LiAM 6005

5A@60V Bipolar
Linear Amplifier Module

CAENels
Gear For Science

User's Manual

Rev. 1.3 – October 2014

MAGNET POWER SUPPLY SYSTEMS

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0.0	February 1st 2013	Document created
0.1	February 26th 2013	First draft release
1.0	March 8th 2013	First release
1.1	March 21st 2013	MTUNE command explanation
1.2	February 10th 2014	Output and Input power protection cover added
1.3	October 30th 2014	Manual graphics changed

Safety information - Warnings

CAEN ELS will repair or replace any product within the guarantee period if the Guarantor declares that the product is defective due to workmanship or materials and has not been caused by mishandling, negligence on behalf of the User, accident or any abnormal conditions or operations.

Please read carefully the manual before operating any part of the instrument

⚠WARNING⚠

High voltage, do NOT open the boxes

CAEN ELS d.o.o. declines all responsibility for damages or injuries caused by an improper use of the Modules due to negligence on behalf of the User. It is strongly recommended to read thoroughly this User's Manual before any kind of operation.

CAEN ELS d.o.o. reserves the right to change partially or entirely the contents of this Manual at any time and without giving any notice.

Disposal of the Product

The product must never be dumped in the Municipal Waste. Please check your local regulations for disposal of electronics products.

Read over the instruction manual carefully before using the instrument.
The following precautions should be strictly observed before using the LiAM:

WARNING

- Do not use this product in any manner not specified by the manufacturer. The protective features of this product may be impaired if it is used in a manner not specified in this manual.
- Do not use the device if it is damaged. Before you use the device, inspect the instrument for possible cracks or breaks before each use.
- Do not operate the device around explosives gas, vapor or dust.
- Always use the device with the cables provided.
- Turn off the device before establishing any connection.
- Do not operate the device with the cover removed or loosened.
- Do not install substitute parts or perform any unauthorized modification to the product.
- Return the product to the manufacturer for service and repair to ensure that safety features are maintained

CAUTION

- This instrument is designed for indoor use and in area with low condensation.

The following table shows the general environmental requirements for a correct operation of the instrument:

Environmental Conditions	Requirements
Operating Temperature	5°C to 45°C
Operating Humidity	30% to 85% RH (non-condensing)
Storage Temperature	-10°C to 60°C
Storage Humidity	5% to 90% RH (non-condensing)

1. Introduction

This chapter describes the general characteristics and main features of the LiAM linear bipolar power supply unit.

1.1 LiAM Overview

This power supply system for electromagnets is a compact linear current-controlled power supply system named LiAM 6005 (LInear Amplifier Module ±60V@±5A).

The unit is designed in order to have true bipolar operation – i.e. real zero-crossing – that allows smooth transitions around the zero-current level. Low-noise and high-stability are the main characteristics of these bipolar modules in order to obtain maximum performances on the relatively-generated magnetic field in the accelerator facility.

The input ratings of the power supply unit are three-phase 180-220VAC@50-60Hz, adaptable to either the Japanese or US mains distribution network. Single-phase versions for the European market are available upon request.

Output current and output voltage values are displayed on a large display placed on the module front panel. LEDs, also placed on the module front panel, give indication of the module operational status.

Remote connectivity to LIAM 6005, as for all other CAENels instrumentation, is guaranteed by means of a standard RJ-45 Ethernet connection (TCP-IP) that allows to easily control and monitor the functionalities of the power supply unit (current setting, output current reading and setting, temperature monitoring, etc.).

The "digital" control solution with respect to external analog one gives the advantages of greatly improved noise immunity: the analog voltage control signals that come from external DACs are subject to noise pick-up and this effect is greatly amplified when needing very precise output currents or output voltages.

Easiness of control of large installations is also one of the big advantages of Ethernet connectivity since everything can be handled from the control system directly to the modules. Maintenance issues are also easier and faster to carry out with the fact that the firmware for all the modules can be upgraded remotely.

Accuracy of the output current is also a great advantage of using digital interface: the calibration of the output current is performed, using a digital third-order polynomial fit curve, directly on the module itself so that external DACs drifts or nonlinearity are avoided/bypassed (since they would not be included in the computation of the calibration curves).

This LIAM 6005 power unit, rated at 300W output power, is based on the cascade of a linear three-phase AC/DC stage and a linear current-controlled output stage. A particular technique allows for automatic rail switching – i.e. voltage rails switch between different voltage levels in order to optimize efficiency – an also a dedicated *automatic load recognition* procedure was implemented (see dedicated sections for further details).

Auxiliary AC/DC and DC/DC power supplies are also linear in order to avoid any switching noise that could be generated by the device. Linear transformers are optimized to reduce magnetic flux leakage that could cause EMI (Electro-Magnetic Interference).

Control of the output current is made by a high-resolution and low-drift Digital-to-Analog converter (DAC) that sets a resolution of about 160µA on the module output current setpoint.

Current sensing is performed with a particular array of precise shunt resistors that guarantees extremely low temperature drifts and excellent linearity.

External configurable interlocks are also provided on the LiAM 6005 rear panel in order to have the power supply connected, if needed, to some external devices/safety circuitries. A solid-state status output is also available on the rear panel of the device: it allows the monitoring of the module output stage (enabled/disabled) by opening/closing a contact.

A load energy protection/damping circuit is implemented in order to protect the power supply and the load from over-voltage conditions. This feature is necessary when having large current in large inductive loads since the energy that gets stored into the load can be of a large entity and it could cause problems and damages.

A monitor output – rated at ±10V for a ±5A output current – is also present on the rear panel of the power supply on a BNC connector and it can be used for external monitoring purposes.

The cooling of the LiAM 6005, a critical task when using linear power supplies, is performed by speed-regulated fan forced-air convection with a front-to-rear direction.

Other features of the LiAM power units, as remote firmware upgrade, short-circuit stability, etc. are further on described in this manual.

1.2 System Structure

A LiAM 6005 power supply unit (**Figure 1**) is composed by a standard 2U-19" crate with a depth of 550 mm (a maximum of 578 mm considering also AC input, interlocks and output terminal connectors).

Figure 1: front view of a LiAM 6005 unit

On the rear side of the power supply unit are visible the air outlets for cooling, output connection terminals, interlock and output status connector, three-phase inputs, rail fuses and the analog output monitor coaxial connector.

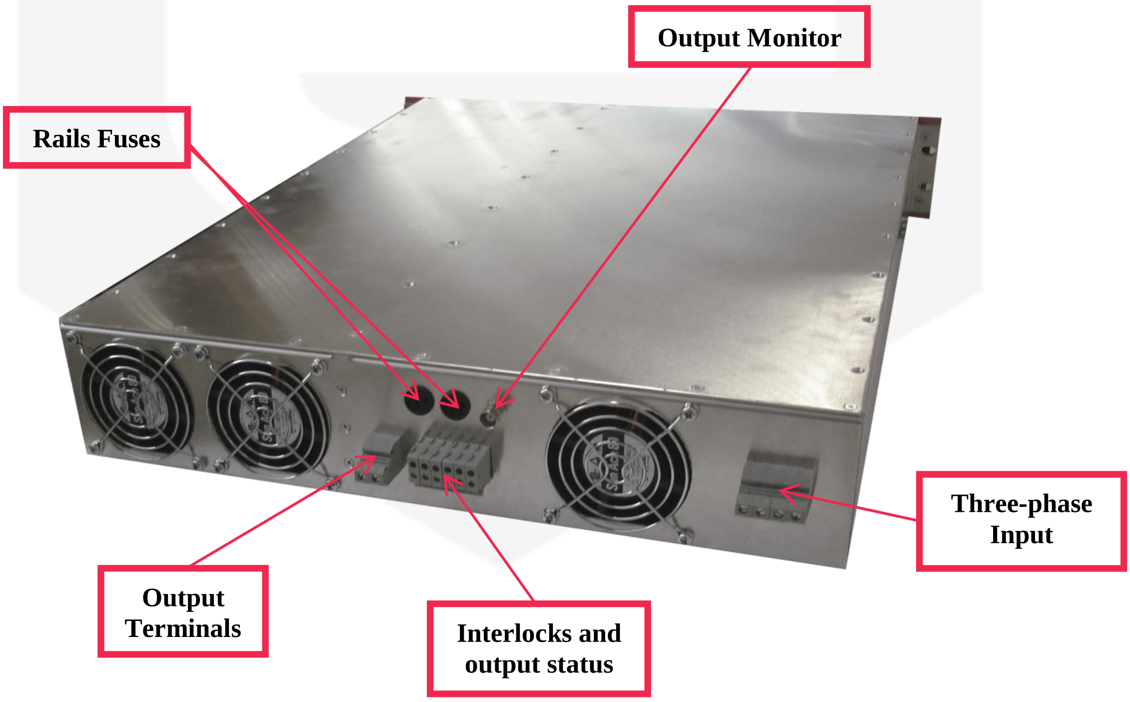


Figure 2: rear view of a LiAM 6005 unit

Channel interlock and current output connectors, AC line input and DC-Link power and control signals are all available on the SY3634 rear panel, as shown in **Figure** 2.

The LIAM 6005 Linear Power Supply main block diagram, with its principal features, is hereafter presented in **Figure 3**.

The proposed control scheme is a well-known topology that guarantees high stability and high reliability for the entire system.

The three-phase transformers convert the mains input power, rated at 200VAC and 50-60 Hz, to different DC voltages: $+V_{DD}$, $-V_{DD}$ and $\pm V_{AUX}$ and they act as the main AC/DC section

Please note that, for safety and protection issues, all input phases are protected with circuit breakers (**carefully read Installation section in order to safely and correctly install LiAM 6005 power units**).

The V_{AUX} voltages are used to power up the control electronic sections of the power supply and are obtained from different windings with respect to the power voltages.

The digital control section of the LIAM 6005 takes care of the general power supply diagnostics, the interfacing to the Ethernet communication module, the control of the DAC, the display handling and some other tasks.

Module can perform waveforms as sine or square waves (or any other user-defined waveform) controlling the LIAM 6005 via Ethernet connection; this can easily be performed by transmitting to the power supply the desired waveform on a point-by-point basis (the maximum data-rate frequency for the set-points is more than 100Hz).

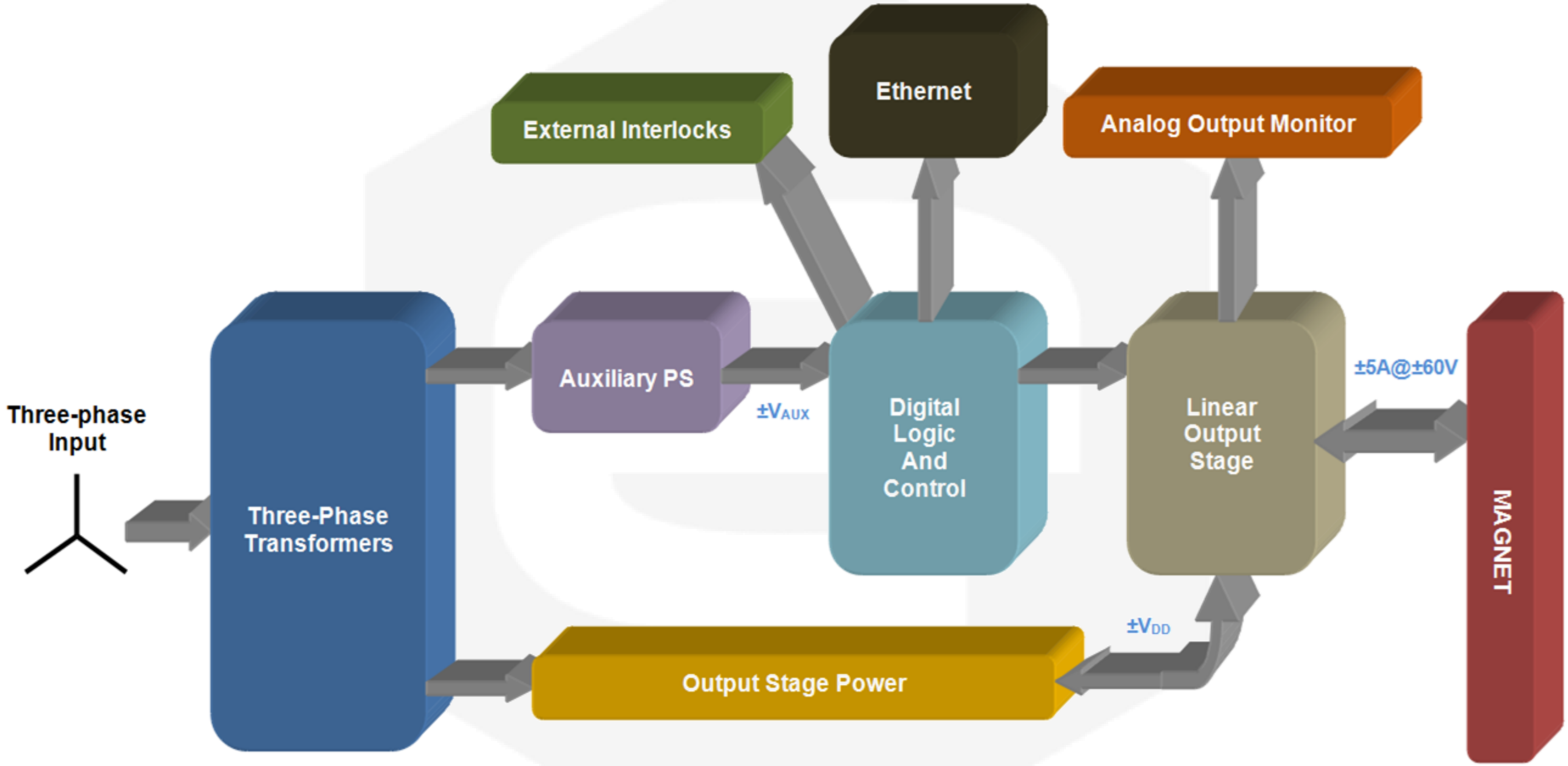


Figure 3: simplified block diagram of the LiAM unit

2. Safety and Installation

Please read carefully this general safety and installation information before using the product.

2.1 General Safety Information

This section contains the fundamental safety rules for the installation and operation of the system. Read thoroughly this section before starting any procedure of installation or operation of the product.

Safety Terms and Symbols on the Product

These terms may appear on the product:

- DANGER indicates an injury hazard immediately accessible as you read the marking;
- WARNING indicates an injury hazard not immediately accessible as you read the marking;
- CAUTION indicates a hazard to property including the product.

2.2 Initial Inspection

Prior to shipment this system was inspected and found free of mechanical or electrical defects. Upon unpacking of the system, inspect for any damage, which may have occurred in transit. The inspection should confirm that there is no exterior damage to the system such as broken knobs or connectors and that the front panels are not scratched or cracked.

Keep all packing material until the inspection has been completed. If damage is detected, file a claim with carrier immediately and notify CAEN ELS d.o.o. service personnel (via fax or via e-mail message to info@caenels.com).

2.3 Injury Precautions

This section contains the fundamental safety rules for the installation and operation of the system in order to avoid injuries.

2.3.1 Caution

The following safety precautions must be observed during all phases of operation, service and repair of this equipment. Failure to comply with the safety precautions or warnings in this document violates safety standards of design, manufacture and intended use of this equipment and may impair the built-in protections within.

CAEN ELS d.o.o. shall not be liable for user's failure to comply with these requirements.

To avoid electrical shock or fire hazard, do not apply a voltage to a load that is outside the range specified for that load.

Do Not Operate Without Covers.

To avoid electric shock or fire hazard, do not operate this product with covers or panels removed.

Do Not Operate in Wet/Damp Conditions.

To avoid electrical shock, do not operate this product in wet or damp conditions.

Do Not Operate in an Explosive Atmosphere.

To avoid injury or fire hazard, do not operate this product in an explosive atmosphere.

Do Not Operate With Suspected Failures.

If you suspect there is damage to this product, have it inspected by qualified service personnel.

2.4 Grounding

To minimize shock hazard, the LiAM power supply unit must be connected to an electrical ground. The ground terminal is present on the mains sockets on the back side of the crate and it is directly connected inside the chassis.

2.5 Input Ratings

Do not use AC supply which exceeds the input voltage and frequency ratings of this instrument. For input voltage and frequency rating of the module see Chapter 0.

For safety reasons, the mains supply voltage fluctuations should not exceed above voltage range.

2.6 Output Connectors

Do not plug or unplug output connections when power converters are on and the power units are regulating current on the electrical load.

2.7 Live Circuits

Operating personnel must not remove the 19" crates covers NOR touch the external terminal screw connection that may be supplied at dangerous potential.
No internal adjustment or component replacement is allowed to non-CAEN ELS d.o.o. personnel. Never replace components with power cables connected.

In order to avoid injuries, always disconnect power plugs directly from the wall mains, discharge circuits and remove external voltage source before touching components (wait 5 minutes at least).

2.8 Part Replacement and Modifications

Always disconnect power terminals, discharge circuits and remove external voltage source prior to fuse replacement (wait 5 minutes at least).

Other parts substitutions and modifications are allowed by authorized CAEN ELS d.o.o. service personnel only.

2.9 Installation Instructions

Follow these instructions in order to correctly install the LiAM power supply system.

PLEASE READ THIS SECTION CAREFULLY IN ORDER TO AVOID ANY SHOCK HAZARD.

Install the 2U LiAM 6005 system crate in a standard 19" cabinet as shown in the following **Figure 4**:

Figure 4: installation of LiAM units in a 19" cabinet

The three-phase input connections – i.e. earth and the three lines L1, L2 and L3 – are placed on a terminal block connector on the rear of the crate, as shown in **Figure 5**:

Figure 5: rating plate and three-phase input terminal connector

The power supply rating plate can be found on the rear panel of the LiAM power unit, indicating input ratings:

- 3 × 200 VAC ± 10%;
- 50-60 Hz;
- 550W input power.

WARNING

Please connect the EARTH cable to the terminal connection marked with the following symbol FIRST:

WARNING

BE AWARE THAT ONCE CONNECTED, THE AC VOLTAGE LINES *L1*, *L2* and *L3* are ACCESSIBLE FROM THE REAR SCREW HOLE TERMINALS AS INDICATED IN THE FOLLOWING FIGURE

Figure 6: screw terminals at dangerous potential

NEVER connect L1, L2 and L3 lines if AC power is present on the corresponding cables. Always disconnect wall AC plugs before making these connections. Using a screwdriver on these screw terminal connection may cause a serious ELECTRICAL SHOCK (refer to **Figure 6**).

2.9.1 Installation and Cabling Procedure

Connections to the LiAM power supply units must be carried out in the order herein presented. Please read and follow these indications carefully:

1) **<u>connect the ground terminal of the input connector first;</u>**

Figure 7: connection of EARTH conductor

2) **<u>(*optional*) connect the interlock terminals to the load interlock signals and the output relay status if needed (only connection of interlock #2 is shown in the picture);</u>**

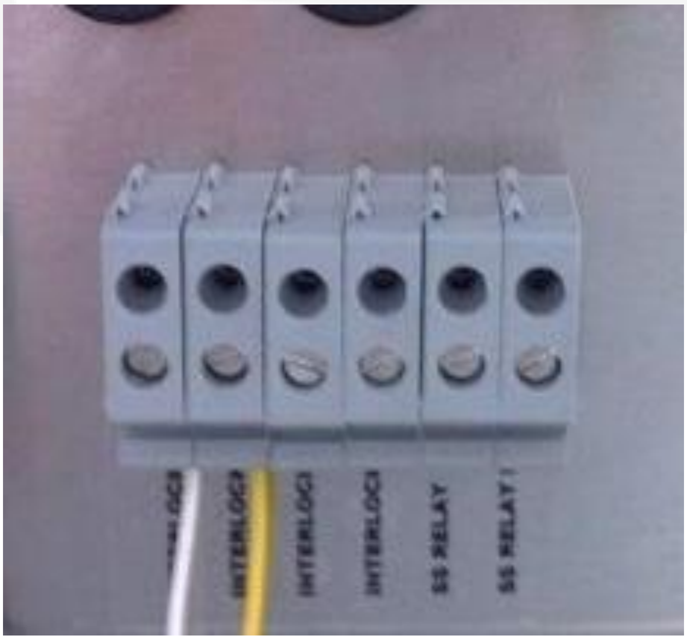


Figure 8: sample connection of interlock #2 (yellow = positive, white = negative)

3) **<u>connect the current output terminals to the magnet to be supplied;</u>**

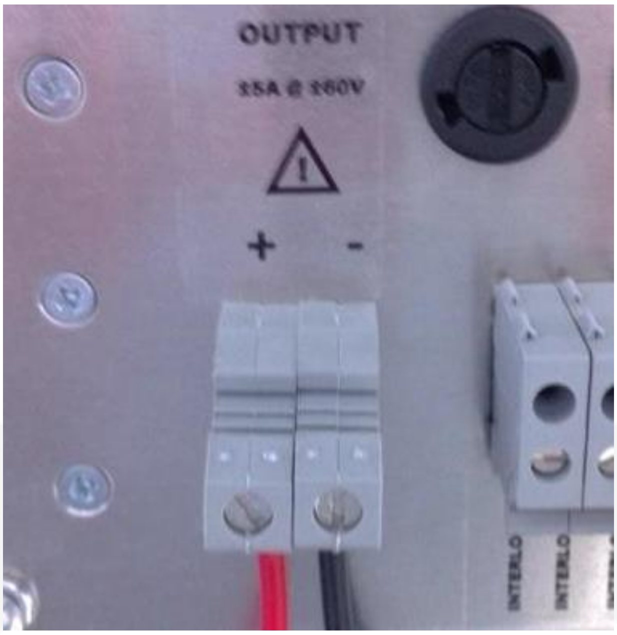


Figure 9: output connections to load

4) **<u>handle out and connect the three-phase line inputs to the power supply (ENSURE THAT THE CONNECTION TO THE WALL AC THREE-PHASE MAINS IS NOT ACTIVE AND POWER CANNOT BE DRAWN).</u>**

Figure 10: connection of line phases L1, L2 and L3 (unplug wall AC mains before executing this operation)

2.9.2 Protection Covers - *optional*

Plastic protections can be provided and can be installed on the rear side of the crate in order to avoid contact of the users with conductors at a dangerous potential. The cablings of the three-phase input conductors are shown hereafter. Please be sure to execute all these operations with the AC mains unplugged from the power distribution network.

The AC mains cable needs to be fit inside the hole centering also a plastic cable tie that it is housed inside the plastic housing (pass the cable tie inside the two small holes as shown in **Figure 11**).

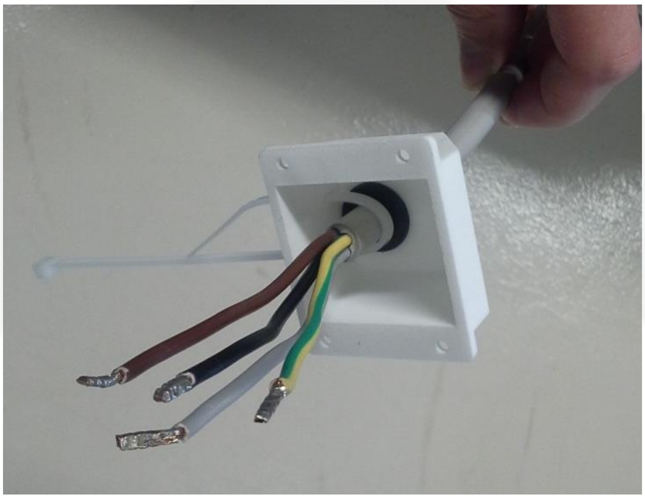


Figure 11: AC mains conductors and cable-tie

Now fix the three conductors and the PE cable to the screw terminals placed on the rear side of the crate as shown in **Figure 12**.

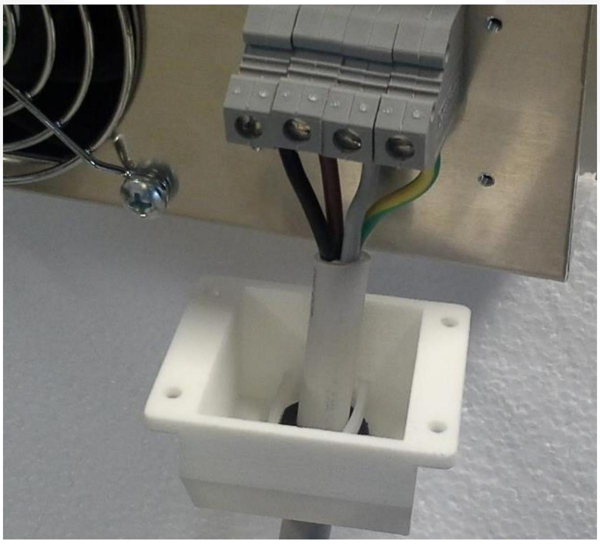


Figure 12: AC mains conductors connected to the terminal blocks

The plastic protection can now be fixed to the rear panel by screwing the four screws placed on the four corners of the housing. Once connected, it is necessary to tie the cable tie in order to secure the connection of the main conductors to the casing as shown in **Figure 13**.

Figure 13: protection cover of AC mains in its final configuration

Once everything is fixed you can cut the exceeding plastic part of the cable tie and then finally turn on the AC mains on the wall plug.

The suggested cable to be installed with this plastic protection cover is a 4 × 15 mm^2 type.

An example of a typical installation cabinet combined with a 1U 24-port Ethernet switch on top-first slot is herein shown in **Figure 14**:

Figure 14: 19"- cabinet containing sixteen LiAM modules

2.10 Suggested cable sections

The suggested cable sections for the LiAM rear panel connections are all included in the range 0.2 mm^2 → 4 mm^2, i.e. 24 AWG → 11 AWG, and presented in **Table 1**.

	mm^2	AWG
AC Mains	1	17
Interlocks and Output Status	0.25	23
Output Terminals	1.5 → 2	15 → 14

Table 1: suggested conductor sections

Please remember connect the power supply to the EARTH ground connection first.

2.11 Voltage Rail Fuses

The voltages used for generating the power "rails" on the LiAM output stage are protected with two fuses (one for each rail), placed on the rear panel.

The current rating of both these fuses is **8A-T** (standard 5 × 20 mm dimension) and they are used to protect the output stages and circuitry from fault conditions.

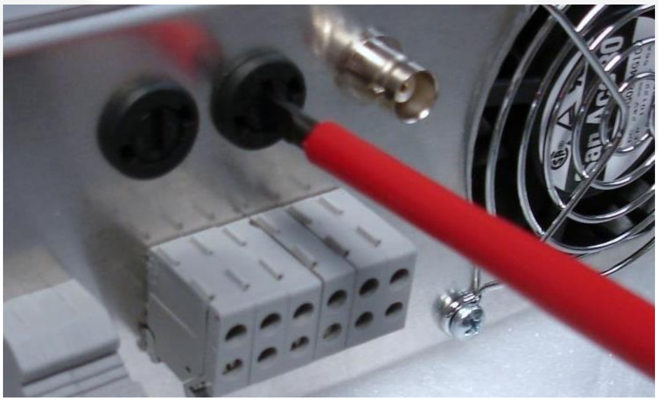


Figure 15: fuse-holder

A simple screw-driver is needed in order to remove fuse holders and to replace these fuses, as shown in **Figure 15**.

Figure 16: substitution of voltage rail fuses

Please remove the blown fuses in the corresponding fuse holder and replace them with new ones with the same current rating and characteristics as shown in **Figure 16**.

Please refer to the "Liam 6005 Distribution Unit – Installation Guide" for installation of the 6U 16-channel distribution unit.

3. LiAM Description

A description of the LiAM module is herein presented with some in-depth explanations on the basic power supply functionalities.

3.1 General Description

The LiAM power supply front panel (**Figure 17**) presents the three-phase circuit breaker, two holes for the air inlet, necessary for the front-to-rear fan cooling system, a standard RJ-45 Ethernet socket, a local display, a rotary encoder with push-button capability, a small hole for accessing the local unit reset and four LED indicators.

Figure 17: LiAM module front view

As can be seen from the following picture, **Figure 18**, the Ethernet communication has two different integrated LEDs – i.e. "Activity" and "Link" – that present the behavior described in **Table 2**.

"Activity" LED	Meaning
Off	No activity
Amber	Half-duplex
Green	Full-duplex

"Link" LED	Meaning
Off	No link
Amber	10 Mbps
Green	100 Mbps

Table 2: RJ-45 indicators

Figure 18: LiAM front panel details

The LEDs are indicators of the power supply status and have to be interpreted as follows:

- **FAULT** LED: the red light indicates that the LiAM module has experienced a generic fault that can be either an internal protection trip or an external interlock intervention. This light does not turn off after a fault until a unit status register reset has been performed and the cause of the fault has been removed;
- **DIAGNOSTICS** LED: the white light it is serviced – i.e. toggled – by the control electronics at every diagnostic routine execution. If this LED is not toggling between on and off state, the internal diagnostics is not correctly executed by the module;
- **AC OK** LED: the green light indicates that the AC mains input for the modules are correctly working;
- **OUTPUT** LED: the blue light indicates that the LiAM module is in ON state and it is correctly regulating the output current;

It is important to notice that the blue OUTPUT light and the red FAULT light cannot be on at the same moment because the module cannot correctly regulate output current if a fault is experienced and the output stage of the power supply is turned off.

The "RESET" hole, accessible by using a small screw-driver, allows performing a re-initialization of the LiAM internal firmware.

3.1.1 Internal Protections

Each LiAM module is equipped with multiple internal protections (hardware and software) to avoid unwanted behaviors or eventual damages to the unit and also to let users run the power supply safely.

All hardware protections are installed into the LiAM power units and are here listed:

- CB (CrowBar protection);

- Voltage rail fuses;
- Circuit breaker;

Several firmware protections, some of them redundant, are also implemented and here listed:

- Rails undervoltage protection;
- AC-phase fail;
- Over-temperature;
- Output over-voltage;
- Regulation fault;
- Load fault.

Protection redundancy – i.e. hardware and software – was especially implemented in order to guarantee a double level of reliability for the specified type of power supplies.

An overview of all available protections, as well as a brief description of their behavior, is presented in the following sections.

3.1.1.1 CB – CrowBar

The LiAM module protection against output over-voltage conditions is guaranteed by a crowbar protection circuit that, as in the case of the over-current protection one, has a double level of reliability – i.e. both hardware and software.

This protection is hardware-activated when the output voltage crosses a threshold of about double rating with respect to the maximum output voltage:

$$V_{CB\_TH} = 130\text{V}$$

that is usually caused by a large di(t)/dt value on a large reactive load.

The crowbar circuit also guarantees dissipation of the residual energy stored in the load when turning off the power supply output stage from a high current value on a high inductive load (i.e. 5A on a 100mH magnet).

This protection also activates a galvanically-isolated logic signal that generates a firmware interrupt on the on-module Digital Signal Processor: when this signal is activated, the processor sets a flag in the status register that needs to be reset before re-enabling the channel output again.

3.1.1.1 Voltage Rail Fuses

The current drawn from the voltage rails (both positive and negative) is protected by fuses.

The rated fusing current is 8A-T and both the fuse holders are accessible from the module rear panel and can be substituted. Installed fuses are 5 × 20 mm format.

3.1.1.1 Circuit Breaker

The circuit breaker, placed in front of the power supply unit, allows users to turn on and off the LiAM power unit and also protects it from faults caused by transformers malfunctions and/or short circuits. The circuit breaker turns the power supply off if a fault condition arises. The circuit breaker position should be found as shown in **Figure 19** after a fault condition – i.e. set to 0.

Figure 19: input circuit breaker

3.1.1.1 Rails Under-voltage Protection

The module voltage rails are continuously monitored by the internal logic in order to verify their correct operation. If at least one of the two voltage rails (positive and/or negative) drops below a pre-defined threshold, the module signals a fault condition. This fault protection always trips whenever a voltage rail fuses has blown.

3.1.1.1 AC-Phase Fail

If at least one of the phases is missing, the module internal protection of AC-phase fail trips and generates a fault condition that automatically turns the module output off.

The AC OK green light on the module front panel turns off every time this fault occurs. When all three input phases are correctly into operation, the module front LED should be as in **Figure 20**:

Figure 20: AC OK front-panel light indicator

Please note that the loss of the phase dedicated to supply the control and auxiliary circuit will turn off module communication, making the LiAM connectivity inaccessible.

3.1.1.1 Over-Temperature

The output stage of the LiAM power supply is monitored by high-gain and high-precision temperature sensors in different places.

The module internal logic disables the output when the maximum temperature among these rises above a user-defined threshold value and sets an "Over-temperature" flag in the status register, thus generating a FAULT condition that, as in the other cases, needs to be reset before enabling the output again.

The over-temperature fault trips whenever the following condition is true:

$$\max(T_1, T_2) > T_{TH}$$

where T_1 and T_2 are the internal measured temperature values and T_{TH} the pre-defined factory threshold chosen for correct and safe operation.

3.1.1.1 Output Over-Voltage

The output voltage of the LiAM power unit is protected from over-voltages by an internal routine that continuously monitors the voltage readback values and turns the power supply off (by ramping its current to 0A with a pre-defined slew-rate of 5A/s) whenever the following condition applies:

$$V_{OUT} > 65\text{V} \qquad \forall n \in [0,1,2,3]$$

i.e. the output voltage value is over the defined threshold (rated output voltage + 5V) for four consecutive sampling periods.

3.1.1.1 Regulation Fault

The module internal logic continuously monitors the actual output current readback with the last stored setpoint. If this absolute difference is larger than a pre-defined threshold, the power supply generates a fault condition that turns the output off since the internal regulation could reach the correct setpoint value.

Considering I_{OUT} as the output current readback value, I_{SET} as the last stored setpoint and I_{TH} as the pre-defined threshold, the regulation fault trips if the following condition is verified:

$$|I_{SET} - I_{OUT}| > I_{TH}$$

This situation could occur if, for example, a 4A current setpoint is fed to a LiAM power unit that has a 30-**Ω** resistive load connected to it. Since the output voltage (i.e. 120V) is beyond rated output voltage, the LiAM unit generates a regulation fault condition. This fault flag should be reset before turning the output on again.

Most common operating conditions that may generate the tripping of this fault are hereafter listed:

- instability of the output current control loop;
- a current leakage to earth/ground due to an improper connection of the load;
- excessive value of the connected resistive load.

3.1.1.1 Load Fault

The "load fault" protection monitors that the resistive value of the load remains within a defined value interval. This protection is very useful in order to check if all the loads connected to the power supplies in a large facility installation are correct and recognizes abnormal load variations.

Considering I_{OUT} as the output current readback value, I_{SET} as the last stored setpoint and I_{TH} as the pre-defined threshold, the regulation fault trips if the following condition is verified:

$$|R_{EST} \cdot I_{OUT} - V_{OUT}| > V_{TH}$$

where R_{EST} is the estimated load resistive value (computed running the function 'MTUNE\r').

The actual real resistive value can be then be expressed by the following relation:

$$V_{OUT} = R_{LOAD} \cdot I_{OUT}$$

By substituting this last equation into the previous one, the load fault condition can be further expressed as follows:

$$|R_{EST} - R_{LOAD}| > \left|\frac{V_{TH}}{I_{OUT}}\right|$$

$$|R_{EST} - R_{LOAD}| > \Delta R$$

where $\Delta R = |V_{TH} / I_{OUT}|$ and can be considered as the maximum allowable and acceptable load variation.

This fault could trip, for example, if the connected load changes after the last time an 'MTUNE\r' procedure was ran on the power supply: this fault helps keeping the installation correctly into operation as planned.

3.1.2 External Interlocks

Each LiAM power supply module has two different input interlocks and an output status signal/contact couple that are directly available on the rear panel interlock connector.

The pin index is summarized in **Table 3**:

Pin Number	Function
1	Interlock 2 -
2	Interlock 2 +
3	Interlock 1 -
4	Interlock 1 +
5	Solid State Relay return
6	Solid State Relay

Table 3: rear interlock terminal connector pinout

This connector is a 6-position "terminal block" – type connector. The corresponding pinout is shown in **Figure 21**.

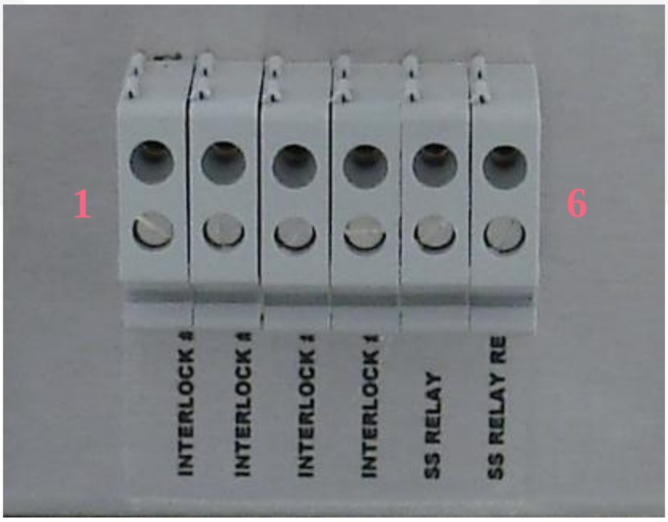


Figure 21: interlock terminals on LiAM rear panel

Please notice that all interlock pins are galvanically isolated from ground and from outputs terminals, nevertheless the absolute maximum voltage, referred to ground, that pins can sustain is 13V.

Note: The absolute maximum current that can be sunk/sourced by the output status relays (solid state relay pins 5 and 6) is 100mA.

Interlock 1 (the displayed interlock name shown on the front display can be changed with the user requirements, see 'MWF command' and Memory mapping sections for further details) is hardware-activated when at least high-level LVTTL 3.3V are applied between pin 2 and return pin 1.

Suggested cable section for interlocks and output status connections is 0.25 mm^2 (i.e. 23 AWG).

3.1.2.1 Interlocks Enabling/Disabling

Each LiAM external interlock can be enabled and disabled by writing to the interlock enable mask to the EEPROM cell 48. A value of '1' means that the interlock is enabled while a '0' value that the corresponding interlock is disabled.

The value to be written is the ASCII character, formed by a single hexadecimal digit, which corresponds to the binary enabling/disabling mask; the two external interlocks are numbered from #1 and #2.

Example: if only interlock #2 has to be enabled, the following command needs to be sent to the power supply:

MWG:48:2\r

The sent string has to be so interpreted:

2			
0	**0**	**1**	**0**
don't care	*don't care*	Interlock 2 *Enabled*	Interlock 1 *Disabled*

In order to make this command taking effect it is necessary to perform a 'MUP\r' (Module Update Parameters) command – see "MUP command" section for further details.

The MRG:48\r command returns a string containing the ASCII correspondent of the interlock enable mask and contains information about what interlocks are enabled and what are disabled.

3.1.2.2 Interlocks Activation States

Each LiAM external interlock can be chosen to trip at a HIGH or a LOW logic level. A value of '1' means that the interlock trips when the input signal to the corresponding interlock is shorted and a '0' that the corresponding interlock trips when the input is open.

The value to be written is the ASCII string, formed by 2 hexadecimal digits, that corresponds to the binary activation state mask; the eight external interlocks, as for the interlock enable/disable mask, are numbered from 0 to 7.

Example: consider that both interlocks #1 and #2 are enabled – i.e. a "3" string is contained in the EEPROM cell 48 – and interlock #2 needs to trip when the corresponding input signals are shorted (LOW level) while interlock #1 when its input is supplied from and external source (HIGH level); the value to be written to the EEPROM cell 49 is the following:

MWG:49:1\r

The sent string has to be so interpreted:

1			
0	**0**	**0**	**1**
don't care	*don't care*	Interlock 2 *LOW*	Interlock 1 *HIGH*

In order to make this command taking effect it is necessary to perform a 'MUP\r' (Module Update Parameters) command – see "MUP command" section for further details.

Content of the interlock enable/disable mask – i.e. EEPROM cell 48 – overrides the content of the cell 49 so that the values contained in cell 49 are discarded if the corresponding bit in cell 48 is '0' (and the interlock is disabled).

The MRG:49\r command returns a string containing the ASCII correspondent of the interlock enable mask and contains information about what interlocks are activated at a LOW state and what are activated at a HIGH state.

3.1.2.3 Interlock Configuration Example

Magnets can be water-cooled and there is a usual need for an interlock in case of the water cooling system fault.

Let's consider a water flow switch that, by choice, can be connected to interlock #2 of a LiAM interlock connector on the rear panel.

Water flow switch signals needs to be connected between pins 4 (+) and 3 (-) of the rear interlock connector; in order to activate only interlock #2, the following command need to be sent to the LiAM module:

MWG:48:2\r

A correct operation of the magnet cooling keeps the interlock input pins shorted while a fault has to be generated when the input becomes open (a power source is needed with a pull-up resistor); the interlock #2 activation level needs to be set to HIGH with the following command:

MWG:49:2\r

In order to make this settings take effect (permanently since they are stored in non-volatile memory), a 'MUP\r" command needs to be sent to the power supply.

3.1.3 Analog Current Monitor

Each LiAM power supply has an output monitor signal that is fed to the rear panel BNC (Bayonet Neill–Concelman) connector, as shown in **Figure 22**.

Figure 22: analog current monitor coaxial connector

This signal is a scaled version of the actual output current of the module and is directly obtained from buffering the current sensing circuit.
This output monitor, rated at ±10V, can be very useful in order to check and debug the power supply current behavior directly with an oscilloscope.

The gain and bandwidth characteristics of this buffered voltage output are the following:

$$G = \frac{1}{0.51}\,\mathrm{V/A} \cong 2\,\mathrm{V/A}$$

$$f_{-3dB} = 50\ \mathrm{kHz}$$

Please note that this signal, being the connector directly mounted on the power supply chassis, is ground-referred and the maximum current that can be sunk/sourced in order to maintain full output swing is rated at ±5mA – i.e. 2-kΩ load resistor.

3.2 Internal Memory Mapping

Each LiAM power supply module has an on-board EEPROM memory that stores all information about calibration parameters, module identification, thresholds, interlock configuration, etc.

Some of these fields can be user-defined and are extremely useful in order to exactly fit the power supply to the specific application.

EEPROM memory size is 256Kbits and is divided into two main different sections, each one consisting of 128Kbits. One of these two sections is not used in the LiAM power supply series (it is used in other power units by CAENels). The only section used is the following:

- **VALUE** section.

This structure can be seen in **Figure 23**.

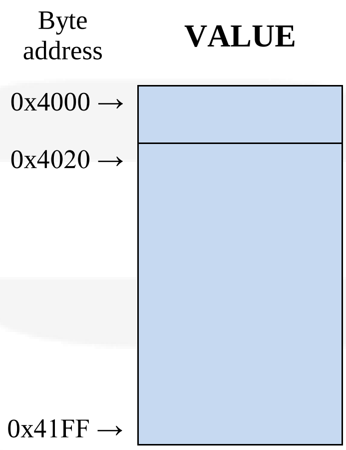


Figure 23: EEPROM memory structure

The EEPROM cell size is 0x20 bytes – i.e. 32 bytes – and, being the content stored in ASCII string format, the total string can contain 31 bytes + '\r' termination character (mandatory to correctly read and store the content).

Some EEPROM cells are password protected and can be unlocked using the 'PASSWORD' command (these cells are only accessible by experienced CAENels personnel).

The EEPROM **"value"** structure and the cell content description are presented in **Table 4**:

Cell #	Cell Caption	Description
0	c_0 I_set	Zero-order current calibration coefficient
1	c_1 I_set	1^{st}-order current calibration coefficient
2	c_2 I_set	2^{nd}-order current calibration coefficient
3	c_3 I_set	3^{rd}-order current calibration coefficient
4	I_{MAX}	Maximum settable current set-point
5	c_0 I_read	Zero-order current calibration coefficient
6	c_1 I_read	1^{st}-order current calibration coefficient
7	c_2 I_read	2^{nd}-order current calibration coefficient
8	c_3 I_read	3^{rd}-order current calibration coefficient
9	c_0 V_read	Zero-order voltage calibration coefficient
10	c_1 V_read	1^{st}-order voltage calibration coefficient
11	c_2 V_read	2^{nd}-order voltage calibration coefficient
12	c_3 V_read	3^{rd}-order voltage calibration coefficient
13…19	*reserved*	-
20	Max Temperature	Maximum heatsink temperature
21	Load Resistance	Load resistive part value
22	Serial Number	Module serial number
23	AC Phase Undervoltage Protection	Under-voltage protection threshold (13.5V)
24	Rail Switching Voltage Threshold	Voltage threshold for switching rail voltage
25	Rail Switching Voltage Hysteresis	Voltage hysteresis on rail value
26	Calibration Date	Date of last calibration
27	Identification	Module identification name
28 … 29	*reserved*	-
30	Slew Rate [A/s]	Module slew rate value
31… 36	*reserved*	-
37	Regulation fault threshold [A]	Maximum allowable regulation fault current
38	*reserved*	-
39	Load fault threshold [V]	Maximum allowable voltage difference
40	Load fault and regulation iterations	Number of iterations to "trip" faults
41 … 46	*reserved*	-
48	Interlock Enable/Disable Mask	Enabling/disabling external interlocks
49	Interlock Activation State Mask	Definition of external interlocks active state

Table 4: internal EEPROM "Value" section

Please note that:

- cells marked in **blue** are password-protected.

All settable parameters (either password or non-password protected) need to be updated in order to take immediate effect on the module operation: a 'MUP\r' command needs to be sent to the LiAM module after all parameters have been set by 'MWG' commands.

Please note again that cells marked in **blue** are password-protected and need to be unlocked in order to write their content.

Please refer to **Table 4** and to write values to configure correctly the LiAM module and note that the command to be used is:

- 'MWG' command to write the respective "value" cell content.

The LiAM power unit controller automatically handles EEPROM addresses for the "value" cell section so that the MWG command is almost transparent to the users and there is no need to write complicated cell addresses.

Example: suppose that the maximum settable current – I_{MAX} – for the specific LiAM module has to be changed to 3.88A. Referring to **Table 4**, this value is not password protected and it is placed at "value" section cell number 4.
The following command needs to be sent to the LiAM unit:

MWG:4:3.88\r

and should receive an acknowledgment reply from the power supply – i.e. '#AK\r'. Now, the value 3.88 is stored in the "value" cell number 4 (which is the cell 0x4080 since the "value" section offset is equal to 0x4000 bytes and each cell length is 0x20 byte). The I_{MAX} value, not being password-protected, takes effect on the module operation **but only after** a 'MUP\r' command is sent to the LiAM.

3.2.1 "Value" Section Cells

Herein, in order to correctly configure and check the power supply operation, a brief description of the "value" section user-definable cells is presented:

- **I_{MAX}** – *cell 4*: the value contained in this cell defines the maximum current [A] that a user can set to the LiAM module. This value needs to be included between a lower limit 0A and (rated output current + 0.1)A;

- **Max Temperature** – *cell 20*: this value [°C] defines the temperature threshold above what the power supply generates an over-temperature fault condition. The temperature is directly measured on different points of the output stage and the highest value is taken into account;

- **Load Resistance** – *cell 21*: this value [Ω] defines the estimated value (calculated automatically from the power supply) of the load resistive part – i.e. magnet + cabling. Please refer to the 'MTUNE\r' command for further details;

- **Serial Number** – *cell 22*: this cell contains the serial number of the power supply;

- **AC Phase Under-Voltage Protection** – *cell 23*: this value [V] defines the voltage threshold below what the power supply generates an AC fault condition;

- **Rail Switching Voltage Threshold** – *cell 24*: this value [V] defines the centered value of the voltage threshold that switches the rail voltages to a higher or lower level in order to optimize power dissipation;

- **Rail Switching Voltage Hysteresis** – *cell 25*: this value [V] defines the voltage hysteresis that enables the rail voltages to a higher or lower level in order to optimize power dissipation. This voltage hysteresis value was especially implemented in order not to have continuous rail switching when working at voltage levels close to threshold defined in *cell 24*;

- **Calibration Date** – *cell 26:* this value, a string, contains the date of the last calibration of the LiAM. The name of the magnet connected or its identification can be directly written into this cell;

- **Identification** – *cell 27*: this value, a string, defines the LiAM module identification name (and can be read with the 'MRID\r' command). The name of the magnet connected or its identification can be directly written into this cell;

- **Slew Rate** – *cell 30*: this value [A/s] determines the slew-rate value of the power supply. The module ramps, using the command 'MRM\r', at a defined set-point with this pre-defined value of slew-rate;

- **Regulation Fault Threshold** – *cell 37*: this value [A] defines the maximum allowable value, calculated as the difference from the actual output current set-point, before generating a fault condition;

- **Load Fault Threshold** – *cell 39*: this value [V] defines the maximum allowable voltage difference, measured as the difference between the predicted voltage value and the actual value of the output voltage;

- **Interlock Enable/Disable Mask**– *cell 48*: this cell contains and defines the 1-digit hexadecimal ASCII number that represents the binary mask for the individual setting of interlocks #1 and #2 (see "Interlocks Enabling/Disabling" for further information);

- **Interlock Activation State Mask**– *cell 49*: this cell contains and defines the 1-digit hexadecimal ASCII number that represents the binary mask for the individual setting of activation state of interlocks #1 and #2 (see "Interlocks Activation State" for further information);

3.3 Status Register

Each LiAM module has an internal 16-bit status register that contains all useful information about the power supply operation; this register is updated in real-time and it is always accessible by the users via the remote connection.

The internal status register structure is presented in **Table 5** (bit 15 is the MSB and bit 0 the LSB):

Status bit	Cell Caption
15	TURNING OFF
14	RAMP EXECUTION FLAG
13…12	RAIL STATUS [1…0]
11	*reserved*
10	OVER-VOLTAGE
9	LOAD FAULT STATUS
8	RAIL UNDERVOLTAGE
7	REGULATION FAULT
6	INTERLOCK #2
5	INTERLOCK #1
4	CROWBAR
3	OVER-TEMPERATURE
2	AC FAULT
1	FAULT
0	MODULE ON

Table 5: 16-bit (2-byte) internal status register

The status register value can be directly read by users using the 'MST\r' command. The returned item is a 2-digit hexadecimal ASCII string, corresponding to the equivalent status register. A brief description of all the binary flags is here presented:

- **Module ON** – *bit 0*: this bit is set if the module is enabled and correctly regulating output current;

- **Fault** – *bit 1*: this bit is set if the module has experienced a fault – e.g. generated by an external interlock or an internal protection trip – and the status register has not been reset;

- **AC Fault** – *bit 2*: this value is an AC fault condition is present (e.g. a phase loss);

- **Over-Temperature** – *bit 3*: this bit is set when an internal over-temperature condition has been experienced. The setting of this bit implies the simultaneous setting of the fault bit;

- **Crowbar** – *bit 4:* this bit is set when the voltage at the output terminals of the module triggers the crowbar protection (see "Internal Protections" section for further details). The setting of this bit implies the simultaneous setting of the fault bit;

- **Interlock #1** – *bit 5*: this bit is set when the corresponding enabled external interlock trip. This bit does not give any information about the activation state of the interlock signal #1. The setting of this bit implies the simultaneous setting of the fault bit;

- **Interlock #2** – *bit 6*: this bit is set when the corresponding enabled external interlock trip. This bit does not give any information about the activation state of the interlock signal #2. The setting of this bit implies the simultaneous setting of the fault bit;

- **Regulation Fault** – *bit 7*: this bit is set when a regulation fault is experienced. The setting of this bit implies the simultaneous setting of the fault bit;

- **Rail Undervoltage** – *bit 8*: this bit is set when an under-voltage condition of one of the voltage rails – i.e. voltage drops below a user-defined threshold – has been recognized. As in other cases, the setting of this bit implies the simultaneous setting of the fault bit;

- **Load Fault Status** – *bit 9*: this bit is set when a load fault condition appears: this can be caused by an earth leakage current or an unknown change in the load resistance. As in other cases, the setting of this bit implies the simultaneous setting of the fault bit;

- **Over-Voltage –** *bit 10*: this bit is set when an over voltage condition has been experienced on the output terminals of the LiAM unit (on thus on the load if correctly connected). The setting of this bit implies the simultaneous setting of the fault bit;

- **Rail Status [0...1]** – *bit 12…13*: the LiAM power supply unit has an "adaptive" behaviour of the voltage rails used to supply the output stage. Voltage rails can be switched among three different levels – i.e. off, mid-voltage, max-voltage – increasing the overall efficiency and making it similar to a "Class-G" amplifier. If these bits are set to 00 the rails are off, if set to 01 are at mid-voltage and if set to 10 are at max-voltage level.

- **Ramp Execution Flag** – *bit 14:* this bit is set when the LiAM unit is performing a ramp to a new set-point. After the ramp is finished, and the new set-point is reached, this flag is cleared;

- **Turning Off** – *bit 15:* this bit is set while the LiAM module is turning off. The power supply, in order to avoid undesired over-voltage due to the connected inductive load, turns the output off by following a smooth behaviour – i.e. ramps down to zero-current level with a pre-defined slew rate of 5A/s;

3.4 Adaptive Rail Switching

The LiAM power supply is designed in order to obtain minimum irradiated and conducted noise by using linear AC/DC stages, linear DC/DC stages and analog control loop of the output current.

In order to optimize the overall efficiency of the unit, thus reducing internal power dissipation (and cooling) and increasing reliability, an “adaptive” technique of voltage rail switching was especially implemented.

The output stage is composed of a linear bipolar (true zero-crossing) power circuit configuration which sources or sinks current from two symmetrical voltage rails – i.e. positive and negative.

An internal automatic rail switching technique allows the rails of the units to switch between three different voltage levels:

- OFF;
- MID voltage;
- HIGH voltage.

This technique works correctly in conjunction with the automatic load recognition function – i.e. MTUNE\r – and yields a “predictive” switching of these rail values in a completely transparent way for the users, taking part of the advantages of class-G amplifiers, even though the LiAM is not a class-G).

3.5 Automatic Load Recognition

An automatic procedure to estimate load resistive value was implemented in order to guarantee more efficient and safe operation on the LiAM power supply units.

By running the "MTUNE\r" command the power supply automatically start a procedure that recognizes the connected load resistive value by setting the output current to pre-defined levels (±1A value), then measuring the output voltage and storing the content in the internal non-volatile memory.

Once launched, the entire procedure last 13 seconds so that the module communication is not accessible by the user during this time interval.

The procedure result is R_{EST} [Ω], computed as follows:

$$R_{EST} = \frac{V_{OUT}}{I_{OUT}}$$

where V_{OUT} and I_{OUT} are the output voltage [V] and output current [A] readback values respectively. Maximum value for R_{EST} is 25Ω.

This resistance value is then stored (only if the process is successful) in the module internal memory and it is used into normal operation to perform diagnostics (e.g. regulation fault routine) and to operate the *Adaptive Rail Switching*.

In order to check if the estimated resistive value of the load has been correctly estimated, the user needs to send to the power supply an 'MRR\r' command that returns the value of the last stored resistance.

Please note that in order to make the computed R_{EST} value take effect in the module operation, a 'MUP\r' command needs to be sent to the power supply unit.

Example 1. Consider now running the automatic load procedure by sending an 'MTUNE\r' command to the power supply connected to a magnet load. The R_{EST} value computed from this procedure is found to be 4.35Ω. In normal operation, the LiAM power supply automatically recognizes that the maximum required output voltage for this load is equal to:

$$V_{OUT}|_{MAX} = R_{EST} \cdot 5\text{ A} = 21.75\text{ V}$$

where "5A" is the maximum output current rating of the power supply.

The load connected to the LiAM unit would then never need the voltage rails to be at HIGH level and into normal operation then only the MID voltage configuration will be used, thus drastically reducing the internal power dissipation of the module.

The behavior of the unit output current, output voltage and the voltage rails considering this example situation is shown in **Figure 24** (please note that a point-by-point 0.1-Hz current sine wave is fed to the power supply):

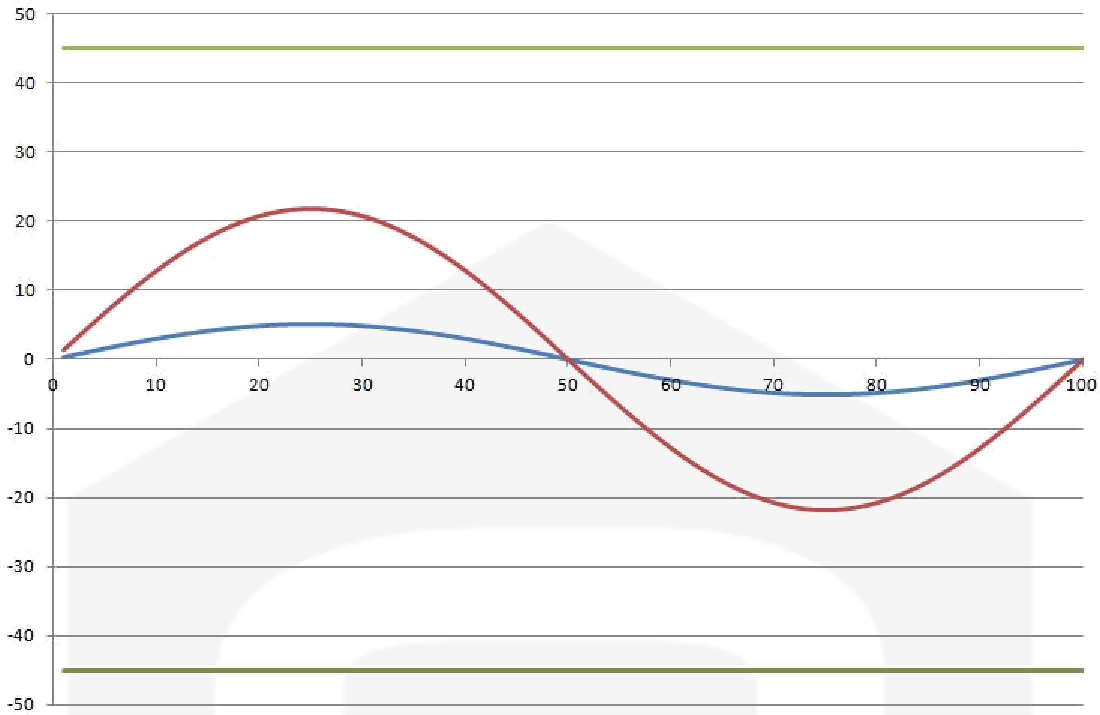


Figure 24: voltage rails behavior for a low-value resistive load

where the **BLUE** line is the output current, the **RED** one the output voltage and the **GREEN** ones the rail voltages values.

Example 2. Consider now running the automatic load procedure by sending an 'MTUNE\r' command to the power supply connected to a magnet load and that the R_{EST} value computed from this procedure is found to be 11.23Ω. In normal operation, the LiAM power supply recognizes that the maximum required output voltage for this load is equal to:

$$V_{OUT}|_{MAX} = R_{EST} \cdot 5\text{ A} = 56.15\text{ V}$$

where "5A" is the maximum output current rating for the power supply.

In this case the LiAM power unit automatically recognized the "output" voltage needs when setting a new current value and uses an hysteresis threshold in order not to have several voltage rail commutations.

The behavior of the unit output current, output voltage and the voltage rails considering this example situation is shown in **Figure 25** (please note that a point-by-point 0.1-Hz current sine wave is fed to the power supply):

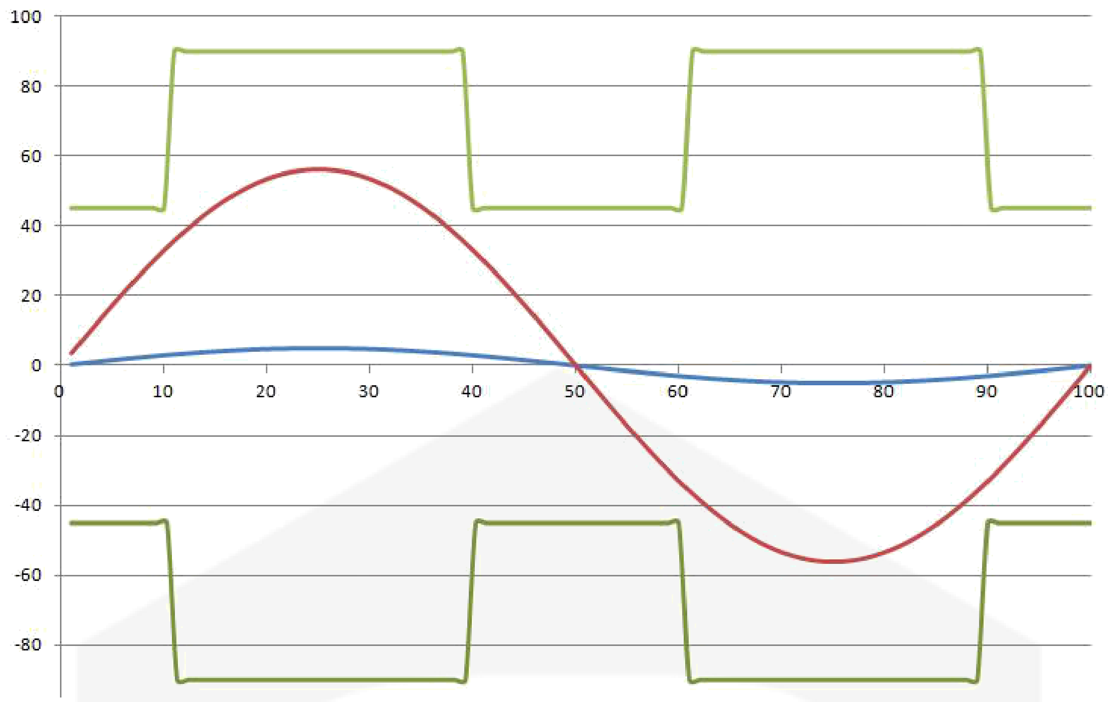


Figure 25: voltage rails behavior for a high-value resistive load

where the **BLUE** line is the output current, the **RED** one the output voltage and the **GREEN** ones the rail voltages values.

4. Local Display

This chapter provides a brief description on the LiAM front panel local display indications and different operation screens/pages.

4.1 *Boot-up* Page

During power-up or reset of the LiAM power supply unit, the module model and the installed firmware version are displayed as shown in the following picture (**Figure 26**).

Figure 26: *Boot-up* display screen

The internal firmware version check can be also performed remotely by using the 'VER' command (please see the Remote Control section for further information).

4.2 Monitor Page

Three (3) seconds after *power-up* or reset of the unit, the *boot-up* screen page disappears to visualize the monitor page of the LiAM 6005.

The display is divided into for lines and the following data/information are shown and updated every second:

- power supply or magnet identification – i.e. ID;
- output current readout value [A] with a 100µA resolution;
- output voltage readout value [V] with a 100µV resolution;
- the power supply status.

A sample of the monitor page of a LiAM power unit when the module output is off is shown in **Figure 27**.

Figure 27: *Readout* display screen when module is OFF

The unit identification name identifies the specific power supply or the magnet it is connected to. This ID is user defined and can be stored in the module internal memory (on cell #27, please read the "memory mapping" section for further information on this). The identification string is shown in the module first row and the same value can be read remotely from EEPROM cell #27 or by using the MRID command (check the remote communication section for further details).

Figure 28: *Readout* display screen when module is ON and regulating 1-A current

This field is factory defined as *LIAM_XXXXXX* where *XXXXXX* are digits (0 to 9) representing the serial number of the power supply module.

The second line shows the internal readback of the module actual output current value with a resolution of 100 µA on the displayed value.

The third line shows the internal readback of the module actual output voltage value with a resolution of 100 µV on the displayed value.

The fourth line indicates the status of the power supply unit. This status can be one of the following:

- OK: the module is correctly operating;
- FAULT: the module has experienced a fault condition.

The fault condition can be caused by either an internal protection trip (e.g. AC fault, over-temperature condition, etc.) or an external fault – i.e. external interlocks.

The "Status: FAULT" indication is always combined with the red FAULT light lit up on the module front panel. A remote reset of the power supply status register must be performed in order to clear this status (only if the conditions that generated the fault had been removed).

Please note that the "Status: OK" indication does not indicate that the module is turned on and/or sinking/sourcing current to the load (the indication of the "ON" status of the power unit can be monitored by the blue OUTPUT light on the front panel).

4.3 Automatic Load Recognition Page

When launching the automatic load recognition procedure by sending an 'MTUNE\r' command to the unit, the power supply will not respond to any other command until the procedure is over.

During this time interval – i.e. less than 13 seconds – the power supply monitor will display the message shown in the following **Figure 29**:

Figure 29: display screen when LiAM is running an automatic load recognition procedure

5. Remote Control

The LiAM power supply module can be remotely controlled via a standard Ethernet 10/100 link accessible from the module front panel using a predefined set of commands.

5.1 Preliminary Information

In order to ensure a correct communication with a LiAM module, the following rules have to be pointed out:

- commands **TO** the LiAM power supply module must be sent with a **'\r'** (carriage return, 0x0D hexadecimal number) termination character;
- replies **FROM** the LiAM power supply also have a **'\r'** (carriage return, 0x0D hexadecimal number) termination character.

A complete list of commands (except for reserved commands) is herein presented and an overview for each command syntax and functionality follows.

The configurability of this power supply leads to a very widespread command list, thus typical users may only need a small set of commands in order to run the LiAM unit in a satisfying way.

5.2 List of Commands

The user-available commands, as well as a brief description and their read or write functionality, are summarized in the following table - **Table 6**:

Command	Description	Read/Write
FDB	Feedback command	W
MOFF	Turn the module OFF	W
MON	Turn the module ON	W
MRESET	Reset the module status register	W

MRG	Read selected EEPROM "value" cell	R
MRI	Read output current value	R
MRID	Read module identification	R
MRM	Set output current value (ramp)	W
MRP	Read positive rail voltage value	R
MRN	Read negative rail voltage value	R
MRR	Read estimated resistance value	R
MRT	Read output stage maximum temperature	R
MRV	Read output voltage value	R
MRW	Read estimated active output power value	R
MSP	Read last stored output current setpoint	R
MSR	Read or write slew-rate value	R/W
MST	Read module internal status register	R
MTUNE	Launch automatic load tuning procedure	W
MUP	Update all EEPROM parameters	W
MWG	Write selected EEPROM "value" cell	W
MWI	Set output current value (no ramp)	W
PASSWORD	Write password to unlock password-protected cells	W
VER	Read module model and installed firmware versions	R

Table 6: LiAM module command list

It is important to notice that some commands are write-only commands (e.g. MWI to set output current) and some others are read-only commands (e.g. MRI to read output current value).

The only command that allows reading and setting is the MSR command, which reads or sets the user-defined slew-rate for the power supply (see 'MSR Command' section for further details).

5.3 Commands Overview

The power supply controller replies every time that a termination character '\r' is received. Replies could have different behaviors:

- an acknowledgment '#AK\r' string is sent back in case of a correct setting command;

- a non-acknowledgment '#NAK\r' string is sent back in case of a wrong/unrecognized command or if the system is in local operation mode and a write command is sent to the controller (write commands are marked with a 'W' in **Table 6**);

- a standard reply, preceded by a '#' and followed by a '\r' character, is sent back as a response to a reading command.

A brief description for each command, in alphabetical order, is herein presented with some example annotations; the correct interpretation for these examples is as follows:

Command sent TO the power supply →

← **Reply FROM the power supply**

5.3.1 "FDB" Command

The 'FDB' command is a custom command that was especially implemented, as in all series of power supplies made by CAENels, in order to minimize traffic on the Ethernet 10/100 communication socket, having a dedicated request/reply structure.

The feedback command syntax is as follows:

FDB:set_reg:i_set\r

where:

- *set_reg*: is the setting register of the power supply (8-bit wide);
- *i_set*: is the desired output current setpoint value [A].

The power supply reply, after a FDB command, is in the following format:

#FDB:status_reg:i_set:i_read\r

where

- *status_reg*: is the 16-bit wide *status register* of the PS, formatted in an hexadecimal string; this status string has a fixed-length of 4-byte;
- *i_set*: is the string containing the output current desired setpoint value; string length is 8 bytes (i.e. 8 characters): sign + 2 integers + "." + 4 decimal digits (eg. 1,02A it is returned as +01.0200);
- *i_read*: is the output current readback string; its length is equal to 8 bytes: sign + 2 integers + "." + 4 decimal digits;

The *status_reg* structure is presented in the following table (and in section 3.3):

Status Register Structure (16-bit)	
Bit 15	TURNING OFF
Bit 14	RAMP EXECUTION FLAG
Bit 13…12	RAIL STATUS [1…0]
Bit 11	*reserved*
Bit 10	OVER-VOLTAGE
Bit 9	LOAD FAULT STATUS
Bit 8	RAIL UNDERVOLTAGE
Bit 7	REGULATION FAULT
Bit 6	INTERLOCK #2
Bit 5	INTERLOCK #1

Bit 4	CROWBAR
Bit 3	OVER-TEMPERATURE
Bit 2	AC FAULT
Bit 1	FAULT
Bit 0	MODULE ON

The *set_reg* structure, in order to set the desired behaviour must be interpreted as follows:

FDB command register (8bit):	Bit Function:
Bit 7	**BYPASS COMMAND**
Bit 6	**ON/OFF**
Bit 5	**RESET**
Bit 4	**RAMP**
Bit 3…0	***don't care***

The "BYPASS COMMAND" bit (bit 7 - i.e. MSB) was especially implemented in order to use the 'FDB' command also as a simple read command: by setting this bit the power supply ignores all other data contained in the *set_reg* and in the *i_set* fields, thus replying and giving information on its internal *status_reg*, *i_set* and *i_read*.

Thanks to this feature the power unit can be controlled only with a single command, thus reducing driver (or EPICS IOC) complexity and maximizing bandwidth.

Example:

Suppose that the LiAM power supply unit is turned on and it is regulating a 4.5000A output current (on a 15Ω resistive value).
The user then sends the following command:

FDB:50:-01.2453\r →

← #FDB:6001:-01.2453:+04.5002\r

After sending the FDB command, the PS turns on (it was already ON in this example) and sets its current to -1.2453A reaching this setpoint with a ramp (defined by the slew rate value stored in the power supply non-volatile memory).

The entire reply from the power supply, referred to the format just presented, can be interpreted as follows:

- *Module is ON;*
- *Ramp is executing (Ramp execution flag);*
- *NO faults are present;*
- *the rail at their high level (handled automatically by the LiAM module internally);*

5.3.2 "MOFF" Command

The 'MOFF\r' command is intended to turn off the LiAM power supply output, thus disabling the output current terminals.
The 'MOFF\' command automatically sets output current to 0A (zero) with a 5A/s factory default slew-rate before disabling the output drivers, so that the maximum time for the power unit to turn off from its maximum current value is 1s; this is done in order to avoid voltage overshoots - that would be anyway smoothed and limited by the crowbar - especially for high currents on strongly inductive loads.

Replies from the power supply module to a 'MOFF\r' command are in the acknowledgment form '#AK\r'.

Sending a 'MOFF\r' command when the module output is already disabled generates an acknowledgment response – i.e. '#AK\r'.

Examples:

MOFF example when the LiAM module output is already disabled:

MOFF\r

#AK\r

MOFF example when the LiAM module is ON and supplying current:

MOFF\r

#AK\r

5.3.3 "MON" Command

The 'MON\r' command is intended to turn on the LiAM output, thus enabling the output current terminals and allowing the power supply to regulate and feed current to the connected load.

After the reception of an 'MON\' command, the power supply automatically sets output current to 0A (zero) when enabling the output.

Replies from the power supply to a 'MOFF\r' command are in the form '#AK\r' – when the command is correctly executed - or '#NAK\r'. The '#NAK\r' reply is obtained if:

- the LiAM unit is in a FAULT condition (it is necessary to reset the status register after a generic fault condition in order to turn the power supply ON again - see command 'MRESET\r').
- the module output is already ON.

Examples:

MON example when the bulk power supply is enabled (ON) and no fault conditions:

MON\r →

← #AK\r

MON example when the system is already ON:

MON\r →

← #NAK\r

5.3.4 "MRESET" Command

The 'MRESET\r' command has to be used in order to perform a complete reset of the module status register: this is needed, for example, to enable the channel output again after a fault condition has been fixed.

In order for the power supply to keep its status register values reset it is necessary that the cause of the previous fault condition (if any) has been removed.

Reply from the LiAM module is always '#AK\r', except if the module is off (in this case the power unit replies with a non-acknowledgment '#NAK\r').

Examples:

MRESET example:

MRESET\r →

← #AK\r

5.3.5 "MRG" Command

The 'MRG\r' command returns the value stored in the "value" parameter of a desired internal memory (EEPROM) cell. The correct form for the reading request is as follows:

MRG:cell_num\r

where:

- *cell_num* is the EEPROM cell number.

The on-board EEPROM memory - used to store module information as calibration parameters, identification, thresholds – has 512 cells, so that *cell_num* is limited between 0 and 511; requests containing cell values exceeding these limits obtain a non-acknowledgment reply '#NAK\r'.

The "value" section of the EEPROM is used to store calibration parameters, identification, thresholds, interlock information, etc. and other user-definable factors. For more information on how to write parameters in the "value" area of the memory, please refer to "MWG Command" section.

Replies from the LiAM power supply are in the following format:

cell_content\r

where:

- *cell_content* is the *cell_num* content in an ASCII representation.

The MRG command, being a reading command, returns a response in any module condition.

Examples:

MRG example with cell_num out of limits:

MRG:675\r →

← #NAK\r

MRG example for cell 4 (containing the maximum settable current limit [A]):

MRG:4\r →

← 5.1\r

MRG example for cell 22 (containing the module serial number):

MRG:22\r →

← LIAM_130234\r

5.3.6 "MRI" Command

The 'MRI\r' command returns the readback value of the power supply actual output current.

Current readback values have a 18-bit resolution (17-bit + sign) and they are presented with a 5-digit precision.

Replies from the power supply controller to this command are in the following form:

#MRI:value\r

where:

- *value* is the output current value readback [A].

The MRI command, being a reading command, returns a response in any module condition.

Examples:

MRI example when the module is OFF:

MRI\r →

← #MRI:+0.00004\r

MRI example when the module is ON and regulating:

MRI\r →

← #MRI:-2.34563\r

5.3.7 "MRID" Command

The 'MRID\r' command returns the LiAM module identification name as a string.

The reply from the power supply contains the value stored in cell 27 of the module EEPROM and it assumes the following format:

module_id\r

where:

- *module_id is* the module identification stored in non-volatile memory, as an ASCII string.

This command is equivalent to the 'MRG:27\r' command, being the cited cell content the user-selected module identification name.

The identification of the module can either be the power supply serial number, a user-defined name or the reference name of the magnet that the corresponding LiAM unit supplies (very useful in large installations).

The MRID command, being a reading command, returns a response in any module condition.

Examples:

MRID example with the module identification "SkewMag1.3":

MRID\r →

← SKEWMAG1.3\r

5.3.8 "MRM" Command

The 'MRM' command is used to set the value of the desired output current set-point:

MRM:value\r

where:

- *value* is the output current desired set-point [A].

The difference between the 'MWI\r' command and the 'MRM\r' command is that the first one generates a direct change in output current while the second one makes the power supply go from the previous to the actual current value performing a ramp, defined by a slew-rate (in A/s) stored in the EEPROM cell 30.

The LiAM module responds with acknowledgment command '#AK\r' if the value is correctly set and with a '#NAK\r' if:

- the set *value* is out-of-range (the maximum settable current value is user-defined and stored in EEPROM cell 4);
- the module is OFF (it is necessary to turn the module ON first);
- the module is performing a ramp (it is necessary to wait for the power supply to end the previous ramp);

Examples:

MRM example with the LiAM module in OFF state:

MRM:-2.872\r →

← #NAK\r

MRM example with the LiAM module ON and not ramping:

MRM:3.1234\r →

← #AK\r

5.3.9 "MRP" Command

The 'MRP\r' command returns the value of the positive power rail voltage, i.e. positive DC Link. Readback values have a unipolar 12-bit resolution.

Replies from the LiAM power supply unit to this command are in the following format:

#MRP:value\r

where:

- *value* is the measured DC Link voltage [V].

Even if the internal ADC dedicated to this purpose has a 12-bit resolution, this value is presented to the user only with a 100 mV resolution.

The MRP command, being a reading command, returns a response in any module condition.

Examples:

MRP example when the rail voltages are disabled:

MRP\r →

← #MRP:0.0\r

MRP example when the positive rail is at mid-level:

MRP\r →

← #MRP:55.3\r

5.3.10 "MRN" Command

The 'MRN\r' command returns the value of the negative power rail voltage, i.e. negative DC Link. Readback values have a unipolar 12-bit resolution.

Replies from the LiAM power supply unit to this command are in the following format:

#MRN:value\r

where:

- *value* is the measured DC Link voltage [V].

Even if the internal ADC dedicated to this purpose has a 12-bit resolution, this value is presented to the user only with a 100 mV resolution.

The MRN command, being a reading command, returns a response in any module condition.

Examples:

MRN example when the rail voltages are disabled:

MRN\r →

← #MRN:0.0\r

MRP example when the negative rail is at mid-level voltage:

MRN\r →

← #MRN:-53.6\r

5.3.11 "MRR" Command

The 'MRR\r' command returns the estimated value of the connected load resistive part, obtained directly from an *Automatic Load Recognition* procedure (strongly suggested) or directly written by the user. Please check the 'MTUNE\r' command for further information on how to run this procedure.

Replies from the LiAM power supply unit to this command are in the following format:

#MRR:value\r

where:

- *value* is the measured resistance Link voltage [Ω].

The resistance value is computed from the current and voltage readback values and it is presented with a 4-digit precision.

The MRR command, being a reading command, returns a response in any module condition.

Examples:

MRR example when the rail voltages are disabled:

MRR\r →

← #MRR:2.4435\r

5.3.12 "MRT" Command

The 'MRT\r' command returns the value of the maximum temperature directly measured on the power output stage heatsink. The LiAM has two different temperature sensors and the maximum value between these two is considered.

Even if the internal ADCs have a 12-bit resolution, this value is presented to the user with a 0.1 °C (= 0.1 K) resolution.

Replies from the LiAM power supply unit to this command are in the following form:

#MRT:value\r

where:

- *value* is the temperature value [°C = Celsius] measured on the output stage heatsink.

It is also possible to read the single temperature values by sending the commands 'MRT1\r' and 'MRT2\r' to the unit.

The MRT command, being a reading command, returns a response in any module condition.

Examples:

MRT example:

MRT\r →

← #MRT:37.2\r

MRT1 and MRT2 example:

MRT1\r →

← #MRT:31.3\r

MRT2\r →

← #MRT:37.2\r

5.3.13 "MRV" Command

The 'MRV\r' command returns the readback value of the power supply actual output voltage, measured at the LiAM module output terminals.

As for the output current, voltage readback values have an 18-bit resolution (17-bit + sign) and they are presented with a 5-digit precision.

Replies from the power supply LiAM controller to this command are in the following form:

#MRV:value\r

where:

- *value* is the output voltage readback [V], measured at the module output terminals.

The MRV command, being a reading command, returns a response in any module condition.

Examples:

MRV example when the module is OFF:

MRV\r →

← #MRV:+0.00012\r

MRV example when the module is ON and regulating output current:

MRV\r →

← #MRV:-28.34563\r

5.3.14 "MRW" Command

The 'MRW\r' command returns the actual value of the estimated active power supplied to the connected load.

This estimation, being computed as the product of the output voltage and the output current readback values, has also an 18-bit resolution and it is presented with a 5-digit precision.

Replies from the power supply LiAM controller to this command are in the following form:

#MRW:value\r

where:

- *value* is the output active power readback [W], estimated as the product of output voltage and output current readbacks.

The MRW command, being a reading command, returns a response in any module condition.

Examples:

MRW example when the module is OFF:

MRW\r →

← #MRW:-0.00432\r

MRW example when the module is ON and regulating output current:

MRW\r →

← #MRW:+207.32445\r

5.3.15 "MSP" Command

The 'MSP\r' command returns the value of the power supply last stored set-point current value.

Replies from the LiAM unit controller to this command are in the following form:

#MSP:value\r

where:

- *value* is the last stored output current set-point value [A].

The MSP command, being a reading command, returns a response in any module condition.

Examples:

MSP example:

MSP\r →

← #MSP:+1.23456\r

5.3.16 "MSR" Command

The 'MSR' command it is the only read/write command for LiAM and allows reading and setting of the value of the slew rate, in A/s, of the power supply.

The reading command is structured as follows:

MSR:?\r

and the related reply format is:

#MSR:value\r

where:

- *value* is actual slew-rate value for the power supply [A/s], that is the content of the EEPROM cell 30, with a 5-digit precision.

The value of the slew-rate can also be set, between lower limit of 0 A/s and upper limit of 100 A/s, using the MSR command and adopting the following syntax:

MSR:set_value\r

where:

- *set_value* is desired slew-rate value [A/s].

The MSR setting command generates, upon reception, an acknowledgment – i.e. '#AK\r' - reply if the value is correctly set and with a '#NAK\r' if:

- the set *value* is incorrect (e.g. out of limits);
- the module is still performing a ramp (it is necessary to wait for the power supply to end the previous ramp).

Examples:

MSR reading example:

MSR:?\r →

← #MSR:15.00000\r

MSR setting example with a value out of limits:

MSR:13005\r →

← #NAK\r

MSR setting example to a correct value:

MSR:5.5\r →

← #AK\r

5.3.17 "MST" Command

The 'MST\r' command returns the value of the power supply internal status register (16 bit).

Replies from the LiAM power supply module to this command are in the following format:

#MST:value\r

where:

- *value* is the ASCII representation of the internal status register value, composed by 4 hexadecimal digits, and corresponding to the 16-bit wide status register.

The MST command, being a reading command, returns a response in any module condition.

Examples:

MST example with the module ON, ramping (and voltage rails at mid-level):

MST\r →

← #MST:5001\r

5.3.18 "MUP" Command

The 'MUP\r' (Module UPdate) command performs an update of the power supply LiAM actual parameters with the parameters read from the module internal EEPROM.

As an example, the MWF command updates only the content of the selected EEPROM field but not the corresponding LiAM parameters. In order to make the module update its parameters it is necessary to perform the 'MUP\r' command: this was done not to apply wrong or undesired transmitted values *on-the-fly* without wanting it.

Replies from the power supply are in the form '#AK\r', or '#NAK\r'; this non-acknowledgment reply is generated when:

- the LiAM module is ON (it is necessary to shut-down the channel with MOFF command first).

Examples:

MUP example with the module OFF:

MUP\r →

← #AK\r

MUP example with the module ON:

MUP\r →

← #NAK\r

5.3.20 "VER" Command

The 'VER\r' command returns information about the LiAM power supply model and the currently installed firmware versions.

The response to a 'VER\r' command is in the following format:

#VER:LIAM6005:FW_ver\r

where:

- *FW_ver* is the firmware version currently installed on the module;

Please remember to keep them up to date by checking for updates/upgrades on the website (www.caenels.com).

The VER command, being a reading command, returns a response in any module condition.

Examples:

VER example:

VER\r →

← #VER:LIAM6005:1.0\r

5.3.22 "MWG" Command

The 'MWG' command lets users write a desired "value" item in a defined internal EEPROM cell.

The correct form format for this command is as follows:

MWG:cell_num:cell_content\r

where:

- *cell_num* is the EEPROM cell number;
- *cell_content* is the ASCII content to be written to the EEPROM cell *cell_num*.

The on-board EEPROM memory - used to store module information as calibration parameters, identification, thresholds and divided in two sections, "field" and "value" – has 512 cells, so that *cell_num* is limited between 0 and 511; writing operations containing cell values exceeding these limits obtain a non-acknowledgment reply '#NAK\r'.

This "value" section of the EEPROM is used to store descriptive calibration parameters, identification, thresholds, etc. and some cells are password protected.

Replies from the power supply are in the form '#AK\r', or '#NAK\r'; this non-acknowledgment reply is generated when:

- the cell number *cell_num* is out-of-range (negative or greater than 511);
- the selected cell is password protected.

In order to make changes take effect, a 'MUP\r' command must be sent to the power unit; if not, these changes will take effect at the next LiAM reset or power-cycle.

Examples:

MWG example of a correct write (cell #4) and changes taking effect immediately:

MWG:4:3.8\r →

← #AK\r

MUP\r →

← #AK\r

MWG example (cell #1 is password-protected):

MWG:1:1.234\r →

← #NAK\r

5.3.23 "MWI" Command

The 'MWI' command can be used to set the output current value and it is used when fast set-point changes are needed.

The use of this command is alternative to the MRM (Module RaMping): the power supply reaches the desired output current value just using the internal analog PID regulator parameters, without ramping with the pre-defined slew rate to the new set-point.

This command is usually needed when running feedback-related applications and for small changes in the output current.

The correct form format for this command is as follows:

MWI:value\r

where:

- *value* is the desired output current value [A].

Replies from the LiAM power supply are in the form '#AK\r', or '#NAK\r'; this non-acknowledgment reply is generated, as it is for the MRM command, when:

- the set *value* is out-of-range (the maximum settable current value is user-defined and stored in EEPROM cell 4);
- the module is OFF (it is necessary to turn the module ON first);
- the module performing a ramp (it is necessary to wait for the power supply to end the previous ramp) or a waveform.

Examples:

MWI example with the module OFF:

MWI:-3.55679\r →

← #NAK\r

MWI example with the module ON and already regulating:

MWI:+1.32\r →

← #AK\r

5.3.24 "PASSWORD" Command

The 'PASSWORD' command can be used to unlock the internal EEPROM cells that are password protected in order not to let inexperienced users to change some power supply parameters that might compromise the correct operation of the module.

See "Internal Memory Mapping" section for further details on password-protected cells. These cells are accessible only to CAEN ELS d.o.o. personnel or to experienced users.

The correct form format for this command is as follows:

PASSWORD:password\r

where:

- *password* is the module password to unlock protected EEPROM cells.

Replies from the power supply are in the form '#AK\r', or '#NAK\r'; this non-acknowledgment reply is generated when the written *password* is incorrect.

Examples:

PASSWORD example with a wrong password:

PASSWORD:elephant\r →

← #NAK\r

5.3.25 "MTUNE" Command (*Automatic Tuning Procedure*)

The 'MTUNE\r' command is used in order to launch the *automatic load recognition* procedure on the LiAM power supply. It is strongly suggested to run this procedure the first time a new load is connected to the power unit so that internal parameters are optimized for working with that specific load (e.g. automatic rail switching and some other controls).

In order to run the *automatic load recognition* process, the following command must be fed to the power unit:

MTUNE\r

The LiAM power supply replies with an acknowledgment '#AK\r' command if the procedure is correctly launched. Please note that during the automatic tuning process, lasting for about 13 seconds, the communication is suspended and the power supply Ethernet socket ignores all received commands.

At the end of this procedure, if successful, the power supply stores the value of the estimated resistive part of the load in its internal non-volatile memory.

The LiAM power units reply with a non-acknowledgment '#NAK\r' command when:

- the output is enabled;
- the power supply has experienced a fault.

Please note that in order to make the computed R_{EST} value take effect in the module operation, a 'MUP\r' command needs to be sent to the power supply unit at the end of the procedure.

Examples:

MTUNE example when module is OFF and no faults are present:

MTUNE\r →

← #AK\r

…procedure running for 13 seconds (and power unit ignoring all commands during this time interval…

MTUNE example when module is ON:

MTUNE\r →

← #NAK\r

5.4 IP Address Configuration

The LiAM power supply unit Internet Protocol (IP) address can be configured remotely using two different procedures:

The situations can be mainly two:

- the actual power supply IP address is known by the user. In these case the new IP address configuration can be performed via a basic Telnet connection;
- the actual power supply IP address is NOT known by the user. In these cases the new IP address configuration can be performed by using the DeviceInstaller® software.

An overview of the procedures to be followed using the just cited methods is herein presented.

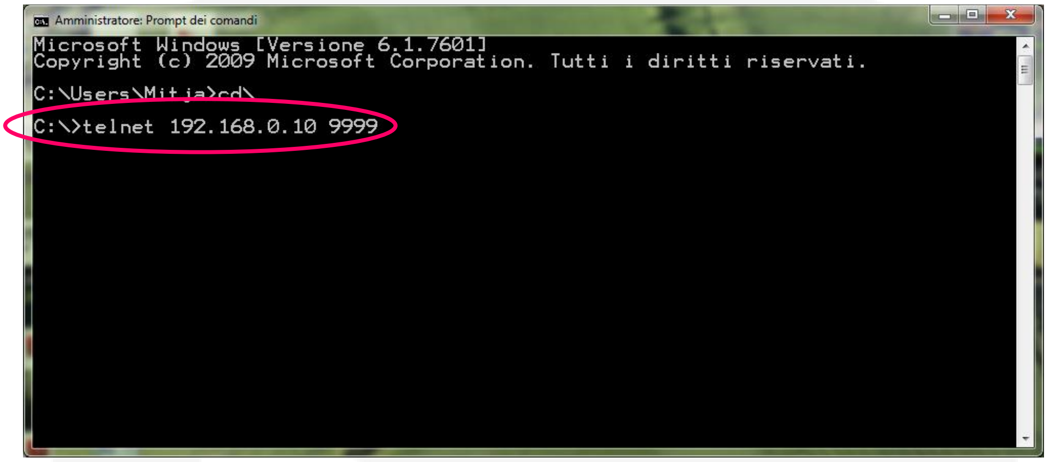
5.4.1 IP Address configuration - TELNET connection

If the power supply IP address is known by the user, it is also possible to configure the new IP address by using a simple TELNET connection.

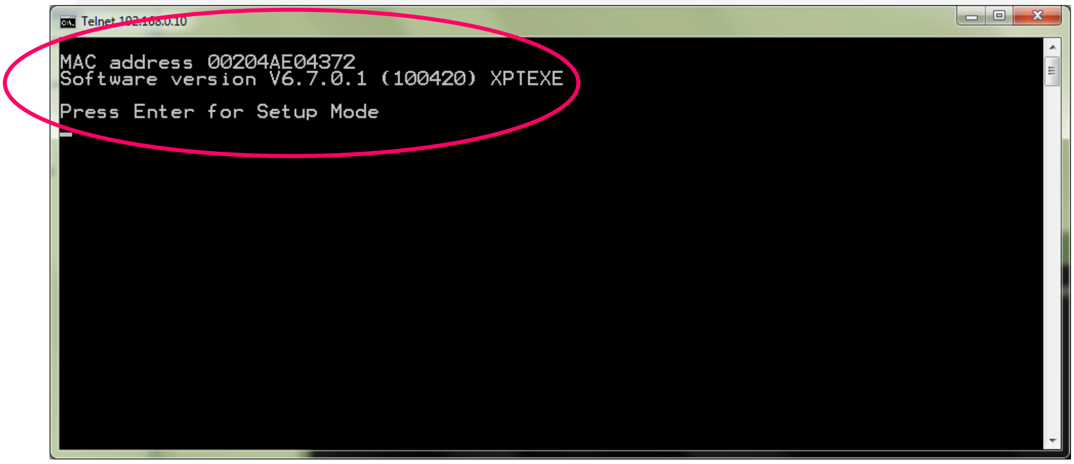
The TELNET connection must be established to **port 9999** of the Ethernet device of the power supply module.

Please carefully follow the instructions in order to correctly set/change the IP address of the LiAM power supply module:

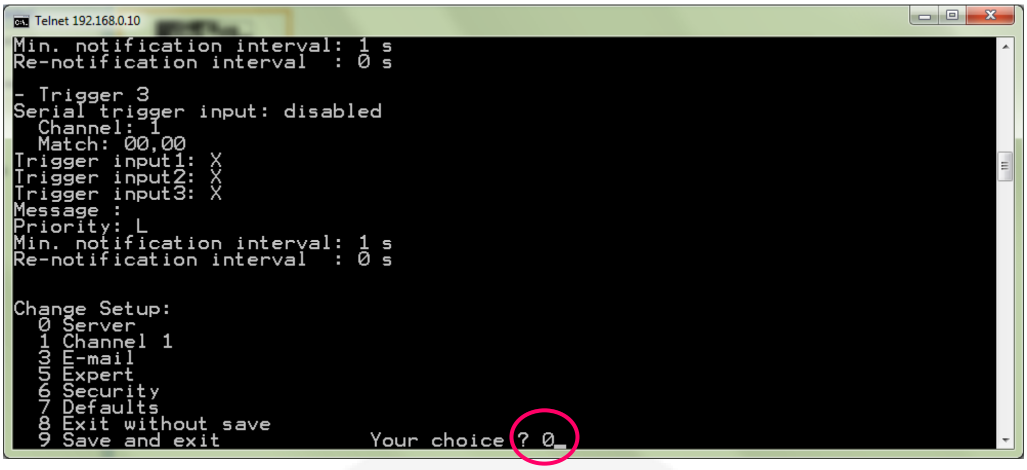
- establish a TELNET connection to port 9999 of the module IP address - e.g. 192.168.0.10;



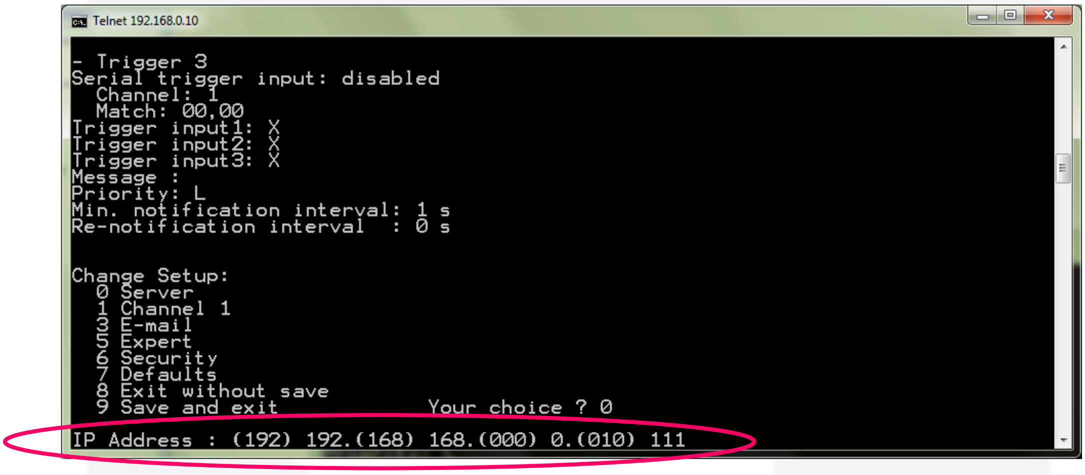
- now press Enter on the prompt to enter configuration menu;



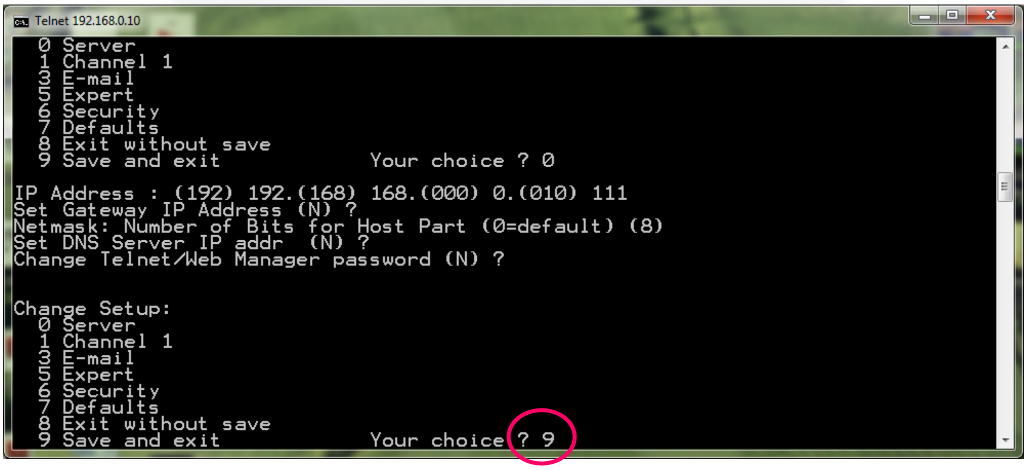
- on the device Telnet-based menu first select the "Server" option by inserting "0" and by pressing Enter on the prompt.



- when asked for the "IP Address" please enter the desired new IP address for the power supply. Please note that the IP address must be entered as 4 three-digit number - e.g. 192.168.0.111;



- Press the Enter key until reaching the "Your choice" screen again. Now insert "9" - i.e. Save and exit - and press Enter again.



The device should now reboot in order for the changes to take effect.

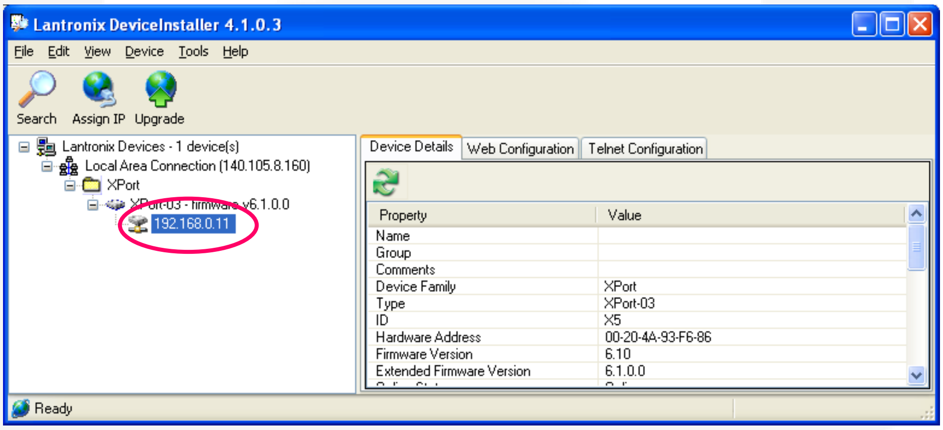
5.4.2 IP Address configuration - DeviceInstaller®

If the power supply IP address is not known by the user the best way to find out and to configure the module IP address is to use the DeviceInstaller® software.

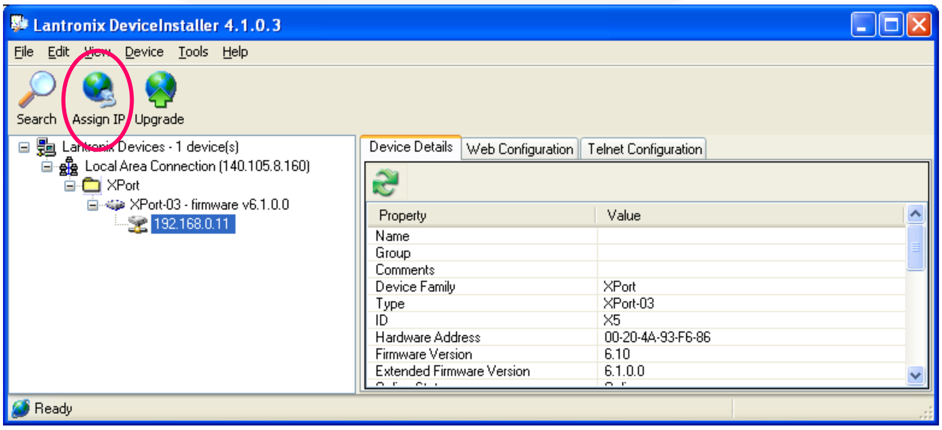
The DeviceInstaller® software can be downloaded for free from the Lantronix website www.lantronix.com. The LiAM modules can be connected to a global LAN or point-to-point (recommended in order to obtain minimum delays, maximum speed performance and to avoid possible communication problems). Please note that for a point-to-point direct connection a twisted Ethernet cable must be used.

The next few steps must be followed in order to assign a new IP address to the LiAM 6005 module:

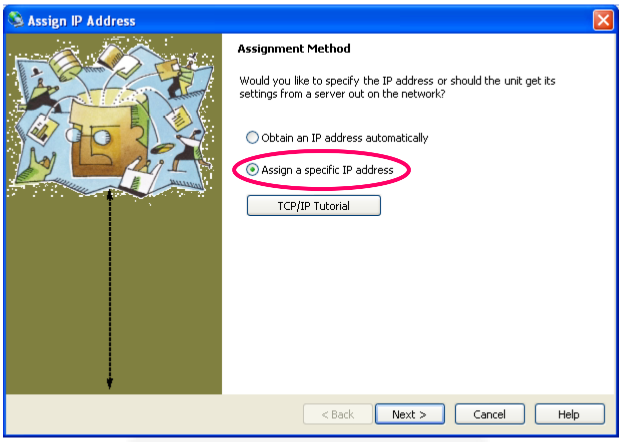
- Connect to the desired LiAM module with a twisted Ethernet cable;
- Verify that the "Link LED" on the RJ45 connector is turned on (amber for a 10Mbps connection or green for a 100Mbps connection);
- Launch the "DeviceInstaller" program;
- Select the XPort device where you want to change the IP address;



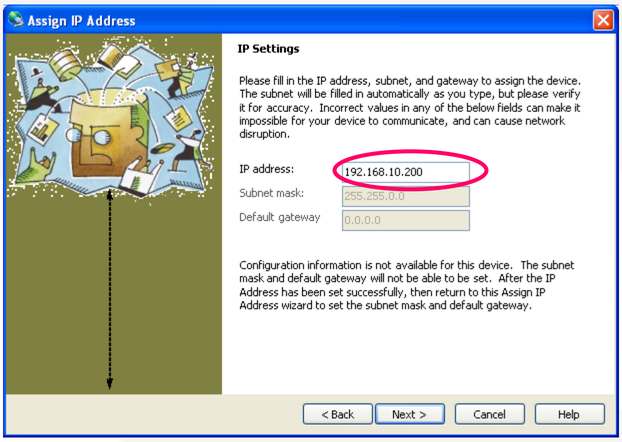
- Click on the "Assign IP" icon;



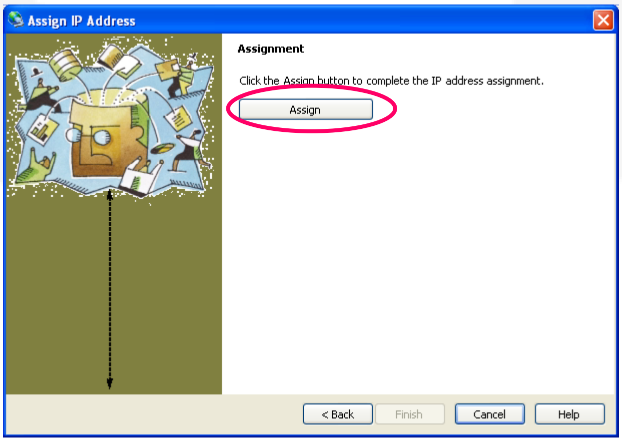
- Select "Assign a specific IP address" and then click "Next";



- Complete the "IP address" field and click on "Next";



- Click on the "Assign" button;



Wait for the assignment procedure to end, and then click "Finish". The new module IP address should now be assigned and the success of the operation can be verified on the "DeviceInstaller" main window (if the window does not refresh, click on "Search").

6. Technical Specifications

Technical Specifications for LiAM 6005 current-controlled bipolar power supplies are herein presented.

LiAM 6005	
Rated Output Current	± 5A
Rated Output Voltage	± 60V
Rated Output Power	300 W
Input Voltage	3 × 200VAC ± 10% 47-63 Hz
Output Topology	Zero-crossing Linear Amplifier
In-rush Current	< 40A
Maximum Inductive Load	100 mH (more upon request)
Current Setting Resolution	160 µA
Output Current Read-Back Resolution	65 µA
Output Voltage Read-Back Resolution	1 mV
Setting Accuracy	< 0.01 %
Readbacks Accuracy	< 0.05 %
Output Ripple (0-100kHz, RMS)*	0.2 mA
Long Term Stability (8h)	0.25 mA
Output Monitor Gain	2 V/A
External Interlocks/States	2 Inputs: configurable 1 Output: indicates if module is ON/OFF
Internal Interlocks	Over-Temperature Over-Voltage Regulation Fault AC Phase Fail Load Fault
Hardware Protections	Load energy dumping (crowbar) Circuit breakers Internal Temperature Voltage Rails Fuses

Auxiliary ADC Read-Backs	Output Current Output Voltage Status Register Voltage Rail Voltages Internal Temperatures Estimated Resistive Load
Cooling	Forced Air Convection
Remote Connectivity	Ethernet TCP-IP
Extra-Features	Firmware Update Short-circuit Stability
Local Display	2.5" display
Mechanical Dimensions	19" × 2U × 550 mm crate (19" × 2U × 578 mm with connectors)

* measured on 1mH load

Annex A - Output Connectors

Connections to the load must be carried out considering that the DC output connector pinout, made by terminal blocks, is presented in **Figure 30**:

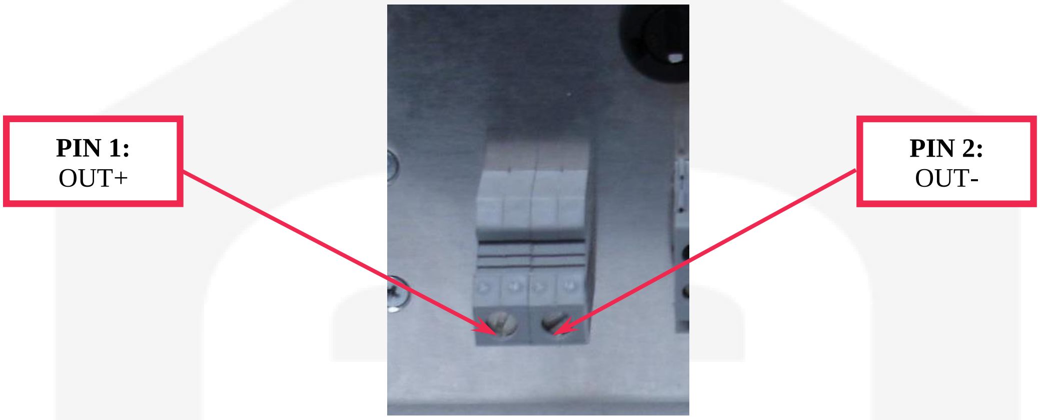


Figure 30: output connector pinout

The corresponding pinout is:

- **pin 1**: positive output terminal;
- **pin 2**: negative output terminal;

as indicated on the label that can be found over the terminal connector (where also output current and output voltage ratings are presented).

Suggested cable section for output is 1.5 mm^2 – 2 mm^2, or 15 AWG - 14 AWG.

⚠WARNING⚠

Please be aware that the output voltage of the LiAM 6005 module can reach a maximum of ±60V so that the screw terminals of these connections can be found at a high voltage with respect to EARTH potential.