12\text{h} + h_{\text{M}\odot} - \lambda$. Starting with the seminal work of Canadian-American astronomer Simon Newcomb, accurate algorithms have been developed for computing the position of the mean Sun for a given UT and date, and for converting this into the position of the apparent Sun, and hence its hour angle $h_{\odot}$.

The recipe for the layout of a ST horizontal sundial consists of three steps. First, we define how the radius of the auxiliary equatorial sundial depends on date and time. Here, we choose the simple recipe

$$R(\text{date}, \text{time}) = 1 + 0.75\,\frac{\text{day number} - 182}{182}, \qquad (2)$$

with the day number running from 1 to 366 through the (leap) year 2024. Second, we apply the procedure detailed in the Appendix at the end of this contribution to compute the apparent Sun's hour angle $h_{\odot}$ for any desired date and ST. Third, together with equations (1) and

(2), this leads to the hour points of an ST horizontal sundial, including the mean correction for atmospheric refraction. Including refraction may seem like overkill, but with a computer, it is no great effort to take it into account and gain a few minutes of accuracy around sunset and sunrise. Figure 2 hows the layout of a ST horizontal sundial, computed for the year 2024 for a dial at latitude $\varphi = 40°$ and longitude $\lambda = -74°$, $\Delta TZ = -5h$ away from WET.

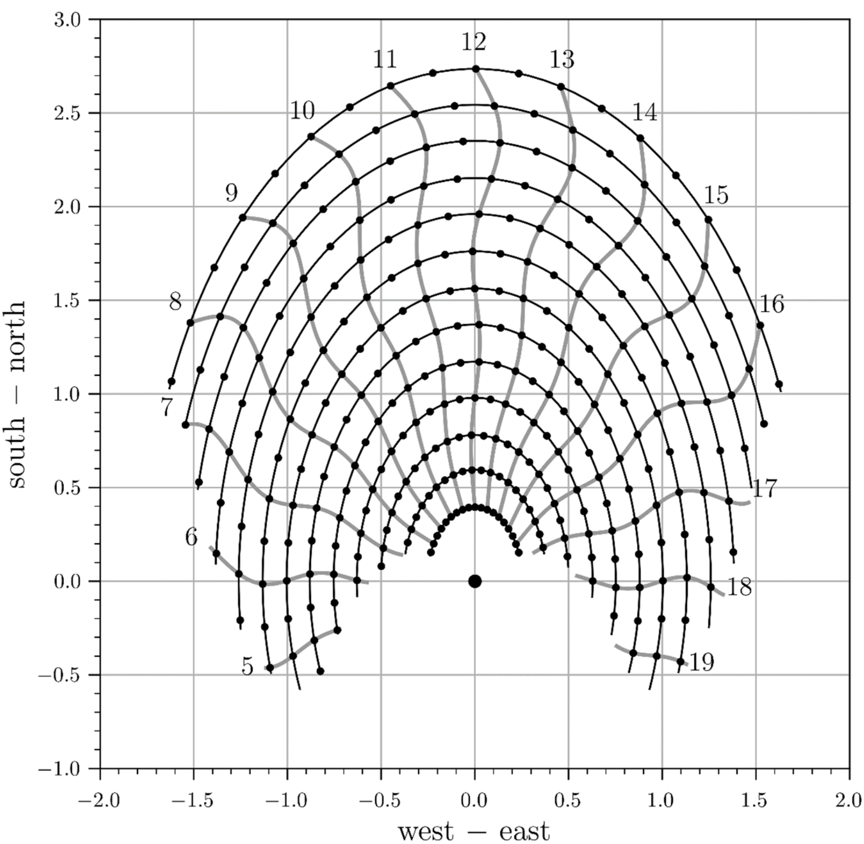

Fig. 2. the layout of a ST horizontal sundial, computed for the year 2024 for a dial at latitude $\varphi = 40°$ and longitude $\lambda = -74°$, $\Delta TZ = -5h$ away from the Greenwich time zone. The style's foot is planted at $(0{,}0)$ (thick black bullet). The grey lines trace the full hours; black bullets in between the grey lines indicate the half hours. Going away from the style's foot point, the thin black lines connect the hour points of January 1, February 1, …, December 1, and December 31. They start at sunrise and end at sunset (upper tip of the apparent Sun on the horizon).

A Local Sidereal Time horizontal sundial

Local Sidereal Time (LST), Θ, measures the hour angle of the mean March equinox with respect to the local meridian. To create a LST sundial, we need to compute the UT for a given LST and date. The procedure for this is given in the Appendix. From that UT, the direction of the apparent Sun, and therefore of the style's shadow, can be computed in the same way as for the ST horizontal sundial. Figure 3 shows the layout of an LST horizontal sundial, computed for the year 2024 for a dial at latitude $\varphi = 40°$ and longitude $\lambda = -74°$, $\Delta\mathrm{TZ} = -5\mathrm{h}$ away from WET. This dial has the same radius function $R(\mathrm{date}, \mathrm{time})$ as the ST dial shown in Figure 2.

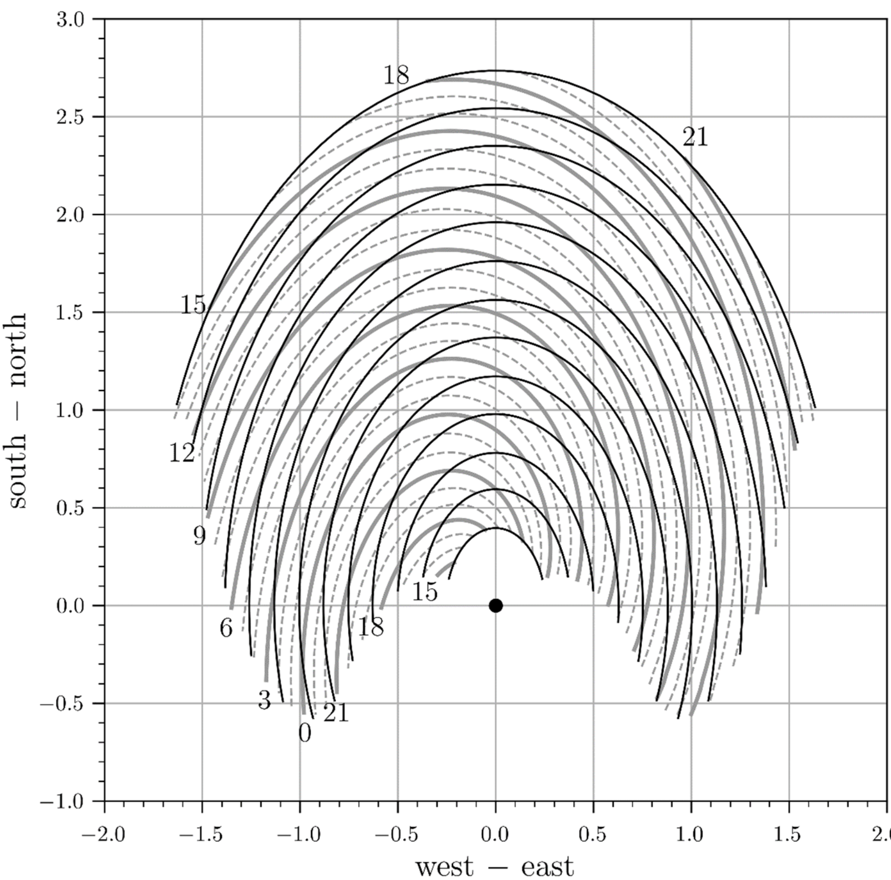

Fig. 3.: the layout of an LST horizontal sundial, computed for the year 2024 for a dial at latitude $\varphi = 40°$ and longitude $\lambda = -74°$, $\Delta TZ = -5h$ away

from the Greenwich time zone. The style's foot is planted at $(0{,}0)$ *(thick black bullet). The grey lines trace the full hours. For clarity, only the sidereal hours* $\Theta = 0h, 3h, 6h, \dots, 21h$ *are traced by full lines and are labeled in the figure; all other sidereal hours are indicated by thinner dashed lines, without label. Going away from the style's foot point, the thin black lines connect the hour points of January 1, February 1, ..., December 1, and December 31. They start at sunrise and end at sunset (upper tip of the apparent Sun on the horizon).*

If the Sun's right ascension would increase at a constant rate throughout the year, the grey curves of constant LST would be perfect Archimedean spirals, stretched by a factor $1/\sin\varphi$ along the north-south direction.

APPENDIX

Because of the way ST has been defined, we need to consider four Suns:

1. The *True Sun*, which is the incandescent ball of gas at the center of the Solar System. It moves around the Earth in the ecliptic plane at a variable rate because of Earth's non-circular orbit. Its mean angular speed is $n \approx 3548''$/day.
2. The *Apparent Sun*, which is the bright light in the sky that causes shadows. It inherits the non-uniform motion of the true Sun, and is, moreover, affected by atmospheric refraction.
3. The *Fictitious Sun*, which is a fictitious object that moves through the ecliptic at a constant angular speed, equal to the mean angular speed n of the true Sun. The fictitious and the true Sun coincide only at Earth's perihelion and aphelion. The ecliptic longitude of the fictitious Sun, $\lambda_{F\odot}$, is called the *mean longitude of the Sun*.
4. The *Mean Sun*, an equally fictitious object that moves through the equatorial plane at a constant angular speed, such that its right

ascension, $\alpha_{M\odot}$, at all times equals the mean longitude of the Sun, $\lambda_{F\odot}$[3].

In what follows, we will need to compute the time elapsed between two days. For this, astronomers have adopted the Julian Day (JD), which is the number of days passed since January 1, 4712 BCE, 12:00 UT. The JD of a particular date is given by the following handy algorithm:

Input:	Y (year), M (month), D (day) in the Gregorian calendar, UT (time in Universal Time)
Output:	JD (Julian Day)
$D = D + \frac{\mathrm{UT}}{24}$ if $M = 1$ or 2: $Y \rightarrow Y - 1$ $M \rightarrow M + 12$ $A = \mathrm{INT}\left(\frac{Y}{100}\right)$ $B = 2 - A + \mathrm{INT}\left(\frac{A}{4}\right)$ $\mathrm{JD} = \mathrm{INT}\big(365.25(Y + 4716)\big) + \mathrm{INT}\big(30.6001(M + 1)\big) + D + B - 1524.5$	

The Julian Century, T, is defined as the time elapsed since January 1, 2000, 12 UT, measured in 'centuries' of 36525 days:

$$T = \frac{\mathrm{JD} - 2451545.0}{36525}.$$

[3] Actually, the correct relation is $\alpha_{M\odot} = \lambda_{F\odot} - 20.49''$, taking into account the fact that during the 8 minutes that it took light to travel from the true Sun to us, the latter moved by $20.49''$ along the ecliptic. This light-travel time effect is called aberration.

The position of the Sun(s)

In the indispensable *Astronomical Algorithms*[4], we find the necessary algorithms to compute the position of the Sun. For the rest of the 21st century, the mean longitude of the Sun can be computed with an accuracy of about $10''$ as

$$\lambda_{\mathrm{F}\odot} = 280.46646° + (36000.76983° + 0.0003032° \times T) \times T.$$

The mean anomaly of the fictitious Sun is given by

$$M_{\mathrm{F}\odot} = 357.52911° + (35999.05029° - 0.0001537° \times T) \times T.$$

From these ingredients, we can compute the ecliptic longitude of the aberrated true Sun, as

$$\lambda_{\mathrm{T}\odot} = \lambda_{\mathrm{F}\odot} + \mathrm{EoC} - 20.49''.$$

Here, the so-called Equation of the Center

$$\begin{aligned}\mathrm{EoC} = (1.914602° - (0.004817° + 0.000014° \times T) \times T) \sin M_{\mathrm{F}\odot} \\ + (0.019993° - 0.000101° \times T) \sin(2M_{\mathrm{F}\odot}) \\ + (0.000289°) \sin(3M_{\mathrm{F}\odot})\end{aligned}$$

quantifies the effects due to Earth's non-circular orbit. With the mean obliquity of the ecliptic given by

$$\begin{aligned}\varepsilon = 23°26'21.448'' \\ - \ (46.8150'' \\ + (0.00059'' - 0.001813'' \times T) \times T) \times T,\end{aligned}$$

the true Sun's equatorial coordinates follow from

$$\tan \alpha_{\mathrm{T}\odot} = \cos \varepsilon \tan \lambda_{\mathrm{T}\odot},$$

$$\sin \delta_{\mathrm{T}\odot} = \sin \varepsilon \sin \lambda_{\mathrm{T}\odot}.$$

Its hour angle derives from the ST as

$$h_{\mathrm{T}\odot} = \mathrm{ST} + \mathrm{EoT} + \lambda - 12\mathrm{h} - \Delta\mathrm{TZ}.$$

The equation of time, EoT, can be computed from the relation

[4] Jean Meeus, Astronomical Algorithms, 2nd edition, 1998, Willmann-Bell, Inc., - ISBN 0-943396-61-1.

$$\text{EoT} = h_{\text{T}\odot} - h_{\text{M}\odot} = \alpha_{\text{M}\odot} - \alpha_{\text{T}\odot} = \lambda_{\text{F}\odot} - 20.49'' - \alpha_{\text{T}\odot}.$$

We already have $\lambda_{\text{F}\odot}$ and $\alpha_{\text{T}\odot}$ so we're all set.

The true Sun's horizontal coordinates, altitude $a_{\text{T}\odot}$ and azimuth $A_{\text{T}\odot}$, follow from the well-known relations

$$\sin a_{\text{T}\odot} = \cos\varphi \cos\delta_{\text{T}\odot} \cos h_{\text{T}\odot} + \sin\varphi \sin\delta_{\text{T}\odot},$$

$$\cos a_{\text{T}\odot} \cos A_{\text{T}\odot} = \sin\varphi \cos\delta_{\text{T}\odot} \cos h_{\text{T}\odot} - \cos\varphi \sin\delta_{\text{T}\odot},$$

$$\cos a_{\text{T}\odot} \sin A_{\text{T}\odot} = \cos\delta_{\text{T}\odot} \sin h_{\text{T}\odot}.$$

Here, φ is the dial's geographic latitude.

All that remains to be done to find the position of the apparent Sun in the sky is to insert atmospheric refraction into the equation. Exact computations of the refraction angle as a function of $a_{\text{T}\odot}$ are highly complex and yield very unwieldy mathematical expressions. Fortunately, accurate approximations have been formulated that capture quite well the average effects of refraction. An often-used expression[5] for the refraction angle is

$$R = \frac{P\,[\text{mbar}]}{1010} \frac{283}{273 + T\,[°\text{C}]} \left[\frac{1.02'}{\tan\left(a_{\text{T}\odot}[°] + \dfrac{10.3}{5.11 + a_{\text{T}\odot}[°]} \right)} + 0.00192792' \right].$$

Here, P and T are the ambient atmospheric pressure and temperature at the position of the dial. Typical values are $P = 1010$ mbar and $T = 10°\text{C}$. The refraction angle varies between $R(a_{\text{T}\odot} = 90°) = 0'$ and $R(a_{\text{T}\odot} = 0°) = 29'$.

Since refraction only affects the Sun's altitude, we finally find that the apparent Sun is located at:

---

[5] þorsteinn Sæmundsson, *Atmospheric Refraction*, Sky and Telescope, 72, 70, 1986

$$a_\odot = a_{T\odot} + R(a_{T\odot}),$$

$$A_\odot = A_{T\odot}.$$

The apparent Sun's corresponding equatorial coordinates $(h_\odot, \delta_\odot)$ follow from the equations

$$\sin\delta_\odot = -\cos\varphi\cos a_\odot\cos A_\odot + \sin\varphi\sin a_\odot,$$

$$\cos\delta_\odot\cos h_\odot = \sin\varphi\cos a_{T\odot}\cos A_\odot + \cos\varphi\sin a_\odot,$$

$$\cos\delta_\odot\sin h_\odot = \cos a_\odot\sin A_\odot.$$

Its right ascension is given by

$$\alpha_\odot = a_{T\odot} + h_{T\odot} - h_\odot.$$

This concludes our computation of the apparent Sun's coordinates for a given time and date.

To convert LST Θ into UT, first compute the Julian Century T for the given date at 0h UT. From this, compute the Sidereal Time with respect to the Greenwich meridian using the formula

$$\Theta_0 = \Big[100.46061837° + \Big(36000.770053608° + \Big(0.000387933° - \frac{T}{38710000}\Big) \times T\Big) \times T\Big].$$

For a given local Sidereal Time Θ at longitude λ, the corresponding UT is given by

$$\mathrm{UT} = \left(\Theta - \frac{\Theta_0 + \lambda}{15}\right) / 1.00273790935.$$

Given the UT and the date, we can simply follow the procedure outlined for the ST horizontal sundial to compute the corresponding direction of the gnomon's shadow.

Sven De Rijcke Sven.DeRijcke@UGent.be

IT'S BIFILAR SUNDIAL TIME!

Gian Casalegno (Castellamonte, Italy)

This article was originally published in Orologi Solari no.32, December 2023, with the title "È arrivata l'ora delle bifilari ?"

Introduction

In 2017, I presented at the Italian National Conference of Valdobbiadene the extension of the *Orologi Solari* program for the design of bifilar sundials, i.e., dials in which the style is made up of two threads of arbitrary shape and position. This same subject was then published in THE COMPENDIUM [1].

Subsequently, I published the preliminary project of possible bifilar dials with styles of the most varied shapes [2]. Unfortunately, due to various different reasons, including a bad destiny, none of these projects could come to fruition.

Today, however, I am happy to be able to announce the creation of two fascinating bifilar sundials.

It is interesting to note that these projects arose from ideas exchanged during meetings between gnomonists and were then developed over time until they become reality. Furthermore, for the first of these projects, the collaboration between different people (gnomonists, technicians, artisans) was essential to reach the final result.

A bifilar sundial in Aiello del Friuli

When I presented my report on bifilar sundials in 2005 in Valdobbiadene, the idea of a dial in which the time is marked by the intersection of the shadows of two wires arranged along two helices emerged, if I remember correctly, from the imaginative mind of Fabio Savian. We discussed the idea and carried out some initial simulations the new version of my program.

However, the idea was for a cylindrical quadrant coaxial to the helix arranged in the polar direction (therefore not manageable with *Orologi Solari* which typically deals with flat quadrants). It materialized with a dial created by Francesco Baggio that was illustrated at the NASS 2018 Conference in Pittsburgh .

It was a solution with a flat dial face that appealed to Pantanali Aurelio, *deus ex machina* of the gnomonic initiatives in Aiello del Friuli. Aurelio proposed a bifilar sundial on the facade of an old church (Fig. 1). The project went ahead and the double helix was built (with the fundamental contribution of Luigi Ghia, who provided the guiding steps to follow for its construction, and of Pantanali who earned a burn on his arm during the work).

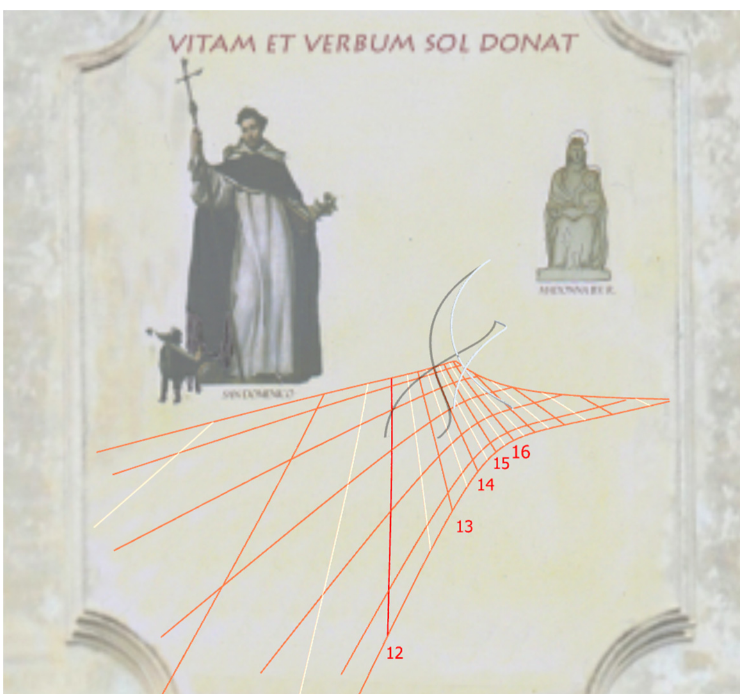

Fig. 1. The first project for Aiello del Friuli.

But fate was against us: in 2017 during a storm, lightning struck the roof of the church, making it unsafe and no longer usable. The project was cancelled.

However Pantanali did not give up, the project remained in his thoughts and in 2023 it was finally realized. The sundial is now registered on Sundial Atlas with the code IT21385[1].

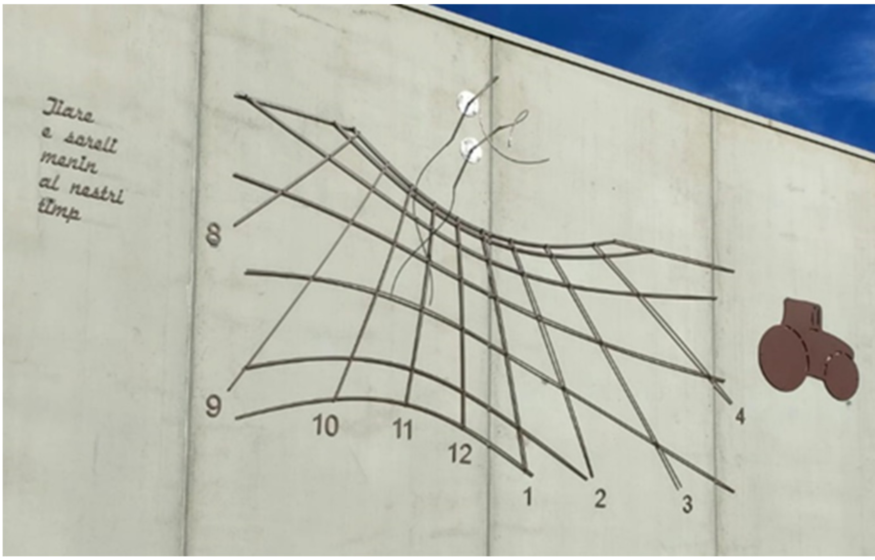

Fig. 2. The bifilar sundial in Aiello del Friuli.

The wall that houses the dial is that of an industrial warehouse (Fig. 2). With the considerable space available, it was decided to increase the size of the dial and therefore of the style. Consequently, the two spiral arms were moved 40 cm away from the wall by means of two simple horizontal rods.

The hour lines were laser cut and then mounted on the wall leaving a couple of centimeters of space between them and the wall, thus allowing the clock to create a pleasant shadow effect.

All the preparation and assembly work was carried out by Samuel Buset (expert craftsman, responsible for the creation of several gnomonic monuments in the *Sundial Courtyard* in Aiello) and, naturally, with the supervision of Pantanali.

[1] www.sundialatlas.eu/atlas.php?sun=IT21385

The tractor represented on the right of the dial recalls the commercial activity of the owner of the warehouse. The motto on the left is in the Friulian language and means *Earth and Sun guide our Time*.

Figures 3, 4, 5 and 6 show some details of the sundial.

For those interested in viewing the project, the related .gnm file is included in this issue's Digital Bonus, together with the 3D model, a simulation video file and some illustrations.

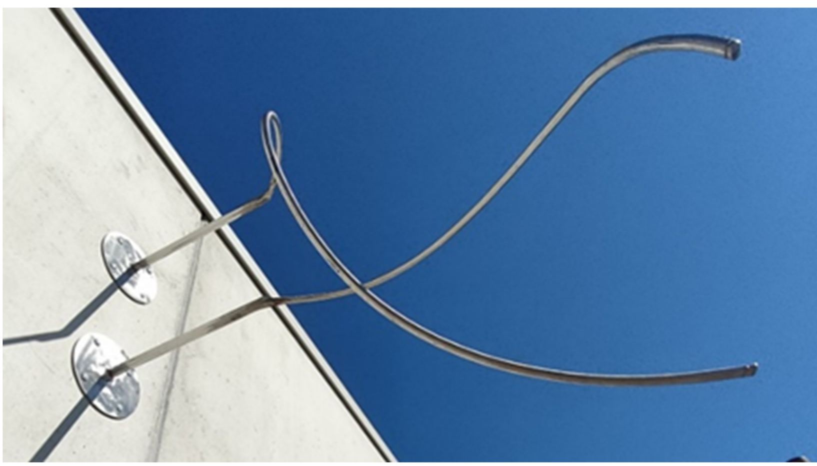

Fig. 3. The bifilar style.

Fig. 4. The style shadow at 8 o'clock.


Fig. 5. The bifilar style.

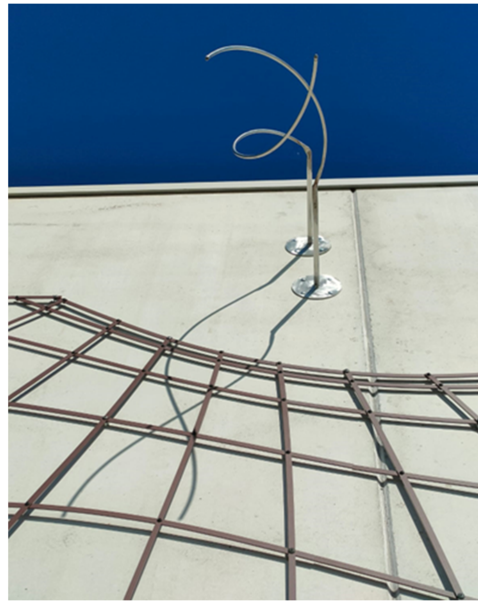
Fig. 6. The shadow at about 10:45.

A bifilar sundial in Castellamonte

This sundial originated also from an idea that came up during a meeting between sundial designers.

I was at the house of my friend Domenico Inaudi, who was showing me some of his creations, including some so-called *Tensegrity* structures i.e. a system of isolated compressed components held together by a network of tensioned ropes [3].

One of the structures created by Domenico was composed of two arches joined by ropes (Fig. 7). The structure is in equilibrium when the central tensioner TC that joins the two arches is of length

$$TC = L * (1 - \frac{\sqrt{2}}{2})$$

where L is the diameter of the two arcs.

Fig. 7. The tensegrity structure in Domenico's house.

To me, these two arches, arranged on planes orthogonal to each other, immediately suggested the equatorial plane and the meridian plane: with the two arches arranged on these two planes there would be the first exactly rectilinear shadow on the days of the equinoxes and the second shadow exactly straight and vertical every day at 12:00 local solar time.

A sundial made like this would be very interesting! As always, however, there is a difference between saying and doing...

The practical creation of this gnomon was not as simple as it seemed, as I always want to use commercial objects.

First, the two arches: after a bit of research, I settled on two appropriately cut basketball hoops. But how to keep them together?

I tried with a steel wire but gave up after many unsuccessful attempts. Ultimately, I decided to forgo the wire tensioners and switched to thin threaded rods instead. Thus, I was finally able to create the desired set of two arches.

However, the problem of fixing them to the wall remained. Here too I solved the problem with products available on the internet: the support for fixing a camera to the wall and two metal clamps for fixing a pipe.

It had taken two years but, in the end, I had created my first bifilar sundial!

The following pictures show the dial at the end of assembly and decoration (the latter done with my hands and therefore not up to what we are used to seeing and admiring on these pages).

The motto (chosen by my daughter who is also the landlady of the house that houses the sundial) contains the words of an American popular song:

You are my sunshine,
my only sunshine.
You make me happy
when skies are grey

and is dedicated to her family, whose members are mentioned in the decoration of the dial.

The following figures show the sundial in its various aspects. Note the double sunset line at the top right: at the top the theoretical one at zero degrees of solar elevation, at the bottom the one that considers the real profile of the mountains on the horizon.

Unfortunately, there is no photo at the equinox: the work was not yet finished on September 23rd... it will be done by next March 20th.

Also for this sundial the .gnm project file is included in this issue's Digital Bonus, together with the 3D model, a simulation video file and some illustrations.

The sundial is registered on Sundial Atlas with the code IT21369 available via https://www.sundialatlas.eu/atlas.php?sun=IT21369.

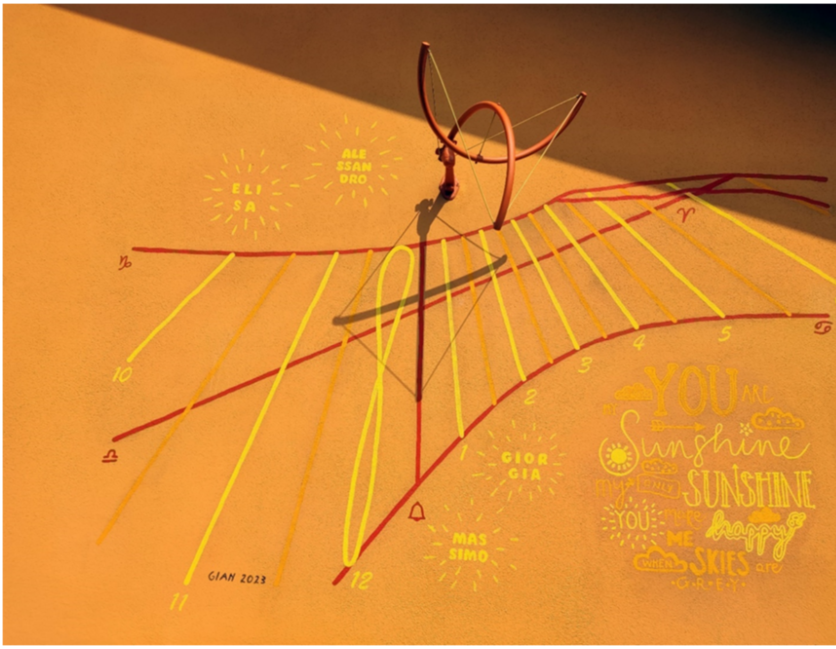

Fig. 8. The bifilar sundial in Castellamonte – photo taken at local solar noon.

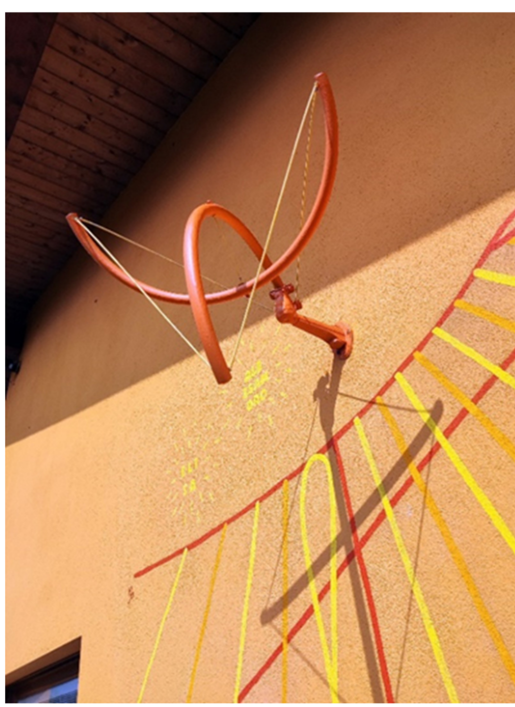

Fig. 9. The style.

Fig. 10. A photo taken at 12:00.

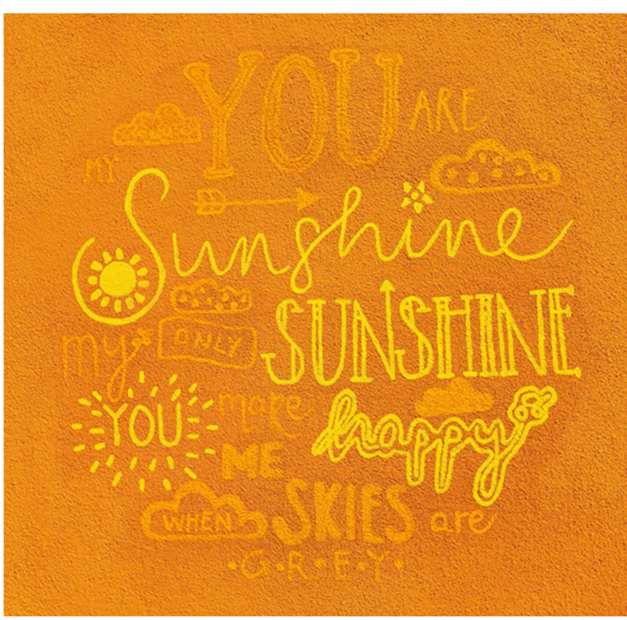

Fig. 11. The motto.

Conclusion

Are bifilar sundials starting to spread? I hope so: they can offer many original solutions compared to the classic sundials we are used to.

The *Orologi Solari* program can be of great help in the project. I realized that some operations can be simplified by small changes to the program that I have recently introduced.

Of course, I am completely available for help, suggestions, explanations to whoever would like to create their own bifilar sundial. Do not hesitate to contact me if you need help!

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Gian Casalegno *gian.casalegno@gmail.com*

FROM THE REGISTRY

Registry #1105. Laie, Hawaii.

On Lunar Volvelles – Part 2

Mark Montgomery (Chesterton, IN)

This is a continuation of an article that appeared in The Compendium 30(4), pp.50-66. The numbering of figures continues from that article, starting at Figure 10, and the reference list applies to both parts.

Lunar Volvelles and Diptych Sundials

Lunar volvelles were a popular addition to compendiums and diptych sundials. However, they were usually simplified, often using only one rotating disc. The ability to capture a faint moon shadow depended heavily on the material used. The best material was ivory, with its pale white color and hairline cracks that provided a matte finish. While harder than wood, elephant tusk ivory was easily cut and carved with woodworking tools. The ivory also accepted dyes and pigments to color the dial furniture. The final step of buffing and polishing to a smooth finish was also accomplished using woodworking skills.

Another favored material for catching moon shadows was silver with a matted finish. Many other types of material were used with varying levels of success.

Many diptych volvelles used a brass moon disc. It would be made either by hand-engraving a blank disc with steel tools, or by the stamp method used to make coins: heating the disc, and then placing it on an anvil where it was struck with a round die, allowing all the hour lines and decorations to be stamped with a single hammer blow.

The first known lunar volvelle attached to a portable sundial was made in 1546 by a maker known only as 'HG.' Volvelles remained popular until around 1800. There were two basic types of diptych lunar volvelles: German and French. The German volvelle (Fig. 10) consists of a base with two scales: a lunar age (1-29½) outer scale and an inner hour scale labeled 1-12 twice. It also has one rotating disc with a pointer and an hour scale, also labeled 1-12 twice.

Once the lunar time is read from the dial, turn the dial over to find the lunar volvelle. Rotate the disc until the pointer indicates the current lunar age as shown on the outermost scale. Find the lunar time on the brass disc and read the solar time from the hour scale on the base.

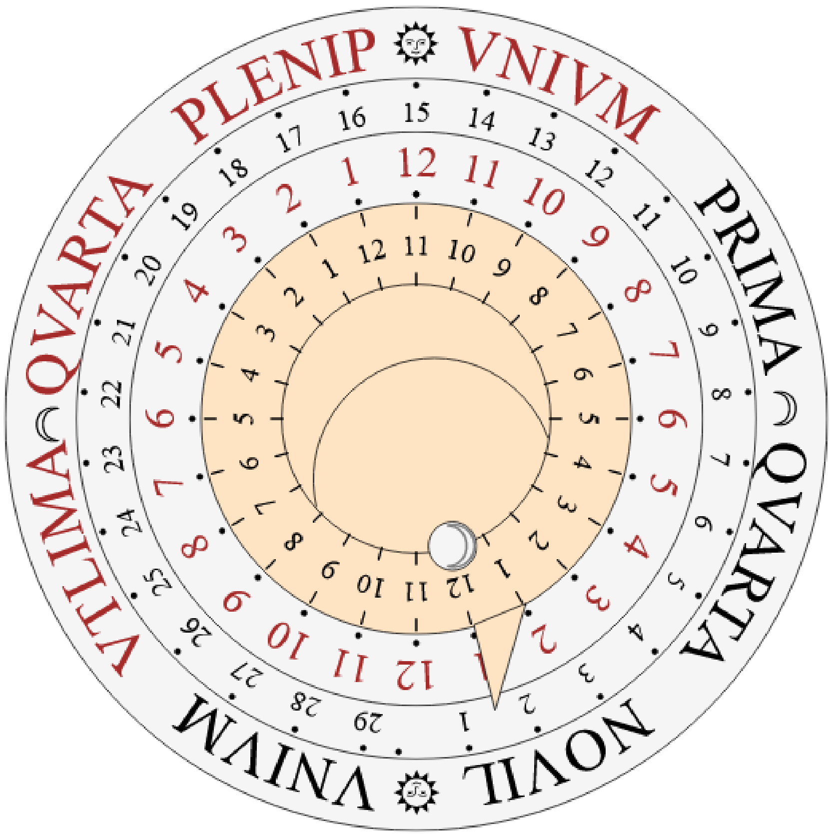

Fig. 10. Sketch of a German lunar volvelle diptych by Hans Ducher III, 1585. The webpage listed in Reference [5] provides photographs of the device, which is in the Harvard Collection of Historical Scientific Instruments, Inv #7830. Note the maker's misspelling of Plenilunium.

The French lunar volvelles come in two sub-types. The Type 1 lunar volvelle has a base and two rotating discs (Fig. 11.) The fixed base contains an hour scale, labeled 1-12 twice. The lower disc is a calendar with 10-day increments (I am uncertain of the calendar's function), the next disc has a lunar age scale, labeled 1 to 29 or 30. This disc may also have a pointer at the lunar age of 0. Finally, the top disc has a single pointer with no scales. It often has a circular window to view the phase of the moon. To find the time, set the pointer (or age 0) of the lunar age disc to the lunar time shown on the sundial. Keeping this disc stationary, rotate the top disc to align the pointer to the lunar age. The pointer on the top disc indicates the local solar time on the base's hour scale.

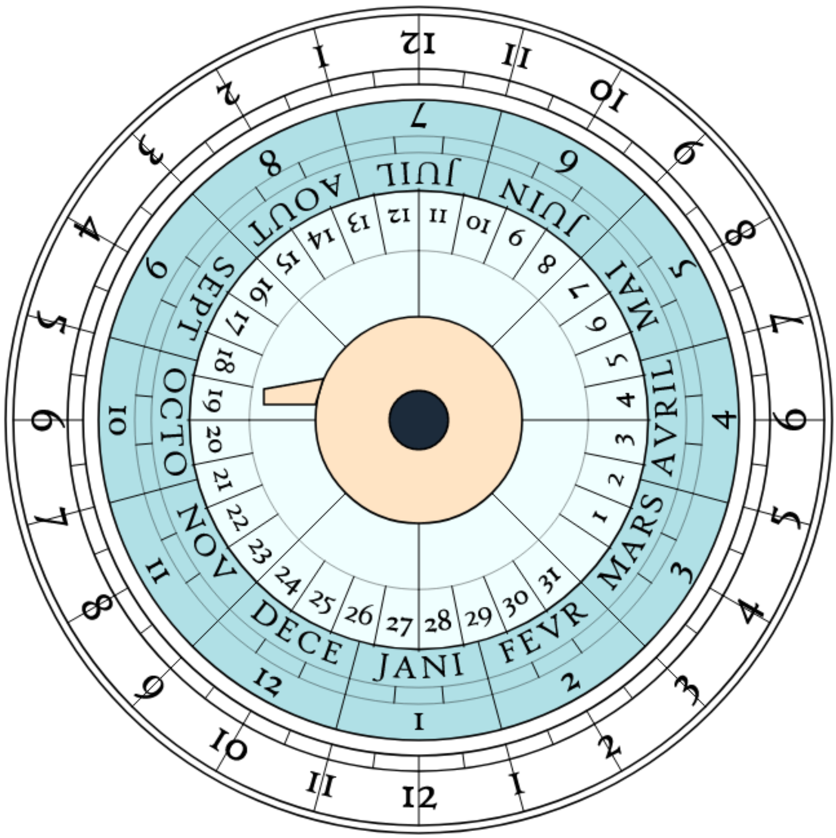

Fig. 11. Sketch of a late 17th c. French Type 1 lunar volvelle (Unsigned. Dieppe, France.) The webpage listed in Reference [6] provides photographs of the device, which is in the Harvard Collection of Historical Scientific Instruments, Inv. #7512).

The second, Type 2 French lunar volvelle (Fig. 12), has only one rotating disc, labeled 1 to 29 or 30, and an index arm located at 0. The base contains a calendar with 10-day increments and the hour scale, labeled 1-12 twice. To find the time, rotate the disc until the index points to the current lunar time. Next, locate the lunar age on the rotating disc and read across to find the local solar time on the fixed disc.

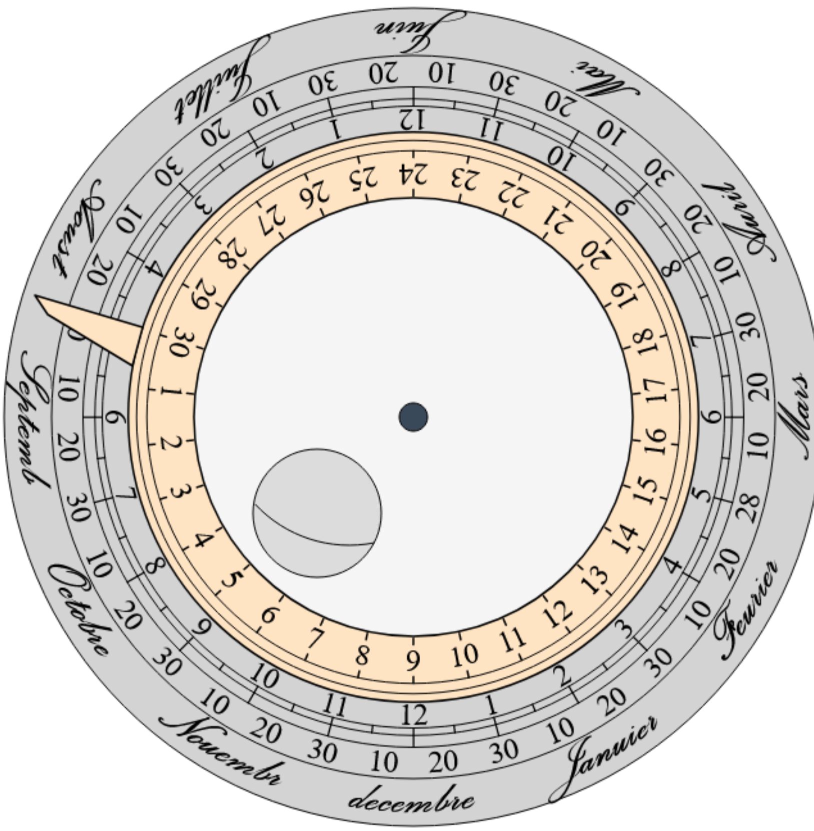

Fig. 12. Sketch of a late 17th c. French Type 2 lunar volvelle (Unsigned.) The webpage listed in Reference [7] provides photographs of the device, which is in the Harvard Collection of Historical Scientific Instruments, Inv. #7517.

Both types of French lunar volvelles can calculate the time of high/low tide; however, the German lunar volvelles cannot. To find the time of high tide, set the lunar age of 0 at the time of high tide at new moon for the port of interest. Knowing the lunar age, read the time of high tide on the hour scale across from the lunar age of interest.

The Epact

There is yet one more scale commonly found on lunar volvelles. The definition of epact is a period of time added to harmonize the lunar and solar calendar. An epact table predicts the lunar age on January 1st of any given year. Figure 13 shows an epact, the two outer rings of 19 numbers, on a lunar volvelle. They are labeled 'EPAGTA GREGORI' and 'EPAGTA IVLIANA' for the Gregorian and Julian calendars.

Fig. 13. Epact made by Thomas Ducher, Nuremberg, c. 1620 Adler Planetarium Object No. T-10. [8]

The solar and lunar years are not equal. The Julian calendar of 365 days exceeds the twelve lunar months (of alternating 29 and 30 days) by 11 days. Thus, if there is a new moon on January 1st this year, next year the date of the January new moon can be found by adding 11 days to get January 12th. The subsequent year, adding 22 days gives the January new moon on January 23rd, and so on. If the calculated number is greater than 30, subtract in multiples of 30 until the resulting number is equal to or below 30. This process continues for 19 years, at which time the lunar and solar calendars align with the original year of the cycle. This 19-year cycle is called the Metonic cycle; 235 lunar months equal 19 solar years.

Each of the 19 years in the Metonic cycle is given a number, referred to as the *Golden Number*. The table below shows the epact cycles for different numbering systems you may find on volvelles.

First, let's find how to determine the Golden Number for any year. In centuries past, this would be common knowledge among the educated. Today, we can calculate the number with a few steps. The epact numbering starts from the birth of Christ. Our calendar jumps from 1 BC to 1 AD, skipping year 0. Since there is no year 0, add 1 to the current year. The sum is divided by 19. This gives the number of 19-year cycles since the birth of Christ. We are interested in the remainder of the division. The remainder is the Golden Number for the year.

Example: (2023 + 1) / 19 = 106, remainder 10. The Golden Number for 2023 is 10 and the age on the new moon on January 1st is 8 in the Lilian Epact from the table below (last column, 1900-2100).

Table: Epact Cycles summarized by Dekker [9]

Golden Number	Medieval Epact	Julian Epact	Gregorian Epact	Lilian Epact		
				1582-1700	1700-1900	1900-2100
1	nulla	11	1	1	0	29
2	11	22	12	12	11	10
3	22	3	23	23	22	21
4	3	14	4	4	3	2
5	14	25	15	15	14	13
6	25	6	26	26	25	24
7	6	**17**	**7**	7	6	5
8	17	28	18	18	17	16
9	28	9	29	29	28	27
10	9	20	10	10	9	8
11	20	1	21	21	20	19
12	1	12	2	2	1	0
13	12	23	13	13	12	11
14	23	4	24	24	23	22
15	4	15	5	5	4	3
16	15	26	16	16	15	14
17	26	7	27	27	26	25
18	7	18	8	8	7	6
19	18	29	19	19	18	17

There were several different medieval epacts, the most famous was developed by The Venerable Bede, an English monk living in the early 8th century (column 2 in the table above). As the number zero was not known at that time, he stipulated the value as 'nulla.'

Since a lunar month is 29 days, 12 hours, 44 minutes, and 3 seconds long, over time, the cumulation of the extra 44 minutes 3 seconds makes the epact values change, at approximately 200-year intervals. No one knows when the Julian epact replaced the medieval epact (column 3). In 1582, the Gregorian calendar was first accepted by a few European countries. The new calendar removed 10 days to align the vernal equinox with March 21st. This necessitated a new, Gregorian epact (columns 3 and 4). To make the dial useful in all countries, both epacts were included on the volvelles.

Aloisius Lilius published a new computational scheme for calculating the Easter Full Moon and was a major contributor to the Gregorian calendar reform. Lilius also projected the value for the epacts through the year 2100 (columns 5-7).

Notice that the epact table shown in Figure 13 starts with the number pair 17 and 7 (shown red in the table above). Why would a dial maker start the epact numbers in the middle of the cycle? This equals the golden number 7 in the above table and suggests the first year in the table was 1621, confirming the dial's manufacture date of 1620-21. Someone purchasing an expensive dial would remember the year they acquired it – an aid in finding the proper epact number. Notice also that the values marked on the dial are incorrect in one place: at the eleventh column of the dial's calendars, the values for the Julian and Gregorian epacts are swapped – a copying error.

Using the Epact

The epact is used to predict the date of Easter: the first Sunday after the first full moon after the vernal equinox. Knowing the lunar age on January 1st, you count days of the month ("Thirty days has September…") against alternating lunar months of 30 and 29 days.

Example: The full moon always occurs on Day 15 of the lunar month (29½ / 2). If the epact number is 7, the first full moon occurs on January 8th (15 − 7). To simplify counting, assume odd number months (Jan., Mar., May, etc.) have a lunar month 30 days long and even number months (Feb., Apr., June, etc.) have 29 days, thus averaging 29½ days for a lunar month. To calculate the date of the next full moon: start with the date of the full moon, add the lunar month, and subtract the number of days in the previous month. Thus, starting from the January 8th full moon, add a 30-day lunar month and subtract 31 days of January. This gives a full moon on February 7th.

For March, add a 29-day lunar month and subtract 28 days to get March 8th. This is before the Spring equinox, so Easter will fall after the next full moon. Similarly, the April full moon falls on April 7th (8 + 30 − 31) and is the first full moon after the Vernal equinox of March 21st. The other full moons for the year are found the same way.

Is April 7th a Sunday? To find the date of a particular day of the week, the ancient Roman date counting system was used. Each day was assigned one of seven letters A-G. January 1st was always A, January 2nd was B, January 7th was G and January 8th went back to A. Counting 7-day weeks all the way to April is tedious and error prone. In England, a rhyme was used to remember the first day of each month: "**A**t **D**over **D**wells **G**eorge **B**rown **E**squire, **G**ood **C**hristopher **F**inch, **A**nd **D**avid **F**ryer." This 12-word sentence with the starting letter of each word using A-G has January 1 being A, the first of February as D, and so on till December which starts with the letter F. But which day is Sunday? The letter for the first Sunday of the year was given by a Dominical Letter. Every day with the Dominical Letter was a Sunday for the remainder of the year.

Example: April 1st is a G from the above rhyme. If the Dominical Letter for the year is C, the first Sunday in April falls 3 days later on April 4th (G, A, B, C). The other Sundays are 11th, 18th, and 25th. Thus, if the full moon is on April 7th, Easter is the next Sunday, April 11th.

For leap years, two Dominical Letters were used to supply correction needed for months after February. However, during that month, the extra day was inserted between the 23rd and the 24th. In essence, February 23rd was 48 hours long on leap years! February 23rd was chosen based on the old Roman calendar system. During the 15th and 16th centuries, the practice of using February 29th was slowly adopted by lawyers who disliked the vague 48-hour day every 4 years.

The epact helps find the date of Easter, but has other uses:

1. Find the day of the week for any date.
2. Find the date for each new moon during the year.
3. Determine the zodiac position of the moon for lunar astrology: foretelling best time for marrying, bloodletting and the like.
4. Calculate the time of tides by combining the epact with the lunar volvelle and a table of port and tide information (see Part 1 of this article.)
5. Knowing lunar age for converting lunar time to solar time.

Making Your Own Volvelle

The lunar volvelle used in the examples above was designed for a latitude of 51° 30′ N, which agrees with London, the source of the book shown in Figure 4 [see Part 1 article]. If you want to build your own volvelle, you may want to make a few changes.

First, the relative alignment of calendar and zodiac scales change with time. Delving into those intricate calculations will require more space than available in this article. Please consult a text on astrolabe construction such as *The Theory, Design, Manufacture, & Use of The Astrolabe* by George Layton Trimble [10].

The latitude-dependent scales are the sun altitude scale and the half-day length scales. The equation for the sun's altitude is:

$$sin\,h = sin\,\delta\,sin\,\varphi + cos\,\varphi\,cos\,\delta\,cos\,H$$

where h is solar altitude, δ is declination, φ is latitude, and H is Hour Angle. Because we want the maximum altitude of the sun, which occurs at noon, we require that H is 0. By selecting the altitudes of interest, you can solve for the declination and use an ephemeris to translate declination to a date.

To calculate the time from sunrise to noon, the half-day scale, use

$$\cos H_0 = -\tan\delta \tan\varphi$$

where H_0 is the hour angle for sunrise/sunset. By selecting H_0 in increments of 15°, you can solve for the declination (date) of each sunrise/sunset hour.

This brings my musings about lunar volvelles to an end. I hope the next time you see the simple lunar volvelle on the back of an old diptych, you may spend more than a moment exploring the creativity and imagination of the dialist in centuries past.

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Mark Montgomery *mark.montgomery2003@yahoo.com*

A HYBRID PEAUCELLIER SUNDIAL

Martin Jenkins (Venn Ottery, Devon, UK)

In the *Dialogues of Plato*, Philebus 51, Socrates said to Protarchus,

> *My meaning is certainly not obvious, and I will endeavour to be plainer. I do not mean by beauty of form such beauty as that of animals or pictures, which the many would suppose to be my meaning, but says the argument, understand me to mean straight lines and circles, and the plane or solid figures which are formed out of them by turning-lathes and rulers and measures of angles; for these I affirm to be not only relatively beautiful, like other things, but they are eternally and absolutely beautiful, and they have peculiar pleasures, quite unlike the pleasures of scratching.*[1]

I think that most engineers can relate to these thoughts, as lines, circles, etc., are involved in all aspects of our daily lives. In many aspects of design, engineers have created linkages to enable straight line motion to overcome some particular problem. For instance, James Watt created a parallel linkage mechanism so that he could pass a piston rod vertically through a seal in his steam engine. However, his original solution was what is known as an ‘approximate straight line’ mechanism because it was only ‘straight line’ correct over a very short movement.[2] Many other straight-line mechanisms suffer the same limitation, i.e., they are only ‘straight line’ over a very short range of movement. When linkage mechanisms are designed to generate ‘exact straight lines’, the level of complexity increases as compared to the mechanisms designed to generate approximate straight-line paths.[3] The first exact straight line generating mechanism was invented by French army officer Charles Nicolas Peaucellier (1832 – 1919) in 1864.[4] So, what bearing does this have on sundials? Well, in 1856 Peaucellier investigated the possibility of designing a functioning sundial which only used straight lines for the hour lines and declination lines. In 2006, Fred Sawyer wrote extensively in the *THE COMPENDIUM* about Peaucellier and his ideas. Fred subsequently developed equations to take Peaucellier's ideas forward.[5] Then in 2021, Fred continued expanding on the design of Peaucellier sundials by developing Hybrid Peaucellier sundials.[6]

In April 2023, the British Sundial Society (BSS) held its annual conference in Exeter, UK. On the Saturday afternoon, it is tradition to have a 'sundial tour' of the local area. However, the conference has been held in Exeter on two previous occasions and so the majority of the delegates have seen the dials in the locality of Exeter before. Janet and I have (at present) twenty-three sundials in our garden, the majority of which have been designed and made by myself. It was decided therefore, for 2023, to invite the delegates to view the sundials in our garden. Fred is a friend, and Patron of the BSS, and knowing that he would be at the conference, I decided to surprise him by designing and making a Peaucellier dial for the garden (Fig.1).

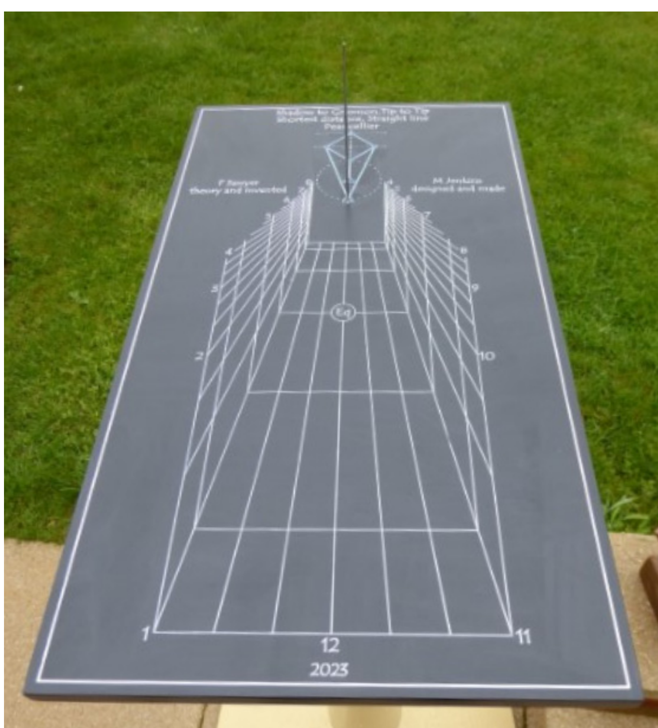

Fig. 1. The finished Peaucellier dial.

I had a suitable piece of Krion (450 mm × 200 mm × 15 mm thickness) from which to make the dial. Krion is the closest material I have yet found to match slate in color and surface finish. Natural slate is a beautiful material, easy to carve, but getting extremely difficult to obtain in small quantities, of high quality, and at a sensible price. Being a homogeneous composite acrylic material, Krion machines beautifully and will hold very fine detail. It also has a very long life outside in all weathers, being used for decorative cladding on modern architectural projects.[7] I used a combination of Fred's equations and Helmut Sonderegger's Sonne 7.0 design software to layout the basics.[8] The line basics can be saved in Sonne 7.0 as a Data Exchange File (DXF) and subsequently exported to a more complex design package for further work. Using a combination of Fred's equations and Sonne 7.0 design software enabled me to develop a Peaucellier sundial design to suit me. If you use Fred's 'Goldilocks' gnomon approach, then the dial layout results in the 11 a.m. – 1 p.m. lines at the solstices being slight curves, thus not really adhering to the Peaucellier objective of all straight lines.[9] So, by not adhering to the 'Goldilocks' gnomon approach, and by varying the input parameters for our latitude in Sonne 7.0, and varying the value for *k*, a constant, I arrived at a design line layout to suit my desired aspect ratio for the overall design and maintaining straight lines throughout. By 'straight lines', I mean straight lines from the engineer's perspective within the constraints of a Peaucellier linkage, because the best mathematical straight-line approach, as determined by Fred, results in a segment of a hyperbola. In addition, it is worth mentioning that Peaucellier's linkage will only produce a straight-line length relative to the size of the linkages used in the mechanism. Once happy with the basics of the line layout, the Sonne 7.0 DXF line layout file was exported to my computer aided design/computer aided manufacture (CADCAM) package, VCarve Pro.[10] With the basic line layout imported into the VCarve Pro design package, the total sundial design process could then be completed, including scaling, adding text, adding embellishments, etc. The design logo of the Peaucellier linkage was created as a separate entity in VCarve Pro and then added to the overall sundial design. When I was happy with the complete sundial design, the appropriate toolpaths and machining protocols were created in VCarve Pro and then exported to the Computer Numerical Control (CNC) machine control package Mach 3 V.2.0.[11]

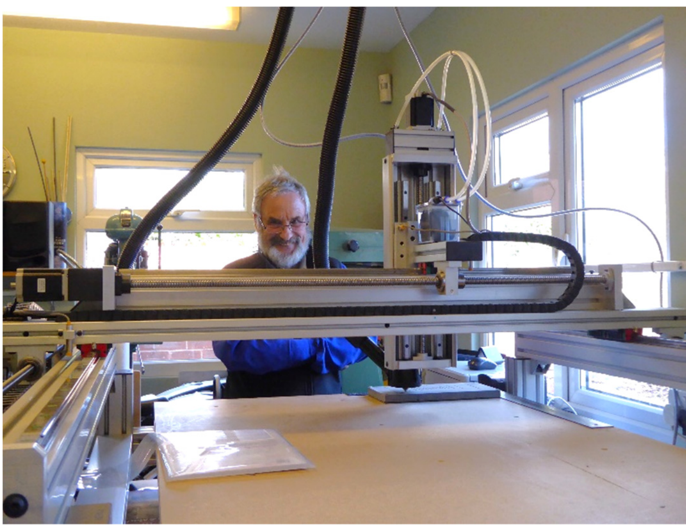

Fig.2. An engineer and his CNC machine.

I am lucky to own a well-equipped workshop which includes a CNC milling/routing/engraving machine designed and manufactured to my specification some years ago (Fig. 2). Once the toolpaths and machining protocols were loaded into the Mach 3 V2.0 machine control package, the CNC controllers could then control the four axes of the CNC machine tool to carry out the machining processes. When all goes well, the end result is a nicely engraved and machined dial (Figs. 3 and 4). Subsequent finishing of the dial entails cleaning up the outer edges, polishing any imperfections out of the surface, painting in the straight-line logo with, in this case, light blue paint, and all other lines in white. A vertical stainless steel rod gnomon 1.5 mm in diameter was added to the sundial and the whole mounted on a plinth for the garden (Fig. 5).

Left: Fig. 3. The finished engraving straight off the CNC machine.

Below: Fig. 4. Close up of the text and logo engraving.

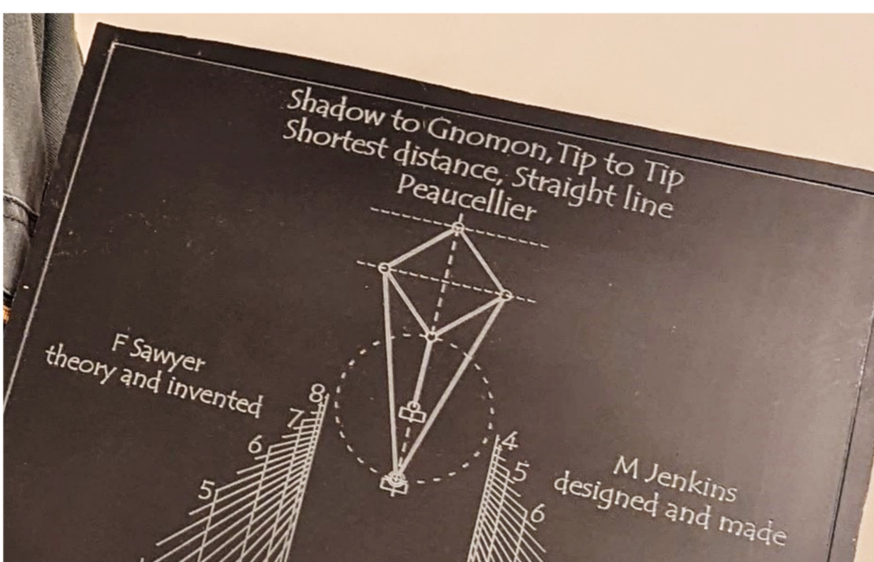

Fig. 5. Dial on its pedestal in the garden, early spring, Venn Ottery.

Fig. 6. A big smile from Fred and BSS friends.

When Fred saw the dial, he smiled, took some photos, and then requested an article for THE COMPENDIUM (Fig. 6). The dial catches the attention of most observers as it is different to the norm of horizontal sundials. Dialists should thank Charles Peaucellier and Fred Sawyer for giving gnomonicists a new type of sundial. I hope that both are pleased to see at least one of its type existing in reality.

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Martin Jenkins *sundialduo@gmail.com*

In the Footsteps Of Hugo Michnik

Maciej Lose (Wrocław, Poland)

In the September 2023 issue of NASS' journal The Compendium, Fred Sawyer published an article on the life of Silesian mathematician, and inventor of the bifilar sundial, Hugo Michnik (1864-1943) [1]. I was told about it by Martins Gills, a colleague dialist from Latvia whom I hosted recently in my hometown of Wrocław (German: Breslau) in Poland, and upon enquiry to the author, I was kindly provided with a copy of it. Reading the essay, I realized that my steps and those of my family crossed with those of Hugo Michnik many times and in many areas of activity. I hope the readers will find interesting this short supplement to Fred Sawyer's essay, written from the local, Silesian perspective.

Hugo Michnik was born in the village of Slawentzitz, Kreis Cosel in the region of Upper Silesia, then in the German state of Prussia. The present name of the neighborhood is Sławięcice, and it is incorporated now as a district of the bi-town Kędzierzyn-Koźle in Poland. Upper Silesia is a region known primarily for its industrial and mining traditions. It developed for centuries at the meeting point of Polish, German and Czech (Moravian) cultures – forming of it a unique blend with its own rich customs and linguistic tradition [2]. From the mid-19th century onwards, the notions of national identity were shaping in the region: German - with extensive administrative influence of the Prussian state, and Polish - in the period of the lack of their own state - mainly through the Catholic Church and social organizations. In the turbulent period after WW I, the region was split between Prussia and the reborn Polish state. Hugo Michnik spent most of his life in Beuthen (Polish: Bytom) working as a teacher in the Königliche Gymnasium. My paternal family comes from Bielszowice, some 10km to the south, where my grandfather was also a teacher. In the pre-WWII period, the state border ran in between.

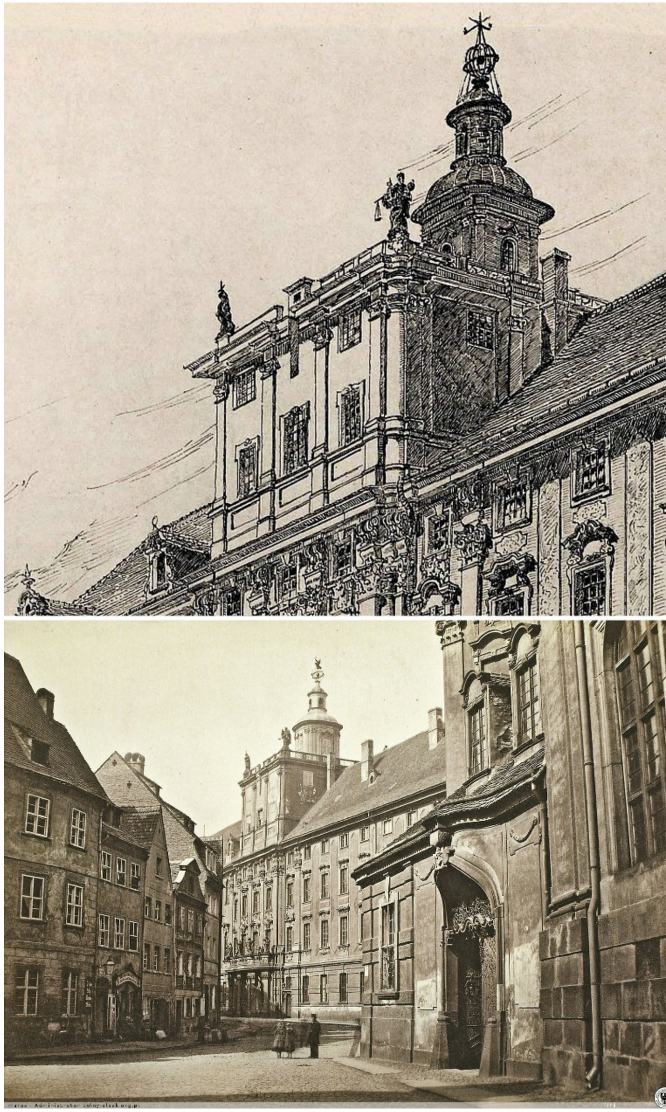

Fig. 1. Mathematical Tower of Wroclaw University – location of the historical astronomical observatory (Breslau Universitäts-Sternwarte). Top: drawing by Otto F. Probst from 1898. Bottom: photograph from ca. 1870-1875 by Hermann Krone, pioneer of photography and former astronomy student in Breslau. The elongated vertical slot between the pillars corresponds with the main meridional cut in the floor of the terrace seen on Figure 4, the gate-like form is a housing of the pinhole of the meridian line. Source: Polska-org.pl

The tangled Silesian complexities are reflected in our surnames – Michnik and Lose. The first is of Polish etymology, the latter of German. The first belonged to a family who likely declared itself as German, the latter Polish. Both were Catholic – though Michniks were more common among Protestants [3], and interestingly both families have roots in Cieszyn Silesia – a subregion bordering Moravia, as evidenced from today's surname distribution maps [4]. Informally both spoke variants of the Silesian language [2] and likely prepared similar meals of local cuisine for the Sunday family dinner [5].

But let's revert from gastronomy to astronomy and come back to Breslau (Polish: Wrocław), the historic capital of Silesia and the capital today of Lower Silesia, where Hugo Michnik, after completing his higher education at the University and waiting for assignment to a teaching post, was engaged in 1892 as a second assistant at the University Observatory (Universitäts-Sternwarte). The observatory, at that time run by Johann Gottfried Galle (1812-1910), co-discoverer of Neptune, was still in its historical location on the fifth floor of the Mathematical Tower of the main building of the University (Fig. 1) [6]. The location of the astronomical observatory in the tower named 'Mathematical' results from the fact that the originally planned Astronomical Tower was never erected due to the Silesian Wars of the mid-18th century [7].

The observatory was established by the Jesuit scholar, Anton Jugnitz (1764-1831) in 1791, and in this same year he built a meridian line there (Fig. 2) [8]. This is probably the northernmost of historical meridian lines in Europe and one of the last. The instrument strictly follows a pattern of the four meridian lines constructed by Maximilián Hell (1720-1792), who was Jugnitz's teacher during his studies in Vienna [9]. At the time of its construction, also due to its location at the top of the tower prone to thermal expansion and wind pressure, it served more of a didactic purpose than one of a precise scientific instrument.

Fig. 2. Meridian line of Mathematical Tower in the main building of Wrocław University, constructed by Anton Jugnitz in 1791 – current state. Photo: Magda Kuchta. https://www.skarbyzpodrozy.pl

Yet, as in the case of all meridian lines, the meridional passage of the projected Sun image crossing the marble line must have been an important experiment and experience for students at the University. Hugo Michnik, as an assistant, must have observed the passage a number of times. And apart from proficiency in astronomy and mathematics acquired at University under Johann Gottfried Galle and Heinrich Eduard Schröter (1829-1892), it must had been a shaping experience for a young man, inspiring his later work on the bifilar sundial.

Fig. 3. Exposition of sundials in the Mathematical Tower of Wrocław University. The highlighted meridian line is visible in the background. Photo: Wojciech Małkowicz.

Although Jugnitz's meridian line is not functional anymore today – the pinhole opening was blocked years before WW II – it is still inspiring and the most important gnomonic monument in Silesia. In 2019, together with the Wrocław University Museum, which is located in the Mathematical Tower and adjacent historical premises, the author arranged an exposition of sundials titled 'Sol omnia regit' at the level of the former observatory with the meridian line [10].

The exposition, which was recently extended for another 5 years, includes 87 historical sundials and objects related to gnomonics (Fig. 3). It consists of 8 display boxes accompanied by information panels [10]. The main themes of the individual displays are: varied gnomonic typologies, master-apprentice links, sundials for different latitudes, and instruments specifically related to the moment of the noon/meridian. Highlights of the exposition include a horizontal dial by John Rowley made for a local patrician family, a LeRoy type sundial with built-in miniature meridian line, a double horizontal sundial by John Allen, and an equinoctial dial by Meurand (reproduced by Bedos de Celles in *La Gnomonique pratique*).

Unfortunately, it does not include a bifilar sundial – which is an obvious *faux pas* in relation to Hugo Michnik!

Hopefully, this is planned to change in the future. On the terrace of the Mathematical Tower, two original observational stone pillars are preserved – one octagonal and the other triangular in horizontal section, both visible on the plan from 1872 (Fig. 4) and on Google Maps [6]. The author is in the process of encouraging Wrocław University Museum to install two sundials on the pillars – a bifilar and a stereographic one. The initial response is positive with design and legal documentation planned for 2024.

The extent of Hugo Michnik's tasks as a second assistant during his three years working at the observatory included performing meteorological observations four times a day and recording the magnetic declination variations three times a day. Both types of observations were started with the founding of Breslau observatory, but it was Galle's predecessor – Palm Heinrich Ludwig von Bogusławski (1789-1851), who brought it to scientific levels. Bogusławski established a magnetic cabinet and took part in the network of observations coordinated by Magnetische Verein in Göttingen, directed by Gauss and Weber. Galle continued this work, though in the second half of the 19th century the conditions for performing magnetic observations significantly deteriorated due to the tram lines established near the main University buildings [11].

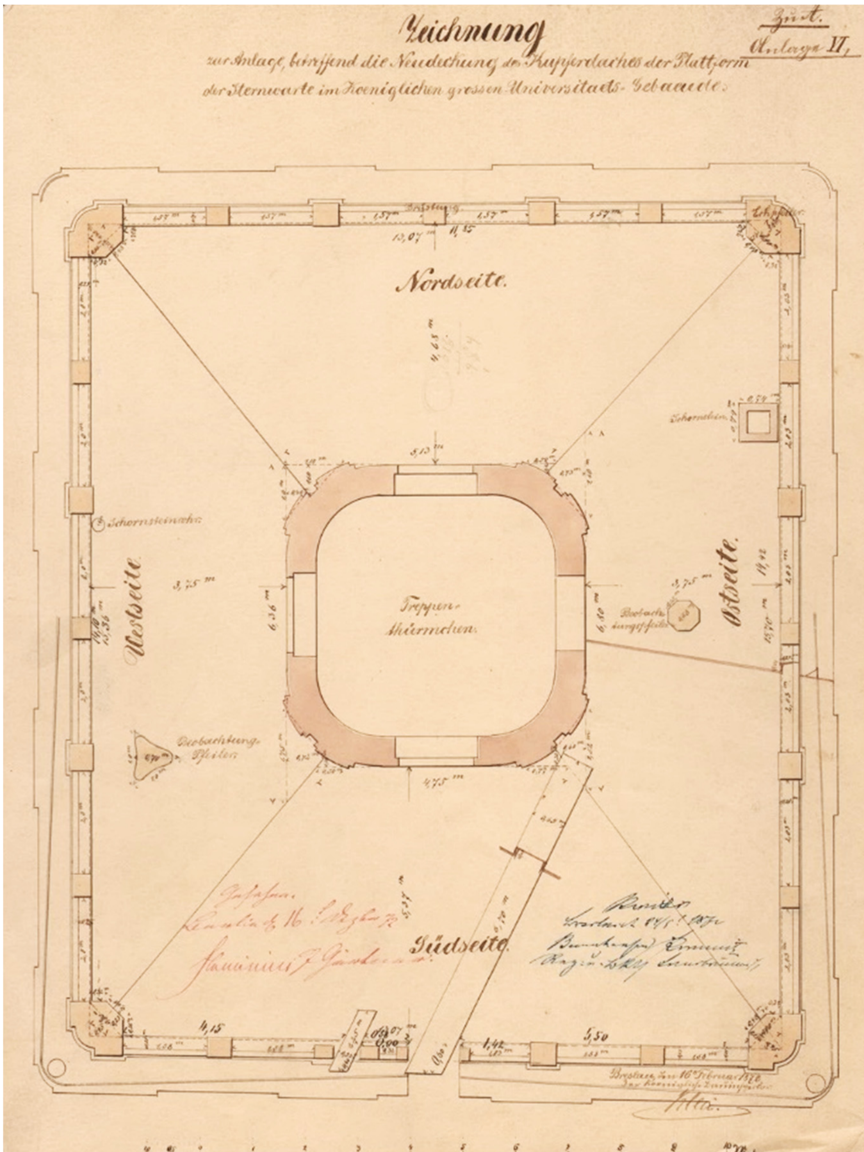

Fig. 4. Plan of the terrace of the Breslau Universitäts-Sternwarte from 1872 (Hugo Michnik was 8 years old). Two meridional cuts in the floor of the terrace are visible. The smaller one is related with the pinhole opening of the meridian line, which unfortunately was blocked before WW II. Source: Muzeum Uniwersytetu Wrocławskiego.

Upon receiving the post of Oberlehrer in the Königliche Gymnasium in Beuthen (Polish: Bytom) [12] in 1895, Hugo Michnik moved to this city in Upper Silesia, where he lived until 1936 at Parkstrasse No. 5. The fine eclectic building from the turn of the century, whose address is now I. Chrzanowskiego St. No. 5, is preserved in good condition. Compared with a photo from 1935 [13], one will notice that not much has changed – even the pharmacy is still on the ground floor!

Fig. 5. Former Königlisches Gymnasium zu Beuthen O.-S., today's State Music School in Bytom. View from the main street and of the auditorium. Photo: Adam Tync. Creative Commons license: CC BY-SA 4.0 DEED.

The Gymnasium building, designed by noted Silesian architect Paul Jackisch, was built in 1867-69 as the Catholic Gymnasium and is the oldest preserved educational building in the city [14]. In 1889 it was nationalized and changed its name to Königlisches Gymnasium zu Beuthen O.-S. (Ober-Schlesien). The building currently houses a State Music Education School for levels I and II. My cousin, now a viola player at the National Philharmonic Orchestra in Warsaw, attended the school for 12 years, and in early years our grandfather accompanied her on the way to her (and Hugo's) school. In 2001 the building was thoroughly restored (Fig 5).

Fig. 6. Gneisenaustrasse No. 5, where Hugo Michnik lived in years 1936-43, can be seen to the left – the house with 2-story oriels. Source: Polska-org.pl

In 1936 Hugo Michnik moved back to Breslau for unknown reasons and lived at Gneisenaustrasse No. 5 II until his death in 1943. The building, which can be seen in the period postcard in Figure 6, was destroyed in WWII. In the late communism in the 1980s, the empty plot was replaced with postmodern housing [15], designed by one of my academic tutors. From today's perspective this is a rather mediocre architecture – though at the time of its erection it was one of the first projects in the city center breaking with the modernism paradigm of free-standing blocks, and adopting the idea of the reconstruction of the historical city blocks. During our dialing walk with Martins Gills in the spring of 2023, we passed the house, unaware that Hugo Michnik had lived at that location.

The good tradition in the design of the educational buildings in Breslau, which Hugo must have appreciated as a school teacher, was that newly designed schools included city coats of arms and sundials. In Figure 7 readers may contemplate three restored examples from the turn of the 19^{th} and 20^{th} centuries.

Fig. 7. Sundials from two school buildings erected in Breslau at the turn of 19^{th} and 20^{th} century and one from the house of the school director (right). Source: Polska-org.pl

Fred Sawyer's article [1], searching for the whereabouts of Hugo's daughter Marie Michnik after his death, describes the tragic consequences for the civilian population of the Nazi's having declared the city a fortress (Festung Breslau). Interestingly, I was lucky to have neighbors who survived it and whose history was unbelievable for the reality of war and the early post-war period – a German girl from Breslau fell in love with a Polish boy, a labor camp prisoner, and when the war was over, she escaped being transported to Germany to stay with him [16]. In their former flat, there lives today an emigrant family with disabilities from Kharkiv in Ukraine – more victims of war driven by nationalist ideology coupled with imperialism.

For readers wishing to further explore Silesia and to follow Hugo Michnik's footsteps live, may I recommend the Hotel Hugo (!) in Sławięcice [17], located on the estate of the former hospital and sanatorium, whose cornerstone was laid in 1884 – the year when Hugo Michnik enrolled at the University. The name of the hotel, and likely that of the gnomonist, comes from Prince Hugo von Hohenlohe (1816-1897), one of whose major residences was in Sławięcice, and who established the said hospital in which Robert Koch, the father of microbiology, worked in the late 19th century.

With a planned visit to my wife's grandmother, who lives 15 km from Sławięcice and is now 103 years old – born just a year before publication of the theory of the bifilar sundial (!) – I will, on behalf of NASS readers and prospective visitors, order the rouladen with red cabbage and Silesian dumplings at the Hugo's restaurant to see if they are worth crossing the Atlantic for!

References and Notes

1. F. Sawyer: "*Hugo Michnik: Curriculum Vitae*". *The Compendium* 30(3), September 2023, pp. 14-35. The article is the source of all the facts referred to Hugo Michnik's life.
2. In the pre-WW II period, inhabitants of Silesia spoke mainly either Silesian German or Upper Silesian, whose core is Slavic, but with many (Silesian) German and some Czech (Moravian) influences. In the course of the post-war population replacement most speakers of Silesian German were transferred to Germany. Today's population of German Silesian users is estimated to be ca. 23,000 and Upper Silesian ca. 450,000.
3. The statistical analysis of the south Silesian surnames conducted in: I. Łuc: "*Słownik nazwisk mieszkańców południowego Śląska XIX wieku*". Wydawnictwo Uniwersytetu Śląskiego. Katowice 2017, pp 52-53, points out that the Michnik surname prevailed in Protestant communities over Catholics.
4. http://nlp.actaforte.pl:8080/Nomina/Ndistr

5. Rouladen with red cabbage and Silesian white and dark dumplings. In some Silesian regions the white dumplings were traditionally called ‘German’, and the dark ones ‘Polish’. For a recipe and instructions see: https://www.facebook.com/SlaskieSmaki/videos/1019562675057860/
6. Location on Google Maps: https://maps.app.goo.gl/Sbs7y8VV31ppqPJr8
7. Despite this fact, the imagined completed building was frequently represented on contemporary engravings. For examples see: https://polska-org.pl/508910,Wroclaw,Uniwersytet_Wroclawski_gmach_glowny.html
8. Photos of the Wrocław meridian line can be found on following websites:
   - http://mbd.muzeum.uni.wroc.pl/dzieje-uniwersytetu/astronomia-we-wrocawiu
   - http://www.matematyka.wroc.pl/doniesienia/wroclawska-meridiana
9. Maximilián Hell constructed meridian lines in: Nagyszombat (today’s Trnava), Eger, Buda, and Gyulafehérvár (today’s Alba Iulia). The meridian lines in Eger and Alba Iulia are preserved, with the one in Eger complete and almost identical to the one constructed in Wrocław/Breslau. The major source on the meridian line in Wrocław/Breslau is: J. Włodarczyk, R. Torge: “*Astronomia w dawnym Wrocławiu. Ludzie i instrumenty*”. Wydawnictwo UMCS. Lublin 2009.
10. For information about all the instruments displayed in the Mathematical Tower of Wrocław University:
    - http://mbd.muzeum.uni.wroc.pl/kolekcje-uniwersyteckie/zegary-sloneczne
    - Some general photos: https://muzeauczelniane.pl/aktualnosci/sol-omnia-regit-gnomoniczne-opowiesci-z-wiezy-matematycznej-wystawa-w-muzeum-uniwersytetu-wroclawskiego/
11. The author is currently working on an edition of letters from P.H.L. v. Bogusławski to his friend and scientific collaborator, the director of Cracow observatory, Maximillian Ritter von Weisse. The letters are a prime source of information about the scientific activity of Breslau and Cracow observatories in the period of 1835-1851.

12. Interestingly, the links between Wrocław and Bytom are older than their respective city charters, granted in 1214 and 1254. On a stone door tympanum found in Wrocław in 1962, which is dated ca. 1160 and originates from a monastery demolished in the 16th century, a scene is depicted of founding a church in Bytom (written as: bITOM) by a Prince Bolesław IV the Curly.
13. Hugo Michnik's house
    - In today's Bytom: https://fotopolska.eu/1375947.foto.html
    - In a photo from 1935: http://www.pastvu.com/591652
    - Location on Google Maps: https://maps.app.goo.gl/DamoLQxp7VCwwSds5
14. https://pl.wikipedia.org/wiki/Budynek_szkoły_muzycznej_w_Bytomiu
    - Location on Google Maps: https://maps.app.goo.gl/D7HqMadZFNYBRQZL6
15. Today's address is: gen. Józef Bem St. No. 5.
    - Location on Google Maps: https://maps.app.goo.gl/DovVk3i6r7Pzdv8U6
16. Rozalia (born: Tannigel) and Stanisław Derda (1924-2018), prisoner at Arbeitserziehungslager Rattwitz and at a prison in today's Łąkowa St. As for my grandfather from Bielszowice, as a teacher he was sent to a concentration camp at Mauthausen, where he spent 3 years. Following the successful bribery of a guard by my family, he was hidden for a year in an earth shelter with his brother. After WWII, although everybody in the family knew German, it was not allowed to be spoken in his presence.
17. http://www.hotelhugo.pl. Location on Google Maps: https://maps.app.goo.gl/1fduAruv1XaJPWPv9

Maciej Lose *mlose@interia.pl*

The Equinoctial Curve In The Bifilar Dial With A Polar Thread

Fabio Savian (Paderno Dugnano, Milano, Italy)

It might seem a little strange to assign the polar direction to one of the threads of a bifilar sundial. It would act as a simple polar style, alienating the function of the other thread in conditioning the direction of the hour lines. However, the second thread can influence the declination curves by modifying the path of the knot, *i.e.* the crossing point of the shadows of the two threads.

A way to analyze this approach is to consider a particularly interesting plane, described in this article as an *overstyle*.

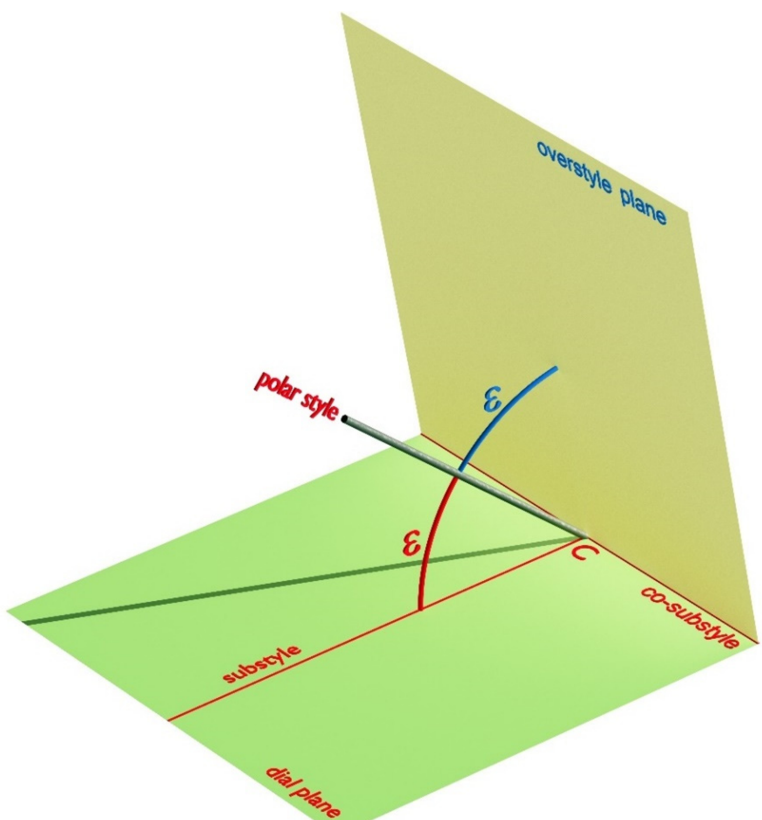

Fig. 1. The overstyl' plane obtained by rotating the dial plane around the co-substyle by twice the elevation of the polar style.

On the dial face, we have the substyle line (usually shortened to substile), so called because it is placed under the polar style, *i.e.* it is the line of intersection of the plane perpendicular to the dial face (that contains the polar style), with the dial face. The angle between the substyle and the polar style is the elevation of the style relative to the dial face, which I shall indicate using symbol ε.

Consider a straight line on the face of the dial, which I will call the *co-substyle*, perpendicular to the substyle and passing through the base C of the polar style, which is the center of the dial.

The plane of the dial face can be rotated around the co-substile by an angle equal to the elevation, reaching the polar style. A further rotation, again equal to the elevation, identifies a new plane, here called overstyle, which forms a dihedral angle with the plane of the dial equal to twice the elevation of the polar style (Fig. 1.)

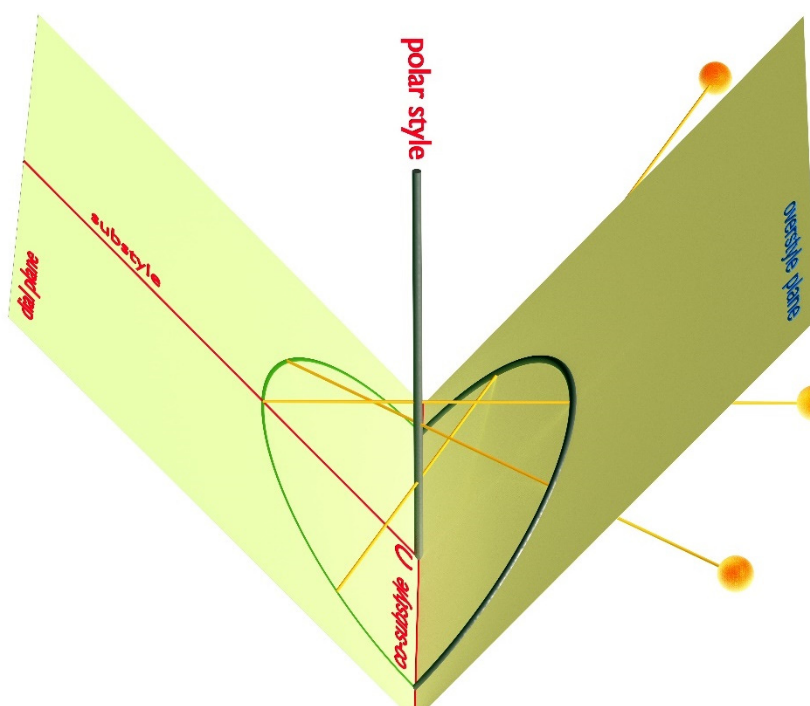

Fig. 2. The thread in the overstyle plane is projected onto the dial at the equinoxes, reproducing itself in a specular way.

By imagining a thread placed in the overstyle plane, we see that at the equinoxes, the projection of the knot on the dial face is a specular curve derived from the thread. This happens because an equinoctial sunray intersects the dial and the overstyle plane in the same points, but opposite with respect to the polar style (Fig. 2.)

This is valid for any shape of the thread, not necessarily straight, allowing you to design an equinoctial line of any shape.

Once the equinoctial curve has been defined, it can first be rotated by 180° with respect to the substyle, then rotated around the co-substyle in the overstyle plane (Fig. 3.) Curves symmetrical to the substyle can be rotated directly in the overstyle plane.

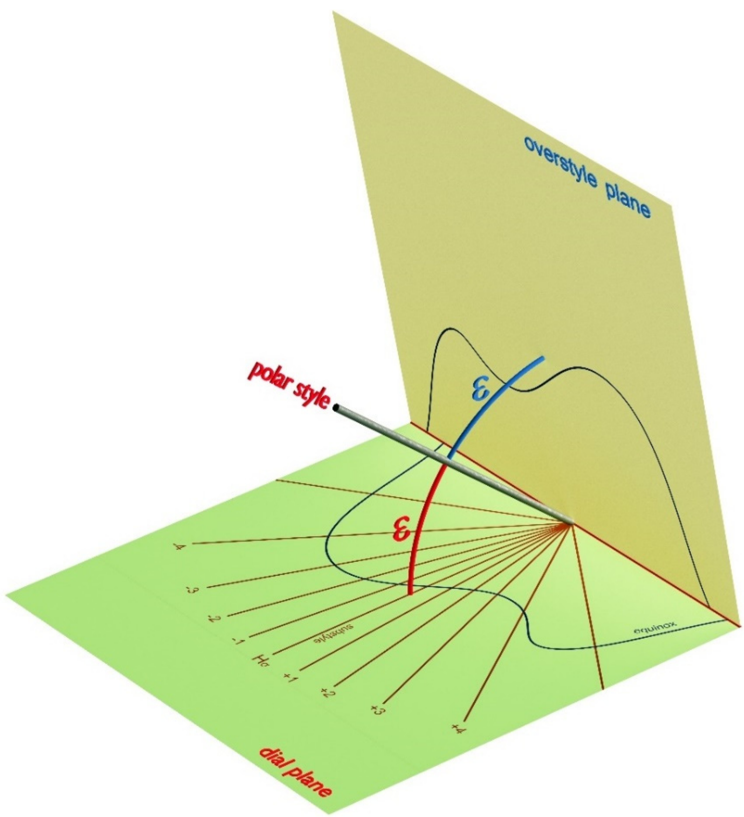

Fig. 3. The thread is obtained by rotating the equinoctial curve by 180° with respect to the substyle line, then elevating the curve twice the elevation, i.e., reaching the overstyle plane.

Note that the previous considerations are valid for a dial with any orientation since this approach concerns the substyle line and the elevation of the style, regardless of the orientation that determined them.

The plane containing the thread can also form a dihedral angle other than twice the elevation, but the overstyle plane is the only one that uses the thread having the same shape as the equinoctial curve.

For non-zero solar declinations, *i.e.* moving away from the equinox, the path of the knot changes, distorting the shape of the thread.

Among the creative hypotheses that can be associated with this anomalous approach to the bifilar, two particularly significant ones are analyzed: the round and square equinoctial curve.

Round equinoctial curve

Since it forms a 90° angle with the substyle, the co-substyle coincides with the hour lines 6 hours away from the time indicated by the substyle. This means that the two half-lines into which the co-substyle is divided are 12 hours apart, and divide the day into two halves.

Imagine, therefore, a circular equinoctial path limited to a semicircle to represent half a day. With its center at the base of the polar style, the semicircle is delimited by the co-substyle, representing a 12-hour journey. The equinoctial curve, symmetrical with respect to the substyle, can therefore be rotated from the plane of the dial to the overstyle plane, obtaining the thread that forces the knot to travel along the curve at the equinoxes.

For non-zero declinations of the Sun, the curves are deformed and the resulting graph is not particularly interesting (Fig. 4) so this type of bifilar sundial is most suitable for representing the equinoctial curve.

The other declination curves undergo deformations that are all the more evident the more they deviate from the equinoctial curve.

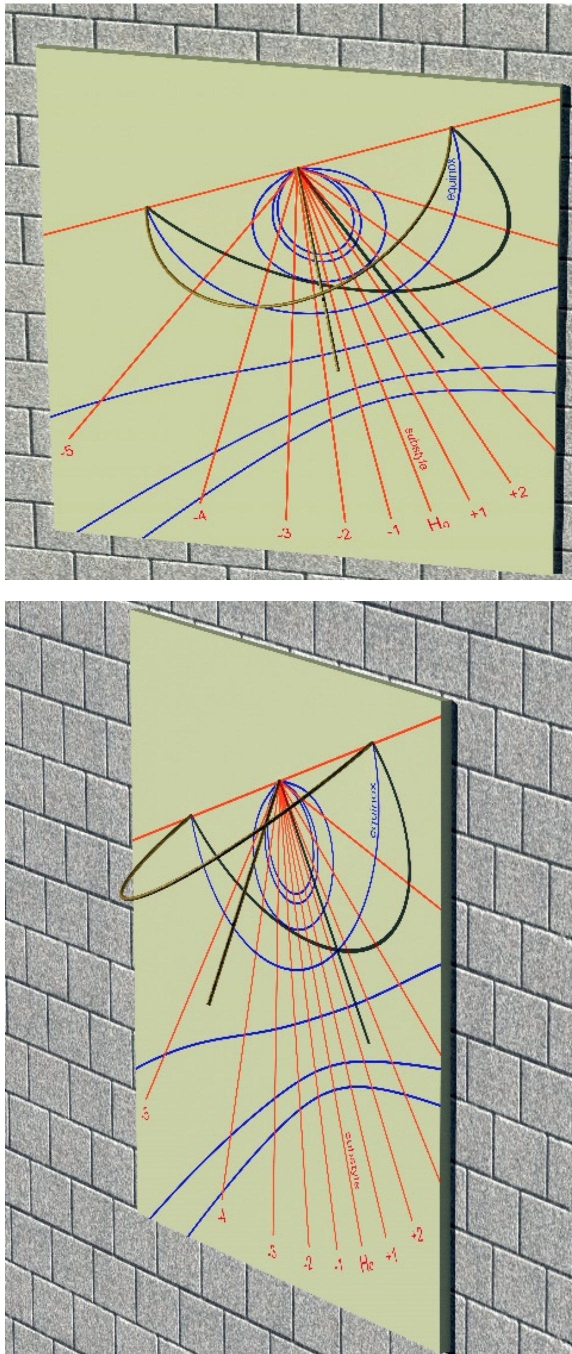

Fig. 4. Declining vertical dial, with elevation of the polar style of 30°. The equinoctial curve is a semicircle like the thread in the overstyle plane. The hour lines refer to intervals of whole hours from the substyle time H_σ.

In order to trace the declination curves, the solar rays that cross the wire are taken into consideration, as a function of the angle τ of a generic hour line and the declination of the Sun δ.

Consider a coordinate system with center at *C*, the *z*-axis directed as the polar style, the *y*-axis directed as the co-substyle and consequently the *x*-axis in the substyle plane (Fig. 5.)

Given *r* the radius of the semicircle and ε the elevation of the polar style, a point A placed on the wire has coordinates

$$\left.\begin{aligned} x_A &= r \cdot cos(\tau) \cdot sin(\varepsilon) \\ y_A &= r \cdot sin(\tau) \\ z_A &= r \cdot cos(\tau) \cdot cos(\varepsilon) \end{aligned}\right\} \qquad (1)$$

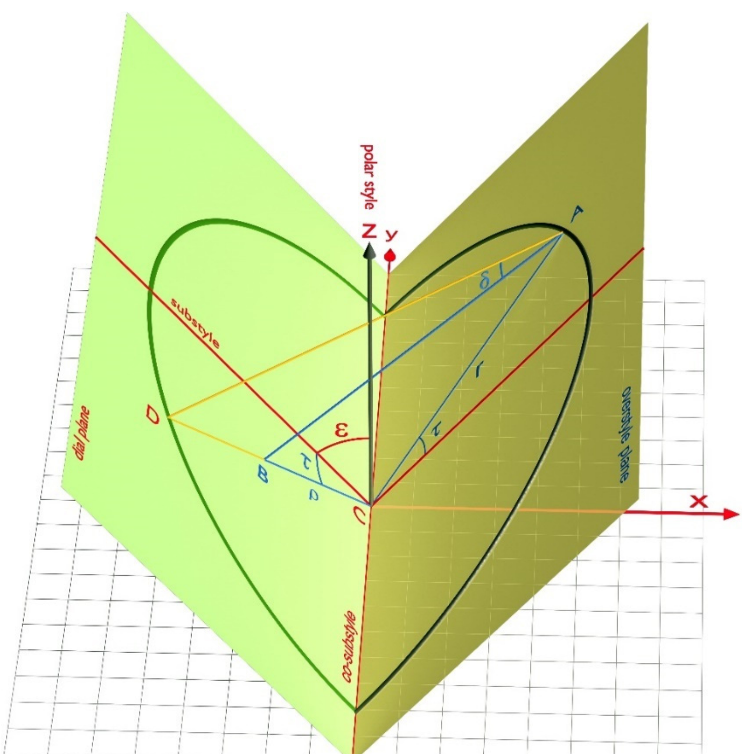

Fig. 5. Reconstruction of the three-dimensional coordinate system to identify the projection of the knot as a function of the declination of the Sun.

Consider the plane containing the z axis and a point A on the thread. This is the plane where the projection takes place since a ray from the Sun crosses the point A on the thread and the polar style, then reaches the quadrant in B as a function of the declination, in particular in the point D with zero declination (Fig. 5.)

With this construction, the triangle *ABC* is identified where the side *CA* is always equal to the radius *r* and the angle *DAC* can be obtained as

$$\widehat{DAC} = \widehat{ADC} = arctan(\frac{z_A}{\sqrt{x_A^2 + y_A^2}}) = arctan(\frac{cos(\tau) \cdot cos(\varepsilon)}{\sqrt{1 - cos(\tau)^2 \cdot cos(\varepsilon)^2}}) \quad (2)$$

By setting a declination δ non-zero, the distance ρ of knot *B* from *C* can be obtained

$$\rho = \frac{r \cdot \sin(\widehat{DAC} - \delta)}{\sin(\widehat{DAC} + \delta)} \quad (3)$$

The distance ρ combined with the angle τ allows us to find the points of the declination curves δ.

Note how Equation 3 allows you to calculate the declination curves of a thread with a generic shape knowing its function expressed in polar coordinates, *i.e* $r = f(\tau)$.

Square equinoctial curve

This approach makes it possible to create sundials with a dial consisting only of a frame with the equinoctial path.

For example, it is possible to elaborate a square equinoctial path, orienting the square thread so that even with a declining vertical dial the equinoctial path obtained has (only) horizontal and vertical sides (Fig. 6.)

The dial can therefore be reduced to a frame that will be crossed by the knot only on the equinoxes, while in the other periods the disappearance of the knot will not prevent reading of the time (thanks to the polar style).

In the example of Figure 6, the polar style is also held by two supports to form the section of a square, thereby inserting square shapes and paths, elements that are normally unavailable in gnomonics.

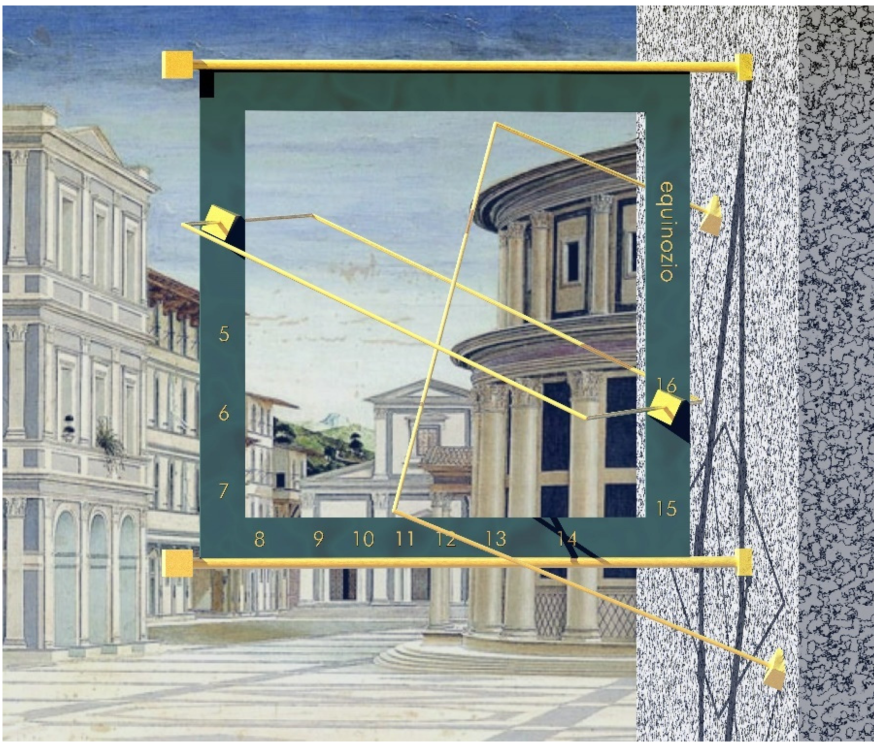

Fig. 6. 3D simulation with a polar style held by two supports to reproduce a square frame, the same as the dial and the thread in the overstyle plane. The knot crosses the dial at the equinoxes, disappears with declinations other than zero, but the hourly indications are in any case guaranteed by the polar style. Developing the thread with a full square allows the sundial to work on both faces.

Fabio Savian *fabio.savian@nonvedolora.it*

John Carmichael (JC) became very well known as a sundial maker in the 1990s and 2000s, working first in stone and later as a stained glass artist. Although now retired from sundial making, he remains available as a consultant for major public sundial projects. His website is www.sundialsculptures.com. John was interviewed by Steve Lelievre (SL.)

SL: How did you get started in sundial making?

JC: I was in the nursery business. I had a wholesale foliage plant nursery for 25 years, down in Mexico. I got tired so I came up here [to Arizona], but I was too young to retire so I picked up sundialing.

An artist friend had given me the Mayalls' book on sundials and I thought "well, this is the perfect combination of art and science, right here" so that's what got me started. But of course, there was nothing on how to make them and how to work with materials. Sundial books tell you how to design them, but not how to make them.

SL: So, the book – what was it about you as a person that made your friend realize it would be a good gift for you?

JC: Yes, she knew me, and that I liked to make things. She knew that I liked art, and she thought I would enjoy the book. And I thought it was just great!

I was born into a family of artists, teachers and preachers. I learned about doing artwork and to appreciate art at a young age. And the people in my family were always making something using their hands and tools. My aunt would be doing a painting and my uncle would be out in the garage making a frame for it. So, I have a good knowledge of working with tools and working with my hands.

I love to work with my hands. In fact, if I can't find something to do with my hands, I feel lost.

The book told me how to design using trigonometry so I had to get my dad's old Navy Trig book from the Second World War and reteach myself trig so I could do those equations. It was tedious work that sometimes took me a week to do.

Then I found out there were sundial design programs. The first one I found was from Fer De Vries. He was just great, and he became a good friend. And then, thanks to the Sundial Mailing List, I discovered DeltaCAD and it transformed everything! And not just for sundials. I use it for my railway layout, my house, and all kinds of things. It was the best money I ever spent.

SL: What kind a person succeeds as a sundial maker?

JC: You have to be a person who likes to work, and you have to like art. Here's the thing with making sundials: if people are going to buy one – and they're expensive – they want something that's 'pretty', that's nice to look at, and if they're spending that kind of money, they want something that works easily.

Some people aren't very handy or arty, or are more interested in the mathematics, so the dials they experiment with are functional but not always very pretty to look at. To make sundials as a business, you need to be able to use both sides of your brain. You need to be a jack-of-all-trades, especially if you work with a lot of mediums like I was.

Over the years I tried to tell other sundialists how I carved my sundials, how I made stained glass sundials, and how I made wall sundials, but there were very few people who took that information and ran with it. It was disappointing to me – some new sundials were made and restorations done, but not many.

SL: Okay, but how do you know what is going to be pleasing in an artistic way? Is that a skill someone can learn?

JC: I don't know. It just comes from within. I can't explain it. It's just a personal thing.

SL: So what can someone who isn't innately arty do?

JC: Well, I don't think about the artwork at first. I design the working parts – the hour lines, the lettering, the numerals, that sort of thing that has to be on the sundial. And then there's always an open blank area, usually on the bottom of the sundial if it's a horizontal. I send the layout to the client, and I tell them "this is the space we've got for art or inscriptions" and what can fit in there. That really helps the customer imagine what it's going to look like, and customers love being involved in the design phase. It can be a bit nerve-racking if they keep changing their minds, but they love that part of it.

SL: What other advice would you give to someone thinking of setting up as a sundial maker?

I taught myself how to do everything thanks to the internet and experiments – except that I did take a class on working in stained glass – but there are ways for technical, mathematical people to get involved in a sundial business without having to do it all themselves: I started out doing everything myself, but after a while, I discovered that I could contract out all kinds of things.

For example, I used to make all my own gnomons out of stone or brass because those were the materials I could work with, but some people wanted aluminum, bronze, or stainless steel.

In every town there's a metal worker – give them a diagram or a drawing or a nice CAD blueprint and they can make almost anything. So, you can farm out the metalwork. You can also farm out the stonework. You can go to places that sell stone, such as granite countertops, and they'll cut out the shape for you, and polish it and bevel it too. And you can have those sundial faces sandblasted or engraved with lasers. Doing the lines and lettering that way is much more accurate and faster than I can do myself by hand. The places that do it are cheap and they're fast. A sundial face that would take three weeks to carve by hand is ready for pick up in a couple of days.

I was still carving the artwork myself because I love that part of stone carving, but you could do it by finding images on the internet and sending those over to the sandblaster, or even better you could let the customer find artwork on the internet and put that into your design. So, you really don't have to be an artist or a stonemason or a metal worker.

And by contracting out, you can produce dials much faster and keep the overall cost down. I wish I had realized all this at the start and not towards the end of my time making stone sundials.

And there's a market for these things. I still get requests every week.

Most people don't know you can put sundials on the walls of buildings. Those are even easier to make than carving stone dials. Painted wall sundials can be the easiest and cheapest of all sundials to make. You may only need paint and a painter. Sign painters can paint a sundial if they have a drawing.

But I never had to advertise because there were so few of us sundial makers in the world, and I could even pick and choose projects.

SL: So how did people get to know about you?

JC: I had a website and people found me. I had a lot to show them – I put a lot of images of stuff that I've done on my website.

SL: You just put up a website?

JC: No. At the start, I was experimenting with wood sundials and a neighborhood guy came over. He asked, “Can you make me a sundial out of stone for my garden?” and I said “Sure!”

I didn’t even know how to carve stone when I said that, but I knew that my Dremel [rotary tool] would be able to do it. The first one I made, I did the math wrong! It was an hour off, so I took a sledgehammer, and I smashed it. And I made him another one, a good one. That was my first sundial. I was stoked and I thought “I can do this!” so I went to all the art galleries and nurseries in town, and I asked if I could put sundials for sale on commission. And they all said yes – for a 50/50 split. After I became known and website sales picked up, I ended the non-profitable commission sales.

That’s how my name got out here in Tucson. It got picked up by *Arizona Highways* [a travelogue and photography magazine] and a couple of local newspapers, and I even got on local TV too. So, my market started locally and then spread nationally and internationally.

So yes, there are places – like art galleries or nurseries – that will display stuff, but it needs to be arty because the people who go to those places are looking for beauty.

I made profit on the sundials – costs were low – but they took a lot of time and that was eating into my profits because they took so long to make. Then I started picking up design commissions and I quickly learned that I could earn more on those because of the time saved and of course, no materials costs. And I love working with competent architects! I can’t make the monumental sundials myself, so I worked with architects and the contractors.

SL: You moved back from Mexico when you retired from the nursery business …

JC: Yes, in 1992. And I moved back to Tucson because I went to college here and I still had friends and connections here, and I didn't want to go up North. It's too cold!

SL: So from 1992 you were semi-retired, and you started doing sundials because the opportunity arose. Did you keep doing them for as long as you did because it was a good business?

JC: Oh yeah, and I loved it. Making sundials was so satisfying. And I was making money from it.

SL: So it was both?

JC: Both, yes! But I wouldn't have stuck with it unless I could make an income. It started out as a hobby and then turned into a business, and that's the best kind of business you can have. To have one that you like, there's nothing better than that.

SL: But eventually you stopped…

JC: Well, I had switched over to doing more outsourcing with a metal fabricator and a sandblaster but because of COVID they both went out of business, and during COVID orders stopped coming in so I decided it was time to quit. And I had been wanting to spend more time on my railroad. That has taken over my time now.

But I'll still do a sundial if someone has a really great project, something that I haven't done before that sounds really interesting. But as for the stone sundials, I quit counting after 300 and I just don't want to make another one of those. I was physically worn out. It was the time.

SL: Changing tack a little bit: of your own pieces, are there any that stand out in your own mind?

JC: There are, but for different reasons. Like the reconstruction I did of a stained glass sundial in Didsbury. When I went to Oxford and saw my first stained glass sundial, it just blew me away! So, that one was a labor of love for me, and it came out so well.

Then there's the commission I did here in Tucson at Innovation Park Drive [NASS Registry 713]. It's modern art and I'm usually more traditional, but I went out on a limb for that one. It's a huge thing. It's 24 feet high and it's my favorite monumental. It's the most expensive and the most impressive. And I liked the living sundial, the plant sundial, I did at the Brookside Botanical Gardens in Maryland [NASS Registry 503].

Oh and there's another monumental that I love a lot, up in Colorado Springs [NASS Registry 604]. It a huge horizontal sundial that fills the back of a school and it's quite beautiful. You can see that one from space.

And there are other ones too. I did a real pretty equatorial for a cemetery, and a lot of ones for private individuals that I've really liked too.

SL: And in terms of other people's work or historical dials that you've seen, are there any that you particularly appreciate?

JC: Oh my! I love the dolphin sundial at Greenwich. I love it when they use people or things as a gnomon. Then you're really using art in science. And of course, all the stained glass ones are just incredible to me. And I love some of the monumental sundials I've seen on sundial tours, like the one at University of Washington in Seattle. And we have some great sundials here in Arizona – Carefree, that's a giant sundial! [NASS Registry 1]

SL: You mentioned Fer de Vries. Are there other sundial people who helped you along the way?

JC: Oh, yes! Tony Moss. Lovely person – invited me to his house and really looked after me. And Christopher Daniel, he couldn't have been nicer and more gracious to me, and he gave me permission to use all his literature, which was indispensable for making a stained glass sundial website. So many people! Mike Shaw, for example. Oh, and Patrick Powers. And Frank King. He was so helpful for Didsbury. Between him and Mike Shaw and Louise Smail, we got that project done. And Robert Adzema was a huge inspiration who showed me that a sundial business was possible – if they are pretty! All great people!

NASS thanks to John Carmichael for agreeing to be interviewed. As well as his successful business, John is known in the North American sundialing community as winner of the Sawyer Dialing Prize for 2002, as our local host for the 2002 conference in Tucson, AZ, and for many other contributions.

The reconstructed Didsbury Sundial. Image: John Carmichael.

DON'T FORGET QUADRANT ARCTANGENT!

Steve Lelievre (Victoria BC)

Arctangent is used fairly often in gnomonics. For example, the standard formula for calculating hour lines for a horizontal dial is $\tan\theta = \sin\varphi\tan\omega$ or equivalently, $\theta = \tan^{-1}(\sin\varphi\tan\omega)$ where θ is the hour line angle, ω is the hour angle, and φ is latitude. However, arctangent yields unsuitable θ for hour angles greater than 90° or less than −90°. This is due to the periodicity of trigonometric functions. For example, tan 45° and tan −135° both have value 1; arctangent provides the value in the range $-90° \leq \theta \leq 90°$.

Until recently, I have dealt with the problem by making minor but unwelcome adjustments to my code, taking the complement of θ in either 180° or −180° according to the value of ω and the geographic hemisphere. I would use something opaque but concise, such as

```
θ = atan(sin(abs(φ)) * tan(ω));
if (abs(ω) > 90) θ = θ + 180 * sign(ω);
θ = θ * sign(φ);
```

Now, I'm kicking myself – after too many years I have finally realized that it is possible to get the result in the desired quadrant directly, because the term $\tan^{-1}(\sin\varphi\tan\omega)$ can also be expressed as $\tan^{-1}\left(\frac{\sin\varphi\sin\omega}{\cos\omega}\right)$. The modified form invites use of the Quadrant Arctangent function, atan2, which is available in both programming languages and spreadsheets[1].

It gives a value of θ in the correct quadrant *and* with the sequence of hours lines automatically running clockwise or anticlockwise as appropriate for the hemisphere. Only one line of code is needed:

```
θ = atan2(sin(φ) * sin(ω), cos(ω));
```

I hope others find this little tip helpful.

Steve Lelievre steve.lelievre.canada@gmail.com

[1] The parameters for atan2 are usually (change in y, change in x) but for Excel the order is reversed.

The Tove's Nest

Send your sundial-related news and announcements to sundial.society+editor@gmail.com.

Publication Delay: Medieval Planispheric Astrolabes, Part II

Part II of the Sept. 2023 article by Alfonso Pastor Moreno & Robert L. Kellogg is now scheduled for later this year. [Ed.]

Eclipse Sundial

Bill Gottesman, billgottesman@gmail.com

Dan Axtell and I have updated the website www.eclipsesundial.com for the April 8, 2024 eclipse. If you're lucky enough to live on the path of the eclipse, you can print out a special sundial for the big day.

The Eclipse Sundial must be placed on a horizontal surface, aligned to True North. A pinhole card is then used match the orientation of the projected sun image's cusps to one of the lines marked on the dial.

Digital Bonus

- Images, animations, and SketchUp models for Gian Casalegno's article (p.19) describing two sundials with curved bifilar styles.
- A 3D model (STL file) by Steve Lelievre showing some of the principal angles used to define the position of the sun. It was created to help beginning dialists distinguish between equatorial and horizontal systems. If your computer lacks an STL viewer, there are online ones aplenty. Steve likes https://3dviewer.net/ and, for iPhone, the *STL Viewer* app.
- An addendum to Steve Lelievre's article on a Beachball Terrella, from The Compendium, 30(2). The addendum proposes some extra markings for aligning the terrella if solar declination is known.

The seed of this hour shall ripen in the course of time.

- Hans Christian Andersen