LI-2020

AUTOMATIC SOLAR TRACKER

INSTRUCTION MANUAL

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SECTION I
GENERAL INFORMATION

1-1. INSTRUMENT DESCRIPTION

The LI-2020 Automatic Solar Tracker is designed to continuously track the sun using an Eppley Normal Incidence Pyrheliometer (NIP) for measurements of normal incidence solar radiation. The LI-2020 consists of two major parts: a mechanical mount, which holds the NIP in proper position, and a control unit, which is housed in a weatherproof case with the batteries.

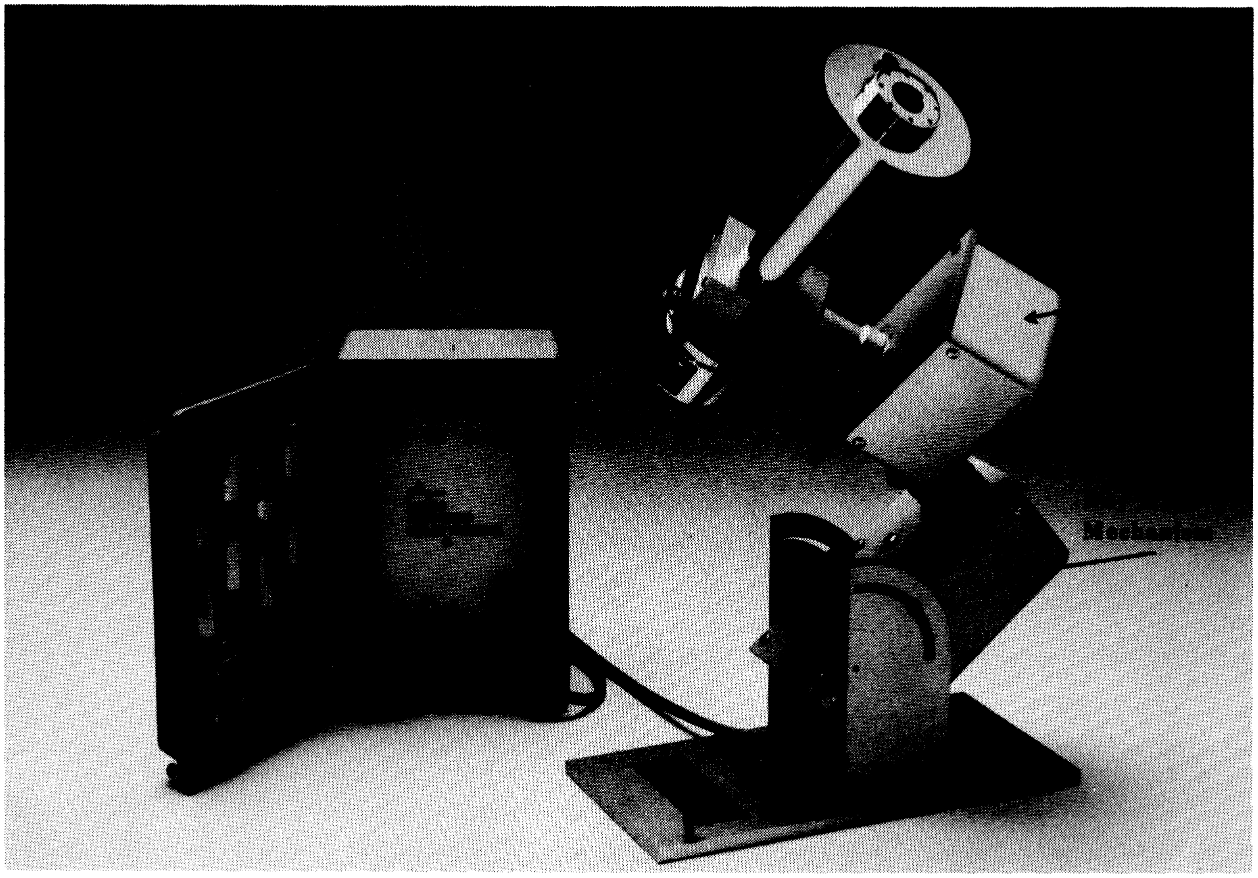
The mechanical mount includes year axis and day axis mechanisms. The year axis mechanism is housed in the upper box, and the day axis mechanism is housed in the lower box. Both mechanisms are driven by stepping motors and timed with a quartz clock. The YEAR AXIS switch on the control unit turns the NIP relative to the year axis box, and the DAY AXIS switch turns the whole year axis box.

1-2. SPECIFICATIONS

Maximum Tracking Error: < ± 1 degree per month.
Clock Accuracy: Within 0.0045 % (-40 to +50 °C).
Power Requirement: 12 alkaline "D" cell batteries, or 108-130/208-240 VAC, 48 to 66 Hz.
Battery Life: > 2 months at 20 °C. (Reduced approximately 10 days for every 10 °C below that.)
Operating Temperature: -40 to +50 °C, 0 to 100% RH (noncondensing).
Storage Temperature: -55 to +60 °C, 0 to 100% RH (noncondensing).

<u>Mechanical Mount</u>
Rewind Time (at midnight): Less than 3 minutes (accounted for in tracking relationship).
Gear Backlash: Within 0.25 degrees.
Latitude adjustment: Within 0.5 degrees using 1 degree division markings. 0 to 90 degrees, north or south.
Horizontal adjustment: Within 0.5 degrees using attached spirit level.
North-South alignment: Accomplished using solar time data or surveying techniques.
Construction: Weatherproof, anodized aluminum with brass and stainless steel hardware.
Size: Overall height with mounted NIP is 51 cm (20 inches).
Weight: 5.2 kg (11.5 lbs) without NIP.

<u>Control Unit</u>
Enclosure: Weatherproof case, accessed by user for initial setup or adjustments.
Circuitry: RCA 1802 CMOS microprocessor, with 2K bytes PROM, 1K bytes RAM, and a quartz crystal oscillator for a time base.
Tracking Algorithm: Includes eccentricity of the earth's orbit.
Size: 24.1 x 15.2 x 15.2 cm (10" x 6" x 6").
Weight: 4.5 kg (10 lbs).



LI-2020 Automatic Solar Tracker

PRE-OPERATION

2-1. CONTROL UNIT PANEL

YEAR AXIS Switch: Causes the Year Axis stepping motor to rotate in the indicated direction. Also used to enter the month during the setup procedure.

DAY AXIS Switch: Causes the Day Axis stepping motor to rotate in the indicated direction. Also used to enter the day during the setup procedure.

IND Lamp: The indicator lamp functions in several modes:
- Steady ON: Self test at POWER ON or battery TEST OK.
- Slow Flash (1 per sec): After POWER ON, waiting for switch entries.
- Off: Failed self test at POWER ON, or normal start time-out, caused by no entry within 5 minutes of POWER ON.

TEST Switch: Used to enter data during the setup operation, and later to test the batteries.

Voltage Select: The line voltage switch should be set to "115" for 108 to 130 volts, or "230" for 208 to 240 volts.

AC Lamp: The AC lamp glows red whenever AC current is being supplied to the instrument.

2-2. BATTERIES

The LI-2020 requires 12 "D" cell alkaline batteries. When installing the batteries there should be proper contact between the batteries and the battery holders. If necessary, carefully bend the contact in toward the batteries for better contact. Battery life should be greater than 60 days, although this is a function of their average temperature. Below is a very conservative estimate of battery life:

TEMP (°C) :	> 20	10	0	-10	-20	-30	-40
# DAYS :	60	55	44	34	22	12	6

When AC power is used, the batteries serve as a backup in the event of AC power failure. Battery power is recommended, as this insures isolation from potentially damaging line current surges. If extended battery operation is desired, leads from an external battery could be soldered to the internal battery connections, and the internal batteries removed.

After the setup procedure is accomplished, the batteries may be tested using the "TEST" switch; when this is pressed, the green indicator lamp should glow. The lamp will fail to glow when less than 15% of the battery life remains. Batteries should then be replaced.

2-3. AC LINE FUSE

The AC line fuse is located within the metal control unit box. To change the fuse, remove the 4 screws at each corner of the box, and lift the front panel straight up. Turn the front panel upside down. The fuse is near the AC line cord. Replace with a 1/2 amp fast blow fuse.

2-4. HEMISPHERE SELECTION

The LI-2020 is shipped from the factory set to the Northern Hemisphere, unless otherwise noted on the instrument. To change the hemisphere setting, remove the 4 screws at the corner of the metal control unit box. Lift the front panel straight up, and turn it upside down. Move the 8 pin jumper plug from the 8 hole group market "NORTH" to the 8 hole group market "SOUTH":

```
  NORTH    SOUTH              NORTH    SOUTH
0 0 0 0 0 0 0 0             0 0 0 0 0 0 0 0
¶ ¶ ¶ ¶                             ¶ ¶ ¶ ¶
0 0 0 0 0 0 0 0             0 0 0 0 0 0 0 0
```

2-5. AC HEATER OPTION

For environments where the temperature is between -40 °C and 0 °C and AC power is available, a 15 watt heater is available as an option for the control unit. The thermostat closes the heater circuit when the temperature falls below 7 °C (45 °F) and opens to turn off the heater when the temperature rises above 16 °C (60 °F). The heater is selectable for 115 VAC or 230 VAC.

2-6. LIGHTNING PROTECTION

The entire instrument should be grounded by running a heavy gauge braided wire from the ground screw on the control box face to an adequate ground. The ground screw is located above and to the left of the live voltage select switch. This will afford protection against local lightning strikes, but not direct or near-miss strikes. The best protection is nearby lightning rods; take care that they do not block the view of the NIP, however.

SECTION III
SETUP PROCEDURE

3-1. INITIAL PLACEMENT

The mechanical mount must be set up on a solid, very flat surface that has an unobstructed view of the sun from sunrise to sunset all year.

The control unit may be set up anywhere within the cable length of the mechanical unit (6 feet). It should NOT be placed in an area likely to collect water, or in direct view of the sun for long periods of time; direct exposure to the sun can produce temperatures inside the box exceeding the maximum operating temperature. The cables should be held in such a manner as to keep water from running down them into the control box.

Position the mechanical mount roughly North-South with the end having the LI-COR label pointing NORTH. In the southern hemisphere, the labeled end should point SOUTH. Level the base plate using the leveling screws, noting the bubble in the spirit level that is attached to the base plate. 0.5 mm bubble displacement corresponds to 0.2 degree.

3-2. LATITUDE ALIGNMENT

Latitude information may be obtained from maps, Geological Survey offices, local governmental agencies, or by applying surveying techniques. Adjust the top edge of the Day Axis plate as nearly as possible to the latitude for that location using the latitude scale on the uprights. Tighten the screws in place.

Latitude must be carefully checked by using a machinist's protractor, such as the 2020P, to measure the angle between the motor plate and base plate. An inclinometer (gravity protractor) such as the Pro Model 900 can also be used. (The Pro Products Company, Inc. Box 2255, Rockford, Illinois, USA 61131.)

IMPORTANT: The latitude adjustment is critical and should be made within 0.125 degrees. One degree of latitude is approximately 70 miles North-South ground distance.

3-3. NORTH-SOUTH ALIGNMENT

North-South alignment may be made using one of several methods, including standard surveying techniques, calculations of shadow angles given the exact time and position on the observer, or by using the Pole Star or Southern Cross. North-South alignment should NOT be made using a magnetic compass, since magnetic north and true north do not always coincide with each other, nor is their relationship stable.

A fairly simple method of finding true north is to determine the exact time of solar noon for that location's latitude and longitude (Appendix A).

At precisely solar noon, adjust the north-south orientation of the mechanical mount until the shadow of the base plate falls exactly parallel to the edge of the base plate.

Whatever method is used, North-South alignment should be within 0.125 degrees.

3-4. HORIZONTAL ADJUSTMENT

Recheck the horizontal leveling and make any necessary adjustment. Carefully tighten the mounting bolts (user supplied) so that the mechanical mount cannot move. A stable platform is crucial for leveling.

3-5. SENSOR MOUNTING

The Eppley NIP mounts in the clamp so that about 1/2 inch of the tube shows between the clamp and the rear disk of the NIP. There is no preferred direction for mounting the NIP.

3-6. POWER

Attach the cable from the mechanical mount to the control unit. If using AC power, note that all outdoor AC instruments should be protected by a Ground Fault Circuit Interrupter (GFCI) for maximum safety. Battery power is automatically accessed if AC power is not used.

3-7. FINAL ALIGNMENT

1. Turn on the control unit. The green indicator lamp should light for approximately 6 seconds and then start to flash. If it lights up but fails to flash in 10 seconds, turn the unit off and then on again. If it fails to light when turned on or if the flashes are very short, most likely the batteries are weak and should be replaced even if AC power is used. If the unit continues to fail this self test even after the batteries have been replaced, the unit has a possible malfunction.

2. Press and hold the YEAR AXIS control switch in the appropriate direction until the NIP is aligned with the "SUMMER SOLSTICE" marking. Note that the green indicator lamp will flicker while the motor is turning at slow speed and then turn off when the motor turns at full speed. The alignment can be made by sighting along the NIP and the edge of the year axis plate and should be made with an accuracy of 0.125 degrees.

3. Press and release the TEST switch. This sets the position of the YEAR AXIS with respect to the time of year into the memory of the control unit. (This step is used to synchronize the LI-2020 with the orbital eccentricity data.)

4. Press and hold the YEAR AXIS control switch and count the green light flashes to enter the month number of the current date (e.g. July = 7 flashes). Release the switch after the correct count.

5. Press and hold the DAY AXIS control switch and count the green light flashes to enter the day number of the current date (e.g. 26 July = 26 flashes). Release the switch after the correct count.

6. Press the TEST switch to signal the control unit that the day and month of the current date have been entered. The year motor will now move to the correct position for the date entered, but at a time of day corresponding to the time of Summer Solstice. This potential error can be corrected later (Step 10).

7. Midnight Definition: Press and hold the DAY AXIS control switch in the appropriate direction until the pyrheliometer is pointed nearly straight downward. Note that the green light will flicker while the motor turns slowly, and turn off when the motor turns at full speed.

   CAUTION: Make sure the cable that is wrapped around the day axis shaft is sufficiently loose. Rotating the day axis too far in the direction of the cable wrap can damage or break the cable connections.

8. Press and release the TEST button. This defines the position of the day motor as midnight, which is where the retrace operation will start at the end of each day. Note that the green light will flash about 6 times while the day motor is automatically backed off a short distance from midnight. The midnight setting need not be particularly accurate as long as the retrace occurs during the night hours.

9. Press and hold the DAY AXIS switch in the (-) direction until the NIP is pointed in the general vicinity of the sun.

10. At this point, the year axis motor can be adjusted to compensate for the error that may have been introduced in Steps 6 and 7; that is, if the time of day of the last Summer Solstice (Appendix C) is different from the time of day that the month and day were entered.

    The day and month entered in Step 6 is not "implemented" until midnight is defined (Step 7). Steps 6 and 7 should therefore be done on the same calendar day.

    There are three methods for removing this error:

    Method 1. Do Steps 6 and 7 at the time of day (GMT) corresponding to the time of day of the last summer solstice. A table of these times is in Appendix C. (GMT means Greenwich Mean Time).

    or

    Method 2. Calculate the number (N) of steps by which the year motor should be adjusted. This is simply

$$N = (G - G')(2.7397) + (J2' - J2)(0.04159)$$

where J2' is the day of the year for that year's Summer Solstice.
J2 is the current (Step 6) day of the year.
G is the GMT at the time Step 6 was performed.
G' is the GMT corresponding to the LAST Summer Solstice.

The second term in this expression is a correction for a very small numerical error in the LI-2020's processor. Note that this term is negative for dates after the Summer Solstice

EXAMPLE: Steps 6 and 7 are performed 15 April, 1982 at 11:45 CST. (CST is Central Standard Time.)

Step 1: Convert 11:45 CST to decimal GMT.

11:45 CST = 11.75 CST + 6 = 17.75 GMT

Step 2: Find G' for the last Summer Solstice.

From Appendix C we find G' for 1981 is 11.50

Step 3: Look up J2 and J2' (Appendix B and C).

J2 for April 15 is 105 (Appendix B).
The summer solstice in 1982 takes place on June 21 (Appendix C), which has a J2 of 171 (Appendix B).

Step 6: Calculate N

$$N = (17.75 - 11.50)(2.7397) + (171 - 105)(0.04159)$$

$$= 17.12 + 2.74$$

$$= +19.86$$

ROUND this number to +20.
Press the YEAR AXIS switch in the + direction and hold it for 20 flashes of the green light. Each flash, or motor step, corresponds to 0.015 degrees.

or

Method 3. Calculate the angle x (deg) that the NIP should make with the Year plate. For any given time, this is given by

$$x = (d - d') = (J - J')(0.986)$$

where J is the current Julian Date,
J' is the Julian Date of the last Summer Solstice,
d is deviation angle due to elliptical orbit (deg),
d' is d at the time of the last Summer Solstice (deg).

Note that at the Summer Solstice, x=0 which means the NIP is parallel to the Year motor plate and pointing toward the Summer Solstice. Angle d is given by

$$d = 1.916 \text{ SIN}(M) + 0.02 \text{ SIN}(2M)$$

where $M = 358.476 + 0.986 J$ (deg)

EXAMPLE: Calculate the angle between the NIP and the Year motor plate on 15 April, 1982 and 11:45 CST (same as last example).

Step 1. Calculate the exact current Julian Date.

J1 for 1982 (Appendix B, Part 1)	=	29949.5
J2 for April 15 (Appendix B, Part 2)	=	105
Fraction of the day = 17.75/24	=	.74
	J =	30055.24

Step 2. Look up J' in Appendix C.

The last Summer Solstice was in 1981, so J' = 29756.9

Step 3. Compute M.

$$M = 258.476 + (0.986)(30055.24)$$
$$= 29992.94$$

Step 4. Compute d.

$$d = 1.916 \text{ SIN } (29992.94) + 0.02 \text{ SIN } (59985.88)$$

$$= 1.764 + (-0.014)$$

$$= 1.75$$

Step 5. Look up d' in Appendix C.

for 1981, d' = 0.423

Step 6. Compute x

$$x = (1.75 - 0.423) = 0.986 \text{ } (30055.24 - 29756.98)$$

$$= 295.41$$

Thus, the angle between the NIP and the Year Motor Plate should be 295.41 degrees on April 15, 1982 at 11:45 CST. Adjust to this value using the Year motor switch and a machinists protractor.

11. Use the DAY AXIS switch to point the NIP directly at the sun. See Section IV for a discussion of optimum dot placement on the NIP. The unit is now set up and tracking. Note: Except for the first three times after power is turned on (Steps 3, 6, and 8), pushing the TEST button has no affect on operation or adjustment; it is used only to test the condition of the batteries.

12. During the first day of operation, check the alignment of the NIP on several occasions, preferably near midday and again near sunset. If the alignment is correct at both of these times, the setup is probably good.

SECTION IV
MECHANICAL SETUP ERRORS

4-1. OPTICAL TARGET

The Eppley NIP optical target has a central black disk, surrounded by a white ring, which in turn is surrounded by a black ring. The projection of the pin hole onto the target yields a light spot which should theoretically be centered on the target.

Nominal dimensions of the target are:

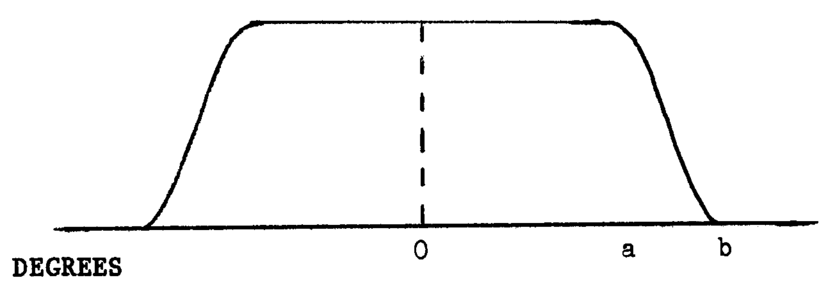
Pin hole (axial center) to central black/white ring	7.25 in.
Black disk diameter	0.083 in.
White ring outer diameter	0.250 in.
Black ring outer diameter	0.500 in.
Angle at edge of black disk	0.33 deg.
Angle at edge of white ring	1.00 deg.
Angle at edge of black ring	2.00 deg.

If the center of the light spot is located on the edge of the black disk, the theoretical misalignment is 0.33 deg. If the center of the light spot is located at the edge of the white ring, the theoretical misalignment is 1.0 deg. If the center of the light spot is located at the edge of the black ring, the theoretical misalignment is 2.0 deg.

4-2. NIP GEOMETRY

The field of view is determined by two apertures, limiting (0.812 in.) and detector (0.312 in.), which are 8.125 inches apart (from Eppley NIP instruction manual).

The theoretical output of the NIP (assuming collimated source) versus angle is:



where $a = \arctan((.812/2-.312/2)/8.125) = 1.76$ deg.
$b = \arctan((.812/2+.312/2)/8.125) = 3.96$ deg.

If the misalignment is greater than 3.96 degrees, the detector will not receive any radiation. If the misalignment is less than 1.76 degrees, there is no vignetting. However, the sun has an angular radius of about 0.26 degree. The misalignment, therefore, must be less than 1.76-0.26 = 1.5 degree to insure that all of the detector "sees" the entire solar disk. In addition, changes in circumsolar radiation due to haze, clouds, etc. will modify the above curve.

In terms of the target, the maximum misalignment would place the center of the light spot at a distance of 0.19 in. from the center of the target. The black ring has an inner radius of 0.125 in. and an outer radius of 0.25 in. Therefore, 0.19 in. is halfway between the inner and outer radius of the black ring.

4-3. ERRORS

The following is a list of potential errors that can cause static alignment and dynamic tracking problems for the LI-2020 Automatic Solar Tracker.

1. Concentricity of the Epply NIP. If the optical target is not aligned at the same distance from the axial center as is the pin hole, the light spot location will depend on the orientation of the NIP when it is clamped to the tracker. A 0.010 in. misalignment translates to 5 minutes of arc misalignment.

2. Optical centering of the two apertures of the Eppley NIP.

3. Variations in sensitivity of the detector across the surface of the detector cause the optical center of the NIP to be different than the mechanical center.

4. There are 11 mechanical surfaces, which if each had 1.5 arc minutes error in machining plus parallelism, would result in an overall root mean square error of 5.0 arc minutes.

5. There are two axial bearing elements which may have a 1 arc minute tolerance each resulting in a possible overall error of 2 arc minutes.

6. Both the day and year motors are driven by precision worm gears. However, there is still minimal gear backlash (due to varying torque directions during different times of day and year). Backlash is on the order of 7.5 arc minutes for each gear train.

7. Latitude should normally be determined from US Geological Survey maps for best accuracy. The best method for adjusting the latitude plate is with a machinist's protractor mounted between the base plate and the latitude plate. Best accuracy is about 5 arc minutes.

8. North-South alignment is accomplished by using a theodolite or measuring the shadow angle (which requires accurate knowledge of both longitude and true time of day). An easier method, but sometimes not possible, is to get the bearings of distant objects and fix north-south accordingly. Best accuracy is about 10 arc minutes.

9. Tilt of the base plate corresponds to a combination of latitude and longitude errors.

Taking into consideration the above errors, it is apparent that setting the time of year and time of day "perfectly" may not center the light spot on the target. Therefore, for optimum tracking performance over extended periods of time, compromises between the location of the light spot and the time of year/day may have to be made.

SECTION V
OPERATION AND MAINTENANCE

5-1. COLD TEMPERATURE CONSIDERATIONS

Operation in cold temperatures will reduce battery life. See the table in Section 2-2 for an estimate of the magnitude of this effect.

Cold temperatures will also tend to increase some of the mechanical errors discussed in Section 4-3. This is because the increased viscosity of the grease on the gears tends to retard their motion. Each gear is thus hindered from finding its natural "center" in any given position, and the errors due to gear backlash accumulate, instead of cancelling out.

This condition is easily remedied by gently twisting the NIP back and forth every few days to "free up" the gearing.

5-2. MAINTENANCE

No maintenance is required on the mechanical mount other than the occassional wiping of dirt from the exterior. The motor boxes are hermethically sealed, and should NOT be opened.

IMPORTANT: Although the LI-2020 tracker can operate unattended for 2 or 3 months at a time, the NIP should be checked every day or so to make sure it is free from dirt and debris that could obstruct its view of the sun.

When replacing the batteries, make sure there is proper contact between the batteries and the battery holders. If necessary carefully bend the contacts in toward the batteries for better contact.

APPENDIX A

COMPUTING SOLAR NOON

Solar noon usually does not occur at 12:00 Local Time. One can consider this difference as being due to 2 factors: time of year and longitude. The number of minutes M after 12:00 Local Time that solar noon occurs is

$$M = L - E$$

where L is the longitude factor and E is the time of year factor. The longitude factor L may be expressed in minutes as

$$L = (h - d)60$$

where h is the longitude expressed in decimal hours (15 degrees = 1 hour), and d is the number of hours difference between Local Time and GMT. Appendix C at the bottom gives several values for d. Note that h and d will both be negative for locations having East longitude. The time of year factor in minutes is

$$E = A \sin(x) + B \cos(x) + C \sin(2x) + D \cos(2x)$$

where

$$x = 0.9863 \left(y - \frac{12 + h}{24} \right),$$

y is the day of the year (Appendix B, Part 2), and A, B, C, and D are -7.65, +0.50, -9.30, -2.90 respectively.

EXAMPLE: Compute the time (EDT) of solar transit (solar noon) at longitude 18° 38' W on 23 September 1982.

1. From Appendix B, Part 2, y is found to be 266.

2. Longitude in hours: 81° 38' W = 81.6333 x 1 hrs/15° = 5.4422 hrs.

3. Compute:

   x = 263.07 degrees
   E = 8.2 minutes
   L = 86.5 minutes
   M = 78.3 minutes

4. Thus, the time of solar noon will be approximately 13:18.3 EDT on 23 September, 1982 at 81° 38' W longitude.

For purposes of aligning the tracker, solar noon should be computed to the nearest 1/2 minute.

APPENDIX B

CENTURY JULIAN DAYS

Add J1 (PART 1) to J2 (PART2) to get J, the Century Julian Day

* PART 1 *

YEAR	J1	YEAR	J1	YEAR	J1	YEAR	J1	YEAR	J1	YEAR	J1
1981	29584.5	1986	31410.5	1991	33236.5	1996	35062.5	2001	36888.5	2006	38714.5
1982	29949.5	1987	31775.5	1992	33601.5	1997	35428.5	2002	37253.5	2007	39079.5
1983	30314.5	1988	32140.5	1993	33967.5	1998	35793.5	2003	37618.5	2008	39444.5
1984	30679.5	1989	32506.5	1994	34332.5	1999	36158.5	2004	37983.5	2009	39810.5
1985	31045.5	1990	32871.5	1995	34697.5	2000	36523.5	2005	38349.5	2010	40175.5

* PART 2 *

NORMAL

Day	JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SPT	OCT	NOV	DEC
1	1	32	60	91	121	152	182	213	244	274	305	335
2	2	33	61	92	122	153	183	214	245	275	306	336
3	3	34	62	93	123	154	184	215	246	276	307	337
4	4	35	63	94	124	155	185	216	247	277	308	338
5	5	36	64	95	125	156	186	217	248	278	309	339
6	6	37	65	96	126	157	187	218	249	279	310	340
7	7	38	66	97	127	158	188	219	250	280	311	341
8	8	39	67	98	128	159	189	220	251	281	312	342
9	9	40	68	99	129	160	190	221	252	282	313	343
10	10	41	69	100	130	161	191	222	253	283	314	344
11	11	42	70	101	131	162	192	223	254	284	315	345
12	12	43	71	102	132	163	193	224	255	285	316	346
13	13	44	72	103	133	164	194	225	256	286	317	347
14	14	45	73	104	134	165	195	226	257	287	318	348
15	15	46	74	105	135	166	196	227	258	288	319	349
16	16	47	75	106	136	167	197	228	259	289	320	350
17	17	48	76	107	137	168	198	229	260	290	321	351
18	18	49	77	108	138	169	199	230	261	291	322	352
19	19	50	78	109	139	170	200	231	262	292	323	353
20	20	51	79	110	140	171	201	232	263	293	324	354
21	21	52	80	111	141	172	202	233	264	294	325	355
22	22	53	81	112	142	173	203	234	265	295	326	356
23	23	54	82	113	143	174	204	235	266	296	327	357
24	24	55	83	114	144	175	205	236	267	297	328	358
25	25	56	84	115	145	176	206	237	268	298	329	359
26	26	57	85	116	146	177	207	238	269	299	330	360
27	27	58	86	117	147	178	208	239	270	300	331	361
28	28	59	87	118	148	179	209	240	271	301	332	362
29	29		88	119	149	180	210	241	272	302	333	363
30	30		89	120	150	181	211	242	273	303	334	364
31	31		90		151		212	243		304		365

LEAP YEAR

Day	JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SPT	OCT	NOV	DEC
1	1	32	61	92	122	153	183	214	245	275	306	336
2	2	33	62	93	123	154	184	215	246	276	307	337
3	3	34	63	94	124	155	185	216	247	277	308	338
4	4	35	64	95	125	156	186	217	248	278	309	339
5	5	36	65	96	126	157	187	218	249	279	310	340
6	6	37	66	97	127	158	188	219	250	280	311	341
7	7	38	67	98	128	159	189	220	251	281	312	342
8	8	39	68	99	129	160	190	221	252	282	313	343
9	9	40	69	100	130	161	191	222	253	283	314	344
10	10	41	70	101	131	162	192	223	254	284	315	345
11	11	42	71	102	132	163	193	224	255	285	316	346
12	12	43	72	103	133	164	194	225	256	286	317	347
13	13	44	73	104	134	165	195	226	257	287	318	348
14	14	45	74	105	135	166	196	227	258	288	319	349
15	15	46	75	106	136	167	197	228	259	289	320	350
16	16	47	76	107	137	168	198	229	260	290	321	351
17	17	48	77	108	138	169	199	230	261	291	322	352
18	18	49	78	109	139	170	200	231	262	292	323	353
19	19	50	79	110	140	171	201	232	263	293	324	354
20	20	51	80	111	141	172	202	233	264	294	325	355
21	21	52	81	112	142	173	203	234	265	295	326	356
22	22	53	82	113	143	174	204	235	266	296	327	357
23	23	54	83	114	144	175	205	236	267	297	328	358
24	24	55	84	115	145	176	206	237	268	298	329	359
25	25	56	85	116	146	177	207	238	269	299	330	360
26	26	57	86	117	147	178	208	239	270	300	331	361
27	27	58	87	118	148	179	209	240	271	301	332	362
28	28	59	88	119	149	180	210	241	272	302	333	363
29	29	60	89	120	150	181	211	242	273	303	334	364
30	30		90	121	151	182	212	243	274	304	335	365
31	31		91		152		213	244		305		366

APPENDIX C

SUMMER SOLSTICE

G' - GMT (hours)
J' - Julian Date
d' - Deviation Angle (deg)

YEAR	JUNE	G'	J'	d'
1981	21	11.50	29756.98	0.42343
1982	21	17.32	30122.22	0.42397
1983	21	23.13	30487.46	0.42451
1984	21	04.93	30852.71	0.42508
1985	21	10.75	31217.95	0.42562
1986	21	16.57	31583.19	0.42617
1987	21	22.38	31948.43	0.42671
1988	21	04.18	32313.67	0.42728
1989	21	10.00	32678.92	0.42782
1990	21	15.82	33044.16	0.42837
1991	21	21.63	33409.40	0.42891
1992	21	03.43	33774.64	0.42948
1993	21	09.25	34139.89	0.43002
1994	21	15.07	34505.13	0.43056
1995	21	20.88	34870.37	0.43111
1996	21	02.68	35235.61	0.43167
1997	21	08.50	35600.85	0.43222
1998	21	14.32	35966.10	0.43276
1999	21	20.13	36331.34	0.43330
2000	22	01.95	36696.58	0.43385

YEAR	JUNE	G'	J'	d'
2001	22	07.75	37061.82	0.43441
2002	22	13.57	37427.07	0.43495
2003	22	19.38	37792.31	0.43550
2004	22	01.20	38157.55	0.43604
2005	22	07.00	38522.79	0.43661
2006	22	12.82	38888.03	0.43715
2007	22	18.63	39253.28	0.43769
2008	22	00.45	39618.52	0.43824
2009	22	06.25	39983.76	0.43880
2010	22	12.07	40349.00	0.43934
2011	22	17.88	40714.25	0.43989
2012	21	23.70	41079.49	0.44043
2013	22	05.52	41444.73	0.44097
2014	22	11.32	41809.97	0.44154
2015	22	17.13	42175.21	0.44208
2016	21	22.95	42540.46	0.44262
2017	22	04.77	42905.70	0.44317
2018	22	10.57	43270.94	0.44373
2019	22	16.38	43636.18	0.44427
2020	21	22.20	44001.43	0.44482

TIME DIFFERENCE TABLE

Add these numbers to LOCAL time to get GMT

PST	PDT	MST	MDT	CST	CDT	EST	EDT	AST	ADT
+8	+7	+7	+6	+6	+5	+5	+4	+4	+3

APPENDIX D

LI-2020 SETUP SUMMARY

The following is a summarized guide to setting up the LI-2020 Tracker. (Steps 2-6 needed only if using solar noon for North-South alignment.)

1. Enter the day of the year. Use Appendix B, Part 2. — 1. __________days

2. Enter your longitude: 2a. __________degrees — b. __________minutes

   Divide line 2b by 60. — c. __________degrees

   Add lines 2a and 2c. — d. __________degrees

   Divide line 2d by 15 to get longitude in hr. If the longitude is East, make this number a negative number. — e. __________hours

3. Compute elapsed time in days since 0 Jan 00GMT:

   Add 12 to line 2e. — 3a. __________hours

   Divide line 3a by 24. — b. __________days

   Add lines 1 and 3b. — c. __________days

4. Equation of Time:

   Multiply line 3c by 0.9863 — 4a. __________degrees

   Multiply line 4a by 2. — b. __________degrees

   SINE of line 4a. c. __________ x (-7.65) = g. __________minutes

   COSINE of line 4a. d. __________ x (0.50) = h. __________minutes

   SINE of line 4b. e. __________ x (-9.30) = i. __________minutes

   COSINE of line 4b. f. __________ x (-2.90) = j. __________minutes

   Add lines 4g thru 4j. — k. __________minutes

5. From the bottom of Appendix C, enter the time difference between local time and GMT. — 5a. __________hours

   Subtract line 5a from line 2e. — b. __________hours

   Multiply line 5b by 60. — c. __________minutes

   Subtract line 4k from line 5c, and round the results to the nearest 0.5 minutes. — d. __________minutes

6. Line 5d is the time difference from 12:00 Local time that solar noon will occur. (For

example, if line 5d were +65, solar noon would be at 1:05 p.m. -33 would be 11:27 a.m., etc.) Enter the time of solar noon to the nearest 0.5 minute. 6. __________LOCAL TIME

7. Set up the tracker according to the instructions in the manual, and set the North-South alignment at the time calculated in line 6.

8. Power ON. Wait for the lamp to begin flashing.

9a. Use the YEAR AXIS switch to point the NIP within 0.125 degrees of the Summer Solstice marking on the year axis plate.
 b. Press and release the TEST button.

10a. Enter the month count using the YEAR AXIS switch by counting the lamp flashes.
 b. Enter the day count using the DAY AXIS switch by counting the lamp flashes.
 c. Press and release the TEST button.

11a. Use the DAY AXIS switch to point the NIP straight down (midnight setting).
 b. Press and release the TEST button.
 c. Wait a few moments while the NIP backs away from midnight.

12. Use the DAY AXIS switch (- direction) to align the NIP in the general vicinity of the sun.

13. Enter the Local Time the Step 10c was performed (24 hr. clock).

13a. __________hours b. __________minutes

Divide line 13b by 60. c. __________hours

Add lines 13c and 13a to get decimal hours. d. __________hours

Add lines 5a and 13d. e. __________hours

Enter G' (Appendix C) for the LAST Summer Solstice to occur. f. __________hours

Subtract line 13f from line 13e. g. __________hours

Multiply line 13g by 2.7397 h. __________steps

Enter 172 for a normal year, or 173 for a leap year. i. __________days

Subtract line 1 from line 13i. j. __________days

Multiply line 13j. by 0.04159 k. __________steps

Add lines 13k and 13h and round to the nearest integer. l. __________steps

14. Press the YEAR AXIS switch in the direction of the sign of the number in line 131 and hold for that number of flashes.

15. Use the DAY AXIS switch to align the NIP straight at the sun. The unit is now setup and tracking.

Limited Warranty

Each LI-COR, INC. instrument is warranted by LI-COR, INC. to be free from defects in material and workmanship; however, LI-COR, INC.'s sole obligation under this warranty shall be to repair or replace any part of the instrument which LI-COR, INC.'s examination discloses to have been defective in material or workmanship without charge and only under the following conditions, which are:

1. The defects are called to the attention of LI-COR, INC. in Lincoln, Nebraska, in writing within one year after the shipping date of the instrument.

2. The instrument has not been maintained, repaired or altered by anyone who was not approved by LI-COR, INC.

3. The instrument was used in the normal, proper and ordinary manner and has not been abused, altered, misused, neglected, involved in an accident or damaged by act of God or other casualty.

4. The purchaser, whether it is a DISTRIBUTOR or a direct customer of LI-COR or a DISTRIBUTOR'S customer, packs and ships or delivers the instrument to LI-COR, INC. at LI-COR, INC.'s factory in Lincoln, Nebraska, U.S.A. within 30 days after LI-COR, INC. has received written notice of the defect. Unless other arrangements have been made in writing, transportation to LI-COR, INC. (by air unless otherwise authorized by LI-COR, INC.) is at customer expense.

5. No-charge repair parts may be sent at LI-COR INC.'s sole discretion to the purchaser for installation by purchaser.

6. LI-COR, INC.'s liability is limited to repair or replace any part of the instrument without charge if LI-COR, INC.'s examination discloses that part to have been defective in material or workmanship.

   THERE ARE NO WARRANTIES, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO ANY IMPLIED WARRANTY OF MERCHANTABILITY OF FITNESS FOR A PARTICULAR PURPOSE ON <u>UNDERWATER</u> <u>CABLES</u> OR ON EXPENDABLES SUCH AS <u>BATTERIES</u> AND <u>LAMPS</u>.

   OTHER THAN THE OBLIGATION OF LI-COR, INC. EXPRESSLY SET FORTH HEREIN, LI-COR, INC. DISCLAIMS ALL WARRANTIES, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. THE FOREGOING CONSTITUTES LI-COR, INC.'S SOLE OBLIGATION AND LIABILITY WITH RESPECT TO DAMAGES RESULTING FROM THE USE OR PERFORMANCE OF THE INSTRUMENT AND IN NO EVENT SHALL LI-COR, INC. OR ITS REPRESENTATIVES BE LIABLE FOR DAMAGES BEYOND THE PRICE PAID FOR THE INSTRUMENT, OR FOR INDIRECT, INCIDENTAL OR CONSEQUENTIAL DAMAGES.

(Over)

The laws of some locations may not allow the exclusion or limitation on implied warranties or on incidental or consequential damages, so the limitations herein may not apply directly. This warranty gives to your customers specific legal rights, and you may have other rights which vary from state to state of the customer. All warranties that apply, whether included by this contract or by law, are limited to the time period of this warranty which is a twelve-month period commencing from the date the instrument is shipped to a user who is a customer or eighteen months from the date of shipment to LI-COR, INC.'s authorized distributor, whichever is earlier.

This warranty supercedes all warranties for products purchased prior to June 1, 1984, unless this warranty is later superceded.

DISTRIBUTOR or the DISTRIBUTOR's customers may ship the instruments directly to LI-COR if they are unable to repair the instrument themselves even though the DISTRIBUTOR has been approved for making such repairs and has agreed with the customer to make such repairs as covered by this limited warranty.

Further information concerning this warranty may be obtained by writing or telephoning Warranty manager at LI-COR, INC.

IMPORTANT: Please return the Warranty Card enclosed with your shipment so that we have an accurate record of your address. Thank you.

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