Motion control standard

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1 Introduction

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

2 Motor controller

MAX IV Laboratory standard motor controller is IcePAP. As mentioned in the introduction, this document describes MAX IV policies while the document 'IcePAP Hardware Manual' is the ultimate reference for the IcePAP motor controller itself. Both documents should be distributed together. In order to assist in the choice of axis names and their positive direction the document 'MAX IV Beamline coordinate system' will be distributed too. Additionally a fourth document 'Guidelines for interfacing external motion controllers to IcePAP' will be distributed in case an external motion controller is necessary for a specific application.

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 color differentiation between supplier (red) and MAX IV (blue) responsibilities. Standard motion systems are those equipped with 2-phase stepper motors with a nominal current up to 7A requiring less than 300W in operation and encoders supported by IcePAP i.e.: pulse/direction or quadrature (TTL or RS422) or absolute SSI and BISS-C.

Supplier must follow all rules described in the next chapter.

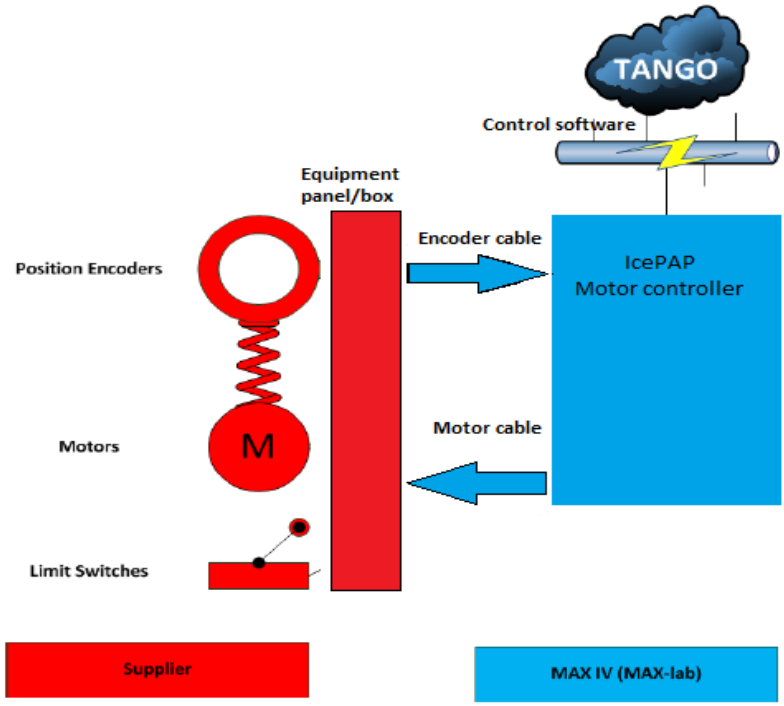


Figure 1. Elements and responsibilities of a standard motion system

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 MAX IV 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 (requiring less than 300W in operation). 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 MAX IV Laboratory 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 2-phase stepper motor types in the equipment side.

Connector on equipment side	Pin	Signal	Description
 12-pin male MIL-C-26482 compatible shell size 14 socket Example of connector codes: Souriau Trim Trio UT001412PH Souriau Trim Trio UT001412PH6	A	Home	Mechanical reference
	B	PhaseA+	Motor power
	C	PhaseA-	
	D	n/c	
	E	PhaseB+	
	F	PhaseB-	
	G	Disable	Remote Disable
	H	Limit+	Travel limits
	J	Limit-	
	K	Shield	
	L	5Vpower	Aux power supply
	M	GND	

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.

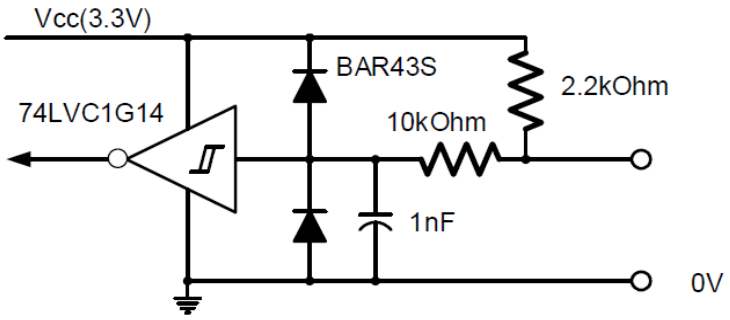


Figure 3. Control lines electrical interface for Limit+, Limit-, Home and Disable. Vcc = 3.3V, 2.2 kOhm pull-up

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 (it can be configured to block movements, among others). Even if the equipment to be driven will not use the disable signal functionality, Disable must be externally connected to GND (i.e. pins G and M have to be connected) to allow the driver to detect cable disconnections. 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.

Other brands of 12-pin MIL-C-26482 compatible shell size 14 equivalent connectors are accepted.

3.2.2 Alternative motor connection for in-vacuum stepper motors up to 2A*

If the motor to control is in vacuum it is possible to interface it through an in-flange male-male sub-d 15 feedthrough too. In that case the pins must be arranged to the configuration in the following table:

Pin in-air	Pin in-vacuum	Motor
1	8	PhaseB-
2	7	PhaseB-
3	6	PhaseB+
4	5	PhaseB+
5	4	PhaseA-
6	3	PhaseA-
7	2	PhaseA+
8	1	PhaseA+
9	15	Limit+
10	14	GND
11	13	Disable
12	12	5Vpower
13	11	Home
14	10	GND
15	9	Limit-

Figure 4. In-vacuum motors. In-air flange side male 15 pin sub-D connector pinout

This table has been updated to place the 5V pin in the center pin, avoiding to damage equipment if a mirroring error happens.

* In case the motor has 8 leads and is wired in parallel using 2 pins per phase, motors up to 4A per phase can use this configuration too.

3.3 Encoders

IcePAP supports both incremental and absolute SSI or BISS-C encoders via its main encoder connector input.
Incremental encoders can be pulse/direction or quadrature.
For absolute encoders the clock frequency can be set to any value among 125kHz, 250kHz, 500kHz, 1.25MHz, 2.5MHz, 7.5MHz, 12.5MHz and 18.75MHz.
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 36 bits and the SSI 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 Motor controller encoder connection

Figure 5 shows the standard connection configuration for encoders at MAX IV Laboratory. External manufacturers should adhere to it, especially when an interconnection box will be built into the equipment. Only in specific cases where no interconnection box is foreseen and after requesting written confirmation from MAX IV Laboratory staff, the schemes from 3.3.2 and later could also be used.
The encoder signal inputs are differential and compatible with RS422 specification.
All differential inputs 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.

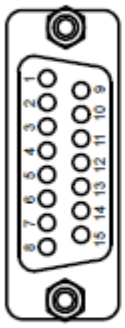
Connector	Pin	Signal	Type/Direction	Description
 *15-pin female sub-D*	1	EncInA+	RS422 input	Encoder signal
	9	EncInA–		
	2	EncInB+	RS422 in/out	
	10	EncInB–		
	3	EncAux+	RS422 in/out	Auxiliary encoder signal
	11	EncAux–		
	4	EncClk+	RS422 out	Encoder clock signal
	12	EncClk–		
	5		n/c	
	13		n/c	
	6		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 5. Standard encoder connector on equipment side

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 (up to 500mA) supply to encoders (pins 15 and 8) and also sense lines to compensate for supply cable voltage drops (pins 14 and 7).

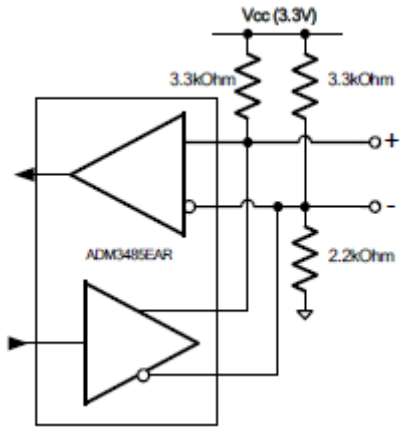


Figure 6. Circuit used for differential RS422 lines (input and output).

3.3.2 Motorized equipment interface for in-vacuum absolute encoders and in-air Renishaw Resolute encoders

The table below shows pinout on the equipment side for the in-vacuum absolute an in-air Renishaw Resolute encoders. Renishaw Resolute in-air in-built connector is accepted as is. In-vacuum SSI absolute, BISS-C absolute and UHV Renishaw Resolute BISS-C encoders will be interfaced via a on flange 9 pin male sub-D connector with the following pinouts at the in-air side (standard MAX IV Laboratory encoder cable has no inner shield):

Pin in-air	Pin in-vacuum	SSI	BISS-C	Renishaw Resolute in-air	Renishaw Resolute UHV flying leads
1	5	0V*	0V*	Inner shield	Inner shield
2	4	CLK+	MA+	MA+	Violet
3	3	CLK-	MA-	MA-	Yellow
4	2	NC	NC	5V	NC
5	1	5V	5V	5V	Brown
6	9	Data+	SLO+	SLO+	Grey
7	8	Data-	SLO-	SLO-	Pink
8	7	NC	NC	0V	NC
9	6	0V	0V	0V	White, Green
Shell	Shell	Shell	Shell	Outer shield	Outer shield

Figure 7. In-vacuum encoders. In-air flange side male 9 pin sub-D connector pinout

3.3.3 Motorized equipment interface for in-vacuum incremental encoders and in-air Renishaw incremental encoders

In-air equipment with Renishaw Tonic encoders or REF interpolators with the pinout in the table below will be interfaced directly via their in-built 15 pin male sub-D connector. In-vacuum incremental encoders will be interfaced through a sub-d 15 pin male-male feedthrough with the pinout described in the table below:

Pin in-air	Pin in-vacuum	In-vacuum incremental	Renishaw incremental
14	10	A+	A+
6	3	A-	A-
13	11	B+	B+
5	4	B-	B-
12	12	Z+	Z+
4	5	Z-	Z-
8	1	5V	5V
9	15	0V	0V
7	2	5V	5V
2	7	0V	0V
Shell	Shell	Outer shield	Outer shield

Figure 9. In-air encoders Renishaw Incremental encoder male 15 pin sub-D connector pinout

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 it must be observed that the inputs already have a 2.2kOhm pull-up to 3.3V. These 5V come from the same supply as the one used for the encoder.
- Normally-closed contacts are preferred.

Typically a dry normally-closed contact is satisfactory (as long as the pull-up to 3.3V in Figure 3 can yield an active signal when open). If a sensor based on different technology is used, it should be stated clearly in the documentation.

The positive limit switch location shall be chosen so that the axis moves towards it when it is actuated in the positive direction according to the document 'MAX IV Beamline coordinate system'.

4 Temperature connectors

The equipment should make available the thermocouples in the equipment or motors via miniature thermocouple connectors (rated to 210°C).

Examples can be found here:
http://www.tcdirect.co.uk/Default.aspx?level=2&department_id=280/1

In case of multiple TC in the same equipment a DSUBXX could be used.

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. Normally Closed (NC) contacts must used.

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

- Overtravel switches
- Safety kill switches (red buttons)
- Collision switches
- Disable motor due to temperature beyond a given threshold
- …

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 (this is typically the case when the axis ONLY has overtravel switches). The decision has to be agreed with the equipment responsible on MAX IV Laboratory side.

5.1.1 Disable with no need of external electronics

This is the typical case when the axis has ONLY two overtravel end-switches (not to confuse with the limit switches). In this case the overtravel switches have to be wired in series between the motor connector disable pin (G) and the motor connector ground pin (M).

5.1.2 Disable with need of external electronics

In this case if the axis has to be disabled (or it might be disabled in the future according to the equipment responsible), it will be done via a PLC (that might be provided by MAX IV Laboratory). 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. The equipment will use one 9 pin SUB-D connector (male).

Pins 1 and 2 of the SUB-D connector will be wired to the G and M pins of the motor connector, allowing the PLC to activate this signal. The rest of the pins are available for the equipment manufacturer to make accessible all the switches or signals that have to be surveyed by the PLC.

Limit switches used for axis disable conditions via external electronics must be replicated via this connector.

It is possible to group signals related to different axes in the same SUB-D connector to reduce the number of connectors. In that case pinout is to be decided by the manufacturer and approved by MAX IV Laboratory later.

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 axes that need/might need the disable for some reason.

See wiring examples for several cases in Apendix A.

- 12.1: Axis wiring example without disable.
- 12.2.1: Axis wiring example for disable with external electronics (via PLC).
  12.2.2: Axis wiring example for disable without external electronics.

6 Non-standard motion systems

Non-standard motion systems are those whose motor is not a 2-phase stepper with nominal current up to 7A (requiring less than 300W in operation) or whose encoder is not directly supported by IcePAP i.e.: outputs different than pulse/direction or quadrature (TTL or RS422) or absolute SSI (for BISS-C, contact MAX IV technical services), or need a supply current higher than 0.5A, for example.

Concerning non-standard motors, the approach for interfacing is different when an external controller (intelligent programmable motion controller) is used to interface the motor (typically Brushless DC motors) or when a simple power driver stage is used (3 or 5 phase stepper motors). In the first case the document mentioned in Chapter 1 'Guidelines for interfacing external motion controllers to IcePAP' will be followed. The second case is discussed in this chapter.

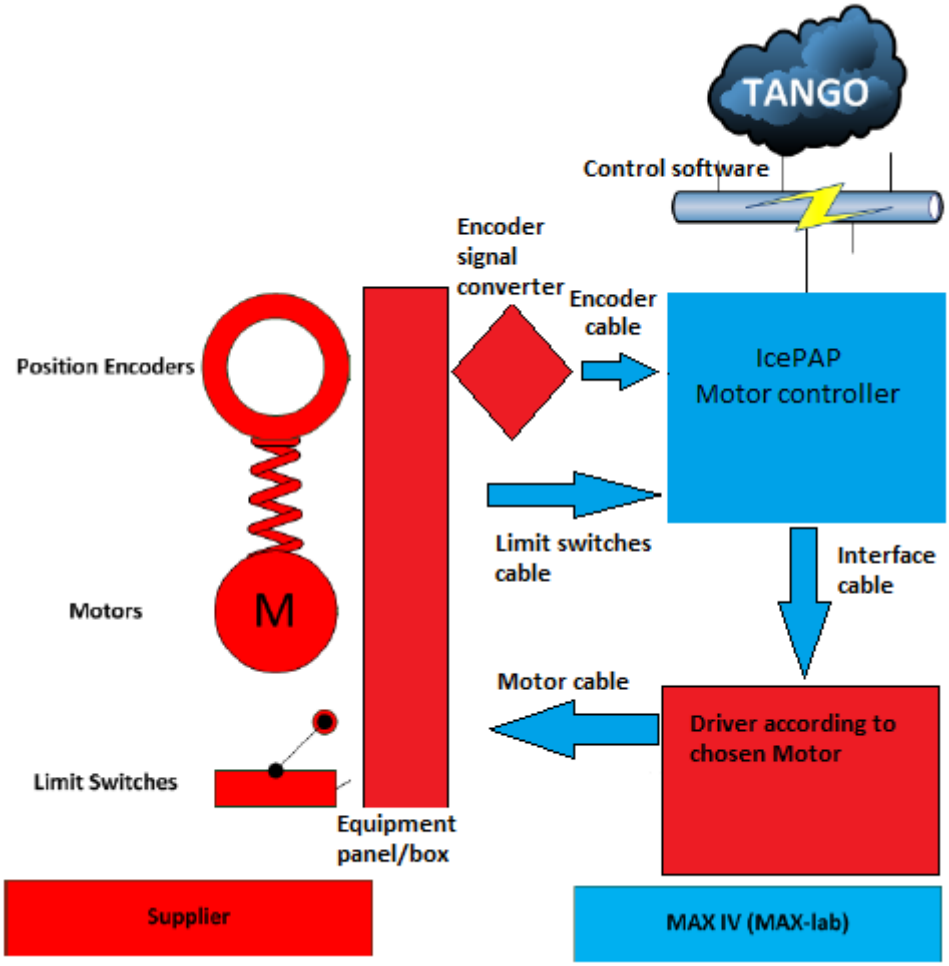


Figure 10. Elements and responsibilities of a standard motion system

Non-standard motor drivers can be driven from IcePAP via its quadrature (or pulse/direction output). Quadrature is preferred (pulse/direction drivers often impose a time before switching direction and IcePAP does not support that option).
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.

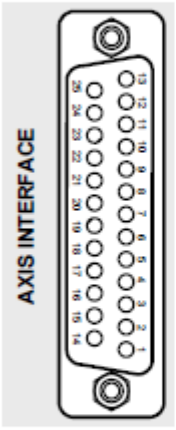
Connector	Pin	Signal	Type/Direction	Description
 *25-pin female Sub-D*	1	+3.3V	power supply	See 2.2.2.1
	14	(reserved)	RS232 I/O	Asynchronous serial port
	2	Tx232		
	15	(reserved)		
	3	Rx232		
	16	GND		
	4	OutPosA+	RS422 output	Output position signal
	17	OutPosA-		
	5	OutPosB +	RS422 output	
	18	OutPosB-		
	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 11: Front axis connector pinout

The quadrature (or pulse/direction) output is obtained from two differential pairs (RS422 compatible) OutPosA (pulses, CW) and OutPosB (direction, CCW). The circuit driving the RS422 signals is a AM26LV31CD (3.3V). These signals can drive TTL inputs too connecting the TTL signal between the positive pin and GND (pin 7) (leaving the negative pin of the pair disconnected).

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 MAX IV technical services.

7 Dampers, double shaft motors and high speed requirements

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, MAX IV Laboratory recommends the use of double shaft motors with an inertial damper attached to the second shaft.

Figure 12. Inertial dampers from two motor manufacturers

Some models:

- Phytron DMP series
- Oriental DxCL clean damper series

8 Brakes

In case a brake is needed, a SUB-D 9 pin male connector will be used to expose the brake signals on the equipment side. Pin 1 and 6 will be used for the actuation signal and its return/gnd, the rest of the pins can be used for other purposes.

9 Cabling and grounding

The standard cable used at MAX IV Laboratory 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.

The standard cable used at MAX IV Laboratory to connect encoder interface at controller and the encoder connector at the equipment has the following characteristics:

- 6x2x0.25mm2 LIYCY cable. Shielded. (Match differential signals with twisted pairs).

Equipment internal cabling does not have to comply with this.

All metallic connector plates must be adequately connected to the earth of the equipment.

10 Documentation

The manufacturer will provide, for each axis, a table with at least the following information:

- Motor:
  - Full model name
  - Current, idle current, step resolution (half step, microstepping factor) and speed recommended for the equipment
  - Steps from home to limit switches or between limit switches and limit switch to start homing from
  - Backlash
  - Disable sources
- Encoder:
  - Full model name
  - Type: Incremental or absolute
  - Encoder counts from home to limit switches or between limit switches if the encoder is incremental or encoder position of the limit switches if the encoder is absolute
- Limit switches:
  - Full model name
  - Type: Dry contact or other technology

MAX IV Laboratory will provide an excel sheet with the structure for all the information listed above. Besides, manufacturer datasheets will be provided for all motors, encoders, switches and other related elements used in the system.

11 Summary

Standard motors	2-phase bipolar steppers
Standard motors nominal currents	Up to 7A, 300W max per axis
Driver DC bus	Software configurable from 75V down to 10V
Incremental encoder interface	Pulse/direction or quadrature (TTL or RS422)
Absolute encoder protocols	SSI, BISS-C (up to 32 bits)
Encoder voltage supply provided by controller	5VDC, 500mA
Absolute encoder clock frequencies	125kHz, 250kHz, 500kHz, 1.25MHz, 2.5MHz, 7.5MHz, 12.5MHz and 18.75MHz
Absolute encoder 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 a 2k2Ohm pull-up to 3.3V
Thermocouples	Miniature thermocouple connectors (rated to °C) http://www.tcdirect.co.uk/Default.aspx?level=2&department_id=280/1
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
Axis direction (positive limit location)	It must be chosen according to the 'MAX IV Beamline Coordinate System' document
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
Brake connector in a motorized equipment's patch panel	9 pin sub-d male

12 Appendix A

12.1 Standard motion system. Motor connector wiring example

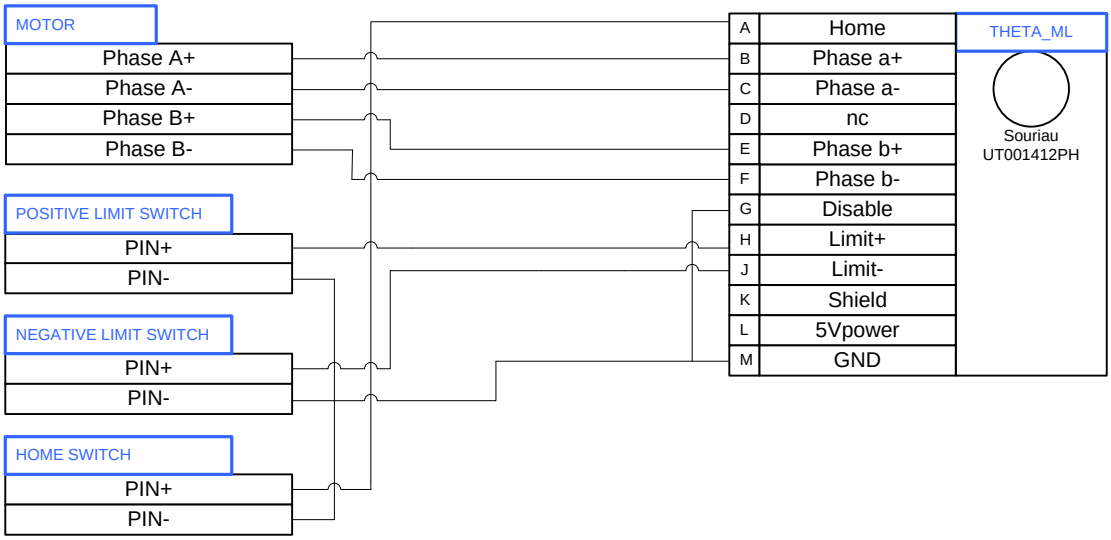


Figure 13. Interface box wiring diagram on motorised equipment.

12.2 Standard motion system. Disable connection wiring examples

12.2.1 Overtravel or safety switch limits via PLC

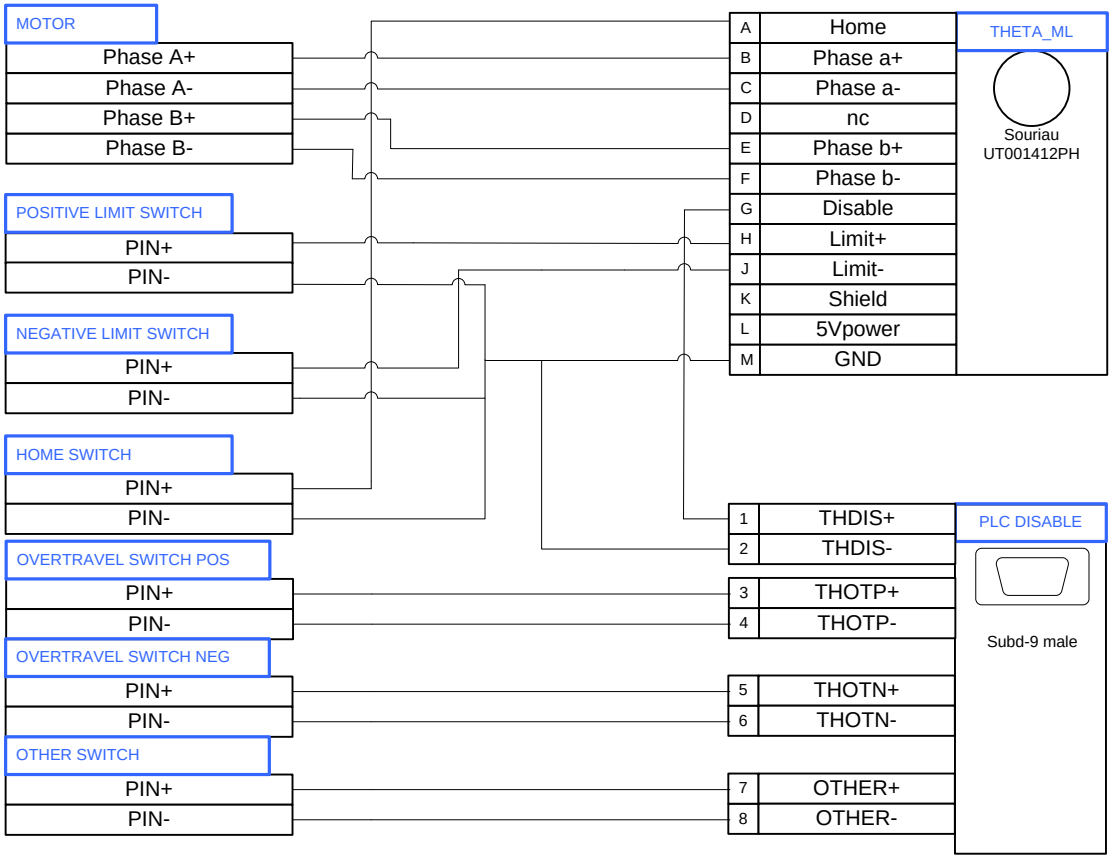


Figure 14. Interface box wiring diagram for overtravel PLC disabled axis

12.2.2 Overtravel or safety switch limits direct to IcePAP

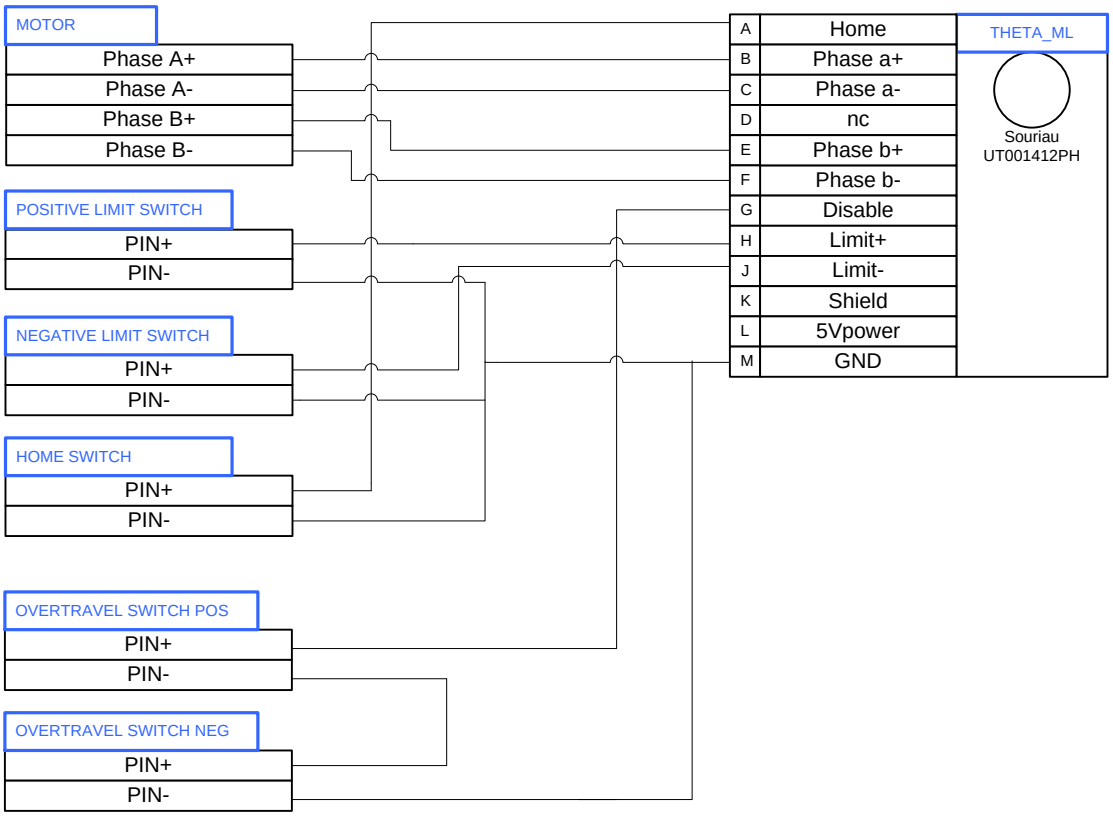


Figure 15. Interface box wiring diagram for overtravel disabled axis without external hardware