

Tap The Sun



The SolarTrak[®] Controller System

Pro-Active Sun Tracking and Peripheral System Control

The SolarTrak® Controller System

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Designed and Built in the U.S.A

Overview and Nomenclature

A solar tracker is an outdoor electro-mechanical device that follows the Sun's relative motion throughout the day, which is to say, it moves! Deliberately! It is a structural system that supports weight and resists external forces such as wind but unlike a building rigidly attached to the ground, it has pivots (axes [plural of axis] of rotation or hinges) and motors (or pistons) to allow the controlled motion of a solar energy collection system (collector or array) riding on a fixed support that is usually a central tower or pair of posts.



The SolarTrak® Controller uses mathematical computation for the Sun's position in the sky and counts electronic pulses (feedback) to determine the actual array (moving part of the solar tracker) position. By making these two positions coincide on a continuous basis throughout the day it will cause the array to follow the Sun.

This type of controller is not aware of clouds or other light distortions and in fact makes no distinction as to whether the Sun is actually visible to the eye. Although this method would seem to waste energy, since the unit will track on cloudy days when there is little available energy, sun sensors that detect the hot spot of the Sun will also often detect the bright edges of moving clouds (lensing effect), following them intermittently then moving back to the Sun, and can even lock on to strong reflections such as those pesky ones that bounce off of a parked-car windshield or, more often, the shiny surface of another tracker. Such distractions which are indistinguishable from the actual Sun by most electronic sensor circuitry, can cause an almost constant motion of the motors while hunting for the hottest part of the sky and actually use high levels of power (full motor current) all day long where the normal assumption is that the array only moves (updates position) once in a while and then only briefly.

The SolarTrak® Controller is designed around a digital microcontroller. The controller computes the local celestial bearing of the Sun with respect to the Earth by applying a published set of equations to characterize the motion of the Earth with respect to the Sun to within 0.01 degrees using the **Local Time, Date, Latitude, Longitude and Time Zone**. A battery-backed, temperature-compensated, on-board real-time clock supplies the time and date while the other system-defining parameters are stored in non-volatile (won't go away when the power goes off) memory within the microcontroller itself. Upon completion of the final calibration procedures, the clock will keep time to within fifteen seconds per year without attention. The tracking accuracy, depending on structural and electronic feedback characteristics, can be maintained to within 0.02 degrees.

The microcontroller is able to detect both digital (high, 5 Volts, or low, zero Volts, referred to as voltage states) and analog (variable voltage) signals, use the information to make comparisons or logical decisions and then exert necessary control over external devices.

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The real-time clock offers the option of time-based peripheral (external device) task scheduling, in addition to providing the basis for this computational tracking approach, and sun-angle-based scheduling such as **Night Stow** where the array moves to an overnight, parked position when the Sun reaches a specified angle (such as setting) and wakes up when the Sun rises back to that angle.

The use of mathematics rather than direct sensing as the basis for pointing the array offers flexibility in the controller's response to the position of the Sun.

- It can, with great dependability, point something directly at the Sun.
- It can position a mirror to reflect a sunbeam to a fixed target.
- It can intentionally miss the Sun, preventing accidental focusing of concentrators while parked.
- It can prevent the shading of adjacent flatplate photovoltaic arrays with the application of a counter-Sun-motion control algorithm known as 'Backtracking'.
- It can systematically shade direct sunlight from passing through a skylight or window while allowing the maximum ambient light.
- The equations for the Sun can be replaced by equations for the Moon to drive a moon-bounce radio antenna or track the Sun during the day and the Moon at night for lighting systems.
- It can ignore the Sun altogether and perform other tasks required by the system on a scheduled or necessary basis.

Environmental Monitoring

For purposes of safety and damage avoidance control, the SolarTrak® Controller continuously monitors wind conditions and system power supply levels to allow a timely move to a less vulnerable emergency stow orientation before damage can occur.

It can be programmed to monitor and control related peripheral equipment associated with the tracking process including, but not limited to multiple slew (motion) rates, thermal protection (off-axis tracking), flow-rate control valves and pressure levels. There is a complete hydraulic control version that includes two-piston commutation on the primary axis and emergency control on a low-oil condition.

The controller will respond to external conditions by activating or deactivating devices or by causing the array to move off-sun (defocus). The auxiliary control of devices such as cooling fans or water valves can be laced into the tracking process to produce a seamless interaction between the sun-tracking and higher level functions.

The Standard Tracking Algorithm

Because the controller does not sense the Sun with optical receptors, it needs to establish a different sort of reference to equate a particular computed angle with a particular mechanical orientation.

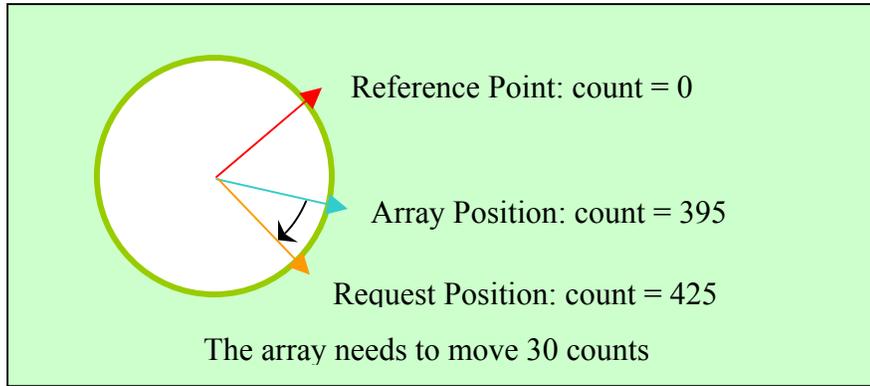
The position of the mechanical system is represented numerically as an offset (measured in counts) from a specific physical reference point. A sensor or other type of device generating an electronic pulse may define that reference point or it may be found by reaching a limit switch that interrupts power to the motor and stops the flow of electronic pulses, a detectable, 'stalled' state. In the case of absolute encoders (the former being incremental), the reference is implicit in the positioning of the device on the moving structure at installation. This also holds true for the positioning of the reference pulse generator for an incremental reporting system.

***** NOTE: It is an absolute requirement that the Reference Point not move with respect to the related mechanical structure and that the count pulse-generator rate not vary with respect to position.**

Repeatability is EVERYTHING.

The central function of the tracking control process is to make the computed angle (**Request Position**) and the actual orientation of the mechanical system (**Array Position**) coincide.

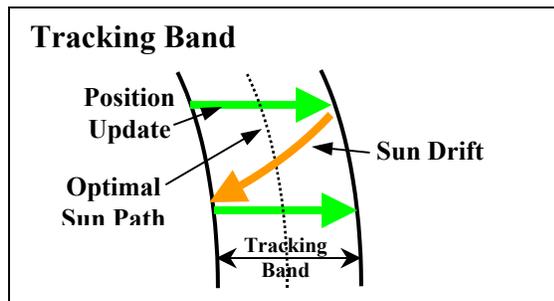
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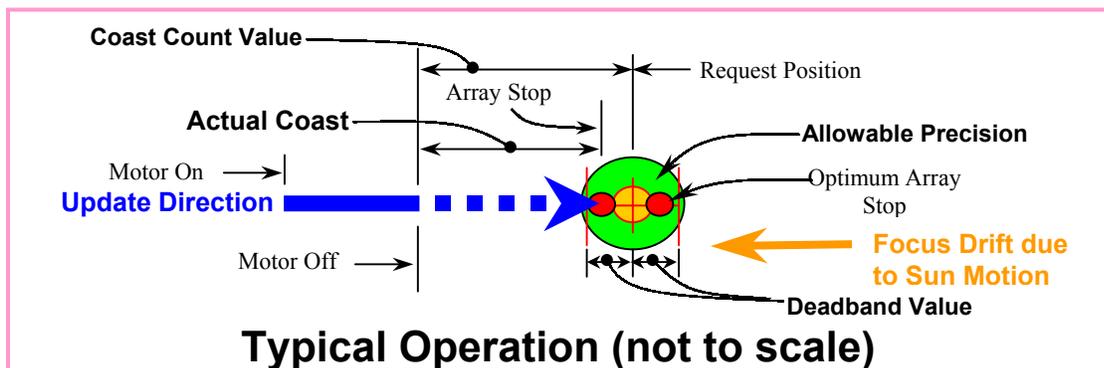
Request Position

The current sun position is recomputed unceasingly. Once one computation is complete another is begun. When a comparison of the reported (Actual) mechanical position is different from the computed (Requested) sun position the controller causes the mechanism to move until the two are once again the same. This 'sameness' can be based on 'fuzzy logic' defined by a 'deadband' centered about the requested sun position.

The 'Tracking Band' is the envelope of the array focal-line path resulting from the zigzag motion implicit in a periodic position update. 'Tracking' is accomplished by waiting until the focal-line drifts (due to relative motion of the Sun) out of the deadband then moving the array (updating) past the Sun, then waiting some more and updating the position again.

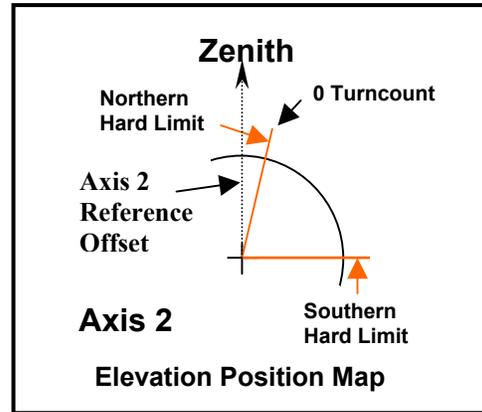
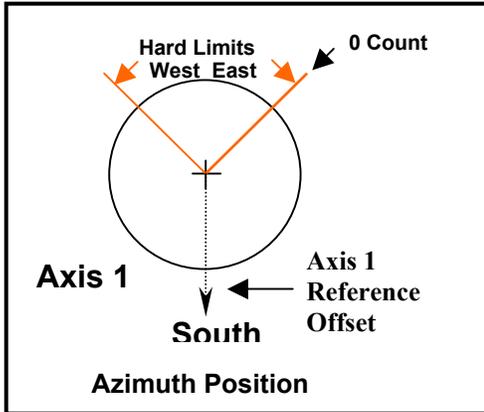


When the Array Position drifts outside the deadband window, the controller turns on the motor (or hydraulic valve) until the position is 'coast counts' away from the Request Position. The Coast Counts parameter allows for system momentum to carry the array further than the motor turn-off point without drastically overshooting the Request Position. The following illustration shows the various values but is not to scale. The motor actually turns on the moment the array position is one turncount outside the window.



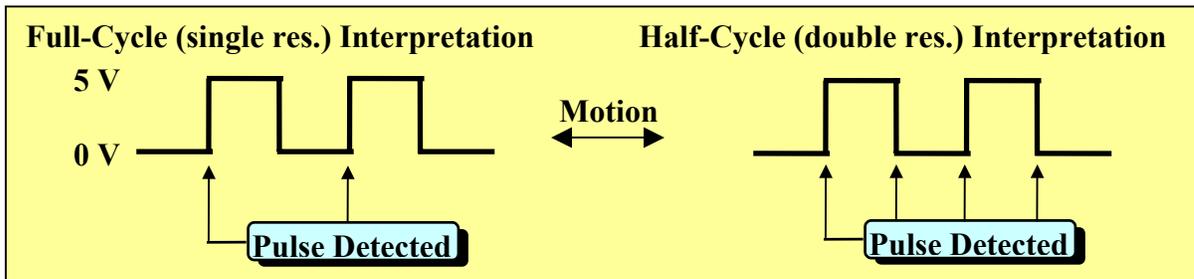
A comparison between the sun angle and the array position is performed by converting the sun angle to array position coordinates (counts) using an equation involving **Gear Ratio**, defined here as **Counts per Radian** (radian = angular arc / radius of arc) then adding in a **Reference Offset** (in counts also) from a fixed zero point established by a **Reference Point (RP)** indicating where in the mechanical range of motion a particular count number occurs such that:

$$\text{Request Position (counts)} = \text{Sun Angle (radians)} * \text{Gear Ratio (counts/radian)} + \text{Reference Offset (counts)}$$



Detection of Incremental Position Feedback Signals

Counts can be detected electronically as a square-wave signal produced by any one of several methods. In general, as the positioning device moves, a contact, either mechanical or solid-state opens and closes producing a change in voltage (from 0V to 5V, rising edge, or 5V to 0V, falling edge) at an input pin on the microcontroller. The controller detects each change of state by sampling the input line at high frequency and, since the controller senses each edge anyway, the standard interpretation is that each edge is a count or double resolution compared to the notion of a 'cycle'.



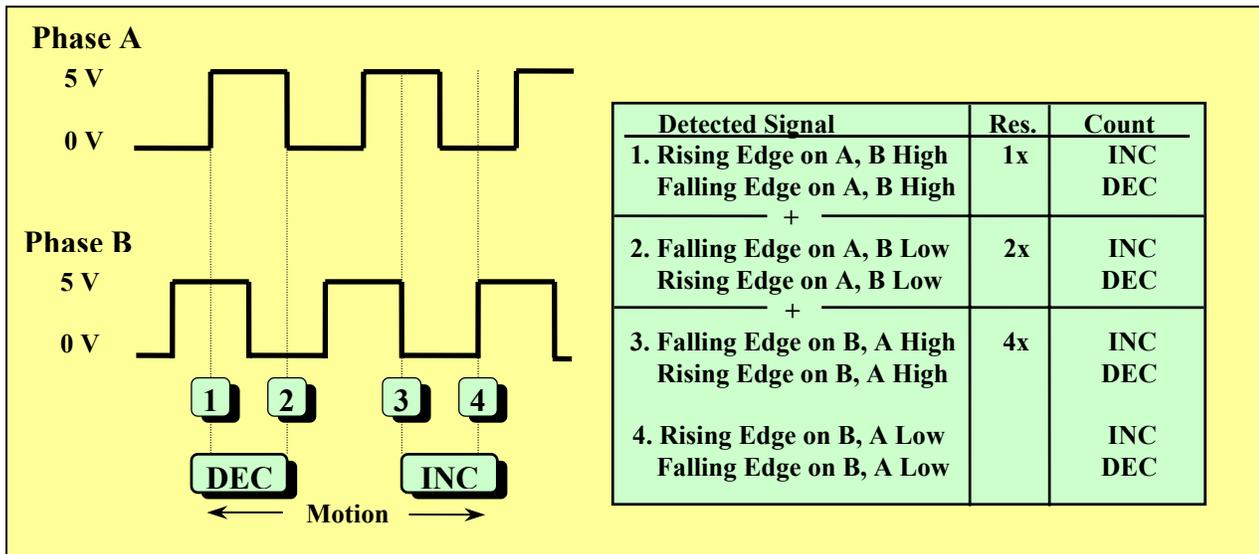
The motion of a magnet passing a magnetically sensitive reed switch, alternately grounding and releasing a current-limited 5-volt source, activates the typical signal pulse-generator. Also used with a moving magnet is a solid-state device known as a **Hall-Effect sensor**, which detects the field polarity of the magnet, north or south, and sets the output signal to 0 or 5 volts respectively. A third, and highly precise signal device is the **optical encoder**.

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Directional Considerations

Upon reflection, one might notice that there can be no distinction in direction of motion using only one signal line per axis. Such a method makes the assumption that the array moves only at the controller's command, in the direction commanded, and does not move in between motion commands. This method does not account for external forces such as high wind that can move the array randomly and independently of motor control.

Quadrature Feedback Sensors: The use of two signal inputs for each axis, such as dual Hall-Effect sensors or optical encoders, achieves a more robust incremental feedback system. By arranging the sensor's relative position, the two signals respond, to a single magnetic pole-pair, 90 degrees out of phase, referred to as a quadrature signal. When an edge in the 'phase-A' signal is detected, 'phase-B' is either High (5V) or Low (0V) but not near an edge. Conversely, when an edge is detected on the 'phase-B' signal line, 'phase-A' is either high or low and not near an edge. The out-of-phase relationship of the two lines produces the ability to tell what direction the array is moving, independent of the motion control commands. The following figure indicates the dual-input quadrature signal interpretation:



To convince oneself that these relationships hold at all times, visually scan the pair of signals from left to right. Each rising edge on the Phase A line is accompanied by a centered High on Phase B, each falling edge on A finds a Low on Phase B. When scanning from Right to Left, the converse is true.

Absolute Encoding: An alternative to incremental encoding, as described above, is absolute encoding. The SolarTrak® has a limited capability to support this type of feedback using a potentiometer to produce an analog signal from 0 to 5 VDC which is transformed through an analog-to-digital converter to a resolution of 256 discrete positions. This method is generally useful only in flat-plate PV applications due to the low-resolution. A minor benefit is that no reference check is needed and the system knows its position even after a prolonged power failure. An incremental system must reset its Reference Point (perform a reference check) after power is restored.

Array Position References:

In referring to various array positions, some latitude :) is taken to provide a workable generality. The North and South limits are the hard limits of the Tilt axis for a Tilt/Roll system or Elevation axis for an Azimuth/Elevation system. The North limit is the furthest position that the array can achieve when moving **away** from the Equator. The South limit is the farthest the array can move **toward** the Equator. In the Southern hemisphere the interpretation of these references is reversed.

The East and West hard limits are best described with the array pitched to the Southern limit, facing the horizon. The East limit is the farthest the array can get from pointing due South moving toward the East either in Roll or Azimuth as the case may be. The West limit is the other way.

In order to maintain tracking precision, the controller needs to periodically reestablish its physical reference point (reference check) and self-adjust its internal clock. The reference point is a unique point in the range of motion for each axis of the array that the controller can detect (either by a pulse on a separate input line or a 'stall' condition when it hits an electrical limit switch) and use to synchronize the physical (actual) array position and the internal position coordinate (count) value. It does this by each morning moving the array toward the East and North until it encounters either the limit switch (which, ideally, interrupts power and stops) or a reference index mark generated by a position encoder. Either method establishes a known position (**Reference point**) upon which to reference future computations and motion adjustments. It then proceeds (moves) to the Sun and follows it for the rest of the day until sundown when it assumes (moves to) the (user-programmable) **Night Stow** position.

Array Position

The coordinate system for internal representation of physical position is integer-based (whole numbers) and has units of **counts** (electronic pulses). These counts are measured in the reference frame of the device that is generating the pulses. Though counts are normally directly proportional to the angular motion (counts/degree is constant) there is at least one acceptable case where the counts must be converted to represent some amount of rotation. When using a linear actuator where the pulses indicate linear extension or retraction, moving a single count at one particular point in the range of motion can mean a different amount of angular motion than moving the same count at another point. This non-linearity when using a linear actuator is accounted for by application of the Law of Cosines when converting the sun position in degrees (radians actually) to counts.

The feedback mechanism can take the form of either an **Absolute encoder** that reports absolute orientation or extension (Position) whether at rest or in motion or an **Incremental encoder** that produces electronic pulses only when in motion.

An **Absolute Encoder** can be as simple as a potentiometer (variable resistor), where a particular resistance relates directly to a particular position by means of changing a voltage on an Analog-to-Digital input. The resulting digital value is interpreted as the current position. There are more complex solutions such as high-resolution two-axis digital clinometers outputting absolute geo-stable orientation with only the Earth's gravitational field as a reference. There are also optical and mechanical digital encoders that produce high-precision absolute position information.

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An **Incremental Encoder** (Open-Loop feedback) utilizes the accumulation of electronic pulses. These electronic pulses are, in this context, referred to as **Counts**. This incremental system is necessarily based on a mechanical or electronic **Reference Point (RP)** within or at the end of the range of motion of each axis. An electrical (power interrupting) limit switch preventing further motion, a magnetic position sensor or a reference pulse from an encoder generally creates this repeatable mechanical position. The array position is reported as the **Reference Offset** (in counts) based on where the zero is established by the **RP**.

Each morning or evening the controller performs a **Reference Check** to establish the Zero'th count by finding the **Reference Point**. As the day progresses and the Sun position is re-computed, the ideal (computed) position (in counts) is compared to the current actual position. If the difference between the ideal and actual positions is greater than the specified allowable 'Deadband' the controller updates the mechanical position. The elapsed time between updates varies throughout the day on non-Polar/Declination geometries because update timing is based on the projection of the sun-speed vector on each axis rather than on a timed update computation.

Sun Angle Computations:

The following steps compute the Sun's angle with respect to a specific position on Earth's surface and at a specific local solar time:

1. Modify 'Local Solar Time' by Time Zone to get GMT.
2. Compute Sun's Right Ascension and Declination at zero latitude (equator) and longitude (Greenwich, UK).
3. Modify angles for Local Latitude and Longitude.

The National Observatory publishes the equations that produce the Earth's position with respect to the Sun. Within the SolarTrak®, the effects of all bodies out to Jupiter are incorporated into these equations.

The Request Position is then calculated from:

$$\text{Sun Position (Counts from R.P.)} = \text{Sun Angle (radians)} * \text{Gear Ratio (counts/radian)} + \text{Reference Offset (Counts from R.P.)}$$

Use of Screwjacks (linear actuators):

When using screwjacks for motion the term 'Sun Angle' in the above 'Sun Position' equation is replaced by a conversion equation when screwjacks are used. The equation utilizes the Law of Cosines to express the angle of one side of a triangle as a function of the length of another side. The Gear Ratio is then expressed in Counts-per-Unit Length.

$$\text{Length} = \sqrt{C3 + C2 * \text{COS}[S1 + C1]}$$

See 'Appendix C' for diagrams and computations.

Range of Motion Issues:

Az/El systems usually allow motion all the way to the Northeast and Northwest allowing direct-normal (pointed-right-at) tracking from morning until evening all year long at most midrange latitudes.

East-west-oriented Tilt/Roll systems are often limited in motion such that direct-normal tracking is only possible when the Sun is in the southern quadrant (south of east and south of west). When direct-normal tracking is beyond the limits of the mechanical system, the controller makes an adjustment to the computed Sun angle to maximize the sunlight on the PV receiver.

Section 3. Manual Control and Emergency Stow Mode

Manual Control Mode - The manual control mode is an override to all motion functions of the controller. It is used when the array motion must be halted for safety while maintenance is performed or when the array must be moved to some unusual position.

Manual mode is turned on using the MANUAL toggle switch at the lower left of the controller board under the joystick. The Manual switch is at the top of the red and white switch block.

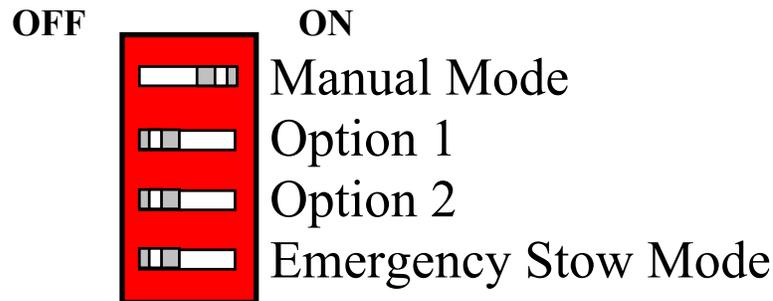


Figure 2.

Once Manual mode has been activated, the joystick may be used to move the array. Pushing UP (toward the TOP of the Controller board) on the joystick points the array more toward the sky, and DOWN points it more toward the horizon.

For Azimuth/Elevation positioners, pushing the joystick to the RIGHT moves the array towards the East and LEFT moves West. For Tilt/Roll positioners the opposite is true.

*** **NOTE:** The Manual switch should always be **ON** when powering-up the Controller to prevent unexpected motion of the array. There will be a slight jump in the motors that should last less than a second as the motor drivers gain control.

Emergency Stow Mode - Emergency stow mode is used to manually interrupt tracking and move the array to a pre-defined position, typically where wind resistance is minimized and the array can be left parked without incurring damage. The Emergency stow switch is at the bottom of the toggle switch box.

*** **NOTE:** The array must be calibrated and have performed a reference check for this function to operate properly. If the controller is not yet calibrated and initialized, Manual Mode should be used to park the array and should be left activated while the array is unattended.

Determining the Current Operational Mode

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The current operational mode is displayed on the micro-monitor (Figure 1) alternating once per second with the current time. This alternating status screen is the default display and implicitly indicates that the SolarTrak® Controller is functioning normally in one mode or another.

Adjust the thumbwheel to the right of the display screen by rolling it up to increase visibility. If there are odd characters or missing letters (like 'ode' instead of 'Mode'), press the Reset Button (to the right of the joystick) again to clear it up.

Additional display screens are available containing status or configuration data that can be viewed with the *Item Button*, and when applicable, edited with the *Adjust Button* and *Value Button*. The display will return to the default display screen after one minute of idleness except while in the *Adjust* mode. Please see section on Displaying and Editing Parameters.

Operational Modes

- **Tracking Mode:** All toggle switches to LEFT (Joystick Inoperative)
System goes through standard tracking scenario: Track during the daytime and assume a programmable Night Stow position while the Sun is below the horizon.
- **Morning Reference Check:** Once each day the SolarTrak will seek out its Eastern and Northern limit to reset its turncount reference to zero.
- **Night STOW:** Normal tracking Function for standard overnight position.
- **Emergency STOW:** Bottom switch (STOW) to RIGHT (all others LEFT)
Array moves to a programmed safe position.
- **Manual Mode:** Top switch (MANUAL) to RIGHT (Overrides ALL automatic motion functions). All motion other than Joystick input is prevented.

Joystick Operation – Manual Mode – SolarTrak facing north, operator facing south:

RIGHT → EAST
LEFT → WEST
UP → NORTH (Screwjack retracts)
DOWN → SOUTH (Screwjack extends)

Display/Edit Parameters on SolarTrak® Controller Board

Displaying Parameters with LCD Micro-Monitor

The LCD Micro-Monitor allows display of a limited combination of calibration parameters and status values. It may be necessary to adjust the contrast using the thumb-pot just above the LCD. (See Figure 1). The standard display shows the current Time alternating with the current controller Mode. The three pushbuttons just below the monitor are, from left to right, ITEM, ADJUST and VALUE.

The mode will be one of the following:

- | | |
|-----------------------|---|
| 1. Tracking | Array is tracking normally |
| 2. Night Stow | Array is parked for the night (will wake in morning) |
| 3. Emergency Stow | Array is parked manually |
| 4. Manual | Array is in Manual Mode |
| 5. Morning Ref. Check | Array is seeking its reference |
| 6. Wind Stow | Array is in Emergency Stow position due to high winds |

There are several parameters and status values that may be displayed on the micro-monitor screen. The following values are accessible:

- | | |
|-------------------|--|
| 1. Time/Mode | Local 24 Hr. Standard, <u>NEVER</u> Daylight Savings |
| 2. Date | Year 2000 compliant |
| 3. Turncount | Axis 1,2 Turncount reading (use 'VAL' to toggle) |
| 4. Temperature | Use 'VAL' to toggle between C & F |
| 5. Set Sun Offset | Calibration Command Function |
| 6. Seconds/Day | Clock correction each day |
| 7. Seconds/Week | Clock correction once per week |
| 8. Latitude | + Northern Hemisphere, - Southern (+/- 90 degrees) |
| 9. Longitude | 0 = Greenwich, UK (Range 0 – 360 degrees West) |
| 10. Time Zone | 0 = Greenwich, 5 = East Coast, 8 = West |
| 11. Version | Version Series and Date |

These values may be displayed, one at a time, by pressing the ITEM button, located just below the monitor. (See Figure 1). Due to space limitations on the screen, the above item descriptions will most often be abbreviated. The buttons are scanned once per second so it may take a moment to see the response. The button should be held down until it registers. The button will repeat its function once per second as long as it is held. After the last screen is displayed, it will start over with the Time. After approximately one minute of inattention, the display will revert back to alternating between the Time and Mode.

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Editing Parameter Values: On-board LCD/Button I/O

***** NOTE: It is strongly recommended that the array be placed in MANUAL mode prior to changing parameters to avoid jumps, spurts and wasted time.**

ADJUST MODE is indicated by a flashing cursor square on the screen. This must be turned OFF by pressing the ADJUST Button before the ITEM Button can be used to change screens again.

To Modify a Parameter:

- Select a parameter that needs to be changed using the ITEM Button.
- The VALUE Button may be required to access a 'second-screen' value.
- Press the ADJUST Button
- Use the ITEM Button to move the cursor Right to the digit to be changed.
(The cursor position will 'wrap' back to the center of the screen at the end)
- Press the VALUE Button to increment the value or change the sign.
 - . All values have bounds and will wrap automatically in most cases
 - . In order to create a negative number from or through zero (the sign will go positive at zero), the number must be made non-zero before changing the sign to negative.
- When all digits are changed, press the ADJUST Button to revert to the normal mode.
There are three basic types of screen content: Status Information, Configuration Parameters and Command Functions.

Status Information is set dynamically by the SolarTrak® during the course of operation. Some values are strictly informative such as the STATE of a switch or voltage level. Others are a relative value that must be referenced to an initial state such as the array position with respect to a limit switch. Still others, such as the Time and Date, must not only be initialized but also calibrated.

Examples of Status Information are:

<u>Description</u>	<u>Available Operations</u>
Operating Mode	Read Only (Controlled Elsewhere)
Local Standard Time	Initialize (Calibrated Elsewhere)
Date	Initialize
Array Position	Initialize to Zero
Battery Voltage	Read Only (Calibrated Elsewhere)
Temperature	Read Only, Switch between 'F' and 'C' scales
Version	Read Only

Configuration Parameters are stored in non-volatile memory (EEPROM) and dictate tracking options, geometric specifications and emergency operation guidelines to the Controller. Such information is installation-specific but will not usually change once installed.

Examples of Configuration Parameters are:

PC Interface Manual and Installation Guide

Latitude, Longitude
Time Zone
Tower-Tilt Error
Seconds-per-Day, Seconds-per-Week Clock Correction
Sun-reference Offsets
Width/Spacing ratio of rows for Backtracking

Command Functions perform specific operations that generally involve multiple parameters or high-level control options. Examples of Command Functions are:

Set Sun Offset	Adjust Sun-reference Offsets for both axes
Set Reflector Offset	Set Target Azimuth/Elevation
Track/Reflect	Switch between Direct and Reflective tracking
Zero Turn-count	Set current axis position to zero (Set Reference Point)
Backtracking On/Off	Toggle Optional Function (single-axis flatplate system)

To support these screen-types, there are three types of button operations: Set Quantity, Invoke Command and Swap Screens. Giving a name to the type simply provides a way to interpret how each screen-type will respond to the buttons.

Therefore, if a quantity can be set:

To Set a Quantity:

1. Using the ITEM button, select the screen that displays the desired quantity.
2. Press ADJUST once to make the Cursor (Black Rectangle) appear.
3. Press ITEM (Surprise! ITEM now makes the cursor move to the RIGHT) to highlight the offending digit. It will 'wrap-around' if you miss.
4. Press VALUE to increment until you're satisfied. Note that the digit value will always wrap-around to zero. If the digit has a known limit other than '9', such as the hour digit in time (2), it will not exceed it but will wrap-around sooner. If the value being entered is NEGATIVE, FIRST set the value to a NON-ZERO number (this computer does not acknowledge -0) then change sign by highlighting it with ITEM then pressing VALUE once.
5. Repeat steps 3 & 4 to produce the desired result then press ADJUST once again to remove the Cursor.
6. Press ITEM to get to the next screen, back to the Time/Mode (default) display or just wait 60 seconds for the screen to revert to the default automatically.

To Invoke a Command:

As before:

1. Display the Command Prompt screen with the ITEM button.
2. Press the ADJUST button to bring up the Cursor (analogous to 'arming' the function)
3. Press the VALUE button to actually invoke it.

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Alternatively, pressing the ADJUST button again instead of pressing VALUE will ‘disarm’ the situation and allow further ITEM button-presses to continue changing the screen display.

To Swap Screen Displays:

Several displayed quantities have a separate value for each axis or, in the case of temperature, two different sets of units. When such a quantity is currently being displayed on the screen, pressing the VALUE button will toggle back and forth or ‘swap’ the displayed values. Once toggled, if the quantity is available for modification (temperature is not) and you choose to do so, have at it.

This method of input, though handy for small things, is tedious, time-consuming and resource-hungry. A great deal of very limited program storage space in the microcontroller chip is used to store the characters you read on the LCD, space better utilized for control strategy options, so not many parameters are available for this type of access.

With so many things to keep track of during any period of time, the SolarTrak® places the buttons at a low priority and samples the button’s state only once per second or so. This results in some inconsistency in their response. If you don’t use them much you won’t care and if you use them a lot, you’ll get used to it.

RESET Button:

The single button next to the Joystick in the upper left of the board is the **RESET** button. **When all else fails and there is no response from the board**, pressing this button will restart the SolarTrak program and display the default alternating time/mode. This is the default display to which the SolarTrak returns when RESET is pressed or the unit is left alone for an extended period of time.

Sun Alignment Sequence

Set Sun Position Reference Offsets

The Axis 1 Reference Offset and Axis 2 Reference Offsets found in the 'Reference Sensor Parameters' screen can be entered directly if so desired. An alternative method, usually with sufficient precision, can be employed that utilizes the LCD monitor and the joystick.

1. Verify that a recent Reference Check has been performed, if not, press RESET and wait for the process to complete.
2. Use the Item button on the controller board to scroll to the screen that displays 'Set Sun Offset'
3. Press the Adjust button until the screen reads, 'Position Array'
4. The array is now in Manual Mode though it will not be displayed.
5. Use the joystick on the controller board to position the array to an acceptable state of focus.
6. Press and hold the Value button on the controller board until the display reverts back to
the Time and Mode.
7. If the array moves away from the sun, repeat steps 2 - 6. When the current reference offsets are too far from correct, the controller can not necessarily compensate fully in one iteration, several may be necessary when trying to calibrate the array early in the morning or late in the afternoon when near the soft limits.

Strategy for Optimization of Tracking Precision

Within the limitations of any given digital electronic position feedback system, it is possible to optimize the amount of on-sun time for the receiver using the programmable parameters stored onboard the SolarTrak®. The set of parameters that affect this aspect of tracking are found in the ‘SolarTrak Drive Parameters’ dataset, specifically, the ‘Coast Counts’ and ‘Deadband’ for each axis.

When a motor (or valve) is turned off after being turned on to reposition the array (‘motor off’), there are three mechanical phenomena that affect where the array actually stops (‘array stop’).

The first, and sometimes uncontrollable, is mechanical backlash. Backlash may be detectable (though still only marginally controllable) if a bi-directional (dual-signal quadrature) feedback circuit is implemented on the final positioning stage directly on the axis of rotation. Without this type of feedback the possibility exists for there to be array motion (ie, from wind or gravity) without the detection of feedback pulses or feedback pulses (motor turns drivetrain only) without detectable array motion. Either circumstance produces a dead zone of operation where the controller can’t know precisely where the array is pointing.

The second is the minute delay between the time the circuit is de-energized and when the motor drive field collapses and the motor stops driving the array in the specified direction. This delay is usually small but still contributes.

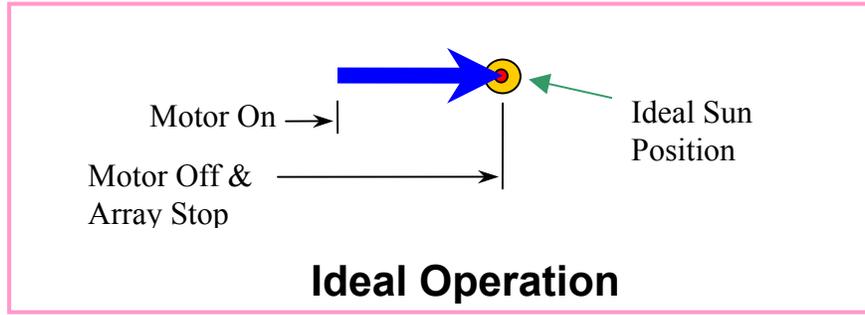
The third, and typically largest, is the momentum of the system. Usually, the effect of inertia of the motor armature or the array itself is limited to causing the array to overshoot the desired position by the time it comes to a complete stop. In this case, the array (controller) will (after the programmed delay) reverse itself and (hopefully) drive back to the correct position without overshooting. Sometimes this can turn into a nearly continuous cycle of updates because the controller (not yet understanding the momentum) turns the circuit on for too long, thereby repeatedly overshooting in both directions. This visibly resembles and is referred to as ‘hunting’.

If there is only a single-signal pulse feedback system (magnetic reed switch, single Hall-effect sensor or photodiode/LED pair), in addition to this overshoot problem caused by momentum, there exists the possibility, in windy or gravity-driven conditions, that motion can occur in the opposite direction than that which the controller had specified during the latest position update. If this motion significantly back-drives the drivetrain to the point that it generates feedback pulses, those pulses will be misinterpreted as counts in the originally-specified direction because when only one signal exists, the controller cannot tell the difference between a proper pulse in the requested direction and one created by externally-driven motion in the other direction. This phenomenon will invalidate the current position by (for example) increasing the turncount value (current position) rather than decreasing it when the system is back-driven. The false array position count, appearing to the controller as an overshoot, will create a response from the computer to ‘drive the system back’ to the correct position from where it now (erroneously) thinks was an inadvertent overshoot. This entire process is most easily perceived as ‘induced confusion’ about the actual position of the array and can only be corrected by performing another reference check to reset the zero turncount position.

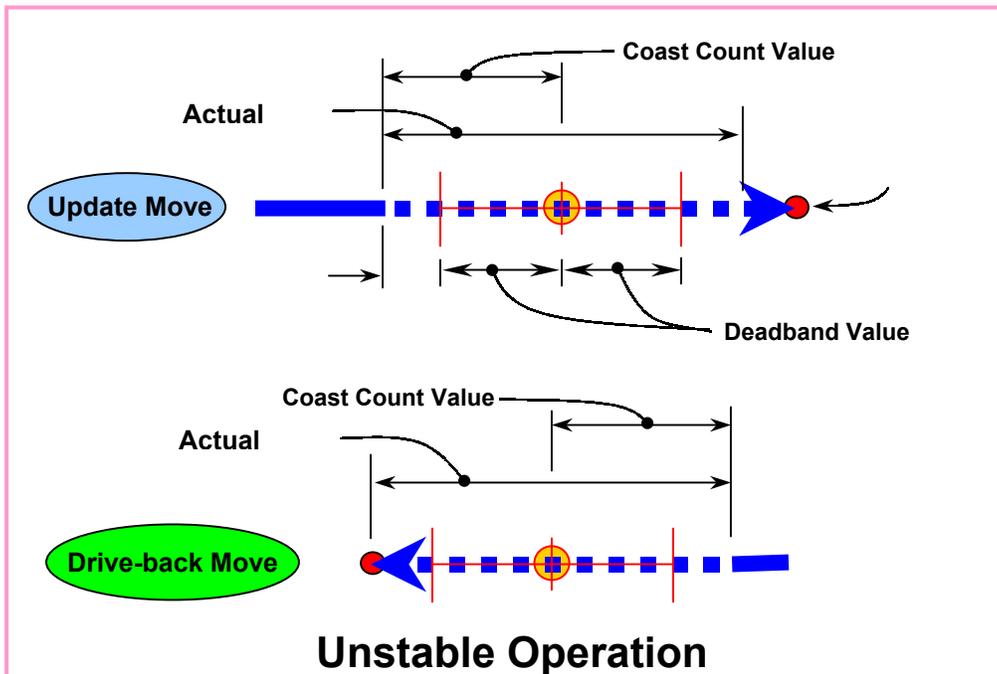
All three effects contribute to the difference between ‘motor off’ and ‘full stop’. Compensation for these effects is implemented with the tandem use of the ‘coast counts’ and ‘deadband’ parameters in the ‘Drive Parameters’ dataset.

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The following illustrations represent (respectively) ideal (translated: unrealistic) motor off-array stop operation, unstable operation (hunting), stable but inaccurate operation and optimized stable operation. Stable, in this context means that it seldom if ever hunts for an acceptable spot within the deadband. The chronology of an update consists of the 'Motor On' event happening when the current position of the group drifts outside the 'Deadband' with respect to the 'Ideal Sun Position'. 'Motor Off' occurs when the current position is 'Coast Counts' from the ISP and 'Array Stop' is when the array actually stops moving.



An approximation of ideal operation can be accomplished with the use of a brake mechanism, either mechanical or inductive (DC only). This solution comes with potential collateral problems in that the abrupt stops can cause large arrays to oscillate structurally, sometimes causing tracking errors of large enough magnitudes to fall outside the range of efficiency. It is quite possible to have oscillations that last as long as the period between updates (becoming continuous) when the tower loading is high enough.



Unstable operation, or hunting, is caused by a coast count value that is too small relative to the actual coast distance and too large for the deadband value to trap. The procedure to alleviate this phenomenon is to systematically increase the coast count value and/or the

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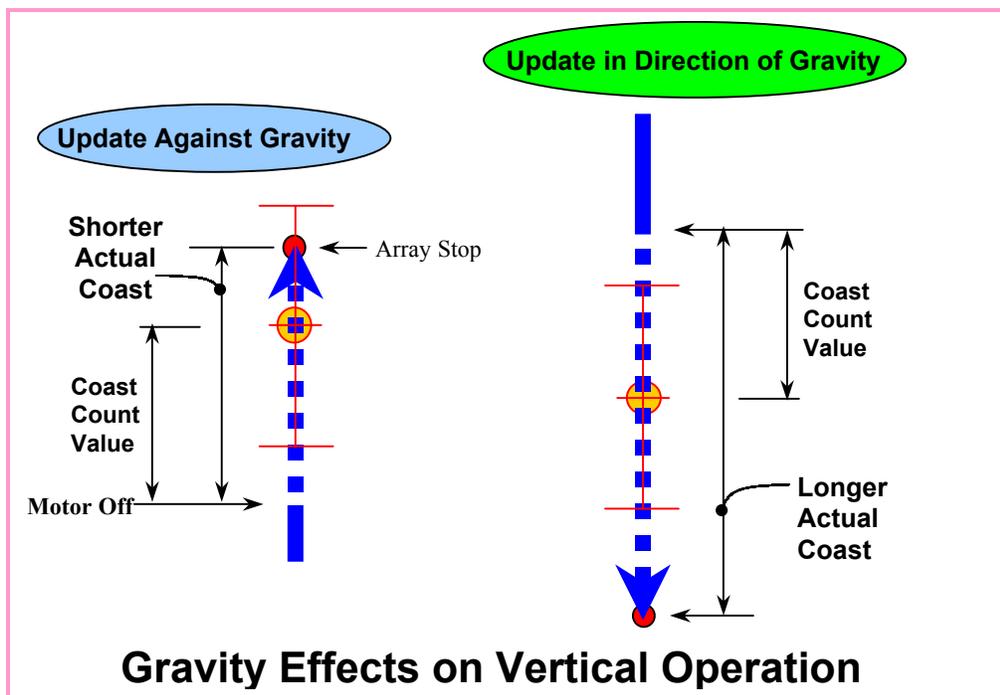
deadband value until the array consistently lands within the deadband range on the first try. This will not solve the accuracy problem but it is a proper start.

There is, as always, another wrinkle to this problem that usually occurs on axes having a large weight imbalance. (Actually, the only balanced axis is usually a vertical (azimuth) axis of rotation. All others are generally subject to gravity at some point in their range of motion. It is certainly possible to provide a counterweight to offset the imbalance, but always at the cost of more weight, inertia and complexity. It is usually more cost effective to minimize the eccentricities from the get-go.)

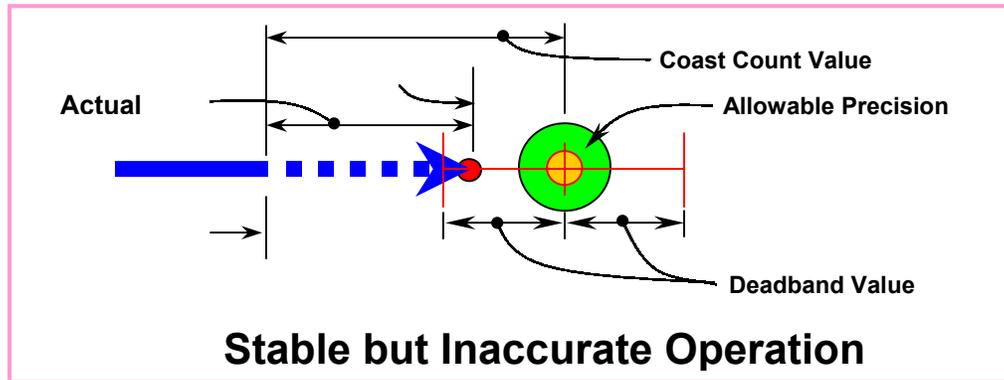
When an update occurs that drives against gravity, the tendency to overshoot is diminished, that is, the actual coast distance is smaller than if gravity was not a factor. Conversely, if the update is in the same direction as gravity, the tendency to overshoot is increased.

In some large systems a braking system is mandatory to prevent backdriving regardless of the direction of the update because the vertical, eccentric gravity-driven load is sufficient to overcome drivetrain friction and accelerate the array from a dead stop.

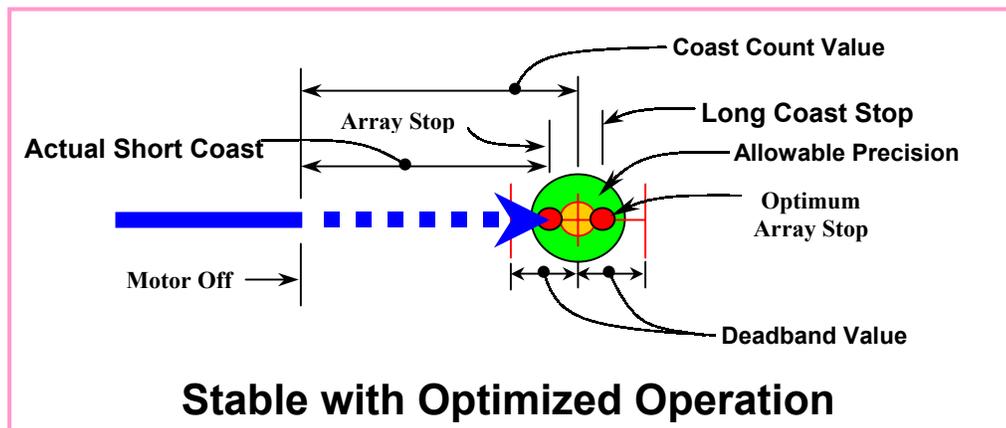
The operative issue in this description is that there is a 'short actual coast' (against gravity) and a 'long actual coast' (with gravity). These 'real world' values must be accommodated by the values selected for 'coast counts' and 'deadband' as discussed below. It should be noted that since this is a moving system, the actual effect of gravity (vertical load component) changes continuously (and non-linearly) with the change in sun elevation and obviates the successful implementation of separate coast count values for each direction and the lack of available code space in the microprocessor precludes more complex solutions.



As mentioned above, hunting can always be stopped by making the deadband value sufficiently large, but at the sacrifice of accuracy. Even though the SolarTrak can compute the sun position to one-hundredth of a degree, a large deadband allows the array to stop, without further adjustment, at relatively large distances from the actual sun position.



To finish the optimization procedure, once the hunting problem has been arrested, it is necessary only to systematically reduce the deadband and increase the coast counts to a point that accommodates both the short and long actual coast distance (if the axis is imbalanced) or simply get the array stop position to consistently occur within the allowable precision band. If time permits and obsession demands, the array stop position of choice will always be just in front of the sun to allow the system to remain at rest for the longest time within acceptable bounds. This is always more difficult when fighting with gravity.



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Timed Motor-On Mode:

There are times when more frequent updates and a tighter tracking band are desirable. For this purpose there is the 'Timed Motor-On Mode', a self-calibrating motor control routine able to shorten the 'ON' pulse until the requested deadband is met.

With extremely high-speed or low-friction motors or geardrives it can be counter-productive to specify a deadband less than 1, however certain systems that move slowly enough can reliably track without hunting at a deadband of zero. It is always worthwhile to give it a try.

Most of the relevant parameters are in the 'Drive Parameters' screen of the PC Interface.

The Ax1 and Ax2 Deadbands can be set down to 1 (or 0 if you can get away with it). The Time/Coast switch will act as the decision point for using the Timed mode and just turning on the motor. If the required motion is greater than the Time/Coast Switch value the motor will be turned on until the turncount is found. If the distance is less, the current timed-mode on-time value is used to pulse the motor. That value is initialized at power-up or RESET to the Ax1 and Ax2 Default Time On values specified in the Miscellaneous SolarTrak Parameters screen.

The Time/Coast Switch should always be larger than the Coast Counts.

A sample set of numbers used for the WAZ geardrive series is:

Ax1 Coast Counts	3
Ax1 Time/Coast Switch	8
Ax1 Deadband	1
Ax2 Coast Counts	2
Ax2 Time/Coast Switch	5
Ax2 Deadband	1

In the right-hand column, turn on the 'Timed Motor-On Mode'.

Continue on to the Miscellaneous Parameter screen and set the two default Time-On values. These values are to speed-up the self calibration process. Each system will have a tendency toward particular basic values most of the time then will oscillate about that value during the day. Usually 50 – 100 will do fine.

No other settings are necessary to implement this option.

Correction of Tracking Errors due to Misalignment of Axes

The SolarTrak® is a mathematically based system. Its perception of the universe is a computerized model (simulation) of the mechanism it controls and the position of the Earth with respect to the Sun at a given instant in time. It is able to compute the Sun's relative position to any point on the planet with an accuracy of less than 1/100th of a degree. Its ability to then properly position a solar collector or reflector rests on the accuracy of the mathematical description of the mechanical system, the stiffness of the mechanical system and the precision of the position feedback system.

The major points of the mechanical description are:

1. The specification of the Ideal Coordinate Reference Frame
2. A mathematical model of motion with respect to position feedback
3. A definition of range of motion

The stiffness of the mechanical system includes:

1. Mechanical Backlash
2. Torsional and bending stiffness of drive members
3. Issues of binding and excessive friction

The precision of the position feedback system involves:

1. Repeatability of actual position vs. reported position
2. Available resolution of feedback pulses (turncounts) per unit rotation

Correctible Errors

For there to be the option of correction, there must be predictability of the error. Tracking errors due to backlash or bending are less than fully predictable using conservative means. In bending situations, the result is generally an accumulation of strain through several components and cross-sections. Measurements can be taken and an approximate correction can be tried. Backlash, depending on the stiffness of the drive train, changes with too many variables. Producing a mechanical situation that forces the system to one limit or the other in the backlash range by utilizing gravity or spring loading is generally the best approach.

Geometrically based errors are much more approachable although there are circumstances that require mechanical rather than mathematical approaches to correction.

Even the best tower installations are subject to slight errors in plumb. And for those who are using something other than a tower, a more fundamental definition would be that any rotation (not translation) in the Primary axis (fixed to Earth) or the Secondary axis (moving reference frame about Primary axis) with respect to the primary axis. When tracking accuracy of less than a half-degree is required, it is best to measure the actual tower tilt and allow the SolarTrak® to compensate. The effects can be extreme near the beginning and end of the solar day where a small tilt can actually be magnified.

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The basic effect is similar to the result of specifying the wrong latitude and longitude or running the clock always an hour slow. The results of a tilted tower.

Screwjack parameters must be computed by the book. That book is attached. A tilt-roll system has zero tilt when the roll is centered and the array is facing straight up vertically. The centered roll has nothing to do with the zero point it just helps to envision the situation.

The roll axis has its zero at Due East. That means at Solar Noon the roll axis is at 90 degrees. This must be kept in mind when computing Beta, SJ#1 for the roll axis.

1. Start the program hooked up to a SolarTrak that has a tracker that you can aim at the Sun.
2. Set the SolarTrak clock to atomic time. Every 24 seconds is a tenth of a degree in polar rotation. Clock accuracy during calibration can be critical if high accuracy is to be achieved.
3. With the array set for a Morning Ref. Check, press the RESET button on the SolarTrak or Ctrl-F7 on the PC keyboard to perform a ref. check before your very eyes. Verify that it does it properly. Later in the day, another ref. check should be done to verify repeatability.
4. Do a 'Set Sun Offset' to put the array exactly on Sun. Watch it track for a minute. Use one end of the update range all the way through. I usually wait for the update and make sure it centers exactly to take data. In actual operation it will fall slightly behind then move slightly ahead for best operation.

*** DO NOT INITIALIZE FILE OR TAKE DATA POINTS WHILE ARRAY IS VERY NEAR LIMITS OF MOTION **** (software or hardware limits)

5. On the PC, press Ctrl-F3 to Initialize the data file. It will ask for verification for performing the command. This command will be done only once but it depends on you to make sure that is the case.
6. Use F2 to take a data point but lazy person that I am, I included the '.' (period) as an alternate key for this command.

Press '.' to take the first data point immediately.

- It will ask if you did a ref check
- It will ask if you did a 'Set Sun Offset'
- It will ask if you like the way it is tracking

It will ask you these same questions for each data point. If you answer NO to any of them, that data point will not be included in the computations although the aborted attempt will be apparent if you look at the data file.

After the third question is answered it will take a few seconds to gather the data. It will take the current sun position and the new references offsets (changed by the 'Set Sun Offset') and log the values in the data file. It *should* say it is doing so but it doesn't do that right so don't hit any keys while this is going on. WAIT for the question about whether to 'store the point or not' comes up.

It lets you reject the data point if you don't think the result (being displayed) is realistic. How to judge that realism is part of the complexity of this procedure. Usually it has something to do with changes in turncounts that don't match observation.

7. To take more data points, repeat at about 30-45-minute intervals doing a 'Set Sun Offset', watching it track for a minute and taking a point on the PC.

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After about five data points, the program will start appending the data point collection process with a display of computed error parameters and then a couple of plots.

The Error Parameters are the current estimated coefficients of the equations:

$$\text{Axis 1 Error} = - [P1 * \text{SIN}(AX1) / \text{TAN}(AX2)] \\ + P2 - [P3 * \text{COS}(AX1) / \text{TAN}(AX2)] - (P5 * AX1)$$

$$\text{Axis 2 Error} = [P1 * \text{COS}(AX1)] - [P3 * \text{SIN}(AX1)] + P4 - (P6 * AX2)$$

Where AX1 and AX2 are the current sun angle in the native reference frame (ie. Tilt-Roll). When error data do not fit into the framework provided by the terms in these equations, they are either ignored (not usually the case) or interpreted in some fashion as doing so.

If the tower (or frame) is only slightly misaligned, the resulting error coefficients should be equally small. Do not expect much if the misalignment is over ten degrees.

You may get the message 'Parameters still unrealistic'. This means that the coefficients are coming out really large and probably don't make any sense. It also probably means that the errors don't properly fit in the available mathematical framework.

That's what can go wrong. If things go better than that, you will get some small numbers on the screen. Cute little things aren't they? Make a mental note (or a real one) of the values. You will be watching from point to point whether they change very much.

Press a key to proceed to the error plot. This takes a little getting used to. It is very rough. The data is presented as dots at the time interval taken with bright amber for Axis 1 errors and bright green for Axis 2. Both sets of data are plotted against Solar Time. Overlaid on that data is series of evenly spaced dots computed from the current error coefficients at ten-minute intervals. Admittedly, this plot can sometimes look more like an explosion. When things are more compliant, the error function will follow the data points to some observable extent.

Part of deciding when you've succeeded in the calibration is based on the point-to-point changes. Large changes in the error coefficients, once they are displayed, are signs of data values falling well outside the predicted error function, which embodies all data thus far. This often occurs within the first ten points but should dissipate rapidly after that. Conversely, successive data points falling more precisely on the previous error function (coefficients are not changing much or at all) show a workable match between the observed (measured) error and the computed error function.

In between data points, you can recompute coefficients and display the data from a given file by pressing F3. Use the space bar to find the correct file then 'Enter' to open it. The file names will be displayed just below the screen title, six lines up from the bottom of the screen.

When you do 'Set Sun Offset's be systematic. If the system needs to be adjusted backward from the current tracking direction, move behind the Sun first then adjust it forward to the correct position. This places some control on the backlash issue.

When the plots look like a good fit, place the unit in Manual then use Ctrl-F5 to save all the misalignment parameters at once.

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Swapping or Installing the SolarTrak® Microcontroller Chip

The most appropriate method to exchange the controller chip is to use a PLCC chip extractor. It uses little prongs extended into the slots at the lower-left and upper-right of the chip, hooks under the chip and lifts it out evenly and smoothly without tipping or cocking the chip in the socket which causes the pins to bind and bend. BAD!

If one uses **Great Caution!** there is an alternate method of extracting the chip. Use a small jeweler's screwdriver to slip into one slot at a time. Gently pry the corner up only a fraction of the necessary amount to free it. Move the screwdriver to the other slot and repeat the gentle pry up. Use your fingers to keep the chip level on the other two corners without slots. Two or three complete repetitions should do it.

When inserting the new chip, there is a corner shaved off that goes on the upper-left of the socket, near the RESET button. Settle the chip into the socket gently and verify all the pins line up and the chip is square with the socket. Gently rocking the chip with a couple of fingers will produce a 'floating' effect on the pins indicating a good placement, then push the chip straight into the socket, again keeping the chip level with several fingers.

Verify that the Manual switch is flipped to the right, power up and check for proper operation.

Moving Parameters between SolarTrak's

When adding new trackers or creating a backup tracking system, it can be tedious to transfer all the parameters unique to your system. Using the download and upload functions as a transfer mechanism is the easiest and least error-prone method.

Step 1: Download the template from the SolarTrak being duplicated. (Alt-F3 from Main Menu)

Step 2: Save template on disk in swap file. (Alt-F5)
Press ESC to enter a filename directly
Type: SWAP then press the 'Enter' key

Step 3: Either power down the SolarTrak and swap the controller chip then power back up...
or
Connect the PC to the new SolarTrak.

Step 4: Load the swap file SWAP.TPL, just to make sure. (Alt-F2)
Press ESC to enter file name directly.
Type: SWAP then press 'Enter' key

Step 5: Upload swap data to New or Replacement SolarTrak (Alt-F4)

When this step completes, it will ask if you want to remain in Manual Mode where it was put to inhibit motion during the upload. Press 'N'.

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If one is cautious to keep the PC program running while changing chips or connections, Step 2 & Step 4 can be omitted. The internal data integrity is maintained once loaded as long as the PC interface software remains running so saving a swap file is just a precaution. The safest approach is to save the file and reload if you think something happened to the data. The internal data set is accessed by pressing 'T' on the keyboard to toggle back and forth. The Unit # changes to a file name designating the difference.

SolarTrak® PC Interface Set-up and Operation

Overview: The Purpose of a PC Interface for a Standalone System

The SolarTrak® Sun-tracking Controller itself is a completely stand-alone system requiring no ongoing control or outside information (other than its own sensors) in order to perform its normal tracking mechanism control function.

It does, however:

1. Need to be configured for the particular mechanical system it is controlling and for its particular location on the planet before it can be expected to track the Sun,
2. Need to be checked for time error periodically and to initially calibrate the clock self-correction mechanism, and
3. Need the option of high-level control through a network link for control of large fields.

There are three methods for communicating with and modifying the SolarTrak®:

1. Access using the onboard buttons and LCD,
2. The User Interface Board (UIB, separate device and document), and
3. The PC Interface software.

Each has its own benefits depending on circumstance. Most notably, the UIB is small, light and is powered directly off of the SolarTrak® power allowing ease of use and portability while the average laptop is heavy, generally requires a power cord after ten minutes and is often difficult to read out in the sunlight where most of this fun and games takes place. On the other hand, the UIB is limited to one parameter value displayed at a time on its 32-character LCD screen while the PC can display a whole group of related parameters at once, up to thirty on a screen, along with always providing current status information. Is the quantity of information offered by the PC Interface software always necessary? No. Sometimes it is the most convenient and useful tool to use for troubleshooting; and sometimes it is clearly more trouble than the UIB and *sometimes* you don't need either one because the buttons and display on the SolarTrak® will do.

Over and above the ability to change parameters on a single SolarTrak®, the PC Interface software allows expansion to a network over which a central location running the PCI can control or monitor the operation of a whole field of independent SolarTrak®'s while maintaining the ability to talk to a single unit when needs be. It also performs support operations and data collection procedures for the high-precision calibration operation required at installation for concentrators, a function far beyond the capabilities and scope of the UIB.

Setup: Installation of DOS-based Software

A: Loading the DOS Ansi.sys Screen Driver

The ALPHA release of the SolarTrak® PC Interface software requires the use of a DOS screen driver named ANSI.SYS which facilitates on-screen text positioning and effects, crude by today's standards, but effective.

A Windows-based version is in development but Windows is currently unable to digest the specialized communications parameters that allow a PC to be part of an ultra-simple serial communications network and insists on continually *fixing* the *unknown-and-therefore-wrong* communications parameters.

These instructions assume you boot your computer from drive 'C:', have a DOS directory (or equivalent) in the PATH and have a floppy drive A: available. Please add the following line to the CONFIG.SYS file found in the root directory of your C: drive. The DOS command EDIT is good enough for this task. (Please see Setup.A.1 for possible Windows rendition of this exercise).

At a DOS prompt type: (pressing ENTER or RETURN after each line)

```
...> C:  
C:\...> CD \           (Gets you to the root directory of 'C' drive)  
C:\> EDIT CONFIG.SYS
```

Inside CONFIG.SYS, insert the following line after HIMEM, SMARTDRV, DOS and other important stuff. The easiest way is to move down (with the DOWN Arrow) to the line above where you decide to insert the line. Press the END key, and then ENTER. A new, empty line will appear.

Then type in:

```
DEVICE=C:\DOS\ANSI.SYS  
or
```

```
DEVICEHIGH=C:\DOS\ANSI.SYS
```

Whew! That was easy! Now to save all your efforts:

Action:	Response:
Press Alt-F (hold down 'Alt' key then press 'F' key)	Dropdown File Menu
Press X (meaning <u>E</u> xit)	Prompt to SAVE? File
Press Y (meaning 'Of course I want to save it!')	Back to DOS PROMPT:\>

You should be back at the root directory prompt now.

```
C:\>
```

***** Please re-boot your computer to install ANSI.SYS before proceeding *****

Setup: Installation of DOS-based Software (cont'd)

A.1: Windows 95, 98 and 2000 users in MSDOS Window:

*****NOTE:** No Guarantees, Windows can be belligerent. No solutions have been found for Windows Millennium or XP. The following usually works:

Use 'Notepad' to edit

CONFIG.SYS in the ROOT directory for Win95, 98

or

C:\WINNT \ SYSTEM32 \ CONFIG.NT for Win2000

Insert the following after other device statements: You might check the path name first using the 'Find Files' command to look for 'ANSI.SYS':

Win 95,98: DEVICE=C:\ WINDOWS \ COMMAND \ ANSI.SYS

Win2000: DEVICE=C:\ WINNT \ SYSTEM32 \ ANSI.SYS

There was a WIN-NT user that was successful with:

DEVICE=C:\ WINNT \ SYSTEM \ ANSI.SYS where CONFIG.SYS was in the root directory

Save and Exit.

The PC computer must be powered all the way down and back up for Windows to use the new 'config.sys' file. 'Restart' does not work reliably.

Note: Windows versions beyond Win98 may not work with the SolarTrak Controller because the Windows operating system uses a driver that defeats the special communication protocol. If you can boot your system directly to DOS that is the best option to take.

B: Moving Files to Hard Drive

After the boot completes, insert the SolarTrak® software diskette into drive 'A'. Type the following to make a directory for the files:

```
...> CD \
```

```
C:\> MD SOLARTRK
```

```
C:\> CD SOLARTRK
```

```
C:\SOLARTRK> COPY A:STN.EXE *.*
```

```
(Response: 1 file(s) copied)
```

```
C:\SOLARTRK> COPY A:*.TPL *.*
```

```
(CPU will list 'n' files. Each a '.TPL' and conclude with: 'n' file(s) copied)
```

DOS Command Line Option Switches

The following command line switches (preceded by a '/', forward slash) allow special initialization options and the ability to work with stored data without being connected to a SolarTrak®. Template files and the Internal Template will be discussed in Section

/Cn **n = a COM port number, i.e. /c3 designates COM3 as the active port**

/Tfn **fn = filename of Template file (.TPL), i.e. /tEAST01 will use EAST01.TPL**
This switch preloads EAST01.TPL but still contacts the SolarTrak®

/Ifn **Same as /Tfn but goes directly to the internal template**
i.e. /iWEST01 loads and displays the data saved in WEST01.TPL without
attempting contact with the SolarTrak®

/M **Monochrome screen operation (graphic plots will be hard to read)**

/Pn **n = a PRINTER port number, i.e. /p2 designates LPT2 as the active printer.**

/Ffn **fn = filename of PC Interface configuration file to use (default =**
ST_NET.CFG)

Ex: /fNONET uses the file NONET.CFG

/W **Data from the on-board thermometer and the wind anemometer (if installed)**
will be collected and stored at 1-2 second intervals in daily files named
WTyymmdd.DAT. Each file is approximately 2.5 Mb. File names change
automatically at midnight.

/Dn **Position data from the on-board computations will be logged every 'n'**
minutes
PDyymmdd.DAT.

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D: The SolarTrak® PCI Configuration File

```
% This is a Remark
/begin          % A slash marks a keyword
/network No % Yes  % Declare Network or Not
%
% if network is yes, specify # of nodes and unit #'s
%   nodes <= 32 ; For the moment
% Network set-up CONFIG file example
/nodes 2
%   Index  name
/unit  1    2
/unit  2    3
% Index must be 1 -> nodes
% names can be any number from 1 to 65535  ie: /unit 1 1
%                                           /unit 2 64231
% Hex (0001 - FFFF) can also be used: /unit 1 0xC3E0
%                                           /unit 2 0xA2D2
%
/Calibrate ON
/Troubleshooting ON
/DaylightSavings OFF
/GUIInterface OFF
/end          % Lets CONFIG routine end gracefully
%
```

The PCI takes direction from both the configuration file and the command line. The elements of the configuration file reflect things that change little if at all. Those on the command line are more apt to change from use to use.

E: Setting up Batch File Execution

Since typing all these things in every time is tedious, putting them in a '.BAT' file is recommended. Type the following:

```
C:\SOLARTRK> EDIT ST.BAT
```

You will get a blank screen with menus all around it. Basically you will want to include any standard switches such as /Cn or /M that you will need each time, and perhaps a default template file if you eventually find that handy. Then add the '%1 %2 %3' to allow extra switches to be declared on the command line as necessary each time the program is run, i.e.

ST will run the program with the standard switches as defined in the batch file lines below.

ST /IWEST01 will override the /TEAST01 entry stored in this ST.BAT file and go directly to the internal template WEST01.TPL without attempting to contact the SolarTrak.

Switches are interpreted in the order they appear on the command line and the last will always apply.

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Moving right along.... Type:

@echo off

c:

cd \solartrk

stn /c3 /tEAST01 /m %1 %2 %3

(put in the one's you really need)

Press Alt-F

(displays dropdown File

Menu)

Press X

(initiates Exit)

Press Y

(answer 'Yes' to

Saving File)

C:\SOLARTRK\> COPY ST.BAT ..

(Puts a copy in the root directory)

Or copy ST.BAT to any directory you normally use for such things in the standard DOS system search path.

Windows Users:

Once this batch file has been created, a DeskTop icon can be created by bringing up Windows Explorer, right-clicking on ST.BAT and selecting 'Create Shortcut'. Move the new shortcut to the DeskTop directory. A full screen window can be established by selecting 'Properties' after right-clicking on the new icon. Assert the following options under the listed tabs:

PROGRAM tab:

Working: indicate the directory in which you put the PCI software

C:\SolarTrk

Run: Maximized

Check box **Close on Exit**

SCREEN tab:

Under **Usage**

Check box **Full-screen**

Misc tab:

Under **Foreground**

Un-Check box **Allow Screen Saver**

Under **Background**

Check box **Always Suspend**

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INITIAL STARTUP:

Connect a serial extension cable (specifically **not** a Null-Modem cable) to the portable's male 9 pin comm port and the SolarTrak's female 9 pin connector. The important pins are 2,3 and 5. They must connect directly to their counterparts at the other end. A cable can be made from good quality telephone wire or shielded signal wire and can be as long as 100 feet and work perfectly.

***** Warning: Do not leave cable attached to SolarTrak® or computer when not in use!**

If necessary: Insert the SolarTrak® boot disk into the A: drive and turn on the computer.

“Main Control Panel” - After the PC Interface program starts, you should see the screen shown below. Later as one enters different sections of the program, this title bar will change. The following instructions will reference the appropriate title bar for each set of instructions.

The screenshot shows a text-based interface on a blue background. At the top left is a white box labeled "Screen Title". At the top right is a "Spinner" icon, a circle with radiating lines, and a label "Spinner". Below the spinner is a dashed box containing "Sun Position Information" with values for Zenith (19.24), Azimuth (51.37), and Elevation (70.76). A label "Indicates direct communication with SolarTrak Unit 4" points to the top left. A label "Spinning indicates active communication" points to the spinner. Below this is a yellow box labeled "Main Control Panel". Inside it, the text "SolarTrak(00004)" is circled, with a label "Current SolarTrak Operational Status". The time and date "9:45:06 7/13/2001" are also circled, with a label "Time and Date from SolarTrak". The "Array Control Menu" is circled, with a label "Function Key Menu". The "Sun Angle" and "Array Angle" sections are circled, with a label "Sun Position in Degrees and turncounts". The "Axis 1" and "Axis 2" labels are circled, with a label "Actual Array Position". At the bottom, function keys are listed: F1:HELP, F2:STOW, F3:TRACK, F5:MANUAL, F9:SET TIME, F10:EXIT.

Sun Position Information	
Zenith	19.24
Azimuth	51.37
Elevation	70.76

Sun Angle		Array Angle		Count	Wind(Mph)
54.56	1292	Axis 1	54.51	1291	0.0
82.12	522	Axis 2	82.17	522	Temp. (F) 91.4
					Batt. (V) 13.8

F1:HELP F2:STOW F3:TRACK F5:MANUAL F9:SET TIME F10:EXIT

Please note the spinning indicator in the center of the 5th line above the “Axis 1” label. Proper communication between the PC and the SolarTrak produces the effect of the ‘Spinner’ spinning clockwise, moving about one position (1/8th turn) per second. The spinner must be spinning in order to enter commands to the program.

There are two reasons why the ‘Spinner’ may spin rapidly instead of its normally slower rate.

PC Interface Manual and Installation Guide

1: When the PC Interface is accessing the internal copy (called a Template and must be downloaded from the SolarTrak or Loaded from a file, see File Operations) the 'SolarTrak[00004]' is replaced by 'File[filename]' and the spinner spins rapidly because there is no communication delay when accessing internal memory. 'Filename' will read 'download' if the template was just downloaded from the controller. Toggle back and forth between the SolarTrak and the internal template by pressing 'T' on the keyboard.

2: There is a communication problem between the computer and the SolarTrak. Likely causes of communication problems include: computer serial port turned off, computer serial port is set to a comm port other than comm port 1 (the default value for the PC Interface program).

If the communications between the computer and the SolarTrak are correctly set, the spinning indicator should step slowly from one position to the next. This indicates that the computer is polling the SolarTrak.

If the spinner is not spinning there are two typical reasons.

1: The communications have been interrupted on a working comm line, in which case the current operating status should read 'Off-Line'.

2: The program is waiting for user input to an activated command such as changing a parameter value.

If the PC Interface software is incorrectly directed to a non-existent comm port it will get garbage in the comm port status and think there is always a new character to read and spin fast as a result. If it is directed to a comm port that exists but is not properly connected to the SolarTrak® it will never get a new character and not spin at all.

Entering a Command

To invoke a command, begin by pressing the forward slash '/'. The Command box will replace the standard sun position display.

The available commands are (abbreviation):

- 1: Configure (CFG) – Set geometric, mathematical and logical parameters for tracking.
- 2: Calibrate (CAL) – Collect, reduce and display data and error function for tilted tower.
- 3: Target (TGT) – Set beam target bearing for HelioTrak® Units

The screenshot shows a blue background with a white box labeled "Command Input Block" containing a yellow box with the text "Enter Command:> CFG". A white arrow points from the box to the yellow box. In the top right corner, there is a sun icon. Below the command input, there is a yellow box labeled "Command Input" containing the following text:

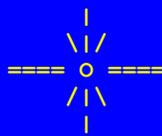
```
SolarTrak[00004] Sun Angle - Count \ Array Angle - Count Wind (Mph) 0.0
Manual 54.56 1292 Axis 1 54.51 1291 Temp. (F) 91.4
9:45:06 7/13/2001 82.12 522 Axis 2 82.17 522 Batt. (V) 13.8
Array Control Menu
F1:HELP F2:STOW F3:TRACK F5:MANUAL F9:SET TIME F10:EXIT
```

The Configure (CFG) Command:

The CFG command will initially produce the following screen:

```

Ax1 Array Positn Cnt: 1291
Ax2 Array Positn Cnt: 522
Latitude (-90 to 90): 35.0525
Longitude (0 to 360): 106.0055
Time Zone (0 to 23) : 7
Clock Adjust:Sec/Day: -4
Clock Adjust:Sec/Wk : -3
Batt Charger State : off
Batt Stw A/D (0-255): 186
Battery Conver Factr: 0.1175
Battery Charger On : 240
Battery Charge Limit: 245
    
```



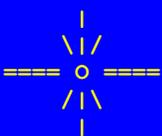
```

=====
| SolarTrak Basic Configuration Parameters |
=====
SolarTrak[00004]  Sun Angle - Count \  Array Angle - Count Wind(Mph)  0.0
Manual          54.56      1292 Axis 1   54.51      1291 Temp. (F)  91.4
9:45:06  7/13/2001  82.12      522 Axis 2   82.17      522 Batt. (V)  13.8
Configuration Menu
F1:HELP  F4:Set Screwjack  F5:MANUAL F9:Set Time  F10:Done
    
```

There are two avenues of approach to adjust things. Press a function key to execute an operation or input information directly into the SolarTrak® using the parameter tables displayed on the upper screen. There are several groups (screens) of adjustable parameters. They can be accessed using the PgUp and PgDn keys. To change a parameter, highlight the offending value using the UP and DOWN arrows then press 'ENTER:

```

Ax1 Array Positn Cnt: 1291
Ax2 Array Positn Cnt: 522
Latitude (-90 to 90): 35.0525
Longitude (0 to 360): 106.0055
Time Zone (0 to 23) : 7
Clock Adjust:Sec/Day: -4
Clock Adjust:Sec/Wk : -3
Batt Charger State : OFF
Batt Stw A/D (0-255): 242
Battery Conver Factr: 0.1175
Battery Charger On : 240
Battery Charge Limit: 245
    
```



Parameter Input Line

Current

Input Value

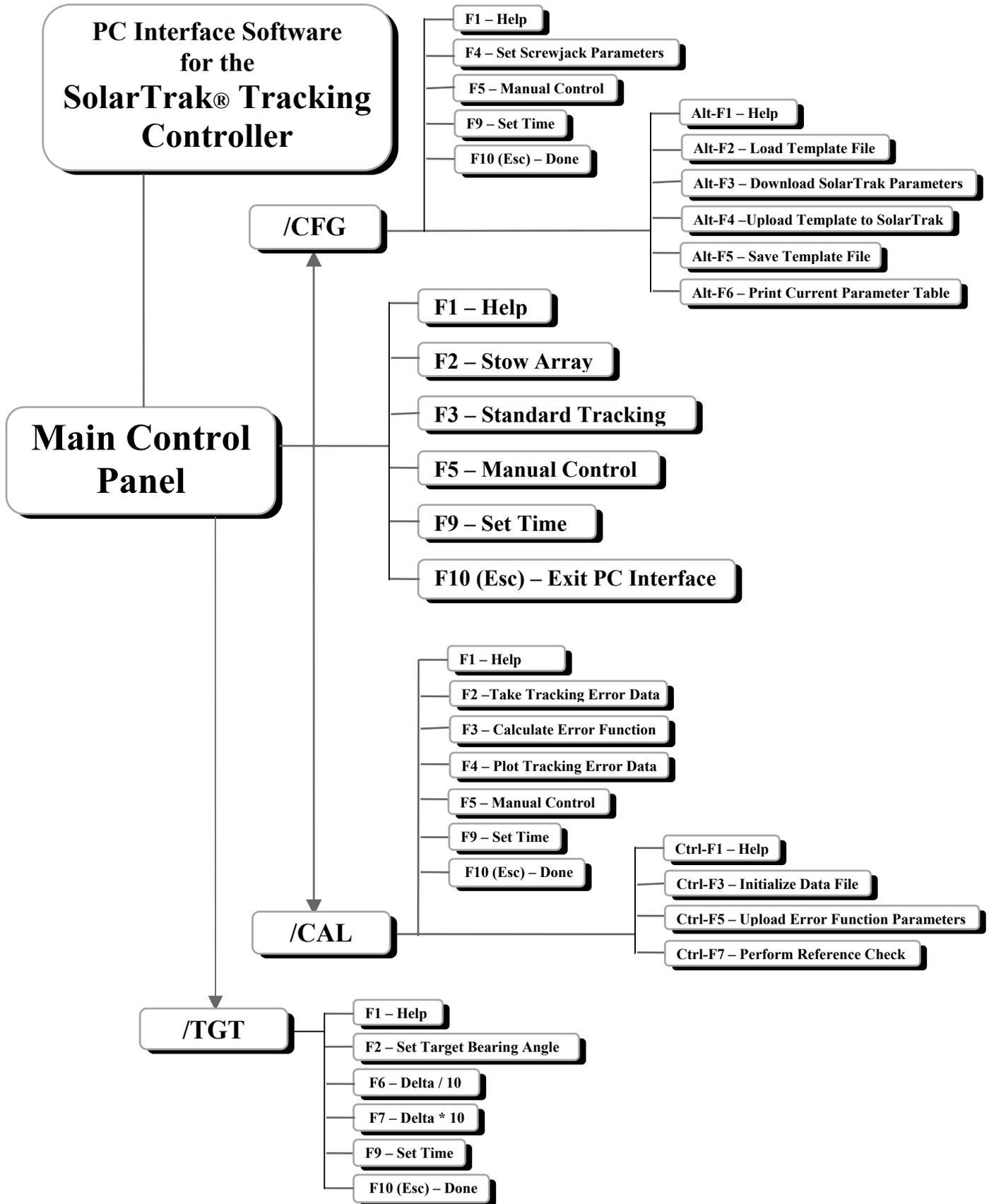
Note that spinner will freeze while waiting for input

```

=====
| SolarTrak Basic Configuration Parameters |
=====
>> Longitude (0 to 360) [106.0055]: 85.0773
SolarTrak[00004]  Sun Angle - Count \  Array Angle - Count Wind(Mph)  .0
Manual          54.56      1292 Axis 1   54.51      1291 Temp. (F)  .4
9:45:06  7/13/2001  82.12      522 Axis 2   82.17      522 Batt. (V)  13.8
Array Control Menu
F1:HELP  F4:Set Screwjack  F5:MANUAL F9:Set Time  F10:Done
    
```

Press ENTER to keep the current value or enter a new value then press ENTER. To TOGGLE a value ON or OFF (or whatever binary function), press ENTER then the SPACE BAR.

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Parameter Tables:

Once in either the configuration or calibration menu, there are several groups (screens) of parameters that can be displayed on the screen by using the PgUp and PgDn keys. They are:

Basic Configuration Parameters	- Common Setup Values
Useful Calibration Parameters	- Status and Adjustment Parameters
Limit and Stow Parameters	- Software Limits and Stow Conditions
Site Parameters	- Site and Array General Description
Drive Parameters	- Geometric Descriptive Parameters
Reference Sensor Parameters	- Reference Check Conditions and Offsets
Misalignment Parameters	- Tower Misalignment Error Correction Function
Miscellaneous Parameters	- Unit #, Battery Charge Parameters and more...
Tracking Status	- Stow status, current Sun Values, Array Position
Toggle Switch Settings	- Access to keyboard control, on-board switch
status	
Thermal Clock Correction Values	- Data on thermal clock correction function
OUCH Circuit Control	- Control of Optional OUCH (defocussing) function

Appendix A. SolarTrak® Configuration Parameters

SolarTrak Basic Configuration Parameters

```

Ax1 Array Positn Cnt:      1291
Ax2 Array Positn Cnt:      522
Latitude (-90 to 90):     35.0525
Longitude (0 to 360):     106.0055
Time Zone (0 to 23) :      7
Clock Adjust:Sec/Day:     -4
Clock Adjust:Sec/Wk :     -3
Batt Charger State : ON
Batt Stw A/D (0-255):     186
Battery Conver Factr:     0.1175
Battery Charger On :      240
Battery Charge Limit:     245
    
```

SolarTrak Basic Configuration Parameters							
SolarTrak[00004]	Sun Angle - Count	\	Array Angle - Count	Wind(Mph)	0.0		
Manual	54.56	1292	Axis 1	54.51	1291	Temp. (F)	91.4
9:45:06	7/13/2001	82.12	Axis 2	82.17	522	Batt. (V)	13.8
Configuration Menu							
F1:HELP F4:Set Screwjack F5:MANUAL F9:Set Time F10:Done							

Ax1 Array Positn Cnt: (Status Variable) – Axis 1 Array Position Count – Current position of the primary axis in counts provided a proper reference check has been performed. Also displayed in lower five lines of screen on Axis 1 line on the right side under the word Count.

Ax2 Array Positn Cnt: (Status Variable) – Axis 2 Array Position Count – Current position of the secondary axis in counts provided a proper reference check has been performed. Also displayed in lower five lines of screen on Axis 2 line on the right side under the word Count.

Latitude (-90 to 90): (Parameter) – Local latitude in degrees – positive for northern hemisphere, negative for southern.

Longitude (0 to 360): (Parameter) – Local longitude in degrees – must be positive measured westward from Greenwich, U.K.

Time Zone (0 to 23) : (Parameter) – Local Time zone – must be positive measured westward from Greenwich, U.K. – India (on half zone) must use time zone = 0 and keep time in Zulu (Greenwich Mean Time).

Clock Adjust: Sec/Day: (Parameter)

Adjustment to clock made on daily basis. This value will be added to the current time at 12:15 AM each day. The SolarTrak will compute this value automatically if set with time-set command from either PC Interface or User Interface Board. The value will be positive if clock runs slow or negative if clock runs fast. This is the **correction** to the clock, not the error.

May be calculated by hand using following method. All time setting must be done with atomic standard time, NEVER use daylight savings time. Each calibration step should be done, ideally, at about the same time of day. Calibration generally takes four time-set iterations using the following schedule.

1. Set time and date – record date that time was set.
2. Wait a week or so – set time – make changes to parameters – record date
3. Wait a month – set time – make changes to parameters – record date
4. Wait two months – set time – make changes – record date

After steps 2, 3 and 4:

1. Count number of days since last time-set. (**days**)
2. Determine number of seconds fast or slow (**secs**, use minus if fast, plus if slow for computations).
3. If the magnitude (sign not considered) of **secs** is less than **days** skip to step 7 else,
4. Divide secs by days and write down the whole part (left of decimal point).

$$\frac{\text{secs}}{\text{days}} = \text{secs-per-day}$$

Clock Adjust: Sec/Wk : (Parameter)

5. Take the remainder and divide by the number of weeks that have passed. The full equation will be:

$$\text{Sec/Wk} = (\text{secs} - (\text{secs-per-day} * \text{days})) / (\text{days} / 7)$$

6. Round off the result to the nearest whole second.

Batt Charger State : (Status Variable)

The battery is actually charged at a much higher frequency than can be shown on the screen (which is updated only about once per second). While this screen is active, if the battery is in its operating range, that is between Battery Charge On and Battery Charge Limit, this value will be changing from On to Off somewhat randomly and simply indicates a full charge. If the battery is low, this value should remain On.

The SolarTrak® Controller System

Batt Stw A/D (0-255): (Status Variable)

The battery voltage level is converted to a digital number by an Analog-to-Digital circuit within the CPU. The voltage is first split down to a 0 – 5 volt range then converted to a number from 0 to 255 (8 binary bits). All decisions regarding the battery are based on this value.

Battery Conver Factr: (Parameter)

This conversion factor is the relationship between the A/D reading and the actual voltage. To set this parameter, measure the voltage at the battery (across both batteries if a pair) then divide that by the A/D reading above.

$$\text{BCF} = \frac{\text{Measured Voltage}}{\text{A/D Reading}}$$

Battery Charger On : (Parameter)

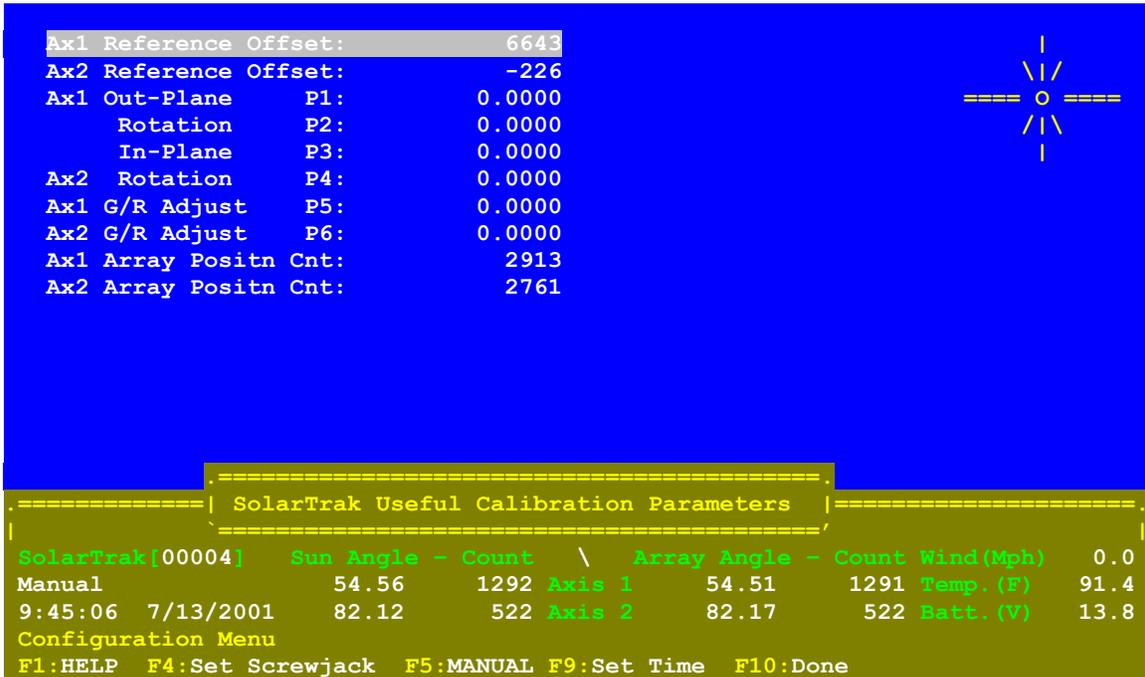
The Charger On parameter should be about a half-volt lower than the Charge Limit. See below.

Battery Charge Limit: (Parameter)

Ascertain the appropriate charge cutoff voltage (limit) for the particular batteries being used. Many 12-volt batteries use 14.2 volts as a proper charge level. Two batteries would use twice that or 28.4 volts. Compute the Battery Charge Limit using the newly computed Battery Conversion Factor according to:

$$\text{BCL} = \frac{28.4}{\text{BCF}} \quad (\text{For two batteries})$$

SolarTrak Basic Configuration Parameters



Ax1 Reference Offset: (Parameter)

Ax2 Reference Offset: (Parameter)

Ax1 Out-Plane P1: (Parameter)

Ax1 Rotation P2: (Parameter)

Ax1 In-Plane P3: (Parameter)

Ax2 Rotation P4: (Parameter)

Ax1 G/R Adjust: (Parameter)

Ax2 G/R Adjust: (Parameter)

Ax1 Array Position Count: (Status Variable)

Ax2 Array Position Count: (Status Variable)

Limit and Stow Parameters – Soft Limits and Control Logic References

```

Ax1 +Limit Position :      52   Wind: Sec Until Stow:      5
Ax1 -Limit Position :    -1286  Wind: Min to Wait   :      5
Ax2 +Limit Position :     4247  Wind: Stow A/D Level:     35
Ax2 -Limit Position :      327  Wind: Active Hi?   :    No
Ax1 Night Stow Pos.  :     1300  Batt: Sec Until Stow:     2
Ax1 Emer. Stow Pos.  :     6704  Batt: Min to Wait   :     30
Ax1 Em Stow Allowed?:    No      Batt: Stow A/D Level:    150
Ax2 Night Stow Pos.  :     1600  Batt: Active Hi?   :    No
Ax2 Emer. Stow Pos.  :      450
Ax2 Em Stow Allowed?:    No

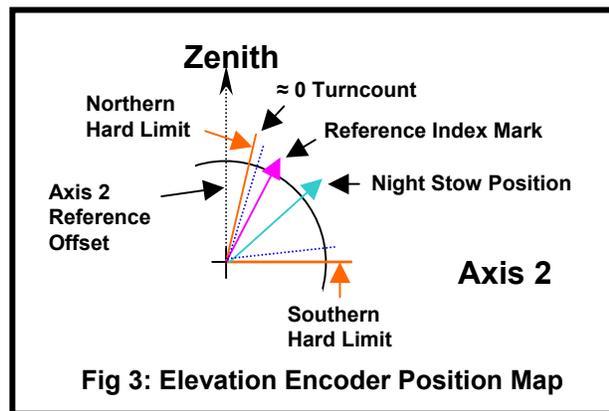
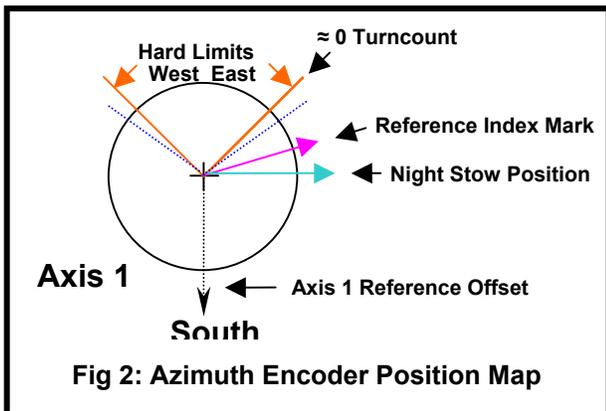
===== SolarTrak Limit and Stow Parameters =====
SolarTrak[00004]  Sun Angle - Count \  Array Angle - Count Wind(Mph)  0.0
Manual          54.56   1292 Axis 1   54.51   1291 Temp.(F)   91.4
9:45:06  7/13/2001  82.12   522 Axis 2   82.17   522 Batt.(V)   13.8
Configuration Menu
F1:HELP  F4:Set Screwjack  F5:MANUAL  F9:Set Time  F10:Done
    
```

Ax1 +Limit Position: The largest allowable turncount of the primary axis reachable by the controller under automatic operation. The value is usually set 2 or 3 degrees of rotation before the unit would hit its hard limit switch. See the blue dotted lines near the hard limits in the figures below.

Ax1 -Limit Position: The smallest allowable turncount of the primary axis.

Ax2 +Limit Position: Same as Ax1.

Ax2 -Limit Position: Same as Ax1.



Ax1 Night Stow Pos. Each night when the Sun’s zenith angle exceeds the **Night Stow Zenith Angle**, the array moves to a predefined stow position that can be set by the user. To set the limits, be sure the array is initialized (has recently performed a reference check so that the

turn count is accurate), and then manually drive the array to the desired stow position. View the array position counts, 'Ax1 Array Position Count' and 'Ax2 Array Position Count' in the **Tracking Status menu** or on the SolarTrak® LCD) and copy them to the 'Ax1 Night Stow Pos.' and 'Ax2 Night Stow Position' parameters.

Ax1 Emerg Stow Pos.: The controller drives to this position in the primary axis if a wind stow, battery stow, or emergency stow (toggle input line) condition is activated. Use the same procedure as Night Stow to set this value.

Ax1 Emer. Stow Allowed? If this is set to NO (advised only for Az/El systems) the controller will continue to track the sun in the primary axis while an emergency stow condition exists.

Ax2 Night Stow Position: Same as Ax1.

Ax2 Emerg Stow Pos.: Same as Ax1.

Ax2 Emer. Stow Allowed?: Same as Ax1.

Night Stow Zenith Angle: The local zenith angle of the sun is used by the controller to determine whether to be in the track or night stow mode. If the local zenith angle of the sun (which depends on the stored latitude and longitude personality parameters and the time and date) is greater than this value, the controller drives to the night stow position. A night stow zenith angle of $>90^\circ$ causes night stow when the sun is below the horizon.

Emerg Pri'ty Over Nite?: A potential priority conflict arises when the controller receives an emergency stow signal when the controller would normally go to the night stow position. (Emergency stow here includes wind stow and battery stow as well as the toggle stow input.) To resolve this conflict, the user indicates which takes priority. If this parameter is set to YES, the controller will go to the emergency stow position. If not, the controller will go to the night stow position. Thus a user can specify a night stow position that may be in a dangerous orientation under high winds by setting this parameter to YES to ensure the tracker will go to the protected stow position under an emergency stow condition.

Wind: Sec. Until Stow (WSTOWSEC)

A short or spurious signal on the wind stow input line could cause the controller to stow for many minutes. To prevent this, the user can set the minimum stow signal length in seconds that is required before the controller initiates a wind stow. The setting depends to some extent on the dynamics of the wind sensor, but a value of 2 to 3 seconds is reasonable.

Wind: Min to Wait (WSTOWMIN)

Once a wind stow is initiated, the controller will drive to stow and stay there for WSTOWMIN minutes to prevent cycling in and out of stow with each gust. After the tracker has reached the stow position, if a new wind stow signal is received, the end-of-stow time is adjusted to be WSTOWMIN after the last stow signal. The end-of-stow minute and hour are accessible in the user-interface board status variables. WSTOWMIN should be set to a value greater than the time it takes to get to the stow position.

The SolarTrak® Controller System

Wind: Stow A/D Level (WINDSTOW)

The wind stow line is connected to an 8-bit analog-to-digital (A/D) convertor on the microcontroller. Thus the signal voltage level which initiates wind stow can be set to be between the A/D reference voltages, V_{rl} and V_{rh}, which are accessible at the control board terminal blocks. Normally V_{rl} and V_{rh} are set to 0 and 5 volts, although sometimes they may be set to values other than these (by making a voltage divider using resistors soldered in the holes near the reference voltage terminals) if required by the self-alignment current sensor. The A/D convertor converts the input voltage level to a 1-byte integer (with a value from 0 to 255) ranging from V_{rl} to V_{rh}. WINDSTOW determines the wind stow actuation level in these units. If using a digital input, and V_{rl} and V_{rh} are set to 0 and 5 volts, WINDSTOW should be set to 128 counts.

When using an anemometer input, this level is set to the MPH over which the array should stow.

Wind: Active High? (WINDHI)

This bit flag determines if the wind stow sensor input line is active-high. This line is pulled down by a 10K-ohm resistor on the control boards. If used with a normally open sensor that closes to 5 volts when activated (or if the wind sensor is not connected), this variable should be set to “Yes” (active-high). If used with a normally closed sensor connected to 5 volts that opens and is pulled low when activated, this variable should be set to “No” (active-low). If the wind stow sensor is analog, one may want to disconnect the pulldown resistor. (Appendices V and VI show where this would be done.) (Not used with anemometer).

Batt: Sec Until Stow (TSTOWSEC)

This parameter is identical to WSTOWSEC (see above), but it operates on the undervoltage stow line instead of the wind stow line.

Batt: Min to Wait (TSTOWMIN)

This parameter is identical to WSTOWMIN (see above), but it operates on the undervoltage stow line instead of the wind stow line.

Batt: Stow A/D Level (THERMSTW)

This parameter is identical to WINDSTOW (see above), but it operates on the undervoltage stow line instead of the wind stow line.

Batt: Active High? (THERMHI)

This parameter is identical to WINDHI (see above), but it operates on the undervoltage stow line instead of the wind stow line.

Site Parameters

Site parameters include installation location and type of tracker parameters.

Latitude (LAT)

Latitude accuracy needs to be only a degree or so if one plans to perform a self-alignment (or manual alignment) after installation. An error in the latitude parameter will affect tracking performance just as an installation misalignment of the primary axis would. It can also cause a small error (of at most a few minutes for a few degrees of error) in the night-stow and morning-wake times.

Longitude (LONG)

Longitude errors cause an effect similar to Latitude errors (see above).

Time Zone (ZONE)

The clock should be set to local standard (not daylight) time. The ZONE value is used to determine the time at Greenwich. If using Eastern Standard Time, ZONE should be 5 hours. Pacific Standard Time corresponds to ZONE equal to 8 hours.

Azim-Elev Tracker? (AZELAXIS)

This bit parameter and the next three determine which of the four standard coordinate systems to use for the tracker description. Thus, only one of the four tracker bit parameters should be selected. AZELAXIS is set if the tracker has a vertical primary axis. (The primary axis does not move relative to the earth.)

Polar-Decl Tracker? (POLAR)

Set this bit if using a polar-axis tracker with the primary axis oriented parallel to the earth's axis.

East-West Tracker? (EWAXIS)

Set this bit if using a tracker with the primary axis oriented east-west.

North-South Tracker? (NSAXIS)

Set this bit if using a tracker with the primary axis oriented north-south.

Single-Axis Tracker? (SINGLAX)

Set this bit if using a tracker with no secondary axis.

Drive Parameters

Parameters describing the drive train, tracking dynamics, and joystick direction assignments are included in this category.

Ax1 Gear Ratio (RATIOA1)

The primary-axis gear ratio is the number of A/B turn count sensor cycles per radian of rotation of the primary axis. (There are 2π radians per revolution.) If using a screwjack, it is the number of A/B turn count sensor cycles per unit of extension of screwjack (the unit being the unit used to characterize the lengths in screwjack parameters 2 and 3). The sign of RATIOA1 determines the direction that the primary-axis turn count increments. During installation it is important that one knows the direction of incrementing turn count because it must correspond to the 1P motor drive direction and the 1P limit sensor. If RATIOA1 is positive, the turn count increments in the same direction as the tracking angle. If it is negative, the turn count decrements in the direction the tracking angle increments. The direction of incrementing tracking angle is determined by the conventions of the chosen standard coordinate system and the sign of the local latitude. (The coordinate system is determined by the tracker type selection parameters in the site parameter menu.) Figure UM18 defines the conventions for the various coordinate systems and hemispheres. The direction of positive turn count may be important if there is tracker backlash because the self-alignment routine scans in the positive-count direction. In this case there may be some preference to making the positive-count direction be the direction of sun travel.

Ax1 Screwjack Param #1 (X1SCRJK1)

X1SCRJK1 is the angle b between R1 and R2 when the tracking angle (in coordinates of the misaligned tracker after adjustment for all misalignment parameters) is zero. In Fig. UM20, this is when $S1=0$. One can check the value of X1SCRJK1 by checking that the screwjack extension length, L , is properly computed by

$$L = \sqrt{X1SCRJK3 + X1SCRJK2 \cdot \cos[S1 + X1SCRJK1]}. \quad \text{Eqn. UM1}$$

The controller needs to compute $S1$ from L by performing the inverse of the function given in Eq. (UM1), so $S1 + X1SCRJK1$ must be between 0° and 180° in the operational range of the screwjack extension. As an example, the Winsmith drive uses a screwjack in axis 2 which has a 5.75" vertical separation between the two screwjack hinge points when the tracker is horizontal. R1 is 40° and R2 is 40.411° . X2SCRJK1 is equal to angle b , which is equal to $\text{atan}\{5.75/40\} = 8.176^\circ$. The zero tracking angle is often different from the zero turn count direction by an amount saved in the REFOSA1 parameter. REFOSA1 is equal to the screwjack extension length between the zero tracking angle and the angle reference sensor multiplied by the counts-per-length ratio, RATIO1. The turn count value is thus equal to:

$$\text{SUNCNT1} = \text{REFOSA1} + L \cdot \text{RATIO1} \quad \text{Eqn. UM2}$$

Ax1 Screwjack Param #2 (X1SCRJK2)

X1SCRJK2 has a value of $+2 \cdot R1 \cdot R2$, where R1 and R2 are in the same units of length use by the gear ratio parameter RATIO1 in computing the counts-per-length conversion.

Figure UM20 defines R1 and R2, the lengths from the tracker hinge to the screwjack hinge points. As S1 increases in Eq. (UM1), $\cos[S1 + X1SCRJK1]$ decreases, so if L increases as S1 increases, the sign of X1SCRJK2 must be negative. If the screwjack is on the other side of the tracker so that L decreases as S1 increases, the sign of X1SCRJK2 is positive. In the Winsmith drive example, the sun angle increases as the screwjack lengthens, so X2SCRJK2 has a value of $-2.40.40.411 = -3232.88$ in².

Ax1 Screwjack Param #3 (X1SCRJK3)

X1SCRJK3 has a value of R12+R22. R1 and R2 are defined in Fig. UM20 and are discussed in X1SCRJK2, above. In the Winsmith drive example, X2SCRJK3 has a value of $402+40.4112=3233.05$ in². Ax2 Gear Ratio (RATIOA2) The secondary-axis gear ratio is the number of A/B turn count sensor cycles per radian of rotation of the secondary axis. If using a screwjack, it is the number of A/B turn count sensor cycles per unit of extension of screwjack (the unit being the unit used to characterize the lengths in screwjack parameters 2 and 3). (See RATIOA1 for a discussion of the sign of RATIOA2.)

Ax2 Screwjack Param #1 (X2SCRJK1)

X2SCRJK1 is identical to X1SCRJK1, but for Axis 2.

Ax2 Screwjack Param #2 (X2SCRJK2)

X2SCRJK2 is identical to X1SCRJK2, but for Axis 2.

Ax2 Screwjack Param #3 (X2SCRJK3)

X2SCRJK3 is identical to X1SCRJK3, but for Axis 2.

Ax1 Coast Counts (COASTA1)

COASTA1 is an estimate of the number of turn counts the tracker takes to coast from full motor speed until stopped. It is used when in the turn-count motor control mode to determine how many counts ahead of the target to stop the motor in the primary axis. The user can try values (by manually offsetting the tracker and then returning it to the track mode) until secondary updates are minimized.

Ax1 Time/Coast Switch (TIMECNT1)

If using the timed-motor control approach for accurate tracking with small position updates, TIMECNT1 determines how large of a turn count move is needed to switch over to the turn-count motor control mode. TIMECNT1 should be larger than COASTA1 so that the tracker does not hunt about the target.

Ax1 Deadband Counts (DEADBND1)

If the tracker is within this number of counts of the target count in the positive axis, no position update will occur. If DEADBND1 is set too small, hunting about the target may occur. If set too large, tracking accuracy suffers.

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Ax2 Coast Counts (COASTA2)

COASTA2 is an estimate of the number of turn counts the tracker takes to coast from full motor speed to stopped. It is used when in the turn-count motor control mode to determine how many counts ahead of the target to stop the motor in the secondary axis. The user can try values (by manually offsetting the tracker and then returning it to the track mode) until secondary updates are minimized.

Ax2 Time/Coast Switch (TIMECNT2)

If using the timed-motor control approach for accurate tracking with small position updates, TIMECNT2 determines how large of a turn count move is needed to switch over to the turn-count motor control mode. TIMECNT2 should be larger than COASTA2 so that the tracker does not hunt about the target.

Ax2 Deadband Counts (DEADBND2)

If the tracker is within this number of counts of the target count in the secondary axis, no position update will occur. If DEADBND2 is set too small, hunting about the target may occur. If set too large, tracking accuracy suffers.

Timed Motor-On Mode? (TIMEON)

If this bit parameter is set, the controller will turn the motors on for an optimum number of hundredths of a second when the distance to the target is less than TIMECNT1 (or TIMECNT2) turn counts. Generally this gives more accurate tracking. Otherwise, the controller turns the motor on until either the distance to the target is COASTA1 (or COASTA2) counts, or until at least one count has registered.

Full-Deadband Mode? (OVERSHOT)

Normally, in the turn-count motor control mode, the tracker stops the motor COASTA1 or COASTA2 counts before the target. If the OVERSHOT bit parameter is set, the controller stops the motor COASTA1 or COASTA2 counts before the edge of the deadband on the far side of the target. When using a larger deadband, this can minimize the frequency of position updates at the expense of tracking accuracy by allowing the sun to traverse the full width of the deadband on either side of the target before updating position.

Ax1 +Joystick Mask (JOY1P)

This parameter, along with the next three parameters, enables the user to assign directions of joystick actuation on the control board to the most appropriate motor drive directions. Each of the four directions on the control board have a bit mask value corresponding to its input port line. Up (towards the sensor terminal strip) has an input mask of 20 (in hexadecimal). Right has a mask of 10. Down has a mask value of 08, and Left has a value of 04. If one wants the left joystick direction to drive the tracker in the primary-axis, positive-count direction, one would set JOY1P to 04. If one wants the right joystick direction to drive the tracker in the primary-axis, positive-count direction, one would set JOY1P to 10, etc. Obviously one can run into problems if one assigns the same joystick direction to multiple tracker directions.

Ax1 -Joystick Mask (JOY1N)

See JOY1P above.

Ax2 +Joystick Mask (JOY2P)

See JOY1P above.

Ax2 -Joystick Mask (JOY2N)

See JOY1P above.

Motor Delay (Sec) (MTRDELAY)

The user can set the minimum motor cycling period in seconds to prevent instantaneous reversal or on/off cycling of motors that could lead to excessive duration of startup currents and motor overheating. Normally a delay of 5 seconds is acceptable. Mtr-Turn Chk Intervl (CNTINCR) This parameter determines the frequency of initiation of the interrupt routine that checks for new motor turn counts and limit switch activation. The normal setting is 3000 E cycles which results in an interrupt frequency of 1.5 msec. [An 8 MHz crystal oscillator gives a 2 MHz clock (E cycle) rate.] If a turn count checking frequency faster than this is needed, one can set this value somewhat lower. The very minimum setting is about 400 E cycles (0.2 msec), the length of time the turn count interrupt routine takes to run. This setting would leave little time for other processing. Track Output Active Hi? (TRACKHI) The controller provides a track/stow output line to indicate whether the tracker has reached a stow position or else is potentially pointed at the sun. One can use the output line to activate receiver cooling for actively cooled systems. To better interface with the user's electronics, the output can be set to be active-high or active-low. If the TRACKHI bit parameter is set, the output line will be high (5 volts) when the tracker is moving, and low (ground) after reaching either the night or emergency stow position. If TRACKHI is cleared, the opposite output is provided.

Reference Sensor Parameters

Several parameters control the daily angle referencing routine which is used to ensure the turn counters are accurately zeroed at a physical reference sensors.

Ax1 Reference Offset (REFOSA1)

REFOSA1 contains the offset in turn counts between the zero tracking angle and the angle reference point in the primary axis.

Ax1 Ref. Setup Range (REFSET1)

REFSET1 determines the initial motion (in turn counts) that the controller moves to drive the unit off the end-point limit switch before it seeks its reference point in the daily reference check. Hysteresis in the switch must be accounted for to avoid shifting of the reference point.

Ax2 Reference Offset (REFOSA2)

REFOSA2 contains the offset in turn counts between the zero tracking angle and the reference point in the secondary axis.

Ax2 Ref. Setup Range (REFSET2)

See the discussion for REFSET1, above.

Ref. Reset in Morning? (MORNREF)

If this bit parameter is set, the controller will run the angle reference check routine upon waking up in the morning. It also will run the routine before tracking upon powering up, which may become an annoyance during checkout.

Ref. Reset in Evening? (NITEREF)

If this bit parameter is set, the controller will run the angle reference check routine upon going to night stow. The user should select either the NITEREF or MORNREF option to ensure the angle reference check is performed regularly. Both can also be set. If the tracker is night stowed pointing towards the east, the NITEREF routine will enable the controller to perform the reference check on its way to night stow after sunset.

Alignment Parameters

The alignment routine is a special routine normally run only once during installation to determine the tracker's unique misalignment parameters. It is implemented using the PC Interface to collect data and compute the following equation coefficients to allow geometric correction by the SolarTrak controller on the fly while tracking according to the following equations:

$$\text{Axis 1 Error} = - [P1 * \text{SIN}(AX1) / \text{TAN}(AX2)] + P2 - [P3 * \text{COS}(AX1) / \text{TAN}(AX2)] - (P5 * AX1)$$

$$\text{Axis 2 Error} = [P1 * \text{COS}(AX1)] - [P3 * \text{SIN}(AX1)] + P4 - (P6 * AX2)$$

Align Parameter #1 (P1)

The six misalignment parameters characterize different installation alignment errors of the tracker on which the controller is mounted. These parameters are used to adjust the computed sun angle to the tracking angle in the tracker's misaligned coordinates. Although one can set initial values for these parameters, normally all six are set to zero initially, and the self-alignment routine computes the optimum values for four, five or six parameters (depending on how many of the optional parameters are enabled). It is generally worthwhile to record the computed values of these parameters after self-alignment. Misalignment parameter #1 characterizes the angular misalignment (tilt) of the primary axis in the direction of the primary axis angle reference (i.e. south tilt of the azimuth axis in an azimuth/elevation tracker located in the northern hemisphere).

Align Parameter #2 (P2)

(See P1 above.) Misalignment parameter #2 characterizes the angular offset of the primary axis angle reference in the positive-angle direction. (i.e. location of the azimuth angle reference sensor east of south plus REFOSA1 turn counts, in an azimuth/elevation tracker located in the northern hemisphere.)

Align Parameter #3 (P3)

(See P1 above.) Misalignment parameter #3 characterizes the angular misalignment (tilt) of the primary axis normal to the primary axis angle reference in the negative-angle direction (i.e. west tilt of the azimuth axis in an azimuth/elevation tracker located in the northern hemisphere).

Align Parameter #4 (P4)

(See P1 above.) Misalignment parameter #4 characterizes the angular offset of the secondary axis angle reference in the positive-angle direction. (i.e. location of the elevation angle reference sensor below zenith plus REFOSA2 turn counts, in an azimuth/elevation tracker located in the northern hemisphere.)

Align Parameter #5 (P5)

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(See P1 above.) Misalignment parameter #5 characterizes the fractional increase in the primary axis gear ratio (RATIOA1) from the value saved in RATIOA1.

Align Parameter #6 (P6)

(See P1 above.) Misalignment parameter #6 characterizes the fractional increase in the secondary axis gear ratio (RATIOA2) from the value saved in RATIOA2.

Miscellaneous Parameters

Unit # : 1
Static Azimuth : 0.0000
Static Zenith : 0.0000
STAR Configuration : 0x00
Refl. Boot Status : 0x00
Ax1 Tgt Az (Def) : 0.0000
Ax2 Tgt Zn (Def) : 0.0000
Ax1 Tgt Az (Aux) : 0.0000
Ax2 Tgt Zn (Aux) : 0.0000
Ax1 Target Azimuth : -28.6479
Ax2 Target Zenith : -28.6479
Clock Adjust:Sec/Day: -5
Clock Adjust:Sec/Wk : -1
Battery Conver Factr: 0.1180
Battery Charger On : 245
Battery Charge Limit: 250
Wind Avg. Wndw 2-14 : 6
Wind Conv. Factor : 1.7080
Ax1 Aux Stow : 8141
Ax2 Aux Stow : 4117
Ax1 Default Time On : 25
Ax2 Default Time On : 25

Appendix B. Descriptions of Controller Status Information

Section 5: Status Variable Descriptions

The user-interface board accesses numerous status variables to assist the user in assessing the current operating mode and to aid in troubleshooting. The status variables are accessed through four lists under the user-interface board's status display menu selection.

The following discussion of these variables follows the sequence used in these lists. The header for each status variable's description includes the status variable's LCD display line and its software name for use in cross-referencing to Tables UM11 through UM14. These tables contain additional information on the stored and displayed variables. Many of the variables can be relocated in different versions of the control board. Addresses for these variables are given as offsets to the data section start address. This address is stored in the personality parameter table (with the name DSCTADDR) for use by the user-interface board.

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Tracking Status Variables

The variables in this group provide information concerning initialization and stow routine status, the computed sun position, the current and requested tracker position, and motor control variables.

Wind Stow is... (WINDFG)

This display shows whether the wind stow mode is active (on) or not (off).

Wind Stow End Minute (WSTOWMNE)

If the wind stow mode is active, the minute at which it ends is displayed. It can be reset manually to extend or shorten the stow period.

Wind Stow End Hour (WSTOWHRE)

(See WSTOWMNE above.)

Temp Stow is... (THERMFG)

This display shows whether the overtemperature stow mode is active (on) or not (off).

Temp Stow End Minute (TSTOWMNE)

If the wind stow mode is active, the minute at which it ends is displayed. It can be reset manually to extend or shorten the stow period.

Temp Stow End Hour (TSTOWHRE)

(See TSTOWMNE above.)

Ax1 Array Positn Count (A1CNT)

Displays the primary-axis turn counter value. If initialization has been completed, this is the array position in turn counts.

Ax1 Reqst Positn Count (A1REQ)

Displays the primary-axis requested turn count value.

Ax2 Array Positn Count (A2CNT)

Displays the secondary-axis turn counter value. If initialization has been completed, this is the array position in turn counts.

Ax2 Reqst Positn Count (A2REQ)

Displays the secondary-axis requested turn count value.

Motor 1P On Time: Hsec (TIMEON1P)

Displays the length of time the motor is activated in the timed-motor on mode going in the positive-count direction in the primary axis.

Motor 1N On Time: Hsec (TIMEON1N)

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Displays the length of time the motor is activated in the timed-motor on mode going in the negative-count direction in the primary axis.

Motor 2P On Time: Hsec (TIMEON2P)

Displays the length of time the motor is activated in the timed-motor on mode going in the positive-count direction in the secondary axis.

Motor 2N On Time: Hsec (TIMEON2N)

Displays the length of time the motor is activated in the timed-motor on mode going in the negative-count direction in the secondary axis.

Sun Azimuth (Degr) (AZIM)

Displays the computed sun position in azimuth in earth-based coordinates (not misaligned tracker coordinates).

Sun Zenith (Degr) (ZENITH)

Displays the computed sun position in zenith in earth-based coordinates (not misaligned tracker coordinates).

Sun Elevation (Degr) (ELEV)

Displays the computed sun position in elevation in earth-based coordinates (not misaligned tracker coordinates).

Sun Hour Angle (Degr) (HRANG)

Displays the computed sun position in hour angle in earth-based coordinates (not misaligned tracker coordinates).

Sun Declination (Degr) (DECL)

Displays the computed sun position in declination in earth-based coordinates (not misaligned tracker coordinates).

Sun Axis 1 (Degr) (ARRAY1)

Displays the computed sun position in the tracker primary axis after adjustment for the misalignment parameters.

Sun Axis 2 (Degr) (ARRAY2)

Displays the computed sun position in the tracker secondary axis after adjustment for the misalignment parameters.

Software Equivalent of Hardware Switches

If one is using the user-interface board at the controller, one does not need to have software versions of the hardware switches (i.e. joystick, and toggles) because there is a set of hardware switches already on the user-interface board. However, if one is accessing the controller by a remote, addressed communication system, one may want to initiate modes or manual drive functions normally initiated by hardware. To facilitate this, certain variables have been included which when set duplicate the function of the hardware switches and input lines. Access to these variables is not included in the user-interface board menu because they are unnecessary.

User Manual Drive (UsrManDr) If set, this bit is equivalent to setting the manual drive toggle. Address 0006:80.

User Self-Alignment (UsrAlign) If set, this bit is equivalent to setting the self-alignment toggle. Address 0006:40.

User Manual Up (UsrUp) If set, this bit is equivalent to setting the manual drive joystick upwards on the control board. Address 0006:20.

User Manual Right (UsrRight) If set, this bit is equivalent to setting the manual drive toggle to the right on the control board. Address 0006:10.

User Manual Down (UsrDown) If set, this bit is equivalent to setting the manual drive toggle downwards on the control board. Address 0006:08.

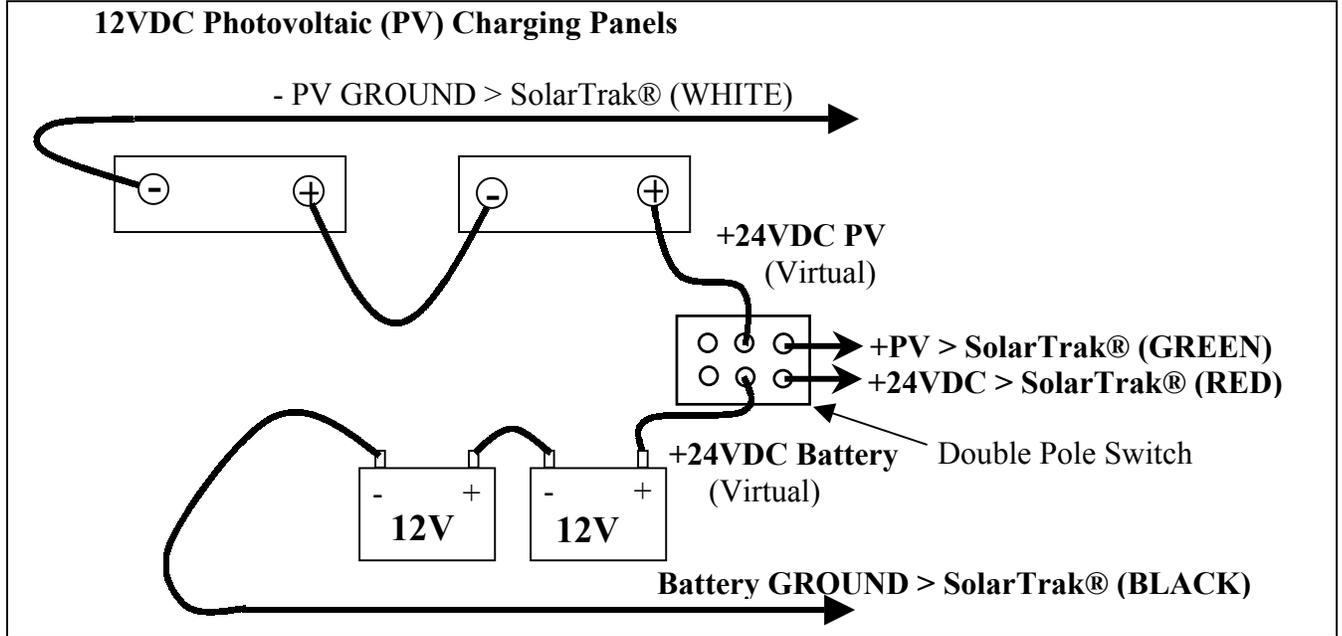
User Manual Left (UsrLeft) If set, this bit is equivalent to setting the manual drive toggle to the Left on the control board. Address 0006:04.

User Wind Stow (UsrWndSt) If set, this bit is equivalent to actuating (with either an active-high or active-low setting) a wind stow input. Address 0005:80.

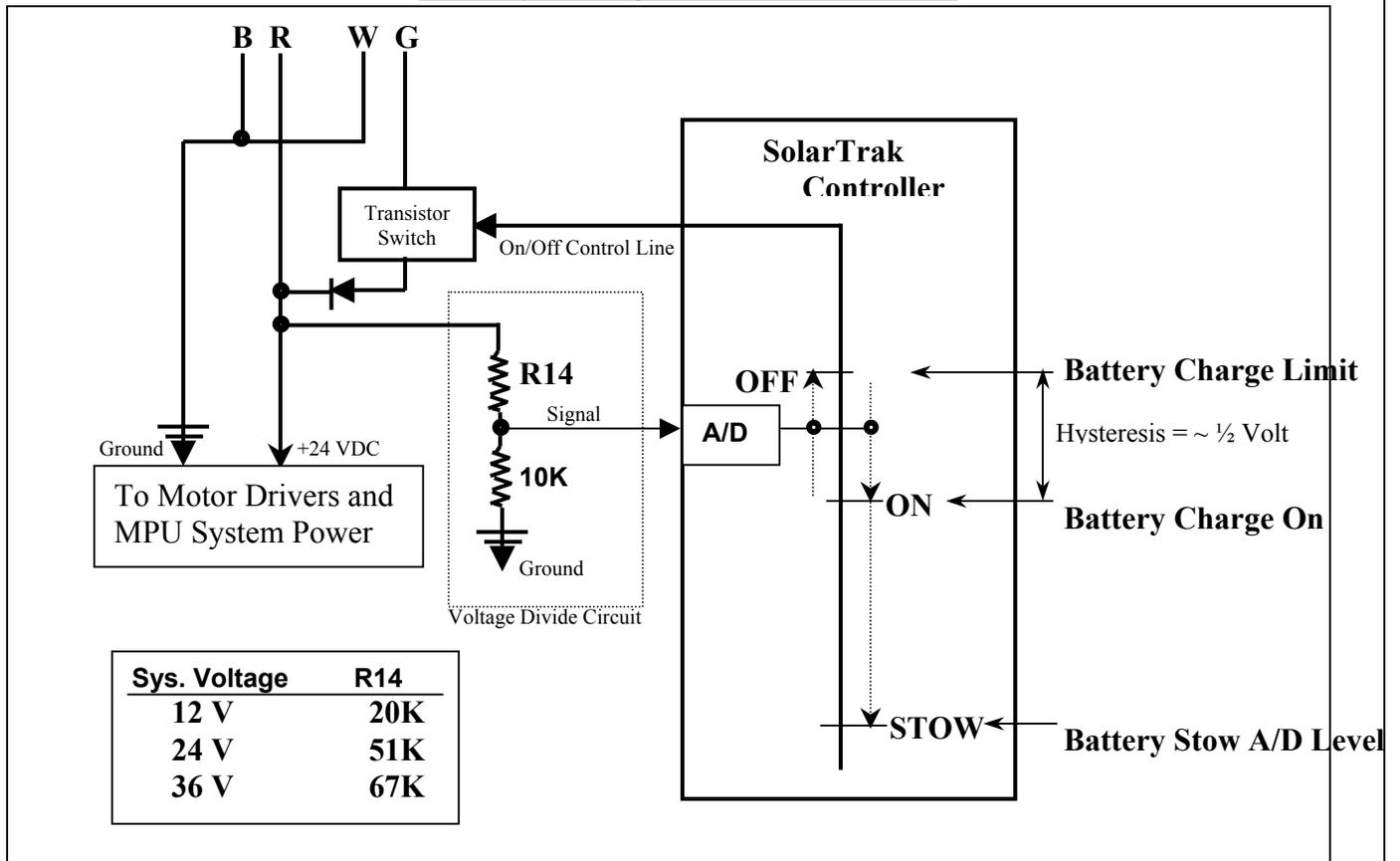
User Overtemperature (UsrThmSt) If set, this bit is equivalent to actuating (with either an active-high or active-low setting) an overtemperature stow input. Address 0005:40.

Operator Stow (UsrEmgSt) If set, this bit is equivalent to setting the emergency stow toggle. This bit is stored in EEPROM so it will not be lost in case of power failure. Address B607:04.

Battery Power Circuit Schematic



Battery Charge Circuit Schematic



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Appendix A. SolarTrak Controller Model ST-2011 Motorola MC68HC711E9CFN2 I/O Port Assignments

Port	I/O	Use	Pull-Up/Dn	Description of use	Pin #
PA0	I		Down	Array Stow Switch	34
PA1	I		Down	Manual Drive Switch	33
PA2	I		Down	Option 2 Enable Switch	32
PA3	I/O	I/O	Up	Dallas 1-Wire Data Line	31
PA4	O			LCD (RS) Reset Line	30
PA5	O			LCD (R/W) Read/!Write Line	29
PA6	O			LCD (E) Clock Line	28
PA7	I/O	I	Down	Option 1 Enable Switch	27
PB0	O			Axis 1 Motor On/Off	42
PB1	O			Axis 1 Motor Direction	41
PB2	O			Axis 2 Motor On/Off	40
PB3	O			Axis 2 Motor Direction	39
PB4	O			Dallas DS-1302 Clock (RS) Reset Line	38
PB5	O			Battery Charge Control Line (or General Purpose)	37
PB6	O			General Purpose Control Line	36
PB7	O			RS-485 Line Driver Control (or General Purpose)	35
PC0	I/O	I/O	Down	Dallas DS-1302 Clock Data Line	9
PC1	I/O	O		Dallas DS-1302 Clock (E) Clock Line	10
PC2	I/O	I/O	Down	General Purpose I/O	11
PC3	I/O	I	Up	Axis 2 [Phase A] Turncount Input	12
PC4	I/O	I	Down	LCD Data Bus 4	13
PC5	I/O	I	Down	LCD Data Bus 5	14
PC6	I/O	I	Down	LCD Data Bus 6	15
PC7	I/O	I	Down	LCD Data Bus 7	16
PD0	I/O	I	Up	Serial port Rx/D	20
PD1	I/O	O	Up	Serial port Tx/D	21
PD2	I/O	I	Down	Joystick Left	22
PD3	I/O	I	Down	Down	23
PD4	I/O	I	Down	Right	24
PD5	I/O	I	Down	Up	25
PE0	A/D-I	I	[Down-] Up	Axis 2 Phase B Turncount Input	43
PE1	A/D-I	I	[Down-] Up	Wind Stow Signal (Discrete or Anemometer Pulse)	45
PE2	A/D-I	A/D	Down	Battery Voltage Level (or General Purpose Input)	47
PE3	A/D-I	I	Up	Axis 1 [Phase A] Turncount Input	49
PE4	I		Up	Axis 1 Phase B Turncount Input	44
PE5	I		Down	LCD 'Adjust' Button	46
PE6	I		Down	LCD 'Item' Select Button	48
PE7	I		Down	LCD 'Value' Change Button	50

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Appendix A.1 SolarTrak Controller Model ST-2011-HELIO Motorola MC68HC711E9CFN2 I/O Port Assignments

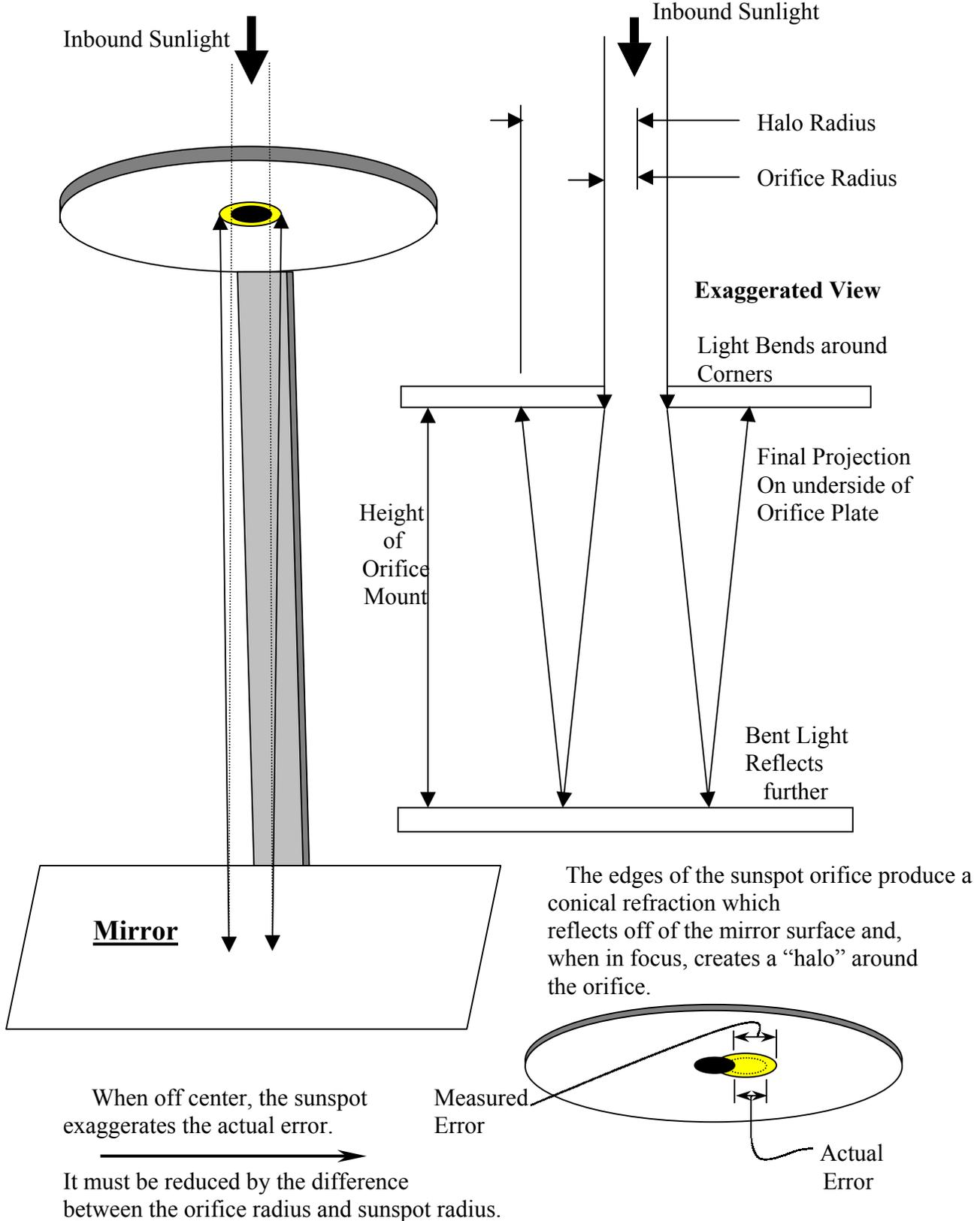
Port	I/O	Use	Pull-Up/Dn	Description of use	Pin #
PA0	I		Down	Array Stow Switch	34
PA1	I		Down	Manual Drive Switch	33
PA2	I		Down	Option 2 Enable Switch (IDX_2)	32
PA3	I/O	I/O	Up	Dallas 1-Wire Data Line	31
PA4	O			LCD (RS) Reset Line	30
PA5	O			LCD (R/W) Read/!Write Line	29
PA6	O			LCD (E) Clock Line	28
PA7	I/O	I	Down	Option 1 Enable Switch (Sticky Manual)	27
PB0	O			Axis 1 Motor On/Off	42
PB1	O			Axis 1 Motor Direction	41
PB2	O			Axis 2 Motor On/Off	40
PB3	O			Axis 2 Motor Direction	39
PB4	O			Dallas DS-1302 Clock (RS) Reset Line	38
PB5	O			Battery Charge Control Line (or General Purpose)	37
PB6	O			General Purpose Control Line	36
PB7	O			RS-485 Line Driver Control (or General Purpose)	35
PC0	I/O	I/O	Down	Dallas DS-1302 Clock Data Line	9
PC1	I/O	O		Dallas DS-1302 Clock (E) Clock Line	10
PC2	I/O	I/O	Down	General Purpose I/O (OUCH Circuit)	11
PC3	I/O	I	Up	Axis 2 [Phase A] Turncount Input	12
PC4	I/O	I	Down	LCD Data Bus 4	13
PC5	I/O	I	Down	LCD Data Bus 5	14
PC6	I/O	I	Down	LCD Data Bus 6	15
PC7	I/O	I	Down	LCD Data Bus 7	16
PD0	I/O	I	Up	Serial port Rx/D	20
PD1	I/O	O	Up	Serial port Tx/D	21
PD2	I/O	I	Down	Joystick Left	22
PD3	I/O	I	Down	Down	23
PD4	I/O	I	Down	Right	24
PD5	I/O	I	Down	Up	25
PE0	A/D-I	I	[Down-] Up	Axis 2 Phase B Turncount Input	43
PE1	A/D-I	I	[Down-] Up	Wind Stow Signal (Discrete or Anemometer Pulse)	45
PE2	A/D-I	A/D	Down	Battery Voltage Level (or General Purpose Input)	47
PE3	A/D-I	I	Up	Axis 1 [Phase A] Turncount Input	49
PE4	I		Up	Axis 1 Phase B Turncount Input	44
PE5	I		Down	LCD 'Adjust' Button	46
PE6	I		Down	LCD 'Item' Select Button	48
PE7	I		Down	LCD 'Value' Change Button	50

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Appendix A.2 SolarTrak Controller Model ST-2011-HYD Motorola MC68HC711E9CFN2 I/O Port Assignments

Port	I/O	Use	Pull-Up/Dn	Description of use	Pin #
PA0	I		Down	Array Stow Switch	34
PA1	I		Down	Manual Drive Switch	33
PA2	I		Down	(Opt. 2) Azimuth Drive-By Index Pulse Input	32
PA3	I/O	I/O	Up	Dallas 1-Wire Data Line	31
PA4	O			LCD (RS) Reset Line	30
PA5	O			LCD (R/W) Read/!Write Line	29
PA6	O			LCD (E) Clock Line	28
PA7	I/O	I	Down	(Opt. 1) High-Speed Manual Drive Switch	27
PB0	O			Axis 1 Motion On/Off	42
PB1	O			Axis 1 Primary Piston Valve Direction Control	41
PB2	O			Axis 2 Motion On/Off	40
PB3	O			Axis 2 Valve Direction Control	39
PB4	O			Dallas DS-1302 Clock (RS) Reset Line	38
PB5	O			Axis 1 Secondary Piston Valve Direction Control	37
PB6	O			Hydraulic Oil Pressure Pump Control	36
PB7	O			RS-485 Line Driver Control (or General Purpose)	35
PC0	I/O	I/O	Down	Dallas DS-1302 Clock Data Line	9
PC1	I/O	O		Dallas DS-1302 Clock (E) Clock Line	10
PC2	I/O	I/O	Down	Oil Pressure Switch Input	11
PC3	I/O	I	Up	Axis 2 (Phase A) Turncount Input	12
PC4	I/O	I	Down	LCD Data Bus 4	13
PC5	I/O	I	Down	LCD Data Bus 5	14
PC6	I/O	I	Down	LCD Data Bus 6	15
PC7	I/O	I	Down	LCD Data Bus 7	16
PD0	I/O	I	Up	Serial port Rx/D	20
PD1	I/O	O	Up	Serial port Tx/D	21
PD2	I/O	I	Down	Joystick Left	22
PD3	I/O	I	Down	Down	23
PD4	I/O	I	Down	Right	24
PD5	I/O	I	Down	Up	25
PE0	A/D-I	I	Up	Axis 2 Phase B Turncount Input	43
PE1	A/D-I	I	Up	Wind Stow Signal (Discrete or Anemometer Pulse)	45
PE2	A/D-I	A/D	Down	Low Oil Level Switch	47
PE3	A/D-I	I	Up	Axis 1 (Phase A) Turncount Input	49
PE4	I		Up	Axis 1 Phase B Turncount Input	44
PE5	I		Down	LCD 'Adjust' Button	46
PE6	I		Down	LCD 'Item' Select Button	48
PE7	I		Down	LCD 'Value' Change Button	50

Appendix B: Reflected Sunspot Pointing Device



The SolarTrak® Controller System

Quantification of Error

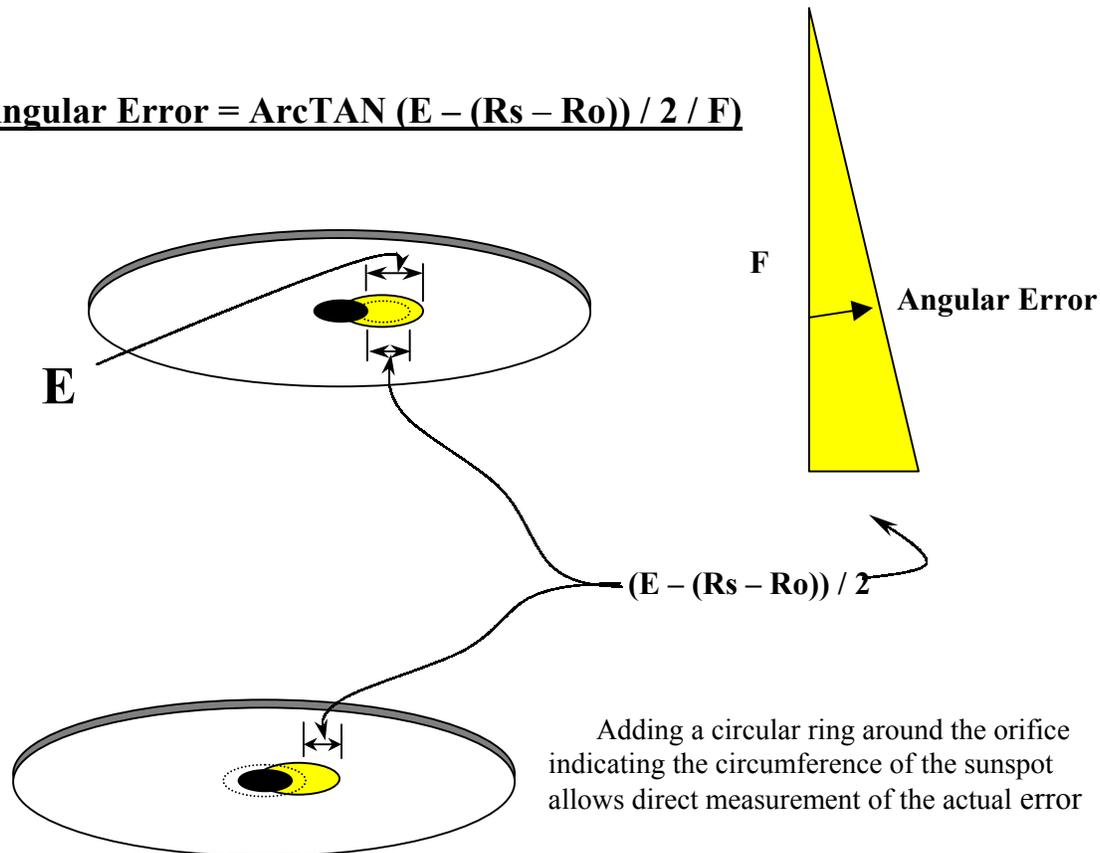
Requirements:

1. Measure 'Height of Orifice Mount' (**H**), Focal length = **F** = 2 * **H**
2. Measure Orifice Diameter (**D_o**), Orifice Radius = **R_o** = **D_o** / 2
3. Measure Sunspot Diameter (**D_s**), Sunspot Radius = **R_s** = **D_s** / 2
4. Measure Error (**E**), from edge of hole to edge of sunspot

*** Any Consistent Units will do ***

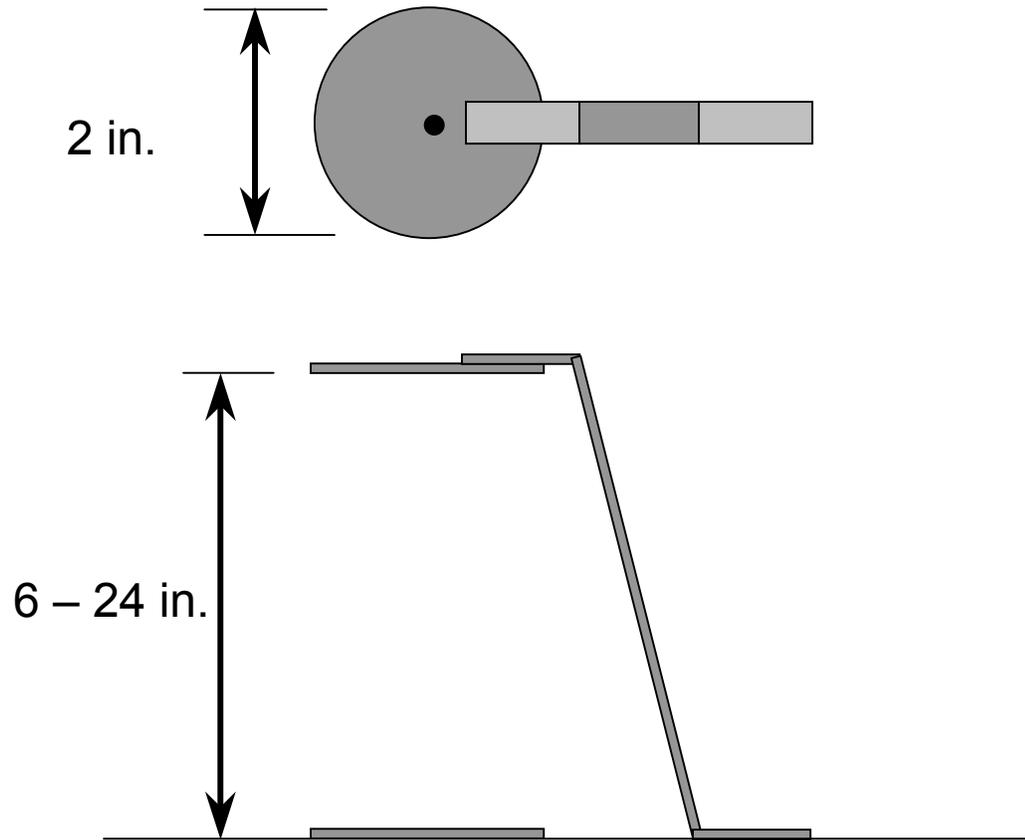
Assumption: Small Angle Rule: $\sin \theta = \theta$ (in radians), $\theta < 0.1$ rad.

$$\underline{\text{Angular Error} = \text{ArcTAN} (E - (R_s - R_o)) / 2 / F)}$$



Adding a circular ring around the orifice indicating the circumference of the sunspot allows direct measurement of the actual error

Basic Pointing Device Design



The mirror must be attached to a surface guaranteed parallel to the Elevation or Roll axis while perpendicular to the Azimuth or Tilt axis.

Appendix C:

SCREWJACK Parameter Computation

SJP #1,2, & 3 are screwjack

parameters stored in the SolarTrak®

R1, R2, R3 & β are constants
(measured in inches)

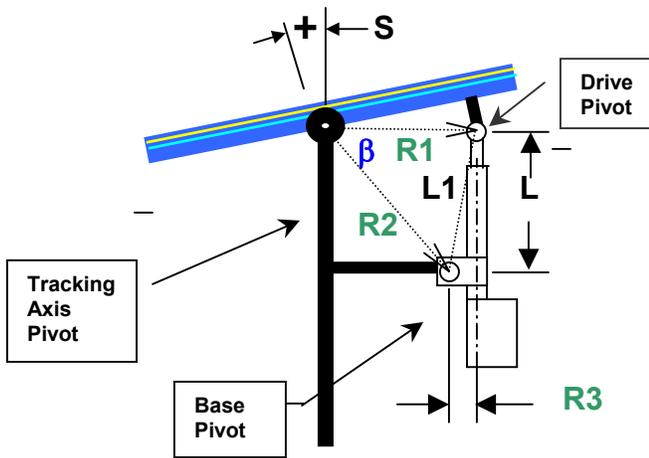
Gear Ratio = (+/-) counts/inch
(+) if S increases with Turncounts

$$\text{SJP \#3} = R1^2 + R2^2 - R3^2$$

$$\text{SJP \#2} = (+/-) 2 * R1 * R2$$

(-) if S increases with L

$$\text{SJP \#1} = \beta$$



$$(1) L = \sqrt{R1^2 + R2^2 - R3^2 - 2 * R1 * R2 * \text{COS}(S + \beta)}$$

$$(2) L = \sqrt{\text{SJP\#3} + \text{SJP\#2} * \text{COS}(S + \beta)}$$

$$(3) \beta = \text{ACOS}\{ (L^2 - R1^2 - R2^2 + R3^2) / (-2 * R1 * R2) \} - S$$

$$(4) \beta = \text{ACOS}\{ (L^2 - \text{SJP\#3}) / \text{SJP\#2} \} - S \quad \text{and} \quad L^2 = L1^2 - R3^2$$

or

$$(5) \beta = \text{ACOS}\{ (L1^2 - R3^2 - \text{SJP\#3}) / \text{SJP\#2} \} - S$$

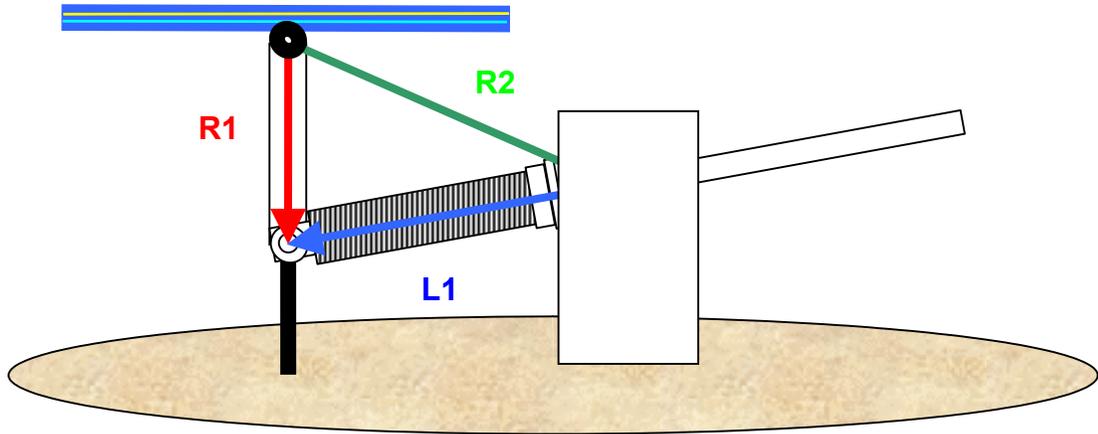
Measure the R1 and R2 Center-to-Center lengths carefully. The line of measurement should always be perpendicular to both centerlines being measured. Measure R3 perpendicular to the centerline of the jack tube to the center of the Base Pivot bolt. For a Von Weise jack, R3 = 2".

Compute β by:

- 1: Measuring the angle accurately.
- 2: Measure L1 (Between Drive Pivot and Base Pivot)
- 3: Compute β using equation (5) above.
- 4: Repeat 1 – 3, using S = some different angle to check for consistency.
- 5: Enter β in degrees.

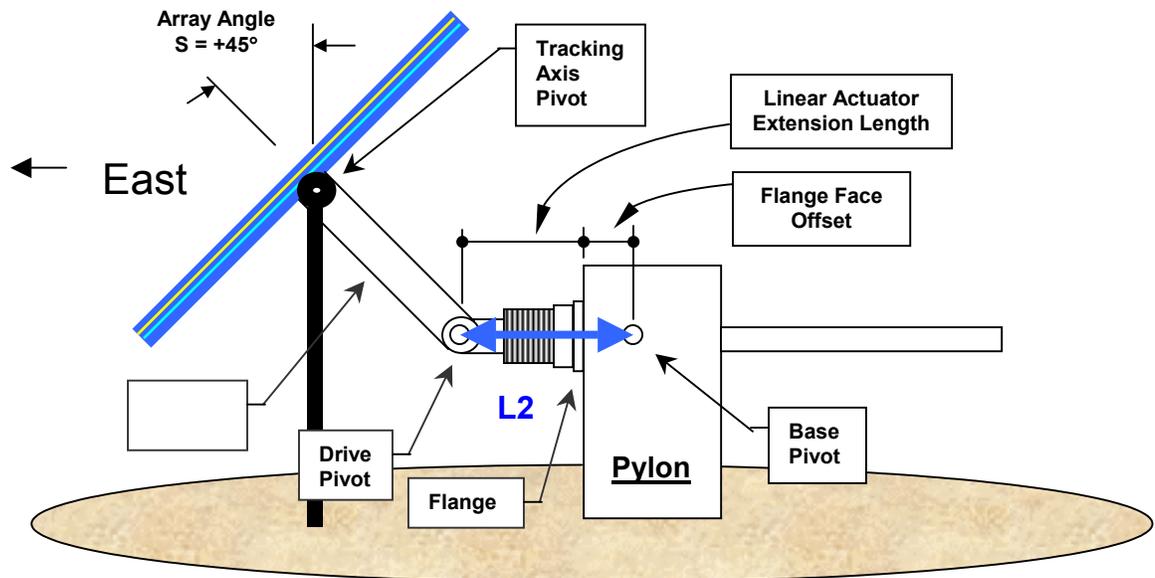
Equation (1) above is used for converting a specific Sun angle to a specific screwjack extension point. Equations 4 or 5 should be used to determine β depending on the quantity (L or L1) measured. If E-W Tilt-Roll is the active geometry, remember that due East (not Up or South) is zero degrees.

SCREWJACK Parameter Computation



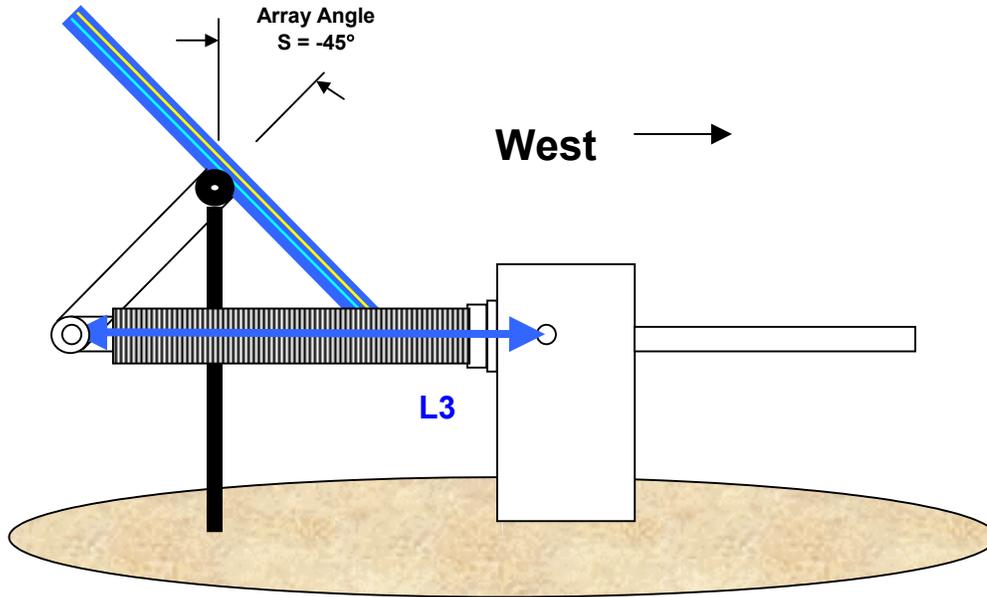
Western Mount Position – View Facing South

Level, Face-up Position



Unit Retracted to Soft Limit, $S = 45^\circ$

The SolarTrak® Controller System



Linear Actuator at Full Extension to Soft Limit. S = -45°

There are three screwjack parameters stored in the SolarTrak® in the 'Drive Parameters' screen, SJP #1-3, computed from the quantities **R1**, **R2**, **L1-3** defined above. Lengths are in inches.

The Law of Cosines is applied to convert the requested angular position to a specific actuator extension. The fundamental equation relating the actuator length and array angle is:

$$(1) \quad L = \sqrt{R1^2 + R2^2 - 2 * R1 * R2 * \cos(S + \beta)}$$

Where **L** is the length of the actuator, **S** is the requested array angle and **β** is an angular offset based on the relative positions of **R1** and **R2** when the array is facing straight up (**S** = 0). Since some of the computations for these terms need only be performed once, the parameters are stored as pre-combined coefficients producing the equivalent equation (2).

$$SJP \#2 = (+/-) 2 * R1 * R2 \quad (+West \text{ Mount, } -East)$$

$$SJP \#3 = R1^2 + R2^2$$

$$(2) \quad L = \sqrt{SJP\#3 + SJP\#2 * \cos(S + \beta)}$$

$$(3) \quad \beta = \text{ACOS} \{ (L^2 - SJP\#3) / SJP\#2 \} - S$$

$$SJP \#1 = \beta$$

Equation (1) above is used for converting a specific Sun angle to a specific screwjack extension point. Equation 3 should be used to determine **β** for **L** equals each of the measurable quantities **L1** (**S** = 0), **L2** (**S** = 45, in radians) and **L3** (**S** = -45). The result found for **β** should be the same in each case.