MICRO Shadows

How to make a simple horizontal sun dial
COOK BOOK FORMAT ~ NO THEORY

Simon Wheaton-Smith
October 2012

Please consider acquiring "ILLUSTRATING TIME'S SHADOW" ~ How to make Sundials for almost anywhere using empirical, geometric, and trigonometric methods as well as computer aided design and spreadsheets.

Or try "SIMPLE SHADOWS" which has all this material plus many pages of explanations focused on the horizontal dial, and gives you a flavor of the main book "ILLUSTRATING TIME'S SHADOW". SIMPLE SHADOWS is also free and you download it.

FREE Please download:- microShadows.xls for Excel

from:- www.illustratingshadows.com

or illustrating-shadows.xls for Excel

which is a conglomeration of spreadsheets for dial design, and also has a reverse engineering spreadsheet for making store bought dials work. There is an Excel as well as an Open Office version. Both provide graphical depictions of sundials.

FREE Please download the Reverse Engineering article for making store bought dials work if you have one, and you are frustrated.

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extracted from Simple Shadows

extracted from Illustrating Time's Shadow

A QUICK HANDS ON PROJECT ~ ~ ~ BUILD IT FIRST – FIX IT NEXT

The next two pages offer a simple "go ahead and build it" horizontal sundial, then see what needs to be done to make it accurate. The rest of the book is the other way around, theory to understand what is going on, then build it. These two pages help you build a horizontal dial and for all readers, this is a good prelude to the rest of the book. And now, some questions…

1. What is your latitude (how far north or south are you from the equator). Many maps show this, and so does a GPS. In the appendices, Table A2.5 may help.

my latitude is:	

2. **EITHER** download the spreadsheet at:

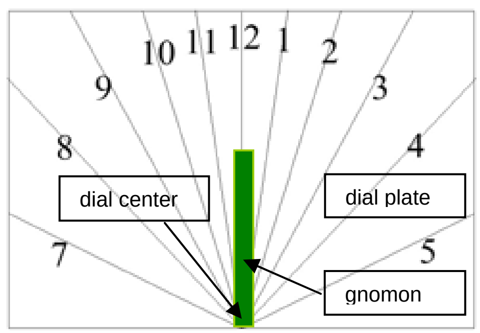
   www.illustratingshadows.com/microShadows.xls

   then enter the latitude. **OR** go to tables A3.1a, A3.1b, or A3.1c in the appendices, look at the latitude at the top of the columns, then find the angles for the hours you wish marked.

6 6	7 5	8 4	9 3	10 2	11 1	noon noon	morning hours afternoon hours

3. Mark the lines on the template "A DRAFTING SHEET FOR HORIZONTAL DIALS" from the appendices. The end result should look roughly like the fan of lines to the right.

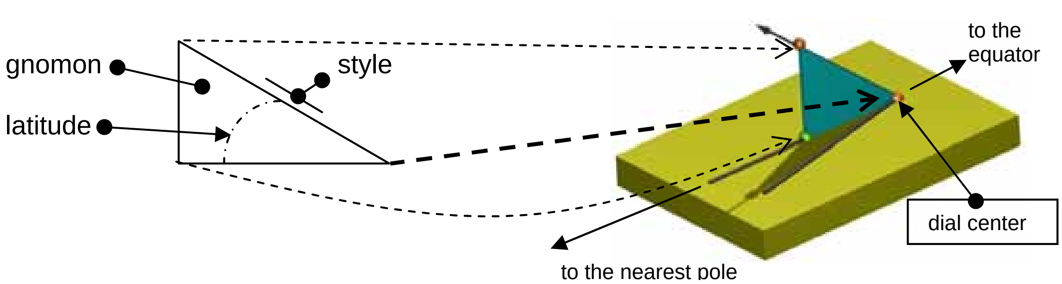
   Noon is going to be on the north south line and the 6am and 6pm lines will be at 90 degrees to that, The other lines will fan out, and their angles depend on your latitude.



4. Transpose the hour lines to wood, PVC, copper, glass, concrete, or any other medium. This is called the dial plate.

5. Build a shadow casting device, called a gnomon, it is a triangle whose angle from the dial plate is equal to the latitude. The angle is important, the length is not, unless you want to add other information related to the time of year, discussed in the main part of the book. **NOTE:** the gnomon should be thin. If it is thick as shown above, then the am and pm hours should be separated at noon to account for it.

6. Affix the gnomon to the dial plate, the latitude angle end rests on top of where the hour lines converge (dial center), and it lies on the north south line, or the noon line.



7. Take the dial plate, it's affixed gnomon on the noon line and place it in the sun.

8. Align the noon line with north/south, and the gnomon's end placed on dial center (where it meets the hour lines), should point to the equator, south in the northern hemisphere or north in the southern hemisphere.

   By north, true north is meant, not the north where a compass points. To find true north, first find magnetic north by using a compass but keep away from metal.

   Then find your location's magnetic variation, or declination as sun dial people call it. If it is an easterly declination you must back away from north to the west. If it is a westerly declination, you must back away from north to the east. Magnetic declinations are often found on maps, and a table and a map in the appendix has declination information.

my magnetic declination:	E W

   Table A2.5 and the maps in appendix 2 may help, and many websites also, you may try: `http://www.magnetic-declination.com/`

9. With the dial plate level, the angled part of the gnomon pointing north south, the dial will now read sun-time, or local-apparent-time or LAT for short. It is still not clock accurate. There are **two corrections** to make. One is to correct for your distance from your time zone's reference **longitude**, the other is for the fact the sun is predictably slow or fast (compared to man made watches) as the year progresses, this correction is called the **equation of time or EOT for short**.

10. Find your **longitude**, it is on your GPS unit, or on a map of your area. Aviation and geological survey maps work, but road maps may not. Once you know your longitude, and your time zone, find your time zone's reference longitude.

my longitude is:		Table A2.5 in the appendices may help.
my time zone reference is:		Table A2.6 in the appendices may help.
difference between the two is:		times 4 is: ______minutes

   If your longitude is larger than the reference longitude, then ADD the difference times 4, this is the minutes to add to correct for your location.

   If your longitude is smaller than the reference longitude, then SUBTRACT the difference times 4, this is the minutes to add to correct for your location.

plus [ ] or minus [ ] _ _ _ minutes to correct for location.

11. We now have a dial built for your latitude, aligned north/south, and corrected for your location's distance from the time zone's reference longitude. However it may still be off by plus or minus up to 16 minutes due to the fact the sun's orbit around the earth varies as the year progresses, and the sun similarly moves north or south of the equator. There is a table of corrections for this **equation of time or EOT**, table A2.1 is by the day.

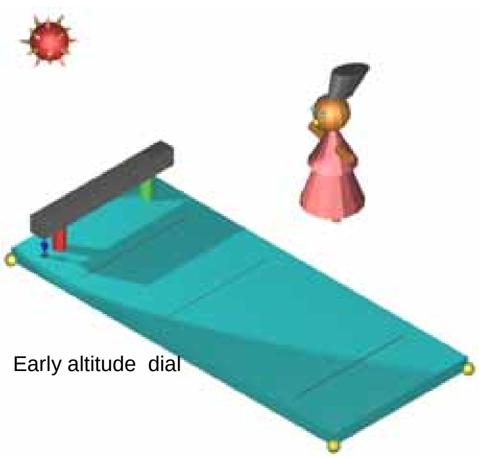
12. That is it! You now have a working horizontal sun dial. To delve into it more, read on . . . .

THE EVOLUTION OF THE DIAL

USEFUL DEFINITIONS –

- The EOT, or equation of time is the difference between the real apparent sun and a virtual perfectly on-time sun that matches the modern "accurate" clock
- Altitude – how high above the horizon the sun is, measured in degrees.
- Azimuth ~ how far east or west of the north-south line the sun is, measured in degrees.

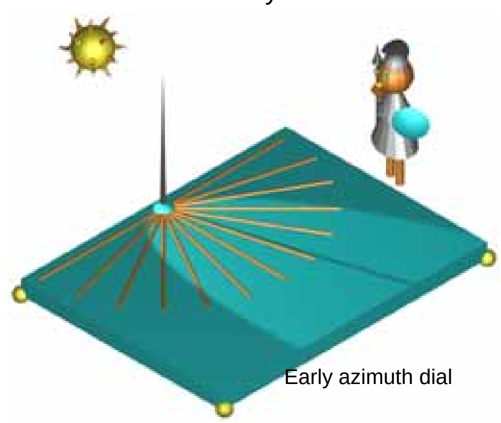
Since the earliest days of the human race, it was important to know when to plant, when to hunt, and a calendar was needed and developed. The sun's angle in the sky compared to the horizon, is its altitude, and early Egyptians employed such dials.


Early altitude dial

The sun woke up and climbed, ran out of energy in mid day, and becoming tired, descended into the arms of Morpheus. The early Egyptians built a simple dial that could be turned toward the sun, and its angle at mid day cast a shadow of decreasing length as the climate became warmer. Alignment with true north or south was not needed for these altitude measuring dials, since the reference was the sun, and the horizon.

For all altitude dials, north south alignment is not used but the date must be known if the one is to tell the time.

As time became more important than the calendar, early Greeks, Arabs, and Romans had business to conduct. And so developed a sundial that measured the azimuth of the sun, its angle compared with true north or south. Such early dials often divided daylight into pieces, yet those pieces were not always of equal duration, sometimes they were just arbitrary divisions. Azimuth dials do not required a gnomon of a calculated height. The line of the shadow aligns with hour lines, or points to hour points.

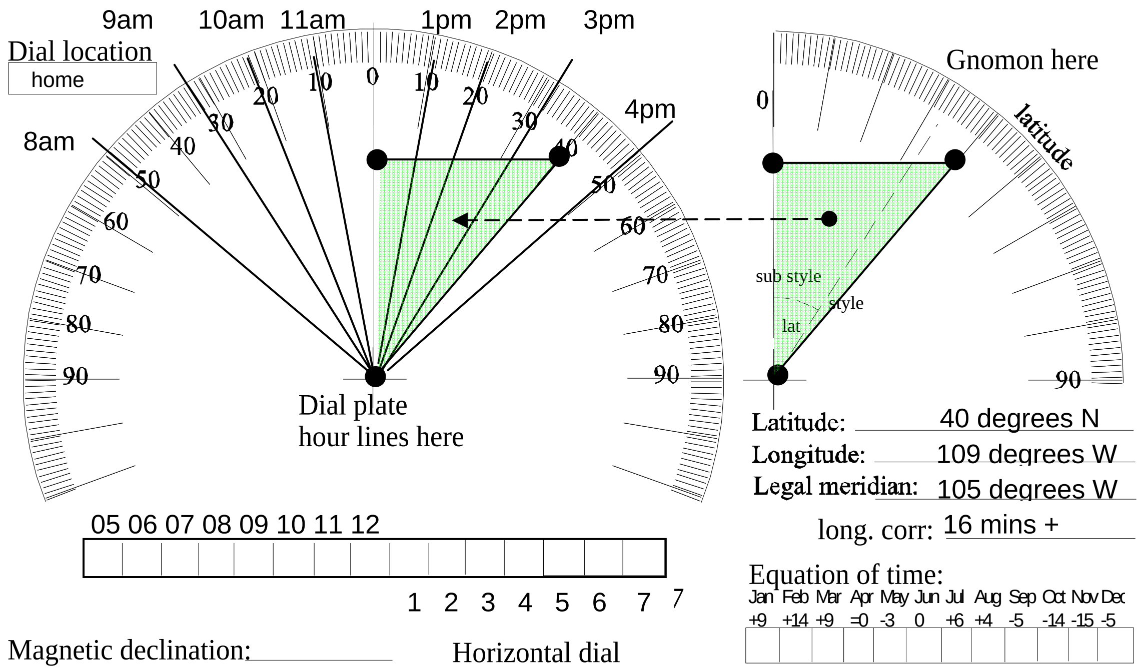

Early azimuth dial

Of course time, altitude, and azimuth are all somewhat related. And a definitive study of dial history may not show such a sequenced development because different areas of the world evolved differently. As the horse and carriage produced rapid transportation, people needed common time keeping, and equal hours. So was ushered in the perfected sundial. That perfected dial used the angle the sun makes as it appears to orbit around the earth's north-south polar axis.

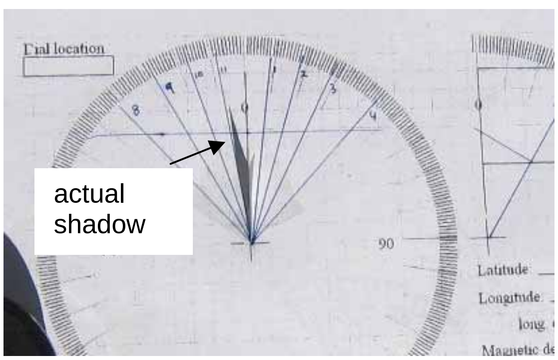
The reader may have noticed that the sun runs slow or fast depending on the day of the year.

Sun dials use the solar position as the basis for date and for time. The earth orbits the sun, however not by an exact number of days, and even those days vary in an annual cycle. So even city slicker watches are not synchronized as well as we might think. Is the synchronization with the daily rotation of the earth, the annual rotation around the sun, or with the fixed stars?

HORIZONTAL DIAL: Method: Using Tables: [appendix 9 has the template used here]



This template may be copied provided credit is given to Illustrating Shadows, www.illustratingshadows.com and Simon Wheaton-Smith



Appendix 3 table A3.1b for latitude 40 provides the following hour line angles assuming no longitude correction.

8am and 4pm	48.07 degrees
9am and 3pm	32.73 degrees
10am and 2pm	20.36 degrees
11am and 1pm	9.77 degrees etc

The hour lines before and after noon are drawn. The gnomon is drawn and moved to dial center. The longitude correction of 4 degrees (at 4 minutes per degree) is 16 minutes, and is west of longitude 105 thus we must add the time. The longitude correction of 16 minutes is added to the equation of time, producing:-

Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec
+25	+30	+25	+16	+13	+16	+22	+20	+11	+2	+1	+11

The dial plate is aligned to true north, and the shadow is mentally corrected with the revised equation of time (EOT). Alternatively the hour lines could be adjusted individually for longitude, however the dial would no longer be portable. If the hour lines were longitude adjusted, they would simple be rotated, but by an angle calculated for a time corrected by the 16 minutes, one hour line at a time. The equinox line is derived by extending the gnomon from the nodus to the sub-style line extended, and perpendicular to the style. Longitude corrections of 4 or more degrees cause the resulting combined EOT table to always have the same sign. That is because 4 degrees is 16 minutes, the maximum EOT deviation. This paper dial can be tested in the sun before the final dial is built as is shown in the inset.

A2.1

APPENDIX 2 - Tables independent of location

EQUATION OF TIME ~ EOT

minutes:seconds **mm.ss**

EQUATION OF TIME TABLE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	3:09	13:34	12:17	3:49	-2:54	-2:09	3:51	6:17	0:02	-10:21	-16:21	-10:52
2	4:07	13:42	12:05	3:32	-3:01	-1:59	4:03	6:13	-0:22	-10:40	-16:22	-10:29
3	4:34	13:48	11:52	3:14	-3:07	-1:50	4:14	6:08	-0:41	-10:59	-16:22	-10:06
4	5:02	13:54	11:39	2:57	-3:13	-1:39	4:25	6:03	-1:01	-11:17	-16:22	-9:42
5	5:28	13:59	11:26	2:39	-3:18	-1:29	4:35	5:57	-1:21	-11:35	-16:20	-9:17
6	5:55	14:03	11:12	2:22	-3:23	-1:18	4:45	5:51	-1:41	-11:53	-16:18	-8:52
7	6:21	14:06	10:58	2:06	-3:27	-1:07	4:55	5:43	-2:01	-12:10	-16:15	-8:27
8	6:46	14:09	10:43	1:49	-3:30	-0:56	5:04	5:36	-2:22	-12:27	-16:11	-8:00
9	7:11	14:10	10:28	1:33	-3:33	-0:44	5:13	5:27	-2:43	-12:43	-16:06	-7:34
10	7:35	14:11	10:13	1:16	-3:35	-0:32	5:22	5:19	-3:03	-12:59	-16:00	-7:07
11	7:59	14:12	9:57	1:01	-3:37	-0:20	5:30	5:09	-3:24	-13:15	-15:54	-6:39
12	8:22	14:11	9:42	0:45	-3:38	-0:08	5:37	4:59	-3:46	-13:30	-15:46	-6:11
13	8:44	14:10	9:25	0:30	-3:39	0:04	5:44	4:48	-4:07	-13:44	-15:38	-5:43
14	9:06	14:08	9:09	0:15	-3:39	0:16	5:51	4:37	-4:28	-13:58	-15:29	-5:15
15	9:27	14:05	8:52	0:00	-3:38	0:29	5:57	4:26	-4:49	-14:12	-15:19	-4:46
16	9:48	14:01	8:35	-0:13	-3:37	0:42	6:03	4:13	-5:11	-14:25	-15:09	-4:17
17	10:08	13:57	8:18	-0:27	-3:36	0:55	6:08	4:01	-5:32	-14:37	-14:57	-3:48
18	10:27	13:52	8:01	-0:40	-3:34	1:08	6:13	3:48	-5:53	-14:49	-14:45	-3:19
19	10:45	13:47	7:43	-0:53	-3:31	1:21	6:17	3:34	-6:15	-15:00	-14:31	-2:49
20	11:03	13:40	7:25	-1:06	-3:27	1:34	6:20	3:20	-6:36	-15:10	-14:17	-2:19
21	11:20	13:33	7:08	-1:18	-3:24	1:47	6:23	3:05	-6:57	-15:20	-14:02	-1:50
22	11:36	13:26	6:50	-1:30	-3:19	2:00	6:26	2:50	-7:18	-15:29	-13:47	-1:20
23	11:52	13:18	6:32	-1:41	-3:14	2:13	6:28	2:34	-7:39	-15:38	-13:30	-0:50
24	12:06	13:09	6:14	-1:52	-3:09	2:26	6:29	2:18	-8:00	-15:46	-13:13	-0:20
25	12:20	13:00	5:56	-2:03	-3:03	2:39	6:30	2:02	-8:21	-15:53	-12:55	0:08
26	12:33	12:50	5:37	-2:12	-2:57	2:51	6:30	1:45	-8:41	-15:59	-12:36	0:38
27	12:45	12:39	5:19	-2:22	-2:50	3:04	6:29	1:28	-9:02	-16:05	-12:17	1:07
28	12:57	12:28	5:01	-2:31	-2:43	3:16	6:28	1:10	-9:22	-16:09	-11:57	1:37
29	13:07		4:43	-2:39	-2:35	3:28	6:26	0:52	-9:42	-16:14	-11:36	2:06
30	13:17		4:25	-2:47	-2:27	3:40	6:24	0:34	-10:01	-16:17	-11:14	2:35
31	12:26		4:07		-2:18		6:21	0:16		-16:19		3:03

If "+" then add to solar time to get mean time as the sun is slow. If " –" then subtract from solar time to get mean time as the sun is fast. Some tables have a plus for our minus and vice versa. If in doubt look at the figure of eight equation of time. **Formulae involving dates** use approximations thus these tables may disagree with other sources using other formulae. This and other publications have figures that are well within drafting tolerances.

A2.3

LONGITUDE TO TIME

Degree (°) to Hours (h) and Minutes (m)

°	hh.mm	°	hh.mm	°	hh.mm	°	hh.mm	°	hh.mm	°	hh.mm
0	0.00	30	2.00	60	4.00	90	6.00	120	8.00	150	10.00
1	0.04	31	2.04	61	4.04	91	6.04	121	8.04	151	10.04
2	0.08	32	2.08	62	4.08	92	6.08	122	8.08	152	10.08
3	0.12	33	2.12	63	4.12	93	6.12	123	8.12	153	10.12
4	0.16	34	2.16	64	4.16	94	6.16	124	8.16	154	10.16
5	0.20	35	2.20	65	4.20	95	6.20	125	8.20	155	10.20
6	0.24	36	2.24	66	4.24	96	6.24	126	8.24	156	10.24
7	0.28	37	2.28	67	4.28	97	6.28	127	8.28	157	10.28
8	0.32	38	2.32	68	4.32	98	6.32	128	8.32	158	10.32
9	0.36	39	2.36	69	4.36	99	6.36	129	8.36	159	10.36
10	0.40	40	2.40	70	4.40	100	6.40	130	8.40	160	10.40
11	0.44	41	2.44	71	4.44	101	6.44	131	8.44	161	10.44
12	0.48	42	2.48	72	4.48	102	6.48	132	8.48	162	10.48
13	0.52	43	2.52	73	4.52	103	6.52	133	8.52	163	10.52
14	0.56	44	2.56	74	4.56	104	6.56	134	8.56	164	10.56
15	1.00	45	3.00	75	5.00	105	7.00	135	9.00	165	11.00
16	1.04	46	3.04	76	5.04	106	7.04	136	9.04	166	11.04
17	1.08	47	3.08	77	5.08	107	7.08	137	9.08	167	11.08
18	1.12	48	3.12	78	5.12	108	7.12	138	9.12	168	11.12
19	1.16	49	3.16	79	5.16	109	7.16	139	9.16	169	11.16
20	1.20	50	3.20	80	5.20	110	7.20	140	9.20	170	11.20
21	1.24	51	3.24	81	5.24	111	7.24	141	9.24	171	11.24
22	1.28	52	3.28	82	5.28	112	7.28	142	9.28	172	11.28
23	1.32	53	3.32	83	5.32	113	7.32	143	9.32	173	11.32
24	1.36	54	3.36	84	5.36	114	7.36	144	9.36	174	11.36
25	1.40	55	3.40	85	5.40	115	7.40	145	9.40	175	11.40
26	1.44	56	3.44	86	5.44	116	7.44	146	9.44	176	11.44
27	1.48	57	3.48	87	5.48	117	7.48	147	9.48	177	11.48
28	1.52	58	3.52	88	5.52	118	7.52	148	9.52	178	11.52
29	1.56	59	3.56	89	5.56	119	7.56	149	9.56	179	11.56
										180	12.00

A2.5

CITY DATA WITH LATITUDE, LONGITUDE AND ITS CORRECTION

City id	Country, State, City			Hemi-sphere	Lat +n -s	Long +w -e	Mag var	Time ref	Long corr
	UK		London	N +ve	51.5	0.5	2.5w	0	2
	UK		Weymouth	N +ve	50.6	2.5	3.4w	0	10
PHX	USA	AZ	Phoenix	N +ve	33.5	112.0	11.8e	105	28
SDL	USA	AZ	Scottsdale	N +ve	33.6	111.9	11.8e	105	27.6
LAX	USA	CA	Los Angeles	N +ve	34.0	118.3	13.4e	120	-6.8
SAN	USA	CA	San Diego	N +ve	32.8	117.2	13.1e	120	-11.2
SFO	USA	CA	San Fransisco	N +ve	37.8	122.5	15.4e	120	10
DEN	USA	CO	Denver	N +ve	39.8	105.0	10.2e	105	0
DCA	USA	DC	Washington	N +ve	38.9	77.0	10.3w	75	8
CHI	USA	IL	Chicago,	N +ve	41.8	87.8	2.2w	90	-8.8
SVC	USA	NM	Silver City	N +ve	32.8	108.2	10.6e	105	12.8
LAS	USA	NV	Las Vegas	N +ve	36.2	115.2	13.3e	120	-19.2
JFK	USA	NY	New York	N +ve	40.7	73.8	13.8w	75	-4.8
OKC	USA	OK	Oklahoma City	N +ve	35.3	97.5	5.4e	90	30
ELP	USA	TX	El Paso	N +ve	31.8	106.5	10.1e	105	6

DAYLIGHT SAVING TIME AND TABLE OF TIME ZONES

A2.6

Zone	Name	Meridian		GMT+
	Newfoundland	52.5		3.5
4	Atlantic	60		4
5	Eastern	75		5
6	Central	90		6
7	Mountain	105		7
8	Pacific	120		8
9	Yukon	135		9
10	Alaska-Hawaii	150		10
11	Bering	165		11
	GMT Greenwich Mean Time			0
	BST British Summer Time			-1
	IST Irish Summer Time			-1
	WET Western Europe Time			0
	WEST Western Europe Summer Time			-1
	CET Central Europe Time			-1
	CEST Central Europe Summer Time			-2
	EET Eastern Europe Time			-2
	EEST Eastern Europe Summer Time			-3
	MSK Moscow Time			-3
	MSD Moscow Summer Time			-4

SUMMER TIME RULES

USA: first Sunday of April to the last Sunday of October. (some exceptions e.g. AZ, HI, etc)
EU: last Sunday in March to the last Sunday in October.
The website: http://webexhibits.org/daylightsaving/ has other useful information.

A3.1 a

APPENDIX 3

TABLES THAT CONSIDER LOCATION

HORIZONTAL (AND VERTICAL DIAL) HOUR LINE ANGLES

HOUR LINE ANGLES Horizontal dial

hour angle DEGREES(ATAN(TAN(RADIANS(15*time))*SIN(RADIANS(lat))))

hour angle H = atan (sin(lat) * tan (ha))

	HORIZONTAL DIAL LATITUDE										
TIME	30	31	32	33	34	35	36	37	38	39	
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	noon
0.25	1.88	1.93	1.99	2.04	2.10	2.15	2.21	2.26	2.31	2.36	11.75
0.50	3.77	3.88	3.99	4.10	4.21	4.32	4.42	4.53	4.63	4.74	11.50
0.75	5.68	5.85	6.02	6.18	6.35	6.51	6.67	6.83	6.98	7.14	11.25
1	7.63	7.86	8.08	8.30	8.52	8.74	8.95	9.16	9.37	9.57	11
1.25	9.63	9.92	10.20	10.47	10.75	11.02	11.28	11.55	11.80	12.06	10.75
1.50	11.70	12.04	12.38	12.71	13.04	13.36	13.68	14.00	14.31	14.61	10.50
1.75	13.85	14.25	14.65	15.03	15.42	15.79	16.16	16.53	16.89	17.24	10.25
2	16.10	16.56	17.01	17.46	17.89	18.32	18.75	19.16	19.57	19.97	10
2.25	18.47	18.99	19.50	20.00	20.49	20.97	21.44	21.91	22.36	22.81	9.75
2.50	20.99	21.56	22.13	22.68	23.22	23.76	24.28	24.79	25.29	25.78	9.50
2.75	23.68	24.31	24.93	25.53	26.12	26.70	27.27	27.82	28.37	28.89	9.25
3	26.57	27.25	27.92	28.57	29.21	29.84	30.45	31.04	31.62	32.18	9
3.25	29.69	30.43	31.14	31.84	32.52	33.19	33.83	34.46	35.07	35.66	8.75
3.50	33.09	33.87	34.63	35.37	36.08	36.78	37.45	38.11	38.74	39.36	8.50
3.75	36.81	37.63	38.42	39.18	39.93	40.64	41.34	42.01	42.66	43.28	8.25
4	40.89	41.74	42.55	43.33	44.08	44.81	45.51	46.19	46.84	47.47	8
4.25	45.40	46.24	47.06	47.84	48.59	49.31	50.00	50.67	51.31	51.92	7.75
4.50	50.36	51.19	51.99	52.75	53.47	54.16	54.83	55.46	56.07	56.65	7.50
4.75	55.83	56.61	57.36	58.07	58.74	59.38	59.99	60.57	61.13	61.66	7.25
5	61.81	62.51	63.18	63.80	64.40	64.96	65.49	66.00	66.48	66.94	7
5.25	68.31	68.88	69.43	69.94	70.42	70.87	71.30	71.71	72.10	72.46	6.75
5.50	75.25	75.66	76.05	76.41	76.75	77.07	77.38	77.66	77.93	78.18	6.50
5.75	82.53	82.75	82.95	83.14	83.31	83.48	83.64	83.78	83.92	84.05	6.25
6	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	6

NOTE: Values are degrees and tenths and hundredths of a degree. Thus latitude 39 at 1pm or 11am shows 9.57 degrees, not 9 degrees, 57 minutes. And 9.57 degrees converts to 9 degrees 34.2 minutes of arc, which is consistent with other publications.

A3.1 b

HOUR LINE ANGLES Horizontal dial

hour angle DEGREES(ATAN(TAN(RADIANS(15*time))*SIN(RADIANS(lat))))

hour angle H = atan (sin(lat) * tan (ha))

	HORIZONTAL DIAL LATITUDE									
TIME	40	41	42	43	44	45	46	47	48	49	
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	noon
0.25	2.41	2.46	2.51	2.56	2.61	2.65	2.70	2.74	2.79	2.83	11.75
0.50	4.84	4.94	5.03	5.13	5.23	5.32	5.41	5.50	5.59	5.67	11.50
0.75	7.29	7.43	7.58	7.73	7.87	8.01	8.14	8.28	8.41	8.54	11.25
1	9.77	9.97	10.16	10.36	10.54	10.73	10.91	11.09	11.26	11.43	11
1.25	12.31	12.56	12.80	13.03	13.27	13.50	13.72	13.94	14.16	14.37	10.75
1.50	14.91	15.20	15.49	15.77	16.05	16.32	16.59	16.85	17.11	17.36	10.50
1.75	17.59	17.93	18.26	18.59	18.91	19.22	19.53	19.83	20.13	20.41	10.25
2	20.36	20.75	21.12	21.49	21.85	22.21	22.55	22.89	23.22	23.54	10
2.25	23.24	23.67	24.09	24.50	24.90	25.29	25.67	26.04	26.41	26.76	9.75
2.50	26.25	26.72	27.18	27.62	28.06	28.48	28.90	29.30	29.69	30.08	9.50
2.75	29.41	29.91	30.40	30.88	31.35	31.80	32.25	32.68	33.09	33.50	9.25
3	32.73	33.27	33.79	34.29	34.79	35.26	35.73	36.18	36.62	37.04	9
3.25	36.24	36.80	37.34	37.87	38.38	38.88	39.36	39.83	40.28	40.71	8.75
3.50	39.95	40.53	41.09	41.63	42.15	42.66	43.15	43.62	44.08	44.53	8.50
3.75	43.89	44.48	45.04	45.59	46.11	46.62	47.11	47.58	48.04	48.48	8.25
4	48.07	48.65	49.21	49.75	50.27	50.77	51.25	51.71	52.16	52.58	8
4.25	52.50	53.07	53.61	54.13	54.63	55.11	55.57	56.01	56.43	56.84	7.75
4.50	57.20	57.73	58.24	58.73	59.19	59.64	60.07	60.47	60.87	61.24	7.50
4.75	62.16	62.64	63.10	63.54	63.96	64.36	64.74	65.10	65.45	65.78	7.25
5	67.37	67.78	68.18	68.55	68.91	69.25	69.57	69.88	70.17	70.45	7
5.25	72.81	73.13	73.44	73.74	74.02	74.29	74.54	74.78	75.02	75.23	6.75
5.50	78.43	78.65	78.87	79.07	79.27	79.45	79.63	79.80	79.95	80.10	6.50
5.75	84.18	84.29	84.41	84.51	84.61	84.70	84.79	84.88	84.96	85.04	6.25
6	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	6

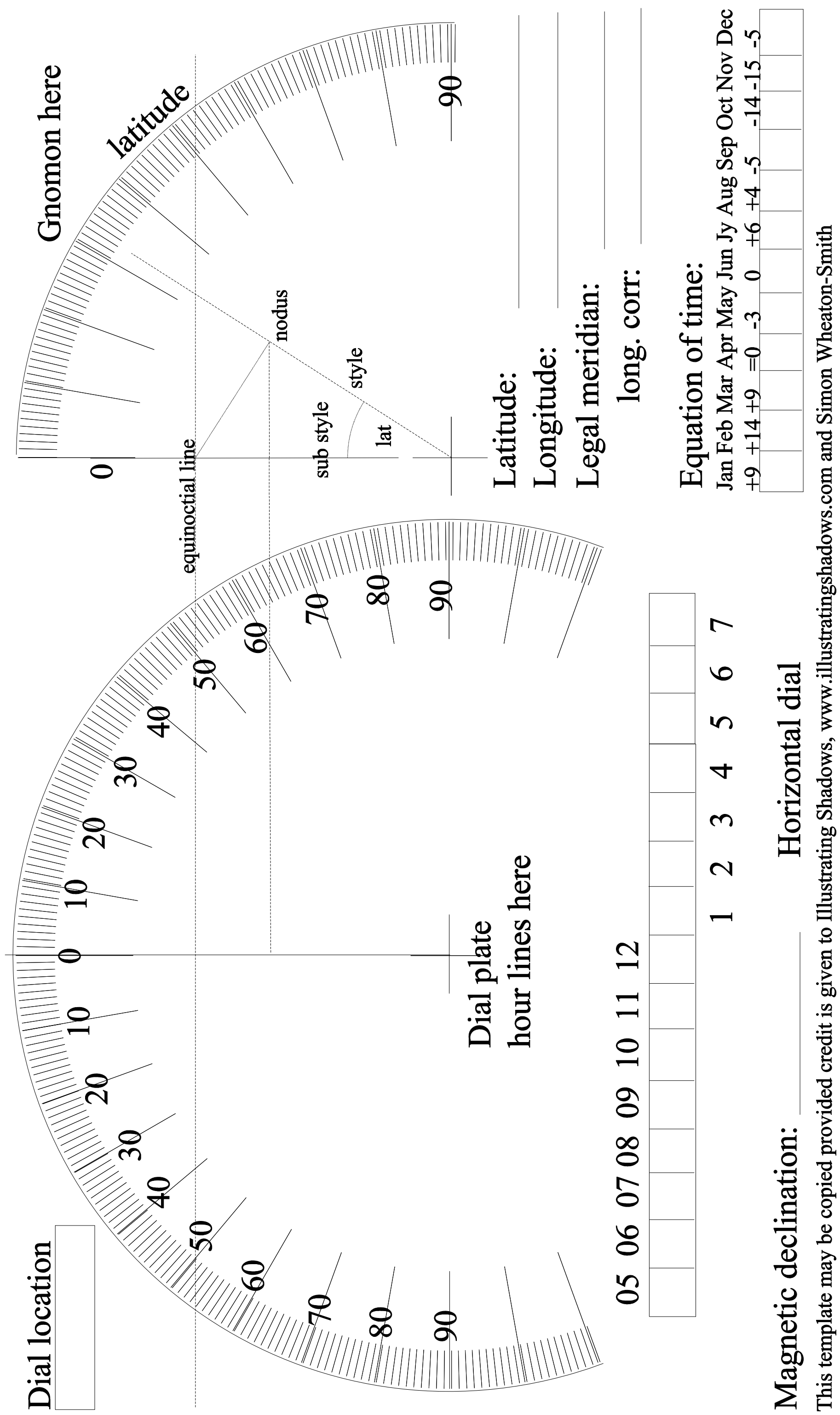
A3.1 c

HOUR LINE ANGLES Horizontal dial

hour angle DEGREES(ATAN(TAN(RADIANS(15*time))*SIN(RADIANS(lat))))
hour angle H = atan (sin(lat) * tan (ha))

	HORIZONTAL DIAL LATITUDE									
TIME	50	51	52	53	54	55	56	57	58	59	
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	noon
0.25	2.87	2.92	2.96	3.00	3.04	3.07	3.11	3.15	3.18	3.22	11.75
0.50	5.76	5.84	5.92	6.00	6.08	6.16	6.23	6.30	6.37	6.44	11.50
0.75	8.66	8.79	8.91	9.03	9.14	9.25	9.36	9.47	9.57	9.68	11.25
1	11.60	11.76	11.92	12.08	12.23	12.38	12.52	12.67	12.80	12.94	11
1.25	14.58	14.78	14.98	15.17	15.36	15.54	15.72	15.89	16.06	16.22	10.75
1.50	17.60	17.84	18.08	18.30	18.53	18.74	18.95	19.16	19.35	19.55	10.50
1.75	20.70	20.97	21.24	21.50	21.75	22.00	22.24	22.47	22.70	22.91	10.25
2	23.86	24.17	24.46	24.75	25.04	25.31	25.58	25.84	26.09	26.33	10
2.25	27.11	27.44	27.77	28.09	28.39	28.69	28.98	29.27	29.54	29.80	9.75
2.50	30.45	30.81	31.16	31.50	31.83	32.15	32.46	32.76	33.05	33.33	9.50
2.75	33.89	34.28	34.65	35.01	35.36	35.69	36.02	36.33	36.64	36.93	9.25
3	37.45	37.85	38.24	38.61	38.97	39.32	39.66	39.99	40.30	40.60	9
3.25	41.14	41.55	41.94	42.32	42.69	43.05	43.39	43.72	44.04	44.35	8.75
3.50	44.95	45.36	45.76	46.15	46.51	46.87	47.21	47.54	47.86	48.17	8.50
3.75	48.90	49.31	49.70	50.08	50.45	50.80	51.13	51.46	51.77	52.06	8.25
4	53.00	53.39	53.77	54.14	54.49	54.82	55.15	55.46	55.75	56.04	8
4.25	57.23	57.60	57.96	58.31	58.64	58.95	59.25	59.54	59.82	60.09	7.75
4.50	61.60	61.94	62.27	62.59	62.89	63.18	63.45	63.72	63.97	64.21	7.50
4.75	66.10	66.40	66.69	66.97	67.24	67.49	67.73	67.96	68.18	68.40	7.25
5	70.72	70.98	71.22	71.45	71.67	71.89	72.09	72.28	72.47	72.64	7
5.25	75.44	75.64	75.83	76.01	76.19	76.35	76.51	76.66	76.80	76.94	6.75
5.50	80.25	80.39	80.52	80.64	80.76	80.87	80.98	81.08	81.18	81.27	6.50
5.75	85.11	85.18	85.25	85.31	85.37	85.43	85.48	85.53	85.58	85.63	6.25
6	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	6

A DRAFTING SHEET FOR HORIZONTAL DIALS



APPENDIX 9

BOOKS

ref 1 Illustrating Time's Shadow, how to make MANY Sundials for anywhere using empirical, geometric, and trigonometric methods as well as computer aided design and the spreadsheet. By Simon Wheaton-Smith

Library of Congress Control Number: 2005900674
ISBN 0-9765286-1-4
available from www.illustratingshadows.com

ref 2 Sundials: History, Theory, and Practice By: Rene R. J. Rohr
A good grounding in the history and theory of most sundial types.

ref 3 Sundials: Their Theory and Construction By: Albert Edmund Waugh
A good book, with good reference material

ref 4 Sundials: Their Construction and Use By: R. Newton Mayall, Margaret W. Mayall
A good book, with good reference material

ref 5 A Choice of Sundials, Winthrop W. Dolan
A good book, good graphical methods for some dials not in other books

ref 6 Sundials - A Simplified Approach by Means of the Equatorial Dial, by Frank W Cousins
A good book, good graphical methods, same as ref 11

ref 7 Sundials Australia. FOLKARD, Margaret and John WARD.
Good work on shadows and on formulae.

ref 8 Sundials And Roses Of Yesterday, Earle, Alice Morse
A somewhat nostalgic book with interesting pictures and other trivia.

ref 9 The Great Sundial Cutout Book, Robert Adzema and Mablen Jones

SOFTWARE OF INTEREST TO THE DIALIST

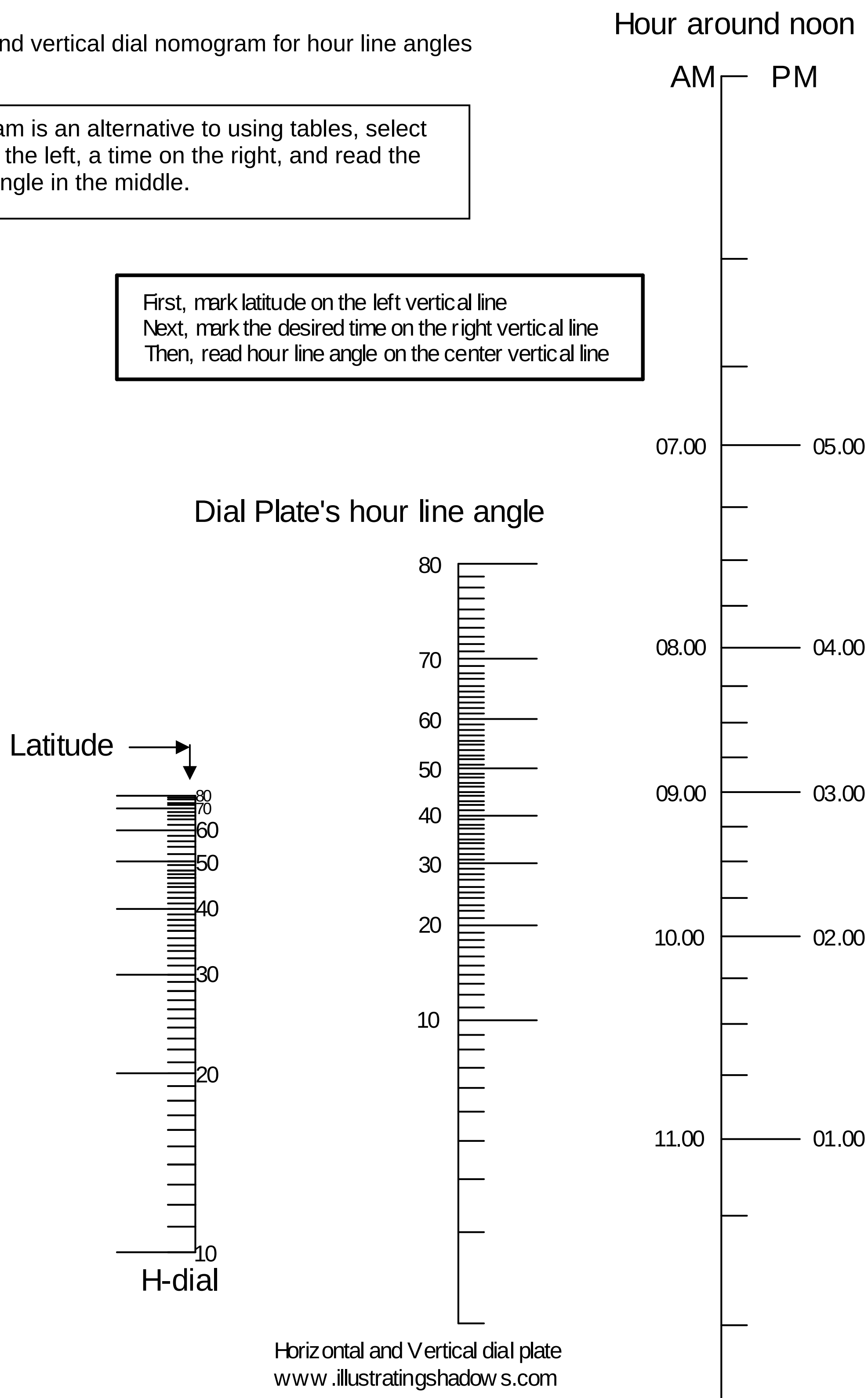
SHADOWS	www.shadowspro.com	most comprehensive, license is reasonable and free version covers many common needs
SUNSET	www.yoredale.uklinux.net/programs/programs.htm	sunset.xls good sunrise and sunset calculator
SUNTIMES	www.fv01.dial.pipex.com/suntimes.shtml	program has a world map and sun times

If you download an almanac, remember that you must still correct it for longitude. There are some very good spreadsheets that calculate sunrise and sunset times that are free.

horizontal and vertical dial nomogram for hour line angles

A nomogram is an alternative to using tables, select latitude on the left, a time on the right, and read the hour line angle in the middle.

First, mark latitude on the left vertical line
Next, mark the desired time on the right vertical line
Then, read hour line angle on the center vertical line



latitude is log(sin(lat)) so scale decreases vertically
longitude is log(tan(lng)) so scale decreases first then increases
hour line angle is log(tan(hla)) so scale decreases first then increases