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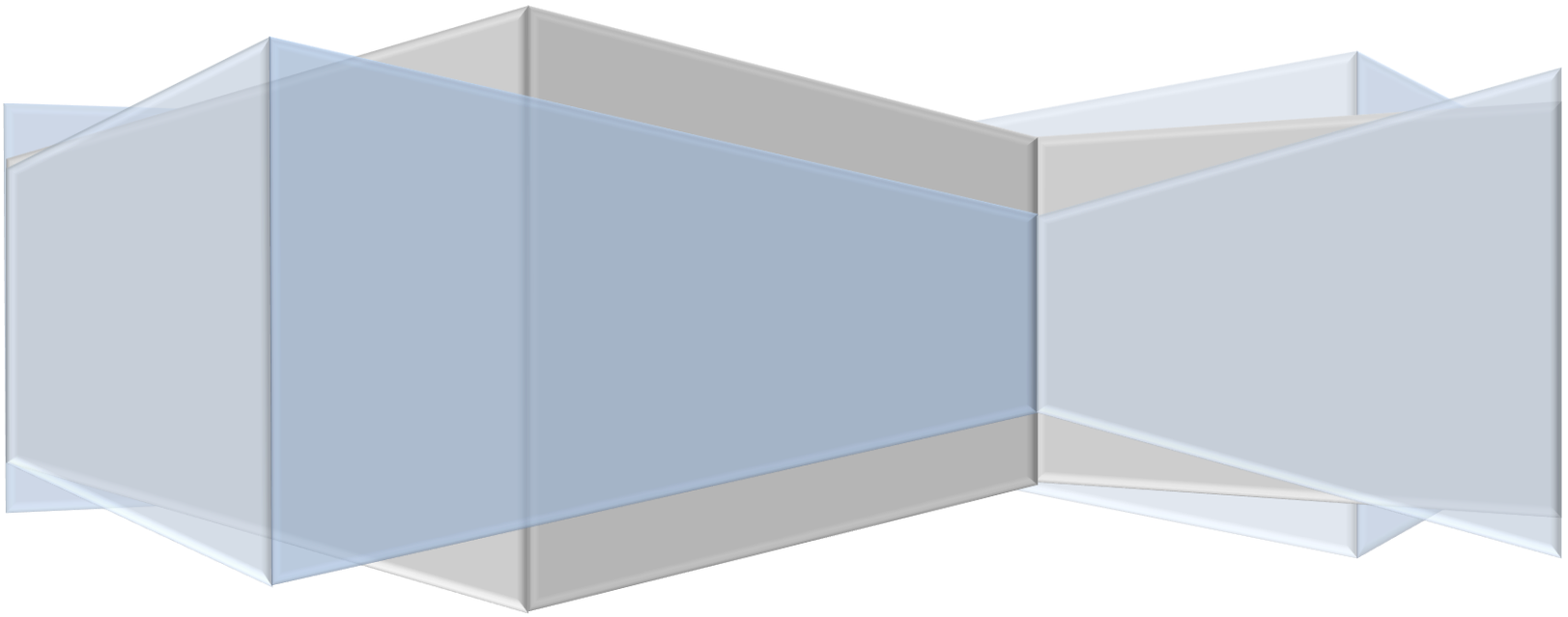
Usage of External Inclinometers in Lauritzen Controllers

V1.3, December-2021



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1. Introduction

The purpose of this application note is to illustrate the usage of inclinometers with Lauritzen solar tracker controllers.

2. Inclinometers, their Purpose & Functionality

An inclinometer is a device that measures the angle of tilt, and can be used to measure where a solar tracker is aimed. One can be used either instead of, or in addition to, an encoder on the elevation drive or to accurately correlate elevation encoder readings with angles.

For early CX2 controller, a dedicated 6-pin mini-DIN connector input was available for inclinometers which provides both power and an RS232 interface. In late model CX2 and all CX3 controllers, a 3- or 4-pin terminal block provides inclinometer power and signal interface.

3. Tracker Orientation

Before discussing inclinometer operation with solar trackers, it is important to review the convention of tracker orientation. There are three types of solar trackers to consider; dual-axis, single-axis and polar-axis trackers.

3.1. Dual-Axis Tracker Orientation

A dual axis tracker is typically using a slewing drive for azimuth (east-west) movement and a linear actuator for elevation (up-down) movement. The home position for a dual-axis tracker is defined as when the tracker is resting against its eastern and upper limit switch. For elevation, the home limit switch is typically placed where the tracker is at or slightly beyond horizontal (facing directly up). The following diagram illustrates the convention.

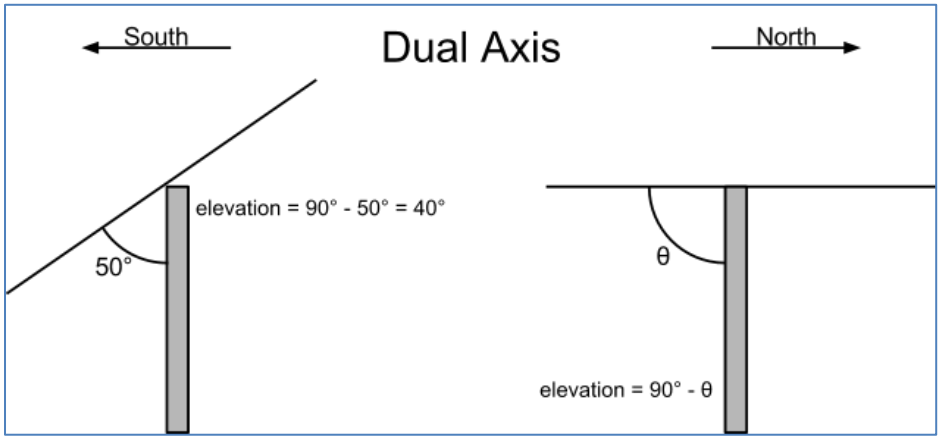

Figure 1; Dual-axis elevation orientation

Assuming a dual-axis tracker is capable of an elevation of 90 degrees, it will be able to directly face the sun at sun-rise/sun-set.

3.2. Single-Axis Tracker Orientation

A single axis tracker is typically using a linear actuator for elevating the tracker in its east-west direction around a north-south axis. The home limit switch for single axis trackers can be either the eastern or western limit. When the tracker is positioned horizontally, the elevation is assumed to be 0 degrees. Tilting the tracker towards east yields a negative elevation, while a western tilt is assumed to be positive. The following diagram illustrates the convention

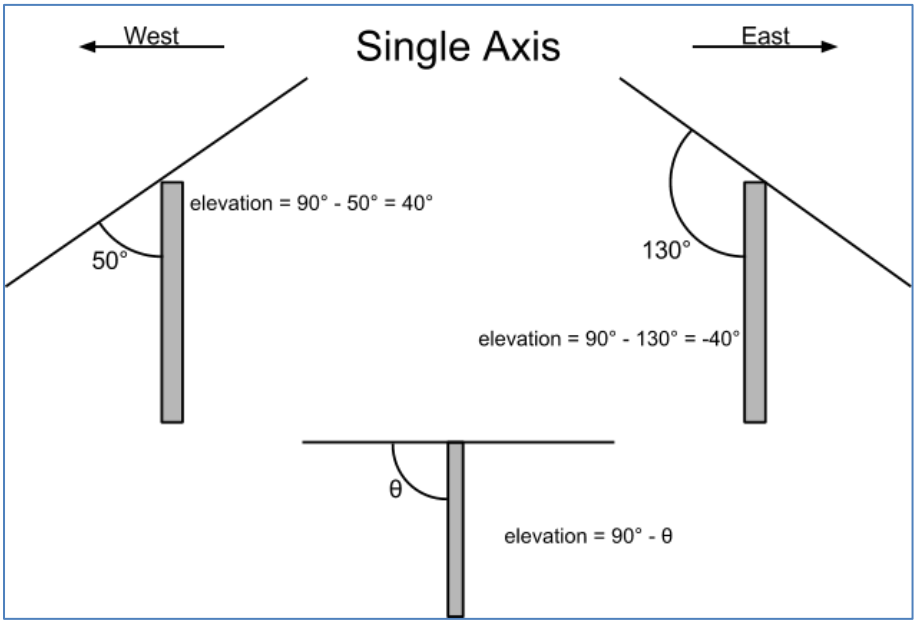

Figure 2; Single axis elevation orientation

4. Target Finder and Modes of Inclinometer Operation

The Target Finder is a software module residing in every solar tracker controller, and its purpose is to translate an angular positional command into a simple move command which can be understood by the servo module. The Target Finder can operate with an external inclinometer for controlling elevation in a number of modes which the following table best illustrates.

Inclinometer Parameter	**Description**	**Requirement**
INCL+ or INCL-	An external inclinometer is permanently installed to provide tracker elevation data to controller.	External inclinometer. Motor encoder feedback is not required for operation, but can be used for additional fault detection. Similarly, limit switches are not necessary, but can be used for additional protection.
ni	Number of operational inclinometers in system.	Note; integrated controller inclinometer is counted as one unit.
iid	Inclinometer ID to be associated with this axis.	Integrated inclinometer is always number 0. External inclinometer starts with number 1.
pl	Inclinometer plane to be associated with axis.	The plane can be either “xy” or “zy”.
ul,dl	Up or down limit. Any raw inclinometer data exceeding the ul/dl angle will result in a fault.	

Figure 3; Target Finder and Inclinometer Modes

Example; specify usage of an external inclinometer in a CX3 system, with an *xy* plane *“fn=incl+,pl=xy,ni=2,iid=1”*.

4.1. Inclinometer Fault Detection

The controller has an algorithm to detect the following inclinometer faults as illustrated in this table. All faults should be cleared by resetting the controller.

Fault Description	Fault Algorithm
Gross Movement	If the controller finds rapid inclinometer movements, it will ignore current inclinometer values, and only resume after values fall within acceptable limits of prior readings.
Wrong Direction	If controller detects is reading wrong inclinometer directional movement during tracker movement, it will stop tracker movement and signal fault.
Stuck Inclinometer	If the inclinometer readings do not change value during a tracker movement, the controller will stop tracker movement and signal fault.
Loss of Inclinometer Data	If the controller stops receiving inclinometer data while moving tracker, it will stop tracker movement and signal fault.

4.2. Inclinometer used during initial Tracker Calibration (ITABLE)

An inclinometer can be used during initial tracker calibration if the Target Finder's elevation function parameter is set to *ITABLE*. In this case, the controller will look for an external inclinometer at time of elevation calibration. Prior to inclinometer based calibration, the following steps **must** be done in sequence:

1) Clip inclinometer to tracker (see section 6)
2) Connect inclinometer to the external inclinometer port (mini-din/PS2 connector)
3) Reset controller (push reset button for minimum 10seconds)

The ITABLE calibration can be invoked through a number of different methods after the external inclinometer has been connected to the controller's inclinometer port. Once the inclinometer based calibration procedure is in progress, the inclinometer LED will be lit solid or blink in case of an error. The different methods of invoking the calibration are as follows;

a) Calibration button is pushed for 2+ seconds until APP/COMM/SYS LED's are blinking in unison. The **UP** or **DOWN** button is now pushed and released to commence calibration. Calibration process can be stopped at any time by pushing and releasing **RESET** or master **STOP**.
b) Through iPhone/Android device, the calibration procedure can be initiated from the Calibration page by pressing the **CalEl** button.
c) Console command ***incl create-table*** can be invoked.

The controller will now commence with the calibration procedure as follows;

1) Move tracker against its upper limit switch
2) Slowly move tracker down while recording encoder and inclinometer values
3) Once the tracker reaches the down-limit, the controller will return the tracker to horizontal (elevation=0 degrees), and not against the upper limit switch – if this happens to be at a negative elevation.
4) The user can now remove the inclinometer, and should reset the controller once again.

The calibration procedure will fail if the inclinometer is not attached or is attached backwards, which will cause the tracker to stop in the middle of the calibration procedure.

If the inclinometer is not mounted so that it is perfectly vertical when the tracker is horizontal, while the initial calibration is performed, then it must be calibrated after removing inclinometer, and resetting the controller.

After removing the inclinometer connector, and resetting the controller, the three methods of fine-tuning the calibration position are as follows:

1) The tracker is moved to horizontal, and then the calibration button is asserted until the APP/COMM/SYS LED's are all blinking in unison. The **UP** or **DOWN** button is then pushed and released to set the calibration offset.
2) The tracker is moved until it is facing the sun and then the **Cal2Sun** button is pressed on an iPhone/Android device on the Calibration page.
3) The tracker is moved to a known position, that position is entered in the Calibration input box an iPhone/Android device, and then the ***CalEl*** button is pressed.

4.3. Inclinometer used for Tracker Elevation Positioning, and Calibration

An inclinometer can be used during normal tracker operation if the Target Finder's elevation function parameter is set to ***INCL+*** or ***INCL-***. The two parameter options refer to the inclinometer being mounted according to the standard convention for mounting an inclinometer, or inverse.

INCL- would be used if the inclinometer was mounted facing the opposite direction than the standard way.

If the inclinometer is not mounted perfectly vertical when the tracker is at horizontal, then it must be calibrated. The different methods of fine-tuning the calibration position are as follows:

1) The tracker is moved to horizontal and then the calibration button is pushed until the APP/COMM/SYS LED's are all blinking in unison. The **UP** or **DOWN** button is then asserted and released to set the calibration offset.
2) The tracker is moved until it is facing the sun and then the **Cal2Sun** button is pushed on an iPhone/Android device on the Calibration page – or using controller buttons – depressing and releasing **CAL** once more.

Yet another method is to move tracker to a known position, and enter the angular tilt in the Calibration input box in an iPhone/Android device, followed by pressing the ***CalEl*** button.

5. IXYZ Inclinometer

The Lauritzen IXYZ inclinometer operates with 3-axis, and is ideal for use with the SCX/TCX controller. The inclinometer requires a voltage supply between 16 and 30V, and in most applications, using the 24V supply from the controller's power input is perfectly satisfactory. Inclinometer power can also be supplied by the AUX output port which has the advantage of forcing inclinometers re-power when the controller is reset.

Positioning the IXYZ inclinometer along a tracker's vertical or horizontal plane doesn't have to be exact, because any difference is accounted for during final tracker calibration.

5.1. IXYZ Electrical Connection to SCX2P4 and up

Starting with the SCX2P4 (including TCX, PVTRK, and FXCX) controller there is a dedicated 3-port inclinometer terminal block which provides power and digital interface to external inclinometers.

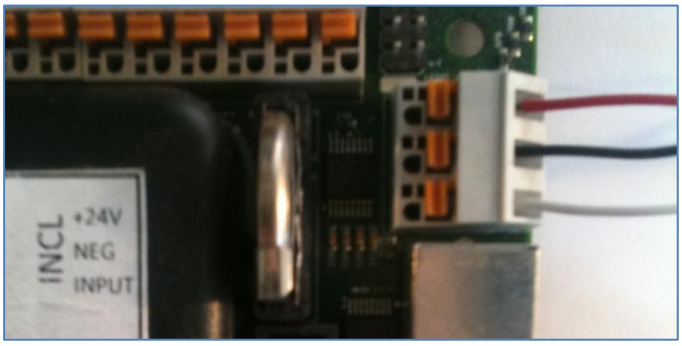

Figure 4; SCX2 Inclinometer Interface

The 3 interface connections from top to bottom are; +24V, NEG and INPUT. The +24V connection is severely current limited, and must ONLY be used to power external inclinometers. As with all interface connections, the controller MUST be powered down when installing/removing connections.

5.2. IXYZ Electrical Connection to SCX3Px

The CX3 controllers have an additional I/O terminal on the inclinometer interface. The additional terminal provides for a serial output, which in most current application is not used. Figure 5 indicates a typical IXYZ inclinometer interface connection.

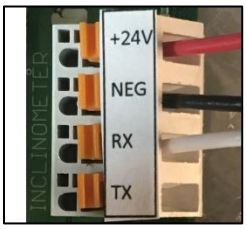

Figure 5; Typical IXYZ inclinometer connection to CX3

5.3. Inclinometer Supply Voltage Selection CX3P7+

Starting with CX3P7, the inclinometer supply voltage can be either +24V or +5V. The selection is done via a shunt and is typically done by Lauritzen at time of shipment. Below is the selection for +24V supply. Please consult with Lauritzen if a supply voltage change must be made.

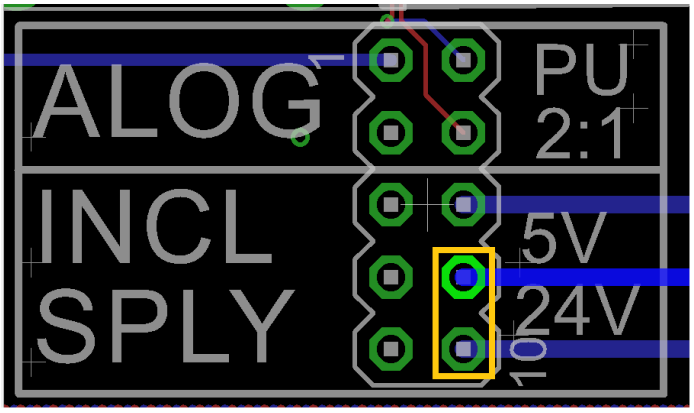

Figure 6; CX3P7 Inclinometer Voltage Selection

5.4. SCX2 Target Finder Parameters for IXYZ

Inclinometer data signaling is done through the controller's RS232 serial port. Both the SCX/TCX controller and IXYZ inclinometer are preprogrammed to use compatible communication settings. However, since the IXYZ produces datasets in two planes, namely XY and ZY, and multiple inclinometers can be used, parameters within the target Finder's parameters have been added to specify inclinometer usage. The parameters are defined as follows:

fn=incl+;pl=(plane);iid=inclinometer_id;ni=number_of_inclinometer

Where ***pl*** refers to which plane to be used, and valid values are either ***xy*** or ***zy***. ***iid*** is used to identify which inclinometer to be referenced in applications of multiple inclinometers, and ***ni*** indicates the total

number of inclinometers connected to the system. The following schematic outlines the inclinometer to controller connectivity.

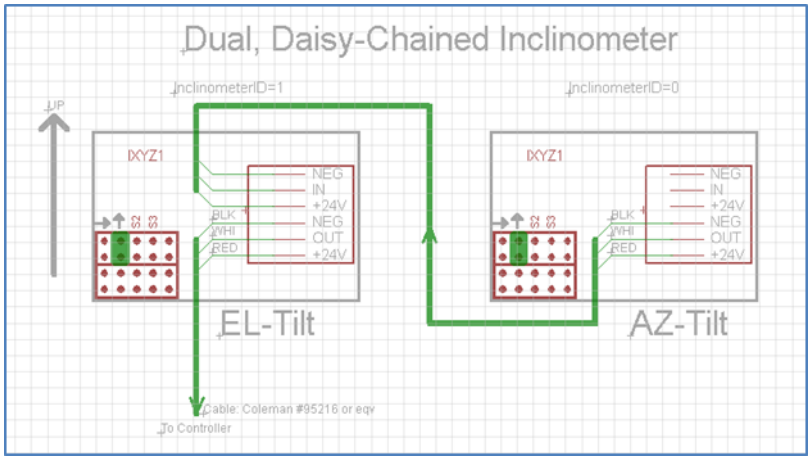

Figure 7; Dual Inclinometer Connectivity

The inclinometer at the end of the daisy chain (in this case AZ-Tilt), is referenced with ***iid=0***, and the next inclinometer (going from right to left) is referenced with ***iid=1***.

6. IXYZ Test and LED Signaling

The IXYZ has two LED's to indicate data traffic, one for input data and the other for output data.

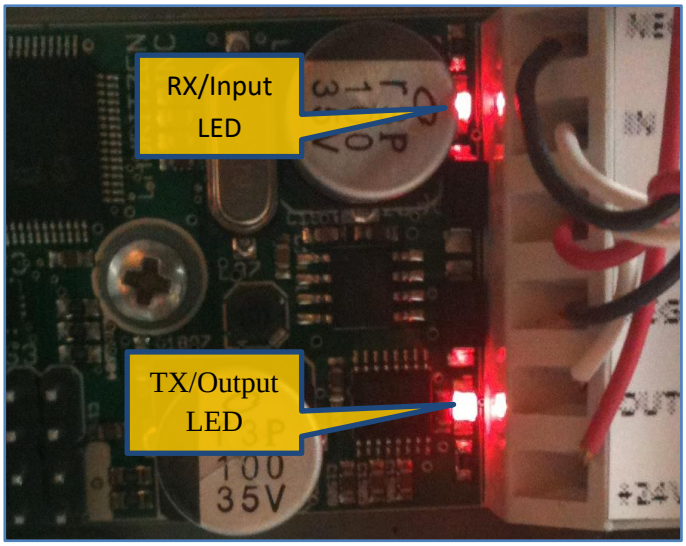

Figure 8; LED Signaling

During normal operation, when input data traffic is detected, the input LED is lit. Similarly, when output data is transmitted, the output LED is lit.

6.1.1. LED Signaling, Horizontal Detection

In certain applications, it is important for the inclinometer to indicate true horizontal inclinometer position. Note; for most solar tracker applications, this is best done by using the control system to calculate an offset between inclinometer position and solar tracker true horizontal. To facilitate true horizontal positioning, the TX LED will flash rapidly at 20Hz when the XY plane is at horizontal. Similarly, the RX LED will flash rapidly at 20Hz when the ZY plane is at horizontal.

6.1.2. LED Signaling, Internal Error

In case of an internal error, the two LED's are flashing alternately at 6Hz. An internal error can be the absence of either landscape and portrait shunts, or an internal Inclinometer error.

6.1.3. LED Signaling, Inclinometer Self-Test

To test the RS232 input receiver and output transmitter, insert a jumper between IN and OUT. Notice that immediately prior to inserting the jumper, the output LED will flash at a rate of 8 times per second. After inserting the jumper, the input and output LED's will occasionally flash simultaneously. Any other behavior indicates a transceiver error.

6.1.4. Debug of Inclinometer while Connected to Controller

Several tools can be used to detect and solve inclinometer errors in the field. In this section we review some errors, how to proceed in the trouble finding, and possible solutions. Here is a list of debug actions;

1) Start by observing that the data output LED within the inclinometer is blinking at approximately 5 times per second. A dark (non-functional) LED can indicate no inclinometer power.
   - In case of a dark LED, check supply voltage with DVM at controller and inclinometer terminals. The DVM probes can be inserted immediately behind the orange terminal tabs at the controller's inclinometer interface as well as the terminal tabs within the inclinometer. The inclinometer voltage for the 5.0V inclinometer must be within the range 4.75-5.25V.
2) Assuming the inclinometer is indicating data output, a DVM can be used to check the arrival of inclinometer data at the controller.
   - Insert DVM probes at a NEG terminal and the corresponding data IN (or RX) terminal. The data signal will be pulled to less than -3V while idle, and momentarily to more than +3V during a data high period. Most DVM's will indicate a less than -3V reading with pulsing higher readings.
3) Assuming data arrival is confirmed at the controller's data IN terminal, a possible error might be found within the controller's Target Finder's parameter set, or a faulty controller. Please contact installer/manufacturer for additional information.

6.2. IXYZ with Single-Axis Tracker

In general, all inclinometers must be mounted so that the inclinometer's cable-exit is pointed vertically down when the tracker is horizontally positioned. The inclinometer positioning should be near the tracker pivot point – as practical.

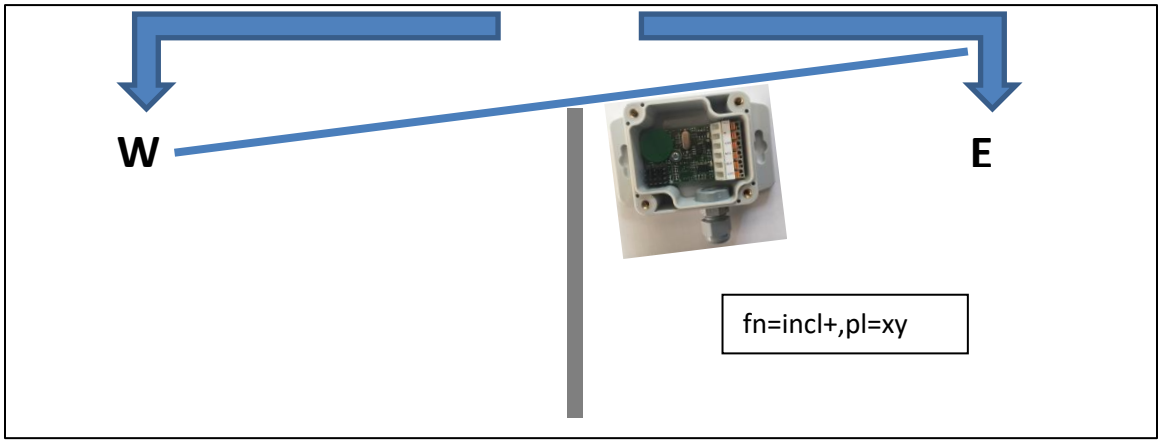

Figure 9; Single axis tracker with positive oriented inclinometer

For single-axis trackers, the IXYZ inclinometer can be mounted in two ways; positive or negative oriented. Neither method affects final functionality, but whichever method is used – must be consistent across all trackers within a field. Ideally, one method would be used, and defined as a standard, for all

trackers across all tracker installations for a given manufacturer. Doing so would allow for a consistent set of controller operational parameters.

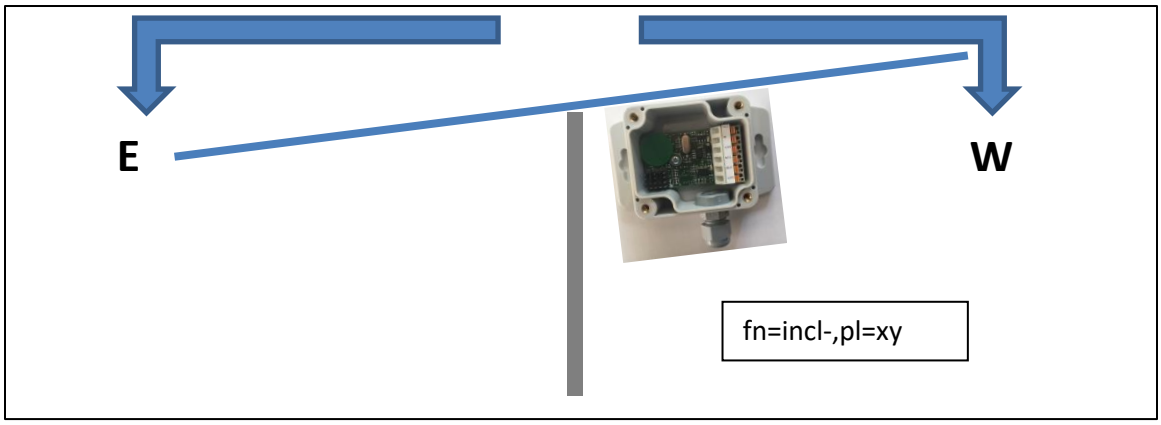

Figure 10; Single axis tracker with negative oriented inclinometer

The inclinometer must be kept out of direct sunlight and is usually mounted in the shade provided by PV panels.

6.3. CX3/DX3 with Single-Axis Tracker

Both CX3 and DX3 controllers have integrated inclinometers. When mounted directly in the shade of a tracker's PV panel, such that the controller will move along with the tracker, the controller's inclinometer measurement is used a tracker feedback. The figure below illustrates how to orient the controller on the tracker. With the tracker positioned at horizontal, the controller should be located such that the controller legend can readily be read.

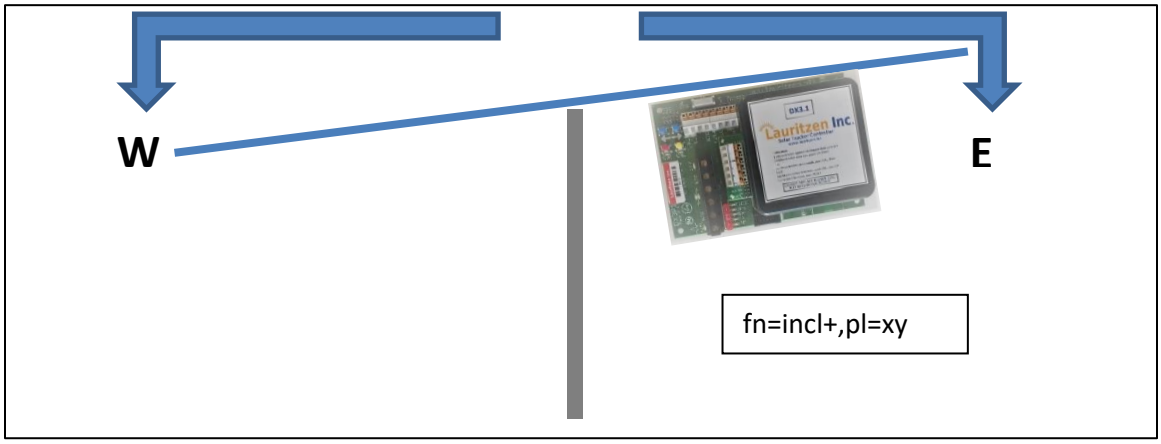

Figure 11; Single-Axis Tracker with DX3

Like the IXYZ inclinometer, the controller may also be mounted such that the inclinometer plane is negated – as seen in the figure below.

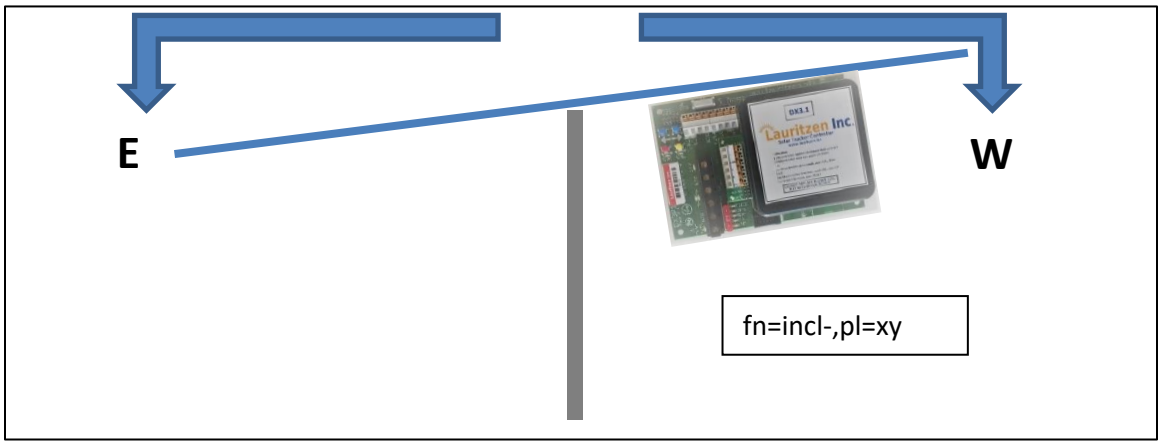

Figure 12; Single-Axis Tracker with DX3

6.4. IXYZ with Dual-Axis Tracker

In general, all inclinometers must be mounted so that the inclinometer's cable-exit is pointed vertically down when the tracker is horizontally positioned. The inclinometer positioning should be near the tracker pivot point – as practical.

Figure 13; Positive oriented inclinometer on dual-axis tracker

Figure 9 illustrates a positive oriented inclinometer on a dual-axis tracker. The tracker is in the northern hemisphere, and at the time of this picture, has an approximately 45 degree tilt. The tracker's pivot pin can be seen in the right side of the picture.

The inclinometer cable must be secured such that it freely moves along with the tracker's operation and such that no particular point along the cable is bending or twisted.

7. Level Development LCH-360-232 Inclinometer

The LCH-360-232 inclinometer from Level Developments can only be used with the SCX2 controller. When ordered from LD, the LCH-360-232 is supplied with a cable containing no controller connector. Thus a mini-din connector must be fitted prior to operation, or a ready-to-go inclinometer can be ordered from Lauritzen Inc. An example of the male connector is Mouser Electronics part #806-KDAX-6P..

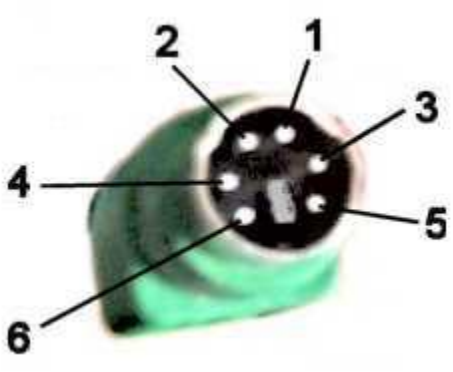

Figure 1; connector pin numbering

Description	Color	Pin Number
Ground/Neg	Black	1
+5V Supply	Red	2
Reserved		3
TX (controller → inclinometer)	Blue	4
RX (inclinometer → controller)	Yellow	5
Reserved		6

8. SCX/TCX Inclinometer LED Signaling

Immediately adjacent to the inclinometer terminal on the SCX/TCX controller is an LED which indicates LED status as follows;

LED State	Diagnosis	Resolution
Off	No inclinometer specified in Target Finder	Define inclinometer parameters in Target Finder
Off	In case of fn=itable, no inclinometer present	Connect inclinometer and reset controller
Constant blink (2x/second)	Mandatory Inclinometer is not present, or inclinometer with error	Check inclinometer connectivity and/or inclinometer functionality
Occasional blink (10 second on, followed by rapid blink)	Inclinometer is functional, and blink indicates number of connected inclinometers	(normal controller function with inclinometer)

9. Revision History

Revision	Release Date	Comments/Changes
V1.0	Dec-1-2018	Initial Version
V1.1	Mar-1-2019	Removed support for incl-table. Clarified inclinometer function use
V1.2	Apr-20-2020	Added CX3P7 inclinometer voltage source selection
V1.3	Dec-28-2021	Added 6.1.4 debug section

10. Contact and Support

Please contact your local tracker manufacturer for support and warranty issues.

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Information in this manual is subject to change…