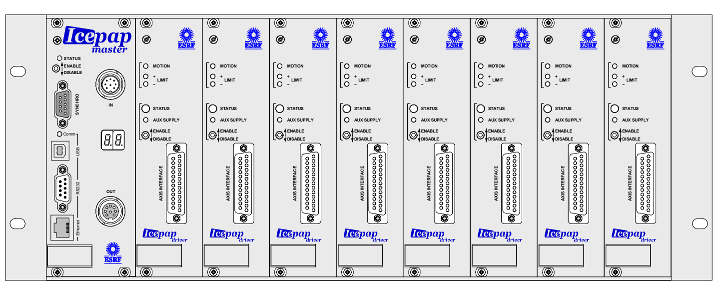
ESRF - Instrument Support Group

Icepap

Intelligent Controller for Positioning Applications

Hardware Manual



DRAFT

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Date	Version	Comments
15/02/2006	0.0a	First draft version.
24/03/2006	0.0b	A new draft version
06/06/2006	0.0c	Corrected encoder connector pinout description, 12pts connector disable signal changed
21/05/2007	0.0d	Corrected motion interface input signals pinout (InPosxx)
06/08/2007	0.0e	Introduction of “controller board” terminology
18/02/2008	0.0f	SSI information added
04/12/2009	0.0g	working version

CONTENTS

MANUAL ORGANIZATION

This manual presents the components and functionality of the IcePAP system:

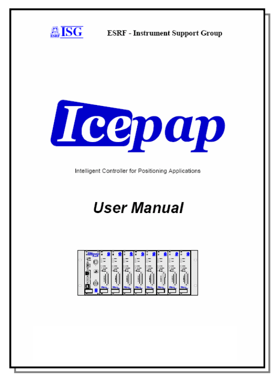
Section 1 gives a brief overview of the overall system, introduces its components and the terminology, like signal names, as well as describes the functional capabilities of IcePAP. The description is made in general terms based on functional block diagrams and it is mostly hardware oriented.

Section 2 presents the individual components, in particular the front and rear panels as well as it details the different connectors and their pinouts. The characteristics of inputs and outputs are illustrated by equivalent electrical circuits.

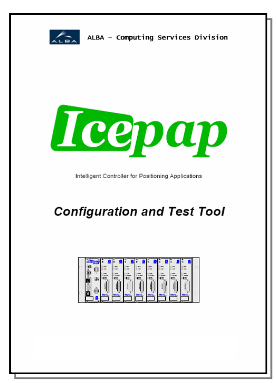
Appendix 1 to 3 present the summary of hardware specifications, the list of cabling accessories and some guidelines to guarantee the proper ventilation of the racks .

Related Documentation

- *IcePAP User Manual*
Provides information about the functional aspects of the IcePAP systems, describes in detail the communication protocol and includes a complete reference of commands and configuration parameters.



- *IcePAP Configuration and Test Tool*
Describes the GUI tool used for driver configuration and testing.



1. System Overview

IcePAP is a motor control system developed at the ESRF and optimised for high resolution position applications. Emphasis has been put in covering most of the requirements found and foreseen for synchrotron radiation experiments at the ESRF beamlines. IcePAP is fully software configurable and provides exhaustive diagnostic capabilities. Most of the functionality relies on programmable components what opens the possibility of adding new features by means of firmware upgrade.

An IcePAP system is axis-oriented, each axis is driven by a dedicated module (driver board) that includes both the high-level control functions like trajectory generation or position regulation, and a high performance PWM power amplifier. Up to 8 driver boards can be installed in the same power rack.

In addition to the power supply, each rack includes a system backplane that distributes communication and synchronisation lines between the drivers. The internal rack wiring transfers the motor and encoder signals from each driver board to rear panel socket connectors. In this way no cable plugging or unplugging interventions are required when the driver boards are replaced.

Each rack must be equipped by a system board (controller board) that among other functions participates to the rack initialisation and the management of common resources like the communication and synchronisation lines. Figure 1 shows the block diagram of an IcePAP rack with 8 driver boards installed.

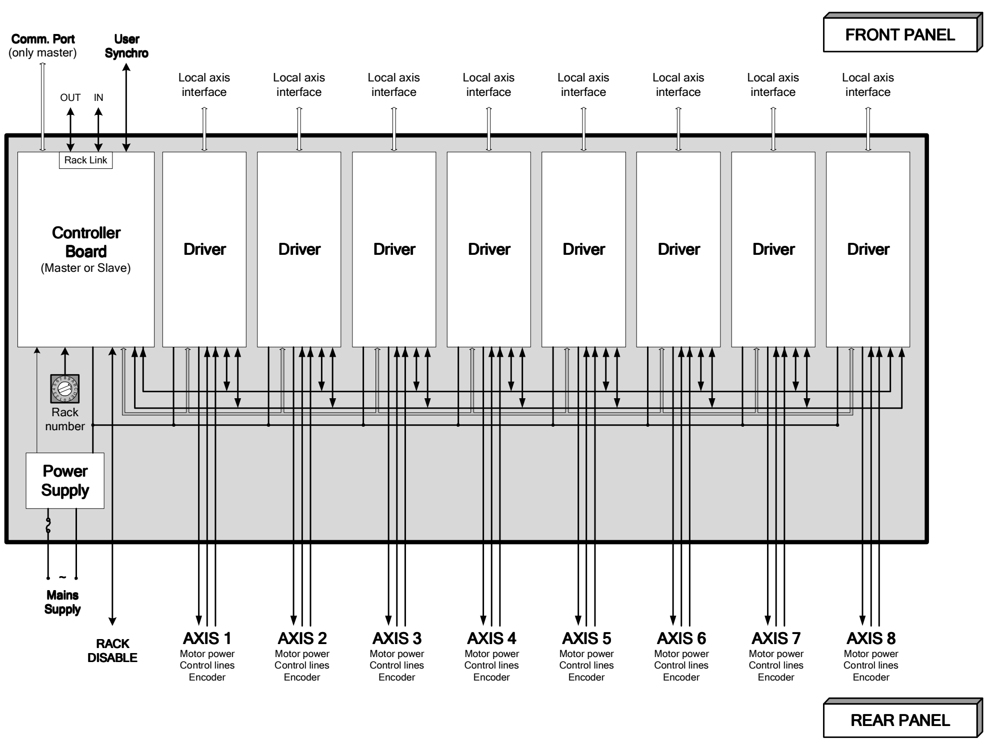


Figure 1: Simplified block diagram of a fully equipped IcePAP rack

Several racks can be connected together to form a single system where each rack is identified by a unique number that is selected by means of a rotary switch mounted at the rack backplane. Racks numbers go from 0 to 15 and therefore an IcePAP system can consist of up to 128 driver boards or axes.

One of the controller boards operates as system master and takes in charge the initialisation of the whole system. The other controllers operate as slaves under the supervision of the system master. The system master board also includes the communication interfaces (Ethernet/TCP, RS232 or USB) that a host computer may use to talk to and remotely control the system. The master communicates with the slave controllers and with all the drivers by an internal serial bus (CANbus). All the internal commands and answers are dispatched through this private bus.

Figure 2 shows and example of an IcePAP system with 17 axes in three racks. In this case, the system is controlled by software running in a host computer through an Ethernet/TCP connection.

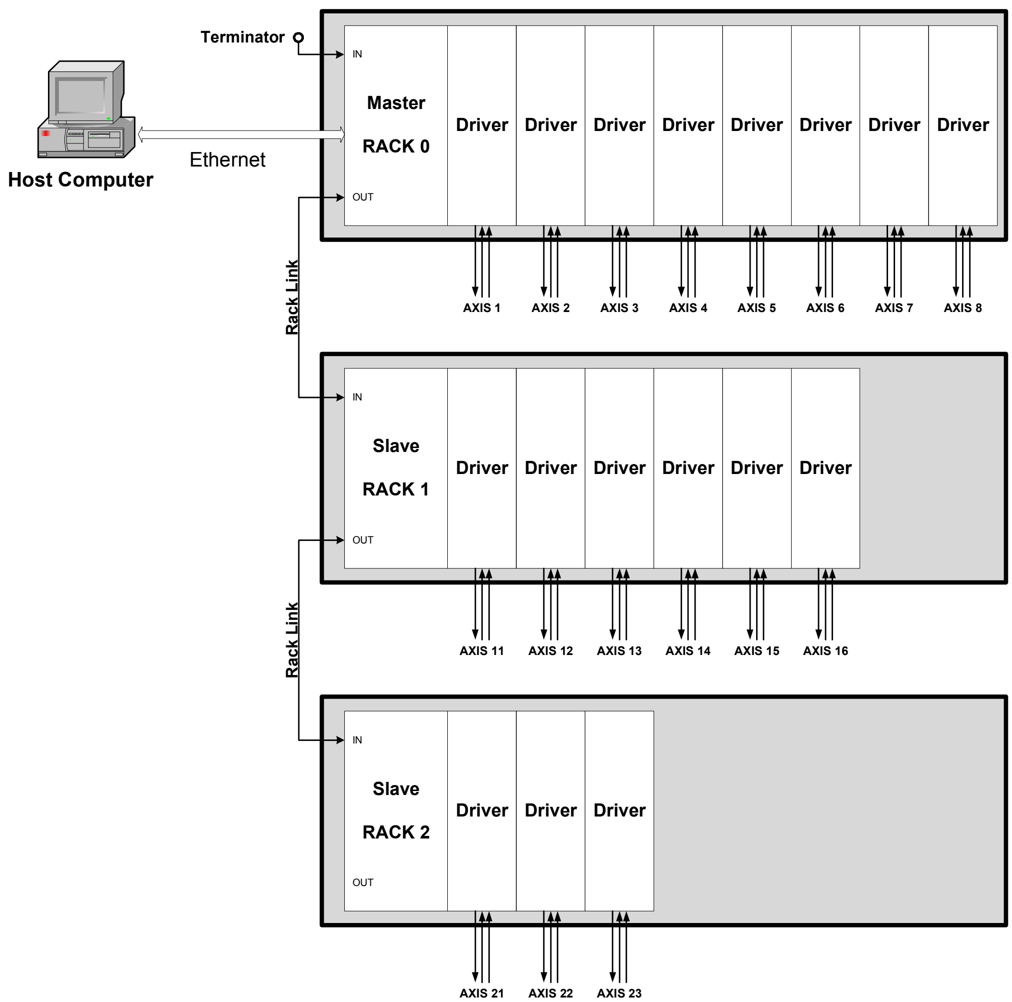


Figure 2: Example of an IcePAP system

1.1. Driver board

The main component of an IcePAP system is the driver board. Each board controls one mechanical axis by driving a motor and reading back the control information associated to it.

The control information includes the travel limits, an absolute mechanical reference and a power disable signal. It also may include an incremental or absolute position encoder.

Figure 3 depicts the connectivity and the different signals used or provided by the driver board. The motor and encoder connections are actually accessible not at the driver board itself, but transferred at the rear panel of the power rack by the internal rack wiring.

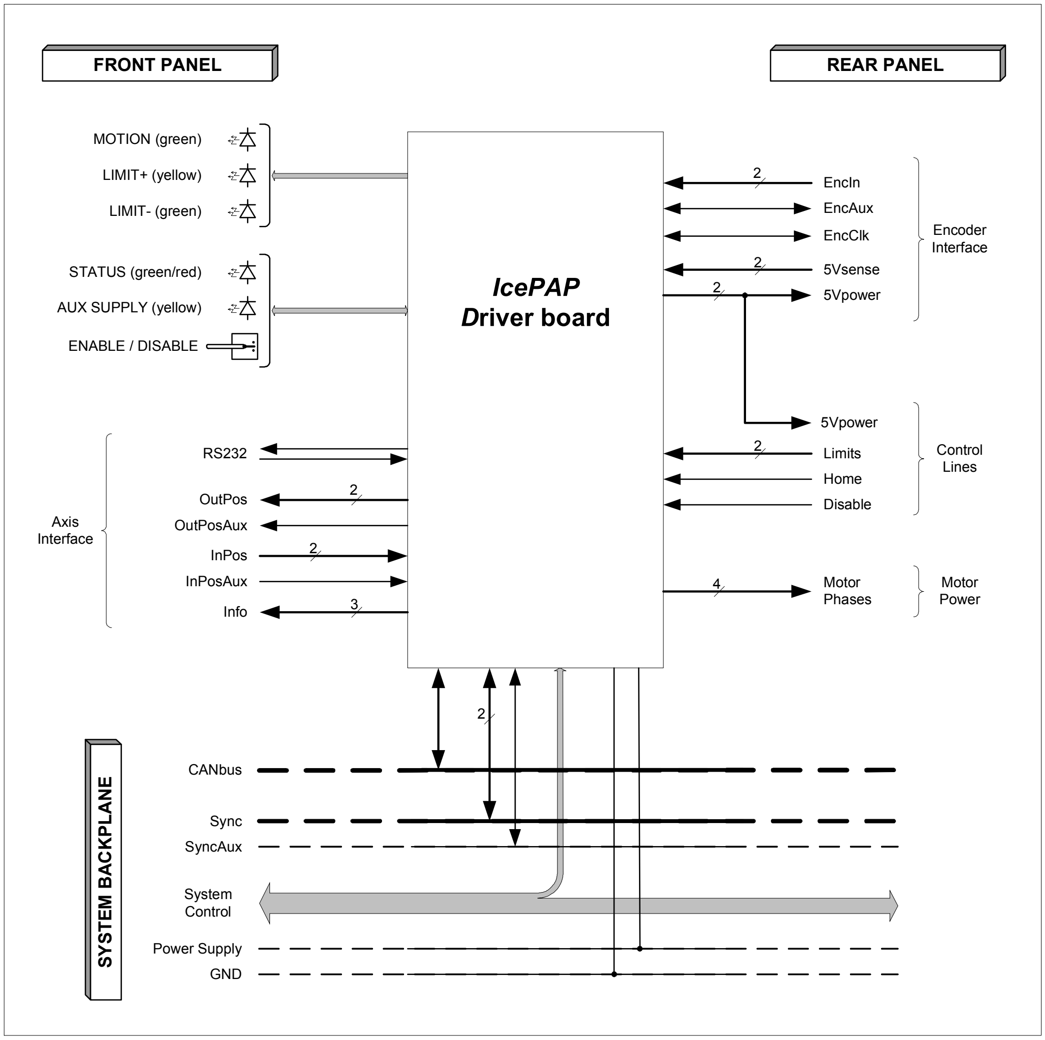


Figure 3: Driver board connections

A number of additional input and output signals are available at the front panel grouped in a so called *axis interface* connector. These signals may be used for special applications like local control from dumb terminals or joystick-like devices, synchronisation and diagnostics, as well as allowing the connection of an additional incremental encoder.

Signals in the axis interface connector may also be used to control an external application specific motor power driver by the internal IcePAP indexer. In these cases the built-in power driver can be disabled. Conversely, the internal indexer may be disabled and the control of the IcePAP power driver passed to an external device like a fully featured multi-axis controller for instance.

Common resources of the IcePAP system are routed to the driver board through the rack backplane. Intrasystem communication and synchronisation is achieved by means of a serial bus (CANbus) and dedicated bidirectional synchronisation lines. The backplane also provides the resources needed for driver identification, initialisation and firmware upgrade.

The functional components of the driver board are represented in Figure 4. The main functional aspects are described below.

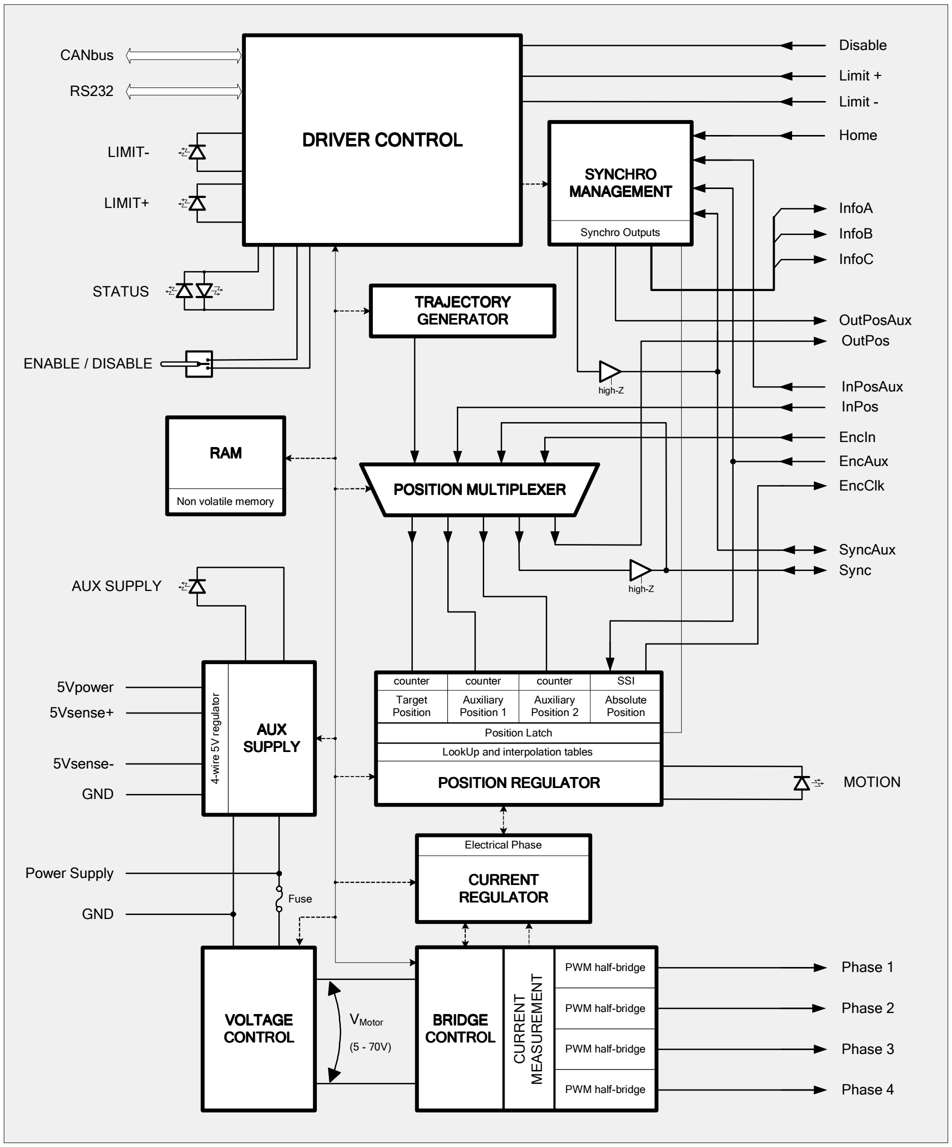


Figure 4: Functional diagram of the driver board

1.1.1. Incremental position signals

IcePAP makes extensive use of incremental position signals for certain position control functionalities and synchronisation as well as for incremental encoder interfacing. Incremental position signals pairs of digital lines that are used with up/down counters in order to follow the position of mechanical devices. These signals may be generated, in addition of incremental encoders, by the internal trajectory generator or by external devices like other motor indexers.

All the incremental position signals can be configured in one of two possible formats: phase counting or step and direction. With every position signal there is an associated auxiliary line that can be used to identify specific positions like absolute mechanical references (encoder index) or trigger points.

1.1.2. Position control

Each driver board includes a trajectory generator that can be programmed to produce a position signal corresponding to different type of movements like point to point displacements or continuous jog in the same way that most of motor controllers do. The actual goal position is updated in the target position register that is used to calculate the desired phase and amplitude of the motor current.

The target position register in the driver may be updated not only by the output of the trajectory generator, but by any of the other available incremental signals. In this way, in addition to programmed displacements, an IcePAP driver may be set to move a motor following an external signal. It is therefore possible to deal with unusual configurations like a single indexer that drives several motors or a motor that follows the movement measured by an incremental encoder mounted on a different axis.

Optionally the position in the target register may be processed through a user-defined lookup table and an interpolation algorithm. This allows implementing parametric trajectories that can be synchronised between different drivers. In this way it is possible to perform non-linear multi-axis movements at variable speed.

The position of the axis is actually controlled by varying the phase and amplitude of the motor current. The position regulator in IcePAP is the module that calculates the target motor current from the target axis position. Different regulations schemes allow various operation modes that go from open or closed loop synchronous control for stepper motors to field oriented control for brushless or torque motors.

In addition to the target position, the position regulator includes two auxiliary registers whose main purpose is to receive information from position encoders. The encoder information is mandatory for closed loop operation in single or dual loop but can also be used for monitoring and diagnostics. One of the auxiliary registers can be loaded with the position from an SSI absolute encoder.

1.1.3. Power amplifier

The IcePAP driver includes a PWM amplifier built on four independent half-bridges. The current is measured at each of the half-bridges independently, what makes possible to reconfigure the power amplifier to drive either one, two or three-phase motors.

The operating voltage of the PWM amplifier is controlled dynamically. The voltage can be increased during movements to deliver the maximum motor torque to the mechanical load. And when motors stop, the voltage can be substantially reduced to minimise vibrations and motor heating.

The resolution of the PWM controllers along with the variable voltage feature and four ranges of current measurement provide very fine control of the motor currents. This allows driving mechanical devices with high position resolution while dealing with a wide range of motor sizes and currents.

The amplifier is protected against overcurrent and overheating. The maximum power delivered to the motor is also limited what implies that the amplifier cannot deliver the maximum current at full voltage.

Each power amplifier can be individually disabled in order to cut off the motor current and ease the connection and disconnection of the motor cables.

1.1.4. Auxiliary power supply

The driver board includes a 5 volt power supply intended to be used by position encoders or other active devices that require electrical power. This supply can operate in 4-wire configuration (power and sense lines) to compensate for voltage drops along the cables that connect the IcePAP rack to the device.

The auxiliary power supply can also be temporarily disabled to simplify proper cable connection and disconnection.

1.1.5. Axis interface

The axis interface includes an asynchronous serial port (RS232), three general purpose output lines and two sets of incremental position signals that can be used for hardware interfacing with external modules.

The RS232 port is intended to be used with dumb terminals or other devices, like intelligent joysticks, for local control, configuration or diagnostic purposes. The driver board may receive any single-axis command through this port. However with multi-axis IcePAP systems, the host computer running the motion software should use the communication ports available in the master board for overall system control.

In the default configuration the general purpose output signals show the logic state of the home signal and travel limits at the rear panel connector. However they can be reconfigured to software selected logic levels or to signal the different states of the axis like stop, motion, constant speed, etc.

The output position signal is and incremental signal that can be configured to track the motor trajectory or any synchronisation signal or incremental encoder connected to the driver. It can be formatted as pulse and direction or phase counting as it is the case for all the external incremental position signals.
The input position signal can be used to connect an external indexer, an additional encoder or any other incremental signal potentially useful for monitoring or synchronisation.

1.2. Controller board

The controller board manages the resources that are common to all drivers in an IcePAP rack. It monitors the power supply and reads the rack number from the rotary switch at the backplane. It is also used for detection and initialisation of the drivers and selects the direction of some of the synchronisation lines.

Each controller includes a switch that allows disabling the motor power in all the drivers in the rack simultaneously with a simple manual operation at the front panel. The same function may be implemented by an external switch connected to a dedicated connector. This feature is useful when a power disable switch next to the motor is required and IcePAP is not in proximity of the mechanics.

Figure 5 depicts the connectivity and the different signals used or provided by the controller board. The DISABLE connector is not mounted in the board itself, but accessible at the rear panel of the power rack.

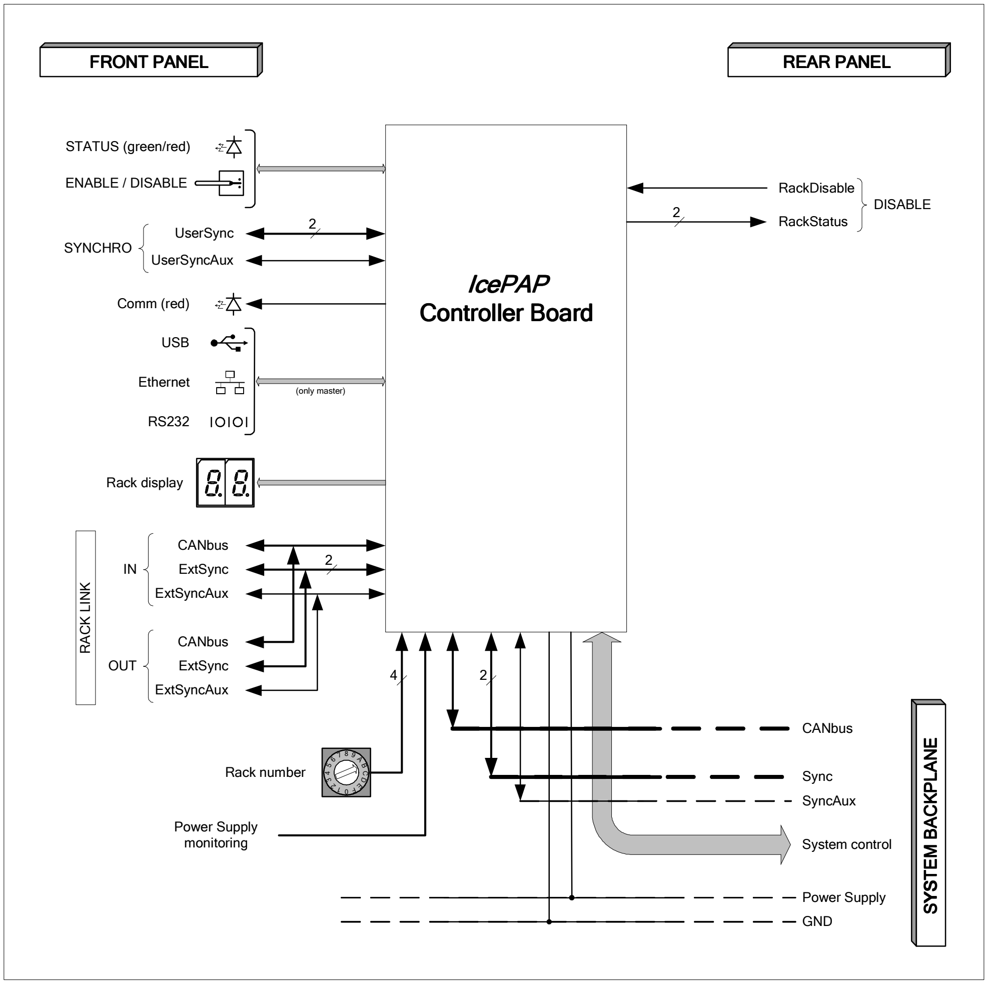


Figure 5: Controller board connections

There are two versions of the controller board: master and slave. In addition to all the functionalities of the slave version, the master includes a dedicated processor with standard communication interfaces: USB, Ethernet and an asynchronous RS232 port.
In any a multi-rack IcePAP system, only one controller board that operates as system master.

The main modules in the controller board are represented in Figure 6. In addition of the system and communication processor, only in the master version, there are some dedicated hardware components to deal with synchronisation features.

1.2.1. Synchronisation lines and virtual axes

The synchronisation lines transmit incremental position signals that transfer position information across the system. They can also be used to get position information or to send it to external devices. The synchronisation lines are organised in bidirectional segments that can be interconnected by means of multiplexers in the controller board.

An example of application of the synchronisation lines is sending the position of any arbitrary motor or encoder connected to the IcePAP system to an external device to synchronise data acquisition with the mechanical position during the movement.

Another application is the implementing parametric movements where one axis follows the position of a different axis according to a user defined functional dependence. In other words, the position of the *slave* axis is a function of the position of the *master* axis. This dependence is arbitrarily defined by the user by means of lookup tables preloaded in the system.

The controller boards includes a trajectory generator analogous to that available in the drivers. A controller can be programmed to generate displacements of a *virtual* axis that does not move any real motor but that are transmitted through the synchronisation lines to one or more driver boards. In this way several real axes can be synchronised with respect to a virtual axis.
The combination of a virtual axis and parametric movements may be used to make synchronised non-linear movements in a multidimensional space.

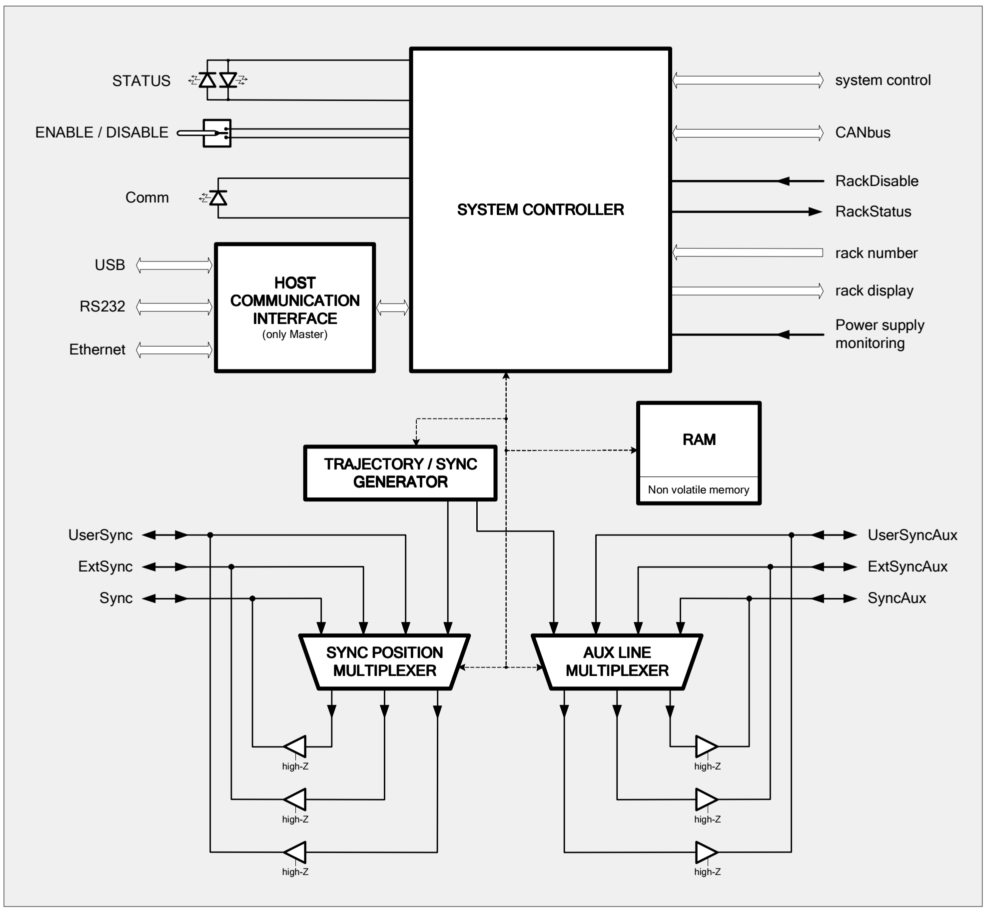


Figure 6: Block diagram of the controller board

2. Hardware Description

An IcePAP rack is composed of the power rack, a controller board (master or slave) and from 1 to 8 driver boards. Each rack is identified by a unique number and several racks may be interconnected to form a single system. In any IcePAP system one of the controllers must be the system master. If a system includes more that one master board, the master board in the lowest number rack operates as system master.

2.1. Power rack

The power rack is a 19” 4U unit that integrates a 1 KW power supply with power factor correction (PFC). The mains supply inlet (220VAC) and the power switch are located at the rear of the unit. The power supply is equipped with a hardware identifier and a temperature sensor that can be read at any time by the system firmware.

The IcePAP rack is a fanless unit cooled by air convection through the openings in the top and bottom covers. The racks are therefore silent and require less maintenance. However during installation, care must be taken to not to block the airflow path in order to allow proper rack ventilation. And in those cases where the drivers operate at high power, high duty cycle or are installed inside closed cabinets, forced ventilation by means of external fan units may be required. See *Appendix C* for installation guidelines.

2.1.1. Rack number and axis identifier

There is a common backplane with 9 emplacements for plug-in boards. The left most is reserved for the controller while the other eight accept driver boards. The rack number is selected by a rotary switch with hexadecimal digits as in the following figure.

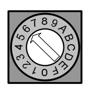


Figure 7: Rack number rotary switch

The switch is mounted at the left side of the backplane and the hexadecimal digits from 0 to F correspond to rack numbers from 0 to 15.

The driver boards are numbered from 1 to 8 according to their emplacement in the rack. In an IcePAP system each axis is identified by a decimal number formed by the rack number taken as high order decimal digits and the driver number as the units digit. For instance, the third axis in the rack number 6 is identified within the whole system as axis 63. The identifiers corresponding the eight axes in rack 0 go from 1 to 8 while in rack number 14 go from 141 to 148.

2.1.2. Rear panel and connectors

In addition to the mains power inlet and the ON/OFF switch, the rear panel of the IcePAP rack includes the motor and encoder connectors for the eight axes and a common rack disable connector. There are two versions A and B of rear panels that differ in the configuration of the motor connectors.

Version A is represented in Figure 8 and includes a single connector for both the motor power and control lines (limits and home signals). Version B makes use of separate connectors for the motor power wires and the control lines and is compatible with the connectivity used in older standard motor controllers used at the ESRF. It is represented in Figure 9.

The encoder and rack disable connectors are identical in both versions A and B.

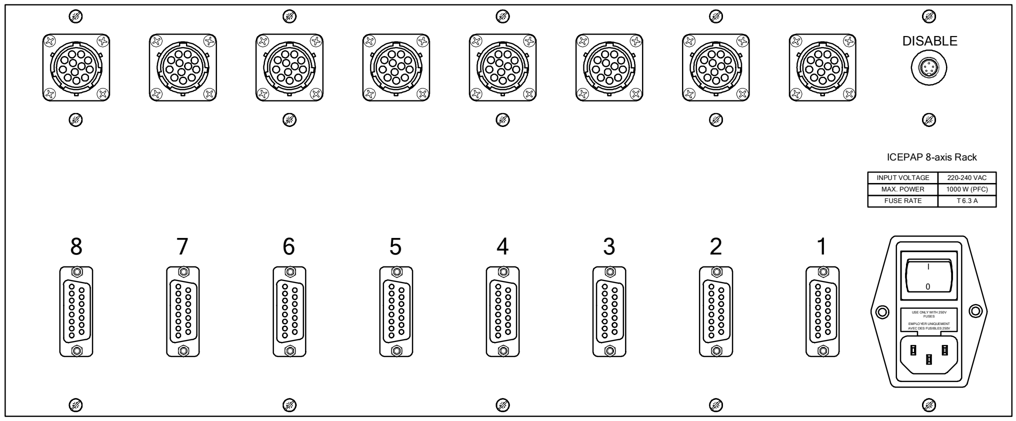


Figure 8: Rear panel. 8-axis Rack version A – single motor connector per axis

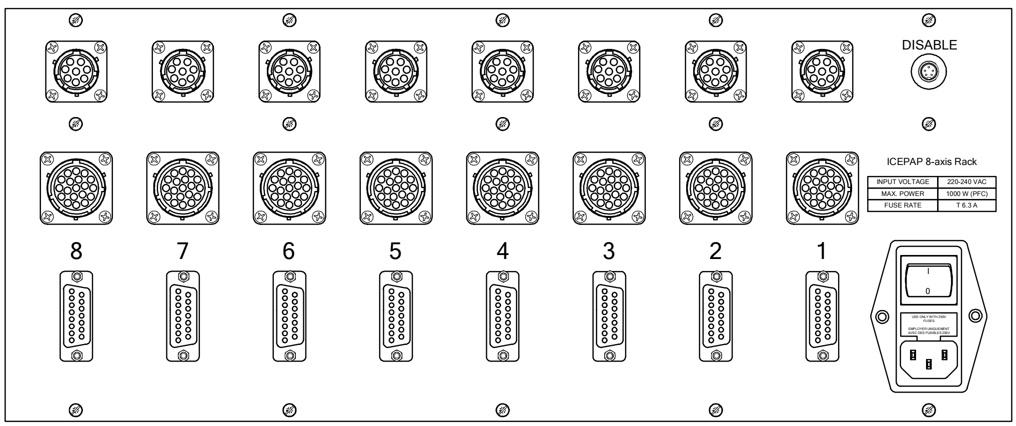


Figure 9: Rear panel. 8-axis Rack version B – 2 motor connectors per axis

2.1.3. Motor connection

2.1.3.2. <u>Motor power</u>

The motor power lines can be configured to drive one, two or three phase motors as depicted in the next figure.

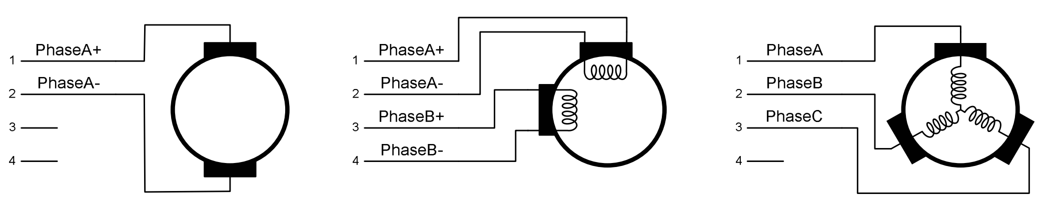


Figure 10: Connection of one, two and three-phase motors

2.1.3.3. Control lines

The control are logic input signals with TTL compatible levels. The *Limit+* and *Limit-* signals are intended to be used with travel limit switches. The *Home* line to connect an absolute mechanical reference and the *Disable* line to shutdown remotely individual axes. The internal pull up resistors in the driver board shown in Figure 11 make possible to drive these control lines with mechanical switches connected to ground.

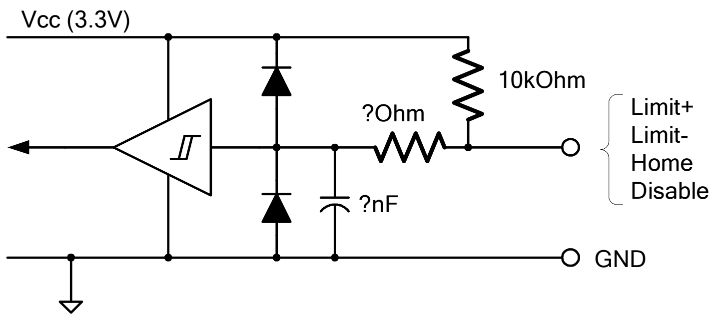


Figure 11: Input circuit used with control lines.

The signal *Disable* 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 in version A 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.

Table 1: Motor connector. Version A

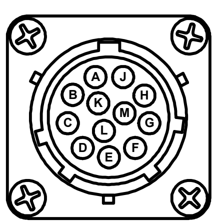
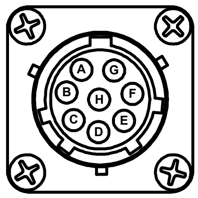
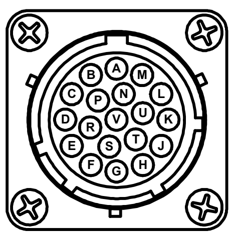
Connector	Pin	Signal			Description
		1-phase	2-phase	3-phase	
 *12-pin female MIL-C-26482 compatible shell size 14 socket*	A	Home			Mechanical reference
	B	PhaseA+	PhaseA+	PhaseA	Motor power
	C	PhaseA-	PhaseA-	PhaseB	
	D	n/c			
	E		PhaseB+	PhaseC	
	F	n/c	PhaseB-	n/c	
	G	Disable			Remote Disable
	H	Limit+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

Table 2: Motor and control connectors. Version B

Connector	Pin	Signal 1-phase	Signal 2-phase	Signal 3-phase	Description
 *8-pin female MIL-C-26482 compatible shell size 12 socket*	B	PhaseA+	PhaseA+	PhaseA	Motor power
	C	PhaseA-	PhaseA-	PhaseB	
	E		PhaseB+	PhaseC	
	F	n/c	PhaseB-	n/c	
	A D G H	n/c			
Examples of mating connectors:	ITT CANNON: TNM6U 1200-08P1L FCI: UTGS6PG128PN				

Connector	Pin	Signal	Description
 *19-pin female MIL-C-26482 compatible shell size 16 socket*	A	Home	Mechanical reference
	B	Limit+	Travel limits
	C	Limit-	
	G	Disable	Remote disable
	P	5Vpower	Aux power supply
	T	GND	
	D,E, F,H, J,K, L,M, N,R, S,U, V	n/c	
Examples of mating connectors:	ITT CANNON: TNM6U 1600-19P1L FCI: UTGS6PG1619PN		

2.1.4. Encoder connection

The rear panel encoder connector integrates a 5 volt auxiliary power supply that can be used to provide power to the encoder. It can accept either the connection of an incremental or and absolute SSI (Serial Synchronous Interface) encoder. The encoder signals are differential and electrically compatible with the RS422 specification as indicated in figure 12.

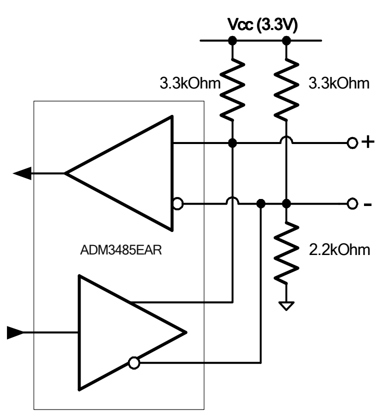
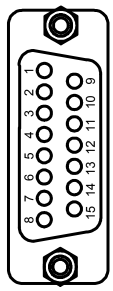


Figure 12: Circuit used for differential RS422 lines.

The pin layout of the encoder connector is summarised in Table 3.

Table 3: Encoder connector

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	

All RS422 signals are TTL compatible according to the following rules:
If the signal is an input: + pin can be driven by TTL signals (– pin must be left unconnected)
If the signal is an output: + and – pins are complementary TTL compatible signals.

2.1.4.1. Incremental encoder

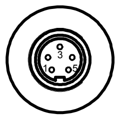
2.1.4.2. Absolute encoder

Absolute encoders can be read through the SSI interface. The EncClk output signal is used for clock generation and EncAux for data input. Both lines are differential and electrically compatible with the RS422 specification.
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.

2.1.4.3. Auxiliary power supply

2.1.5. Rack disable

Table 4: Rack disable connector

Connector	Pin	Signal	Direction	Description
DISABLE  *??-pin female ??*	1	RemDis	input	external NC switch
	2	Red	output	red LED driving
	3	Green	output	green LED driving
	4	GND		common connection point
	5	Shield		cable shield connection point
Mating connector:				

2.2. Driver board

The front panel of the driver board is depicted in the figure below.

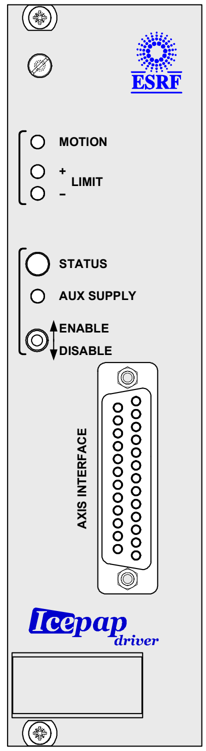
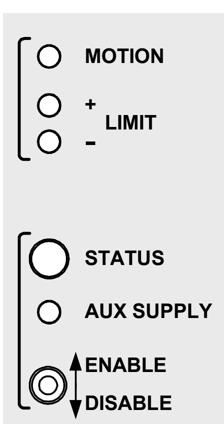


Figure 12: IcePAP driver front panel

2.2.1. Front panel controls and indicators

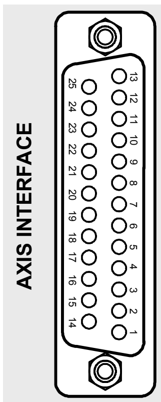
The table below summarises the function and behaviour of each visual indicator.

Table 5: IcePAP driver front panel controls

	LED/switch	Function/Behaviour
	**MOTION** green LED	
	LIMIT yellow and green LED’s	
	STATUS green/red LED	
	AUX SUPPLY yellow LED	Status of the 5V auxiliary power supply.
	ENABLE/DISABLE switch	

2.2.2. Axis interface

Table 6: Axis interface connector

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

2.2.2.1. 3.3V supply. This pin gives access to the internal 3.3V power supply of the driver board. This is provided for user convenience but its use is strongly not recommended. The maximum current that the driver can provide is 500 mA.
There is not any current limitation or specific protection associated to this pin. If excessive current is drained out, the driver board will not work properly and can be eventually damaged.

2.2.2.2. InPos, InAux input signals. The input InPosA, InPosB and InAux can be driven either by a differential RS422 or by a single-ended TTL driver. The proper connection and the equivalent input circuit are represented in Figure 13.

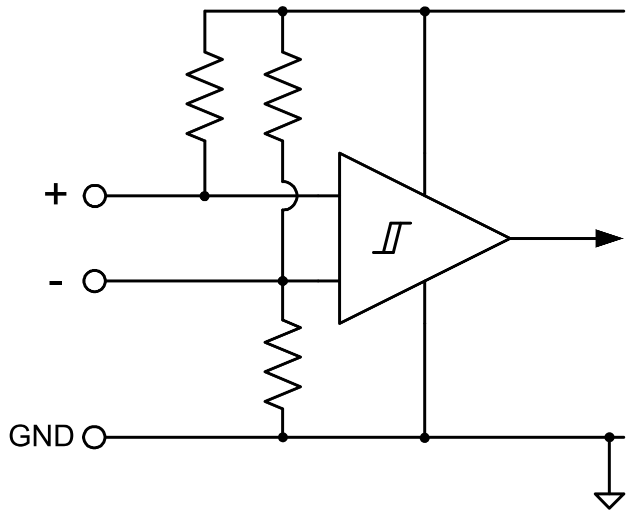


Figure 13: Input circuit used with InPos and InAux signals.

2.3. Controller board

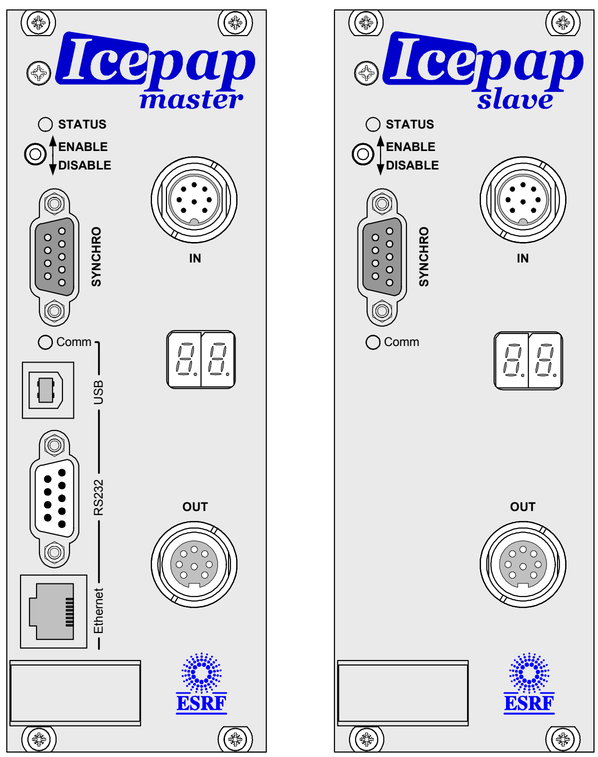
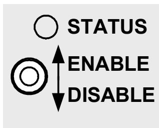
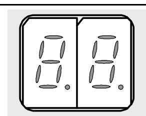


Figure 14: IcePAP master and slave front panels

2.3.1. Front panel controls and indicators

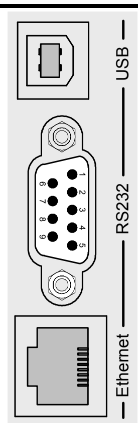
The table below summarises the function and behaviour of each visual indicator.

Table 7: IcePAP master front panel controls

	Indicator/switch	Function/Behaviour
	**STATUS** ??? LED	
	ENABLE/DISABLE switch	
	**Rack Number** two digit display	
	**COMM** red LED	

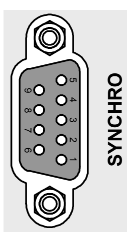
2.3.2. Communication ports

Table 8: Communication connectors

Connector	Interface	Pin	Signal	Description
	USB *xxx socket*	Standard wiring xxx		
	RS232 *9-pin male sub-D*	1		
		2		
		3		
		4		
		5		
		6		
		7		
		8		
	Ethernet *RJ45 socket*	Standard wiring 100 Base-T		10/100 Base-T Ethernet

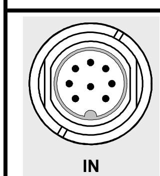
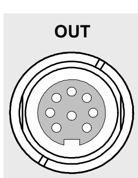
2.3.3. User synchronisation connector

Table 9: User synchronisation connector

Connector	Pin	Signal	Direction	Description
 *9-pin female Sub-D*	1			
	6			
	2			
	7			
	3			
	8			
	4			
	9			
	5			

2.3.4. Rack link

Table 10: Rack link connectors

Connector		Pin	Signal	Description
	*8-pin male* *xxx*	1		
		2		
		3		
		4		
		5		
	*8-pin female* *xxx*	6		
		7		
		8		
	Mating connectors:	??? ???		

Appendix A. Hardware Specifications

System Up to 128 axes Inter-system communication: private CANbus 1Mb/s System synchronisation lines internally multiplexed
Rack Power Supply Output voltage: 83VDC Max total power: 1KW (PFC) Built in temperature sensor: 0.1 degree resolution Connections and emplacements for 8 axes Rack disable input and rack status output signal
Driver board Power amplifier 4 half-bridge PWM amplifiers configurable to drive 1, 2 and 3-phase motors Variable motor voltage: 5 to 75VDC Current regulation: 50mA to 7.5A Max. delivered power: 320W per axis Resolution: < 1/10000 electrical period (> 2500 microsteps per step for stepper motors) Short circuit protection (phase-to-phase, phase-to-ground) Over-temperature protection Indexer Continuous jog and point-to point movements User defined look-up and trajectory interpolation tables. Max output frequency: 2 Mcounts/sec Position regulation Open and closed loop Synchronous control (steppers), FOC (Field Oriented Control) Sampling interval: 54 μs Inputs Control lines: Limit switches, home and disable signals: TTL levels (2.2 KΩ pullup) Incremental encoder: RS422 compatible. max freq.: 20 MHz Absolute encoder: SSI compatible, max clock freq.: 20 MHz Auxiliary position and synchronisation signals Step and direction or phase counting (programmable) RS422 compatible, max freq.: 20 MHz Controller Processor: 150MHz 32-bit DSP RAM: 1 MByte available for diagnostics and trajectory interpolation tables. Non-volatile memory: 32 Kbytes FRAM Unique hardware identifier
Controller board Main controller: 150MHz 32-bit DSP Communication processor: 400 MHz 32-bit CPU Ports: Serial: asynchronous RS232, xxx bauds, …. Ethernet: 10/100 Base-T USB 1.0 Rack disable manual switch Rack link IN / OUT (male/female) connectors Up to 16 linked racks per system. Max. total link length: 20m User synchronisation signals Step and direction or phase counting (programmable) RS422 compatible, max freq.: 20 MHz

Appendix B. Accessories

- *RackLink cable*

IN/OUT cable to connect two adjacent IcePAP racks.

- *RackLink Terminator*

Terminator plug to be connected at the IN connector of the IcePAP master.

- *Blank front panel plates*

Blank 4U plates to cover unused slots in IcePAP racks.

- *Fan unit*

19” 1U module for rack ventilation.

Appendix C. Rack Ventilation Guidelines