Motion control standard

Revision:	0.1
Status:	Preliminary
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Reviewed by:	
Approved by:	
ECM location:	Documents\Maszyna_Machine\Beamlines\standards
Filename:	Solaris_standard_motion_control.doc
Last update:	130723

Revision history

Version	Date	Description	Sign
0.1	130723	First draft	Lukasz Zytniak

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Table of Contents

1 Introduction

This document summarizes the SOLARIS standards on motion control and pretends to advice on best practices in motion cabling.

2 Motor controller

National Synchrotron Radiation Center - „Solaris" standard motor controller is IcePAP.

As mentioned in the introduction, this document describes SOLARIS policies while the document 'IcePAP Hardware Manual' is the ultimate reference for the IcePAP motor controller itself. Both documents should be distributed together.

IcePAP driver can drive virtually any kind of 2 phase bipolar stepper motor and provide signals to steer any kind of external pulse/direction driver used to power a motor of other technology. IcePAP has four main interfaces that will be described in the following sections.

In the Figure 1 appear all the different elements of a standard motion system with a colour differentiation between supplier (red) and SOLARIS (blue) responsibilities. Standard motion systems are those equipped with 2-phase stepper motors with a nominal current up to 7A and encoders supported by IcePAP i.e.: pulse/direction or quadrature (TTL or RS422) or absolute SSI (for BISS- C, contact SOLARIS technical services).

Supplier must follow all rules described in the next chapter.

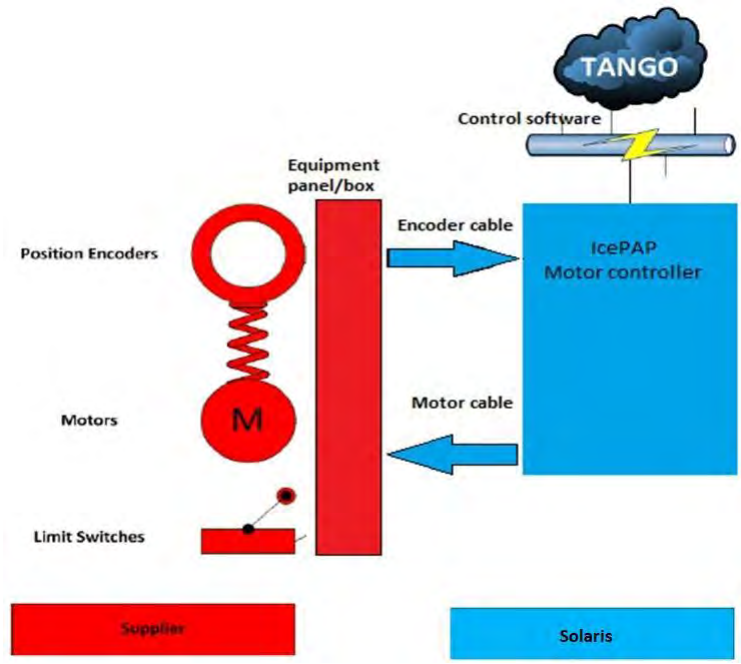


Figure 1. Elements and responsibilities of a standard motion system

3 Standard motion system

3.1 Motors

Standard motion systems are determined by the use of 2-phase bipolar stepper motors up to 7A and encoders supported by IcePAP i.e.: pulse/direction or quadrature (TTL or RS422) or absolute SSI (for BISS-C, contact SOLARIS technical services).
Any other motion system is considered as non-standard and have to follow chapter 'Non-standard motion system'.
As described above IcePAP can drive any 2-phase bipolar stepper motor up to 7A. Thanks to its software configurable DC bus (70V-10V) and current loop PID parameters IcePAP has no problem driving low inductance motors (high current or in-vacuum steppers) or high resistance motors.
In case of doubt selecting a motor for your application don't hesitate to contact National Synchrotron Radiation Center - „Solaris" technical services.

3.2 Motor connection

The motor connector is a 12-pin MIL-C-26482 compatible shell size 14.
Figure 2 shows pin distribution for different motors.

Connector	Pin	Signal			Description
		1-phase	2-phase	3-phase	
 *12-pin female MIL-C-26482 compatible shell size 14 socket*	A	Home			Mechanical reference
	B	PhaseA+	PhaseA+	PhaseA	Motor power
	C	PhaseA-	PhaseA-	PhaseB	
	D	n/c			
	E		PhaseB+	PhaseC	
	F	n/c	PhaseB-	n/c	
	G	Disable			Remote Disable
	H	Limit+			Travel limits
	J	Limit-			
	K	Shield			
	L	5Vpower			Aux power supply
	M	GND			
Examples of mating connectors:		ITT CANNON: TNM6U 1400-12P1L FCI: UTGS6PG1412PN			

Figure 2. IcePAP motor connector.

Control lines, i.e.: Home, Limit+, Limit- and Disable share the same electrical interface shown in Figure 3.
All control lines are to be closed via pin M (GND).
Pin A (Home) is foreseen when electrical switches in the equipment will be used as reference mark for homing purposes. For reference signals provided by encoders, there's already a couple of pin inputs available at the encoder interface.

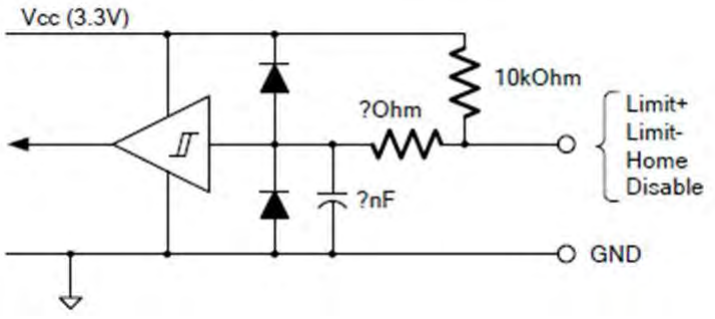


Figure 3. Control lines electrical interface.

Pin L (5V power) should be used to supply active switches.
Pin K is connected to the cable shield and is thought to provide electrical shield continuity in case plastic connectors (discouraged) are to be used.

The signal Disable (Pin G) is always checked by the hardware, and a high level prevents the motor power to be switched on. Even if the equipment to be driven will not use the disable signal functionality, Disable has to be externally connected to GND (i.e. pins G and M have to be connected). A good practice in that case is to connect the disable signal to ground in the last connector before the motor, so that the driver can always detect if the motor is connected or not.

3.2.1 Connector code examples (based on Souriau Trim Trio series)

IcePAP controller has a connector Souriau Trim Trio code UT001412SH
Cable on the IcePAP controller side a UT061412PH
Cable on the motorised equipment side will have a UT061412SH
In the motorised equipment patch panel there should be a UT001412PH
Connector codes finishing with SH/PH can end with SH6/PH6 if IP68 is desired.

Of course, other manufacturers of 12-pin MIL-C-26482 compatible shell size 14 equivalent connector are also accepted.

3.3 Encoders

IcePAP supports both incremental and absolute SSI encoders via its main connector input.
Incremental encoders can be pulse/direction or quadrature.
For SSI absolute encoders the clock frequency can be set to any value among 125kHz, 250kHz, 500kHz, 1.25MHz, 2.5MHz, 5MHz, 12.5MHz and 25MHz.
It is possible to add an extra time interval between consecutive SSI frames. That extra time can be chosen to be: 0, 5µs, 10µs, 20µs, 30µs, 50µs, 100µs or 500µs. Data width can be chosen up to 32 bits and the position value must be encoded either as normal binary or Gray code.
The SSI module may implement also odd or even parity checking. The parity bit must come as a data bit after the position bits.

3.3.1 Encoder connection

The encoder signals are differential and compatible with RS422 specification (see Figure 5 for electrical interface).
All differential signals are also TTL compatible. In that case, the negative signal has to be disconnected and only the positive signal of the differential pair and the GND pin are to be used as interface.

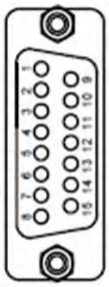
Connector	Pin	Signal	Type/Direction	Description
 *15-pin female sub-D*	1	EncInA+	RS422 input	Encoder signal
	9	EncInA–		
	2	EncInB+	RS422 in/out	
	10	EncInB–		
	3	EncAux+	RS422 in/out	Auxiliary encoder signal
	11	EncAux–		
	4	EncClk+	RS422 out	Encoder clock signal
	12	EncClk–		
	5		n/c	
	13		n/c	
	6		n/c	
	14	5Vsense+	analog input	Aux supply sense
	7	5Vsense–	analog input	
	15	5Vpower	power supply	Aux power supply
	8	GND	power ground	

Figure 4. Encoder connector

EncInA, EncInB and EncAux are to be used with incremental encoders for signals A, B and Index.
EncClk and EncAux are to be used with absolute encoders for Clock and Data inputs.
The auxiliary power supply in the encoder connector provides 5V supply to encoders (pins 15 and 8) and also sense lines to compensate for supply cable voltage drops (pins 14 and 7).
The connector on the motorised equipment panel has to be a 15-pin male sub-D connector with the pinout described in Figure 4.
In case of doubt don't hesitate to contact National Synchrotron Radiation Center - „Solaris" technical services.

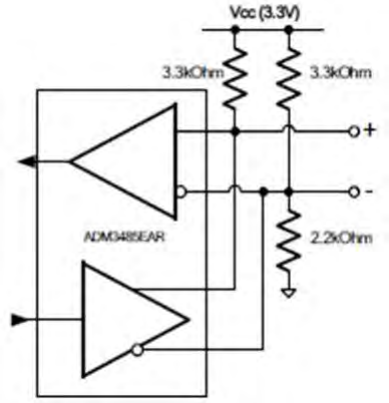


Figure 5. Circuit used for differential RS422 lines (input and output).

3.3.2 Note on use of absolute encoders in continuous-scan-like applications

Absolute encoders (SSI, Biss-C, and any others) readout, unlike incremental ones, is based on a serial transmission. During this transmission the motor controller sends a clock signal and the encoder sends out, bit by bit the position information and some other data.

Motor controllers read that information once every interruption cycle (IcePAP 25kHz, Galil 10kHz,…). That time resolution (provided that the position can be read from the controller at that speed via Ethernet) is not comparable to what is normally obtainable from incremental encoders readout via counter cards where the resolution is much higher (counting edges what can be done with resolution below tenths of microsecond).

For normal positioning applications, this time resolution is not necessary. At 25 kHz the controller will close perfectly any position closed loop, and the control system, from outside will never request position information (encoders) that fast via Ethernet.

But there is a case where the time resolution is important. The continuous scans. This application consists on acquiring different sensors/detectors while the axis is moving at constant speed. Of course with the sensor information, the position at what they were measured must be read out of the controller somehow. And in a synchronous way with the counter card that is triggering the whole acquisition of the experiment.

This synchronization problem is solved easily if the encoder is incremental. The position pulses are just forwarded to the counter card and counted there. The only delay is that of the cables what is normally negligible.

On the other hand, for absolute encoders, the synchronization cannot be done easily via hardware because the motor controller does not give access to when the serial communication is started. Therefore the implementation has to be done via software and the delay of the Ethernet communication and the internal processing time of the controller create a jitter (significant if compared to the readout of incremental encoders).

If your encoder has a high resolution and the axis has a standard speed in the ksteps/second that jitter can transform to a position inaccuracy.

Therefore for that application incremental encoders are recommended. Typical cases are axis like:

- Omega in protein crystallography or powder diffraction diffractometers
- Monochromator axis related to the energy for XAS, or other techniques whose data acquisition is based on photon energy scans.

IcePAP has 3 encoder inputs, allowing having both an absolute and an incremental axis connected to the same driver in case the absolute position would be necessary (for safety or to avoid recurrent homing in long strokes).

3.4 Limit or home switches

As described above, limit or home switches are connected to IcePAP via the motor connector described in Figure 2 and 3.
Standard limit switches meet the following specifications:
- 2 contacts per limit
- Return of the circuit is done via the pin M (GND) pin in the motor connector.
- Activation is defined by their interaction with the input circuitry described in Figure 3.
- 5V supply can be taken from pin L but don't forget that the inputs already have a pull-up to 3.3V.
- Normally-closed contact are preferred.

Typically a dry normally-closed contact is satisfactory. If a sensor based on different technology it should be stated clearly in the documentation.

3.5 Disable

IcePAP provides a pin (G) in its motor connector to allow external hardware to stop the motor drive for safety purposes.

This pin has the same electrical interface as the pins dedicated to positive and negative switches.

There's a number of situations where this pin should/could be used:

- Overtravel switches
- Safety kill switches (red buttons)
- Collision switches
- ...

There are two possibilities to cable these switches depending on whether it is necessary/requested that external electronics survey the state of the switches or whether that is not necessary and the switches can be cabled in series to the disable pin. The decision has to be agreed with the equipment responsible on National Synchrotron Radiation Center - „Solaris" side.

1) In the first case if the axis has to be disabled, it will be done via a PLC (that might be provided by National Synchrotron Radiation Center - „Solaris"). Electrically, this means that the signals/switches giving the alarm
condition have to be wired to the PLC and that the PLC has to activate the disable pin in the motor axis connector.

- For each switch/signal giving the alarm condition a screw terminal will be provided to made the signal accessible to the PLC.
- A 2 contacts screw terminal will be cabled to pins G (+) and M (-) in the motor connector so that the PLC can actuate on the disable signal.

Due to the extra overhead that is required to add the disable screw terminals at a later stage, it is STRONGLY RECOMMENDED to add it in the beginning in case of doubt. This shouldn't be done as default practice though and be kept only to axis that need/might need the disable for some reason.

2) In the second case the switch/switches should be wired in series between disable pin (G) and ground pin (M)

See wiring examples for several cases in Apendix A.

- 8.1: Axis wiring example without disable.
- 8.3.1: Axis wiring example for overtravel or safety limit switches connected to PLC and disable pins available to PLC via screw terminals.
- 8.3.2: Axis wiring example for overtravel or safety limit switches connected directly to IcePAP.

4 Non-standard motion systems

Non-standard motion systems are those whose motor is not a 2-phase stepper with nominal current up to 7A or whose encoder output is not supported by IcePAP i.e.: others than pulse/direction or quadrature (TTL or RS422) or absolute SSI (for BISS-C, contact SOLARIS technical services).

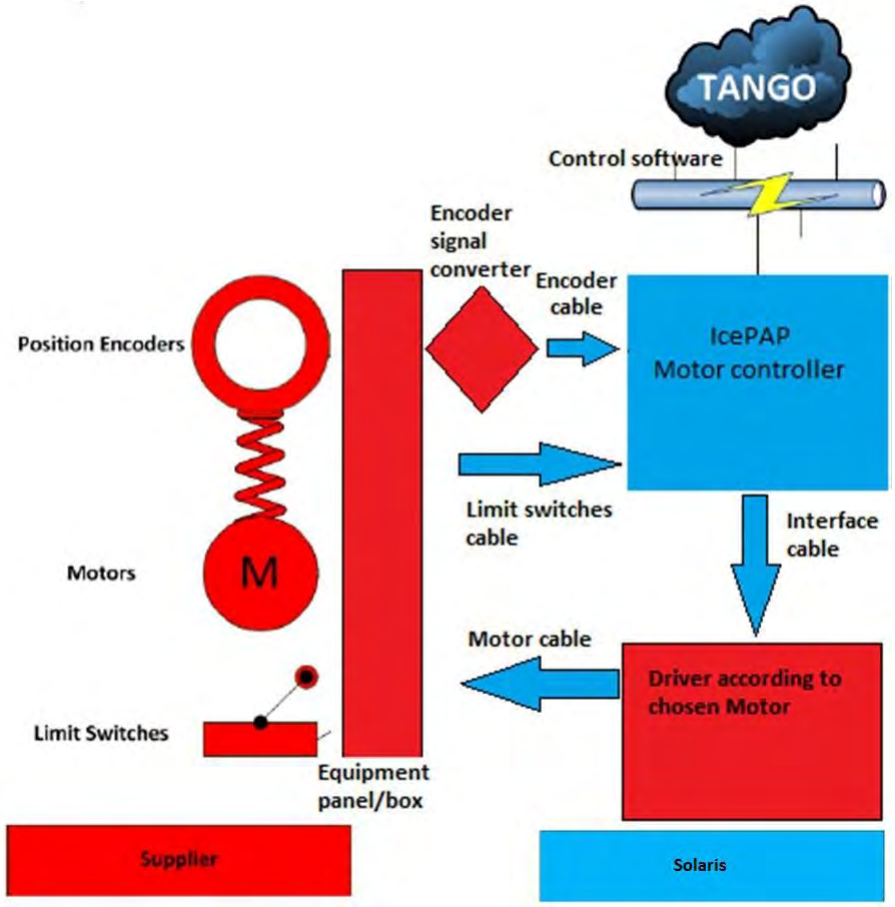


Figure 6. Elements and responsibilities of a standard motion system

Non-standard motors can be driven from IcePAP via its pulse/direction (or quadrature) output. Each IcePAP driver can forward its internal indexer pulses to any other driver that can be steered via pulse and direction or quadrature via its front axis interface keeping at the same time synchronization capabilities with the rest of the IcePAP system. It is up to the supplier to find a suitable power driver for his motor.
In the front axis interface connector, 3 TTL 3.3V can be configured to output information to the driver like power on/off (InfoA), brakes (InfoB) or changing step resolution (from full step to some factor of microstepping).
Limit switches should in this case be wired to the motor interface of the IcePAP driver connected to the external driver. A connector has to be foreseen for that purpose in the equipment interface panel or box. If the limit switches are needed by the external driver, IcePAP can forward those limit signals to the external driver via the 3 TTL 3.3V outputs mentioned above.

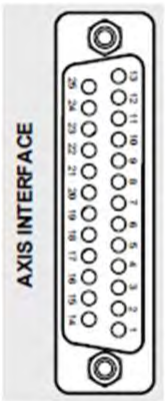
Connector	Pin	Signal	Type/Direction	Description
 *25-pin female Sub-D*	1	+3.3V	power supply	See 2.2.2.1
	14	(reserved)	RS232 I/O	Asynchronous serial port
	2	Tx232		
	15	(reserved)		
	3	Rx232		
	16	GND		
	4	OutPosA+	RS422 output	Output position signal
	17	OutPosA-		
	5	OutPosB +	RS422 output	
	18	OutPosB-		
	6	OutAux+	RS422 output	Auxiliary output signal
	19	OutAux-		
	7	GND		
	20	InPosA+	RS422 or TTL input	Input position signal
	8	InPosA-		
	21	InPosB+	RS422 or TTL input	
	9	InPosB -		
	22	InAux+	RS422 or TTL input	Auxiliary input signal
	10	InAux-		
	23	GND		
	11	GND		Signal ground
	24	InfoA	TTL Output (3.3V)	General purpose output
	12	InfoB	TTL Output (3.3V)	General purpose output
	25	InfoC	TTL Output (3.3V)	General purpose output
	13	GND		Signal ground

Figure 7: Front axis connector pinout

The pulse and direction (or quadrature) output is obtained from two differential pairs (according to RS422 standard) OutPosA (pulses) and OutPosB (direction). These signals can drive TTL inputs too leaving the negative pin of the pair disconnected and closing the circuit via GND (pin 7).
The electrical diagram of these quadrature pairs is the one shown in Figure 5.

In order to use non-standard encoders, the supplier has to provide some kind of converter to the supported encoder signals. It is strongly recommended that you contact before SOLARIS technical services.

5 Dampers

Mechanical dampers have become very common recently in all motor manufacturers catalogs. These inertial bodies filled with hermetically sealed silicon gel suppress stepping motor vibrations and improve high-speed performance allowing steppers to transition through the typical middle frequency resonances at few kHz into the 10kHz region for a very low price.
In systems where high rotary speed is required, National Synchrotron Radiation Center - „Solaris" recommends the use of double shaft motors with one of these dampers attached to the second shaft.

Figure 8. Inertial dampers from two motor manufacturers

6 Cabling

The standard cable used at National Synchrotron Radiation Center - „Solaris" to join motor interface at controller and the motor connector at the equipment has the following characteristics:

- 2x2x0.75mm2 for the motor phases. Shielded.
- 2x3x0.34mm2 for the control lines (limits, home, disable, 5V, gnd). Shielded.
- Overall shield. Outer sheath PUR, halogen free.

Equipment internal cabling does not have to comply with this, but it should be taken as reference for shielding and wire diameters.

The standard cable used at National Synchrotron Radiation Center - „Solaris" to connect encoder interface at controller and the encoder connector at the equipment has the following characteristics:

- 6x2x0.25mm2 LIYCY cable. Shielded

Equipment internal cabling does not have to comply with this, but it should be taken as reference for shielding and wire diameters.

7 Summary

Standard motors	2-phase bipolar steppers
Standard motors nominal currents	Up to 7A
Driver DC bus	Software configurable from 75V down to 10V
Incremental encoder technologies	Pulse/direction or quadrature (TTL or RS422)
Absolute encoder technologies	SSI, BISS-C (contact before SOLARIS technical services)
Encoder voltage supply provided by controller	5VDC
SSI clock frequencies	125kHz, 250kHz, 500kHz, 1.25MHz, 2.5MHz, 5MHz, 12.5MHz and 25MHz
SSI data	Up to 32 bit
SSI others	Gray or binary. Odd or even parity bit after data
Limit switch voltage ratings	Interface is based on pull-up to 3.3V
External driver output	Pulse/direction or quadrature (TTL or RS422) (3.3V)
High speed axis	Inertial dampers on 2nd shaft recommended
Disable signals	In case of doubt add a connector for that purpose
Connector codes (Soriau series)	
Motor connector in a motorised equipment's patch panel	UT001412PH or UT001412PH6
Disable connector in a motorised equipment's patch panel	Screw terminals
Encoder connector in a motorised equipment's patch panel	15 pin sub-d male

8 Appendix A

8.1 Standard motion system. Motor connector wiring example

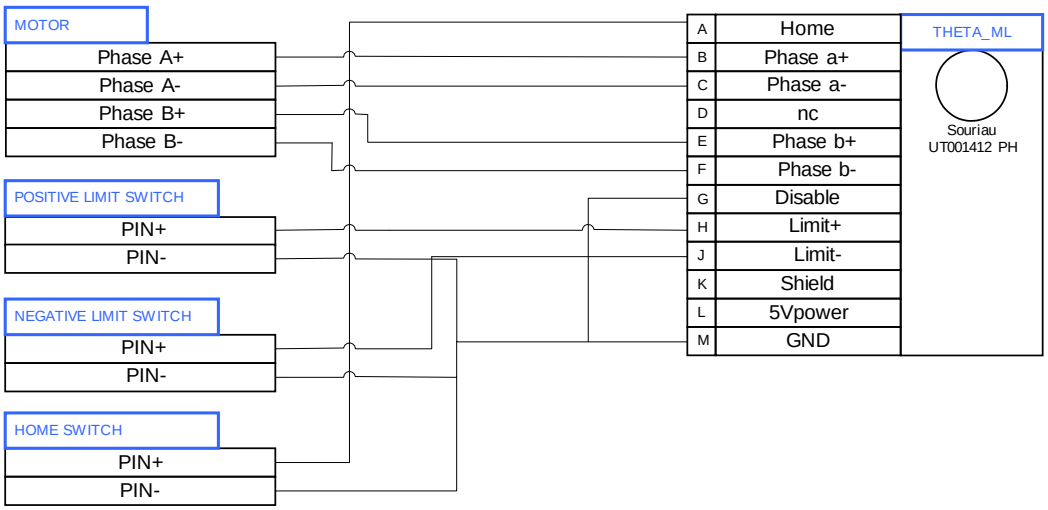


Figure 9. Interface box wiring diagram on motorised equipment.

8.2 Standard motion system. Encoder connection wiring example

8.2.1 Motorised equipment interface box for Renishaw Tonic encoder

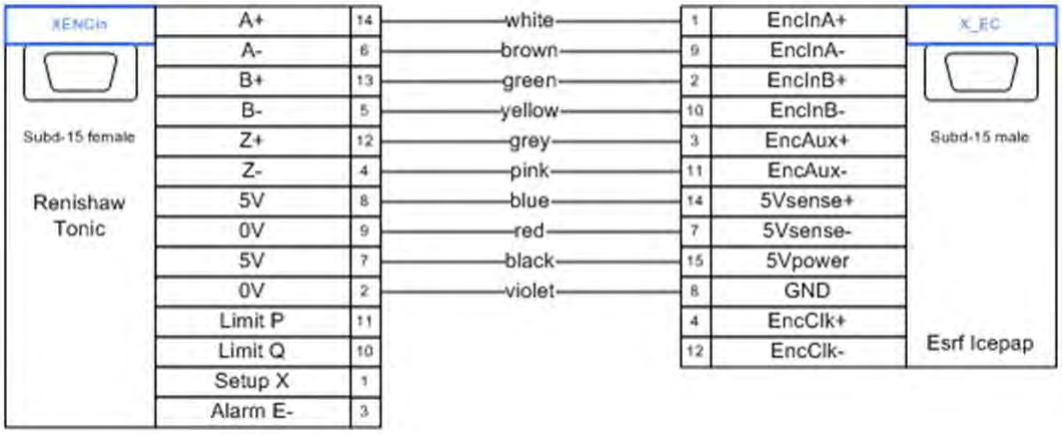


Figure 10. Interface box wiring diagram on motorised equipment for Renishaw Tonic encoders

8.3 Standard motion system. Disable connection wiring examples

8.3.1 Overtravel or safety switch limits to PLC and from there to IcePAP

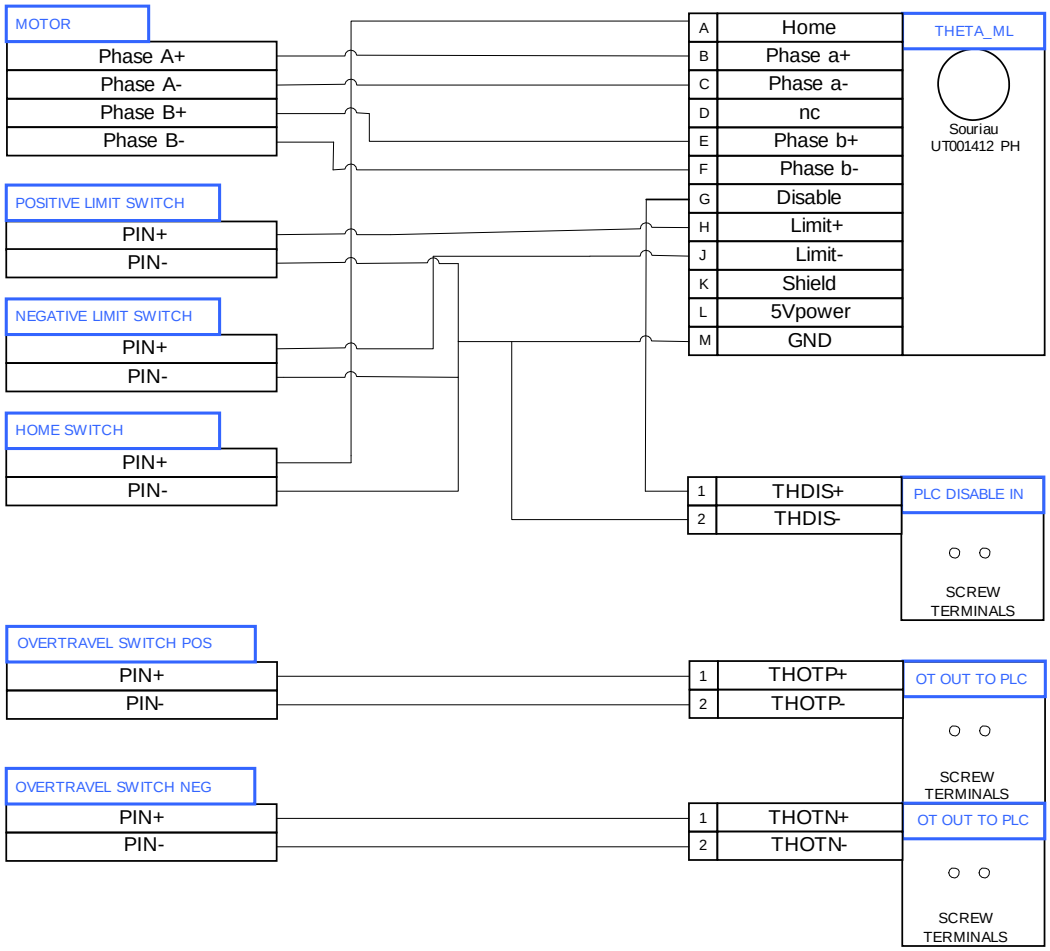


Figure 12. Interface box wiring diagram for overtravel PLC disabled axis

8.3.2 Overtravel or safety switch limits direct to IcePAP

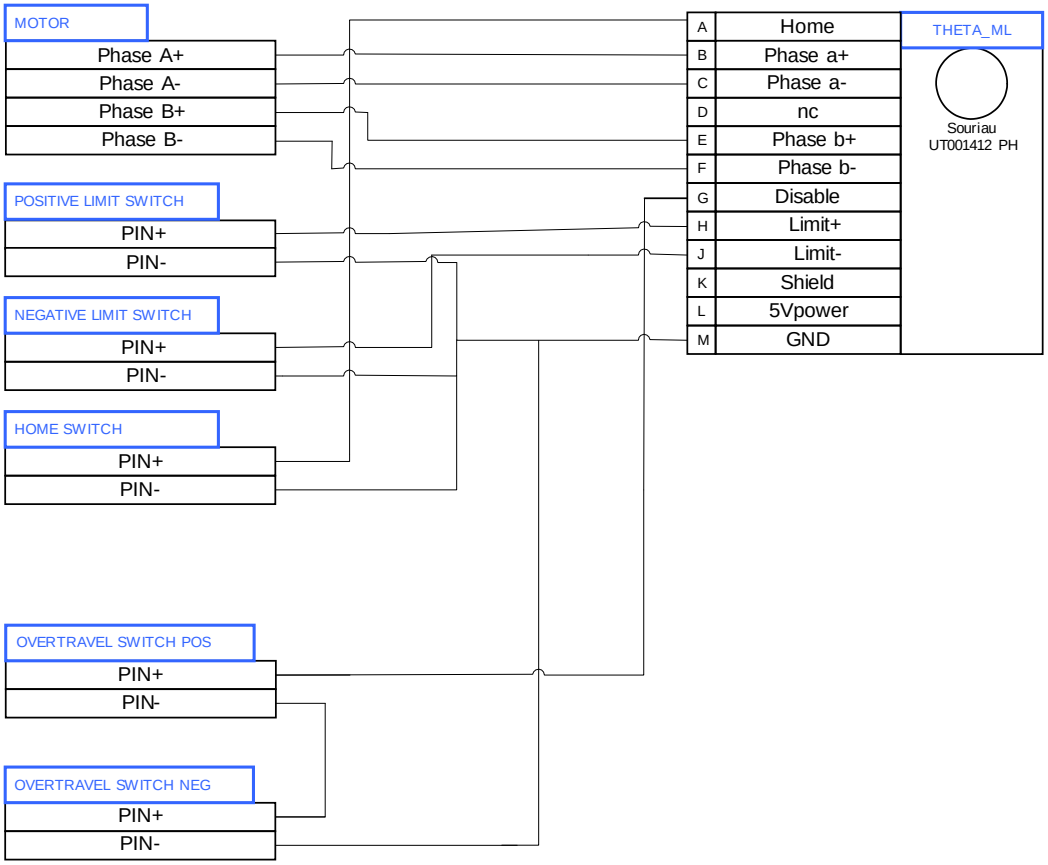


Figure 13. Interface box wiring diagram for overtravel disabled axis without external hardware