TetrAMM

4-Channel Fast Interface Bipolar Picoammeter with Integrated HV Bias Source

CAENels
Gear For Science

User's Manual

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BEAMLINE ELECTRONIC INSTRUMENTATION

This product is CE certified.

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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⚠

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 TetrAMM device:

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	0°C to 40°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 TetrAMM 4-Channel Bipolar Picoammeter with High Voltage Bias Source.

1.1 The TetrAMM Picoammeter

CAENels TetrAMM picoammeter is a 4-channel, 24-bit resolution, wide-bandwidth, wide input dynamic range picoammeter with an integrated high voltage bias source ranging from 0V to 500V (other High Voltage options are available, for more informations see the High voltage source section).

It is composed of a specially designed transimpedance input stage for current sensing combined with analog signal conditioning and filtering stages making use of state-of-the-art electronics. This device can perform bipolar current measurements from ±120 nA (with a resolution of about 15 fA) up to ±120 μA (resolution of 15 pA) with a sampling frequencies of 100 kHz (for 4 channel at 24-bit resolution). Low temperature drifts, good linearity and very low noise levels enable users to perform very high-precision current measurements.

The TetrAMM is housed in a light, robust and extremely compact metallic box that can be placed as close as possible to the current source (detector), in order to reduce cable lengths and minimize possible noise pick-up. It is specially suited for applications where multi-channel simultaneous acquisitions are required, a typical application being the currents readout from 4-quadrant photodiodes used to monitor X-ray beam displacements.

The TetrAMM communication is guaranteed by a standard 10/100/1000 Mbps Ethernet TCP/IP protocol.

1.2 The TetrAMM at a Glance

The TetrAMM unit and its I/O connections can be easily seen in **Figure 1** (front) and in **Figure 2** (rear).

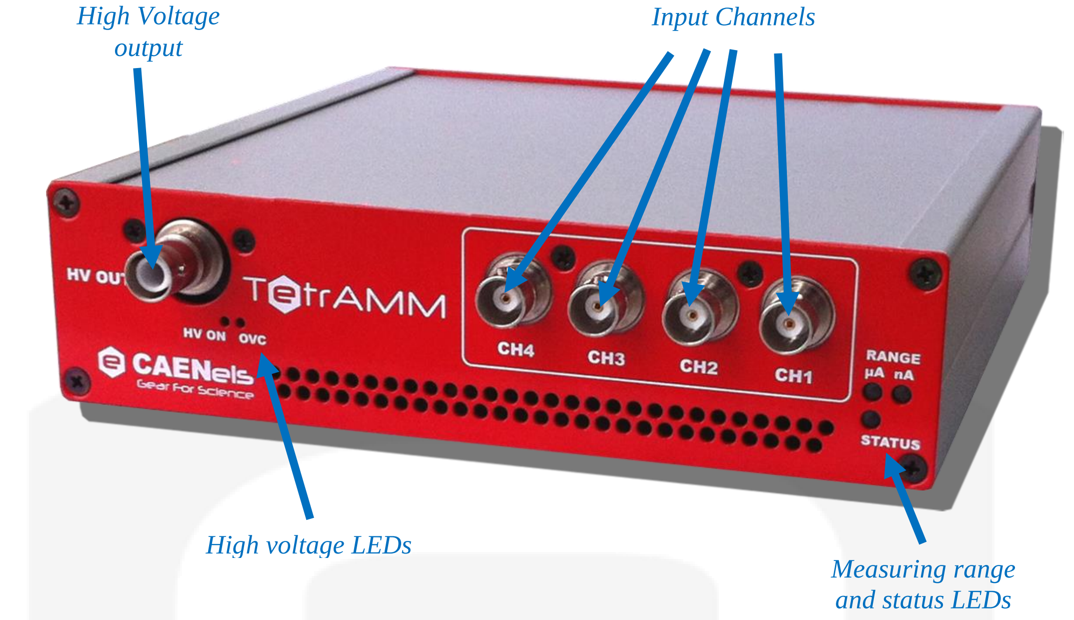


Figure 1: front view of a TetrAMM unit

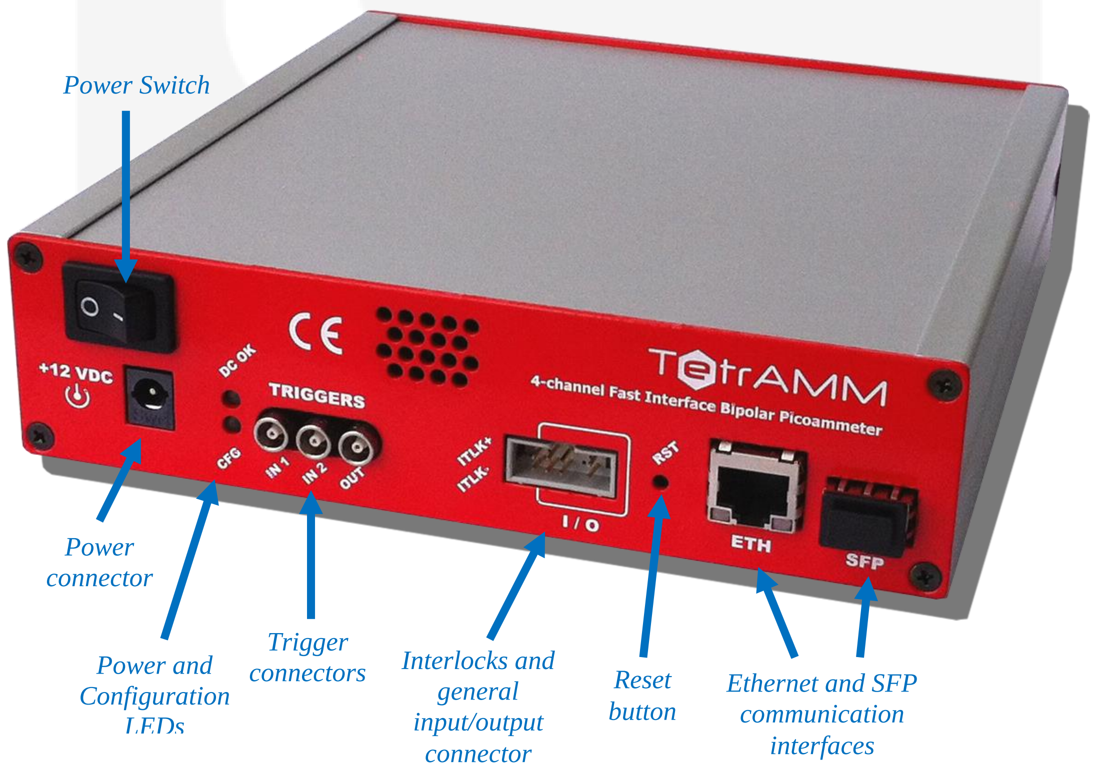


Figure 2: rear view of a TetrAMM unit

On the front side of the TetrAMM unit are placed four analog BNC current input connectors for input current measuring, one High Voltage SHV output connector and various status LEDs.

The two white "Range LEDs" ("µA" and "nA" in the standard configuration) are used in order to signal which of two ranges is currently used to measure the input current. If both LEDs are turned on, then the input channels are using different ranges (for more information see RNG Command section). Right under the "Range LEDs" is placed a blue "Status LED", which is used to signal the correct operation of the picoammeter device. During normal operation of the TetrAMM unit the "Status LED" is blinking with a frequency of 0.5Hz – i.e. the LED changes its status every 2 seconds – on the other hand, if a fault condition arises, the LED blinks with a higher frequency of 2 Hz (the led changes its status every 0.5 seconds). During the boot phase of the TetrAMM unit (which takes about 12 seconds) the "Status LED" and the "Range LED" are all turned on.

Two red "High Voltage LEDSs" are placed under the High Voltage output connector (SHV): the "HV ON" led is used to signal that the High Voltage output is enabled while the "OVC" LED is turned on when the High Voltage module is in an over-current condition.

On the rear panel of the device are placed power connector, power switch, two LEDs, LEMO connectors for I/O triggers, interlock and general I/O connector, a standard RJ45 Ethernet connector and an SFP connector.

The blue "CFG" led shows that the unit's FPGA is correctly configured (in this case the LED is turned on). The green "DC OK" LED indicates that the internal sections are correctly powered.

The three LEMO connectors for I/O triggers are also placed on the rear panel. Please note that only "IN 1" signal is enabled and could be used for a synchronized data acquisition (see the Triggers Connector section). The other two connectors – i.e. "IN 2" and "OUT" – are reserved for future use.

The "Interlocks and general I/O connector" has the pinout configuration shown in **Figure 3**:

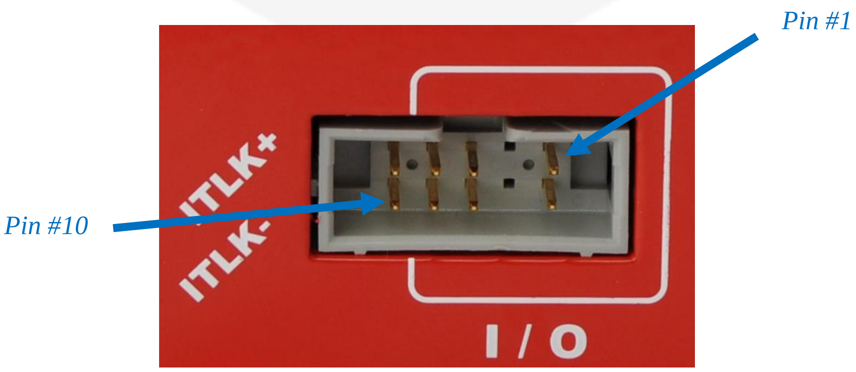


Figure 3: Interlock and general I/O connector

Pin #	Function
1-2	*Reserved*
3-4	*Not present*
5-8	General purpose I/O
9-10	External interlock

The external interlock pins can be used to detect an external event, which can be used to trigger the external interlock fault and so to switch off the High Voltage module (see Interlock and general I/O connector section for more information). This can be for example related to some vacuum-loss switch in beamline applications. Please note that these interlock pins are galvanically isolated from ground.

The General purpose I/O pins are not yet used and they are reserved for future use.

On the rear panel of the TetrAMM there is a small hole that gives access to a reset button ("RST"), which can be used to reset the unit. Next to the reset button are placed a RJ45 Ethernet connector ("ETH"), which is used to communicate with the unit and a Small form-factor pluggable transceiver ("SFP") which will be used for future updates.

1.3 Features

The TetrAMM input stage is based on four inverting transimpedance amplifiers (I/V converter) cascaded with particular signal conditioning stages.

Two standard measuring ranges are available; these range values with their corresponding gains and the resolution (LSB of the 24-bit Analog to Digital Converter) are shown in the following table:

	Full Scale	Gain (V/A)	Resolution (LSB)
RNG 0	$\pm 120\ uA$	$-(20 \cdot 10^3)$	$15\ pA$
RNG 1	$\pm 120\ nA$	$-(20 \cdot 10^6)$	$15\ fA$

A host PC is necessary in order to operate the TetrAMM unit and properly set/check the desired parameters (e.g. range) and to acquire the converted data. Please refer to the Software commands chapter for a complete description of available commands, their purposes and their syntax.

1.4 High voltage source

The TetrAMM device is provided with a low-noise integrated High-Voltage (HV) source that allows users to optionally bias a connected detector. Please note that HV sources installed in the TetrAMM units are referred to ground. This source is perfectly suited to be used as the bias voltage for the detecting system, when necessary, in order to increase the signal value (and thus to increase the signal-to-noise ratio).

This standard version of the TetrAMM includes a 500V@1mA positive HV source but other three different custom options can be configured at the time of purchasing of the unit:

Ordering Code	Product Code	Description
WTETRA05NXAA	TETRA500N	*500V (Negative) Integrated HV Source - option*
WTETRA4KPXAA	TETRA4KP	*4kV (Positive) Integrated HV Source - option*
WTETRA4KNXAA	TETRA4KN	*4kV (Negative) Integrated HV Source - option*

These options can be purchased by adding the corresponding ordering code or the product code to the one for the standard TetrAMM unit at the time of the order.

The digital interface allows setting remotely the set point of the high voltage source and to read the voltage and current readbacks (for more information see the High Voltage Commands section).

The red "HV ON" LED placed on the front panel acts as a status indicator for the high voltage source: it turns on when the output is enabled and it turns off as soon the output voltage returns to zero and the output is disabled.

The high voltage source has also an over current protection feature. When the output current reaches the maximum allowed output current of 1mA, the red "OVC" LED placed on the front panel turns on and the high voltage output is automatically disabled.

The different High Voltage options also have a different maximum allowed output current and different ramp slew rate (the output High Voltage module do not directly apply the selected set-point, but it performs a ramp to reach the desired output voltage value):

High Voltage model	I_{MAX}	Ramp slew rate
500V (Positive) - standard	1 mA	100V/s

500V (Negative) - option	1 mA	100V/s
4kV (Positive) – option	250 µA	500V/s
4kV (Negative) - option	250 µA	500V/s

1.5 Data Format

Acquired data from the TetrAMM unit can be configured to be transmitted in two different formats, depending on status of ASCII Command. ASCII commands allows user to choose between ASCII data format, which is readable by humans and raw floating-point numbers in double precision format (IEEE 754) that are faster to process, they are more accurate and have less overhead during the transmission. For more information about the data transfer see the Acquisition Commands descriptions.

1.6 Sampling Frequency

Internal sampling frequency for each channel is **fixed to 100 kHz** – i.e. 100 ksps. In the standard operation modes (ACQ, GET, NAQ, TRG and GATE Commands – see Acquisition Commands section) an averaging of the sampled data is performed to reduce the transmission data rate (due to the bottleneck caused by the communication link). Furthermore, the averaging also reduces high frequency noise and increases the signal-to-noise ratio.

In addition to the standard operation mode it is also possible to sample a smaller window of data at the maximum sampling frequency without performing averaging (for more information see FASTNAQ Command).

1.7 Offset calibration

The TetrAMM device is already factory-calibrated during the production process. However, user can perform an additional calibration – i.e. User Defined Calibration –perhaps nulling application specific offsets – e.g. dark currents in quadrature photodiode detecting systems.

1.7.1 User Defined Calibration

As previously cited, the TetrAMM device has the capability of handling user-defined linear calibration parameters on each channel in order to obtain the desired response from the unit. This process can be done, for example, when installing the

TetrAMM as the readout device for a photodiode-type detector and it is useful to get automatically rid of the measured dark currents on each channel.

The equivalent current read, by considering the user calibration, it is computed as follows:

$$I_{READ} = Gain_{UD} \cdot I_{raw} + Offset_{UD}$$

where:

- I_{READ} is the user-calibrated current read from the single channel [A];
- $Gain_{UD}$ is the user-defined gain factor [A/A];
- I_{raw} is the raw current read of the device [A];
- $Offset_{UD}$ is the user-defined offset value [A].

The user can enable or disable (as it can also read/write) this calibration values with the specific USRCORR Command. These calibration values are stored internally in a non-volatile memory so that it is possible to recall them at any time, also after a power-cycle of the device.

2. Software commands

This chapter describes the software commands used for the correct configuring of the TetrAMM picoammeter and for its data readout. For more information about the Ethernet settings see the Ethernet Communication chapter.

2.1 Command Syntax

The command syntax used by the TetrAMM protocol is described in the following sections.

Commands must be sent in ASCII format and are composed by a *"command field"* and one, two or none *"parameter field"*, separated by a colon (*'**:**'* or *'0x3A'* in hexadecimal notation). The number of *"parameter fields"* depends on the specific command. Commands are **NOT case sensitive** and therefore the command string can be sent either using uppercase or lowercase characters (conversion to uppercase characters is performed internally). Each instruction must be terminated with a '*carriage return\line feed*' sequence '***\r\n***' (or *'0x0D 0x0A'* in hexadecimal notation or commonly CRLF).

Command Example:

RNG:1\r\n

- *"**RNG**"* is the command field;
- *'**:**'* is the parameter's separation character;
- *'**1**'* is the first parameter field;
- *'**\r\n**'* are the termination sequence of the command.

Commands are processed one at a time; therefore user must wait for a response from the unit before sending the next command. All the responses from the

TetrAMM device are in upper case and are terminated with the same *'carriage return\line feed'* sequence ('**\r\n**') – i.e. CRLF – used in the command.

The reply from the device depends on the given command; for more information about the single command please refer to the specific command section.

There are two specific replies that are commonly used in many command, and that indicate that the command has been correctly elaborated or not. Those replies are hereafter presented:

- **ACK**nowledge (*'**ACK**'*) indicates that the command is valid and it was correctly elaborated by the device:

ACK\r\n

- *"ACK"* is the **ACK**nowledged response to a valid command;
- *'\r\n'* is the termination sequence of the reply.

- **N**ot **A**c**K**nowledge (*'**NAK**'*) indicates that the command is either not valid or that it was not accepted by the device; the *"NAK"* reply is followed by an *"error code"* field, which can be used to determine the cause of the error (see the List of the Error Codes appendix for a detailed list of all possible error codes):

NAK:01\r\n

- *"NAK"* is the **N**ot **A**c**K**nowledged response to an invalid command;
- *':'* is the parameter's separation character;
- *'01'* is a sample error code;
- *'\r\n'* is the termination sequence of the reply.

The list of commands used by the TetrAMM and the corresponding syntax is hereafter presented as well as a description of each command purpose and any special requirements related to the specific command. The commands are hereafter described and are grouped in categories based on their purpose.

2.2 Acquisition Commands

The Acquisition commands are used to acquire data of the measured currents present on the input channels of the TetrAMM device. The internal sampling frequency for each channel, as previously stated, is fixed to 100 kHz (sampling period of 10 µs) but for standard acquisition modes (ACQ Command, GET Command, NAQ Command, TRG Command and GATE Command) an averaging of these full-speed sampled data is performed in order to reduce the required data rate to be transmitted which is limited due to the communication link limitations.

In addition to the standard modes there is also a full-speed acquisition mode (FASTNAQ Command), which allows users to acquire the data at the maximum data rate of 100 kHz (the same as the internal sampling frequency – i.e. without any performed averaging) on a smaller time window.

The mentioned acquisition modes are presented in the following sections.

2.2.1 ACQ Command

The ACQ commands starts or stops the data acquisition from the TetrAMM device. The instrument starts to acquire data at its maximum sampling frequency as soon as the command is received and it immediately sends the generated digital data stream to the connected host PC. A command has to be sent in order to stop the data acquisition.

The acquisition is stopped at power-up *(default)*; the user is then required to start the data acquisition by sending the "ACQ:ON\r\n" command to the TetrAMM in order to start the data conversion and transmission. When the command is correctly processed, the unit starts to acquire samples and it continuously sends the acquired data to the connected host; if the command is not accepted, the unit replies with a "NAK:*xx*\r\n" string, where the *xx* field indicates the error code (see the List of the Error Codes appendix)

To stop the data acquisition the user have to send the "ACQ:OFF\r\n" command to the TetrAMM unit. The unit replies with an acknowledge ("ACK\r\n") string as soon as an "ACQ:OFF\r\n" command is received.

Command	Command description
ACQ:ON\r\n	Start continuosly sampling
ACQ:OFF \r\n	Stop sampling

The transmitted data format (to the host PC) depends on the setting of the "ASCII mode" (see ASCII Command section) and the number of activated channels (see the CHN Command section). The purpose of the number of activated channels is to define the number of simultaneously sampled channels. The ASCII command changes the format of the digital stream generated by the TetrAMM unit. Two possible sample representations are available on the TetrAMM device:

- if ASCII mode is **enabled**, the output stream is displayed in ASCII format so that the user can directly read the acquired data. This data stream is represented as strings in normalized scientific notation with a fixed length;
- if ASCII mode is **disabled**, the output stream is displayed in binary format (the user can not directly read the acquired data since they are represented in binary standard, used in information technology - this is the double precision floating-point - IEEE 754 standard – 64 bits).

Example of a single acquisition on 4 channels with ASCII data stream enabled (data are represented as a string in normalized scientific notation with fixed length; non-printing characters are displayed in red - each channel value is separated by a tab character '\t' and each acquisition is terminated with two termination characters: carriage return/line feed '\r\n'):

+1.12345678E-12\t-2.12345678E-11\t+3.12345678E-12\t+4.12345678E-11\r\n

Ch1 **Ch2** **Ch3** **Ch4**

Tab **Tab** **Tab** **Termination characters**

When ASCII mode is disabled, then the data output format consists of double precision floating point format (IEEE 754 standard – 64 bits row data) and a custom **s**ignaling **N**ot **a** **N**umber (*sNaN*) termination 64-bit sequence (i.e. **0xFFF4 0002 FFFF FFFF** in hexadecimal representation), which denotes the end of a data set.

As an example, the equivalent previous sample data set with the ASCII data stream disabled is shown hereafter (the following binary data is represented in hexadecimal notation):

3D73C3997B2D31CBBDB758FFDDB8F16A3D8B79663EC482F73DC6AB3FDF992B00FFF40002FFFFFFFF

Ch1 **Ch2** **Ch3** **Ch4** ***sNaN* (End of data set)**

Another example is presented when only one channel is active and ASCII mode is enabled; the transferred data sample is as follows (non-printing characters are displayed in red):

+1.12345678E-12\r\n

Ch1 **Termination characters**

The equivalent data with ASCII stream disabled is displayed in the hexadecimal representation as follows:

3D73C3997B2D31CBFFF40002FFFFFFFF

Ch1 **NaN (End of data set)**

The ASCII format setting affects not only the format of the generated output stream but also the maximum data rate of possible data that can be transferred from the TetrAMM to the host PC, due to "number to string" conversion task and larger amount of data to transmit.

As an example, a single acquisition on 4 channels in ASCII format takes 15 character for each channel (this implies a total of 60 characters for 4-channel acquisition) and 5 characters for delimitation tabs and termination characters; the total number of bytes to be transferred is then of 65 – i.e. 65 characters.

On the other hand, if a raw binary transfer (i.e. ASCII mode disabled) is used, the double precision floating number - 64 bits - 8 bytes for each channel and a custom *sNaN* termination needs to be transferred, for a total amount of 40 bytes (5 numbers) in a 4 channel acquisition. The data to be transmitted in this particular situation is then almost 40% less using raw binary data than using ASCII strings.

The maximum data rate transfer limit in the two configurations is:

- 200 acquisitions-per-second (200 Hz) when ASCII format is enabled;
- 20.000 acquisitions-per-second (20 kHz) when ASCII format is disabled.

In both cases internal sampling frequency of the ADCs remains untouched to 100 kHz, but in order to reduce the amount of data to be transmitted to the host PC, the samples are averaged and normalized. The normalized averaging is made on 500 samples in the case of ASCII mode and on only 5 samples in binary format.

Please note that the number of sampled channels (CHN setting) do not affect the data transfer rate limit.

The maximum data rates and the number of averaged samples are indicated in the following table:

Data format	ACQ maximum data rate	Averaged samples @ 100 kHz
ASCII enabled (**string** format)	200 Hz	500 (min value)
ASCII disabled (**binary** format)	20.000 Hz	5 (min value)

The TetrAMM unit allows also to additionally decrease the acquisition transfer rate using the NRSAMP command (see the NRSAMP Command section), which allows to calculate a normalized averaging on a larger number of samples.

It is also possible to increment the acquisition data rate up to a value equal to the ADC internal sampling frequency (i.e. 100 kHz); the acquisition in this case cannot be continuous as when using the ACQ command and thus only time frames (limited time windows) can be acquired.

The use of this particular feature is carried out using the FASTNAQ command (see FASTNAQ Command section).

Examples:

ACQ ON example with ASCII data on 2 channels (the following data are represented in string format):

ACQ:ON\r\n

+1.12345678E-12\t +1.12345680E-12\r\n
+1.12345670E-12\t +1.12345685E-12\r\n
+1.12345682E-12\t +1.12345698E-12\r\n
……….\r\n

ACQ OFF example with ASCII data on 2 channels:

……….\r\n
+1.12345770E-12\t +1.12345680E-12\r\n
+1.12345782E-12\t +1.12345698E-12\r\n
+1.12345795E-12\t +1.12345701E-12\r\n

ACQ:OFF\r\n

ACK\r\n

ACQ ON example with ASCII format disabled on 1 channel (note that following data are represented in hexadecimal format):

ACQ:ON\r\n

3D73C3997B2D31CBFFF40002FFFFFFFF
3D74D3997B2D31CBFFF40002FFFFFFFF
3D75C3997B2D31CBFFF40002FFFFFFFF
……….FFF40002FFFFFFFF

ACQ OFF example with ASCII data enabled on 1 channel:

……….\r\n
+1.12345770E-12\t +1.12345680E-12\r\n
+1.12345782E-12\t +1.12345698E-12\r\n
+1.12345795E-12\t +1.12345701E-12\r\n

ACQ:OFF\r\n

ACK\r\n

2.2.2 GET Command

The purpose of the GET command is to read back a single snapshot of the values for the active channels. The "G\r\n" command is a useful shortcut fully equivalent to the "GET:?\r\n" command.

The format of the returned values is the same as for the ACQ Command and it depends both on the "ASCII mode" settings (refer to ASCII Command) and the active channels settings (see CHN Command section). Please refer to the ACQ Command description for a more accurate explanation of the output stream formatting.

Examples:

GET example with ASCII data on 2 channels (the following data are represented in string format):

GET:?\r\n →

← +1.12345678E-12\t +1.12345680E-12\r\n

or:

G\r\n →

← +1.12345678E-12\t +1.12345680E-12\r\n

GET example with ASCII format disabled on 1 channel (note that following data are represented in hexadecimal format):

GET:?\r\n →

← 3D73C3997B2D31CBFFF40002FFFFFFFF

2.2.3 NAQ Command

The purpose of the NAQ command is to read a fixed number of acquisitions, ranging from 1 to 2.000.000.000 (i.e. 2-billion acquisition cycles), without having to manually stop the acquisition when the desired number of samples has been read (unlike with the ACQ command).

As for the ACQ command, the format of the returned data stream depends on the "ASCII mode" settings (refer to ASCII Command section) and the active channels settings (see CHN Command section). For a more accurate explanation of the output stream formatting see the ACQ Command description. The TetrAMM unit indicates the end of data transfer with an acknowledgement reply ("ACK\r\n").

The maximum acquisition data rate is limited due to the to the communication link limitations so that the maximum data rates are the same as for the ACQ command (for more information see the ACQ Command section). The data rate could be additionally decreased using the NRSAMP command (refer to the NRSAMP Command), which allows to calculate a normalized averaging on a larger number of samples, thus reducing also the equivalent measuring noise value.

Examples:

NAQ example for 3 acquisitions in ASCII on 2 channels (the following data are represented in string format):

NAQ:3\r\n →

← +1.12345678E-12\t +1.12345680E-12\r\n

← +1.12345670E-12\t +1.12345685E-12\r\n

← +1.12345682E-12\t +1.12345698E-12\r\n

← ACK\r\n

NAQ example for 5 acquisitions with ASCII format disabled on 1 channel (note that following data are represented in hexadecimal format, note that the last line "41434B0D0A" in hex format is equivalent to "ACK\r\n" in string format – see the ASCII table*):*

NAQ:5\r\n →

← 3D73C3997B2D31CBFFF40002FFFFFFFF

← 3D74D3997B2D31CBFFF40002FFFFFFFF

← 3D75C4000B2D31CBFFF40002FFFFFFFF

← 3D75C4005B2D31CBFFF40002FFFFFFFF

← 3D75C4080B2D31CBFFF40002FFFFFFFF

← 41434B0D0A

2.2.4 TRG Command

The TRG Command enables to synchronize the TetrAMM current acquisition to an external event via the hardware "Trigger/Gate" signal (refer to the I/O Connectors section). This feature is extremely useful when the picoammeter data acquisition must be synchronized to an external event (e.g. an experimental time window). The "trigger mode" operation is hereafter described.

As soon as the "TRG:ON\r\n" command is received the TetrAMM unit replies with an acknowledge ("ACK\r\n") string and enters the "trigger mode". When entering this mode, the unit searches for a rising edge (positive edge) on the corresponding "Trigger/Gate" input signal.

As soon as this event is detected by the unit, the internal logic starts to elaborate the acquired input data (with a normalized averaging) and to continuously send the sample values to the host. Data are sent to the host as long as the unit does not triggers itself to another rising edge of the corresponding "Trigger/Gate" input signal. This behavior is kept until the "trigger mode" is disabled with the "TRG:OFF\r\n" (*default*) command. Please note that an acknowledgment string is sent back to the host after a "TRG:ON\r\n" or "TRG:OFF\r\n" command is received.

The format of the output stream depends on the ASCII format (see ASCII Command section) and the number of activated channels (see CHN Command section); for a more detailed description of the output stream and the acquisition limitations please refer to the description of the ACQ Command, which uses the same data representation.

In addition to the standard output data stream, the trigger mode adds a header and a footer to the acquired data.

The header indicates a sequence number (i.e. counter) of the trigger events, starting with #0. The sequence number is reset when the "trigger mode" is disabled. The header format also depends on the ASCII mode and the number of activated channels:

- ASCII mode enabled: the header has the following format: "SEQNR:*n*\r\n", where *n* is the sequence number of trigger event in decimal rapresentation;

- ASCII mode disabled: the header format depends on the number of activated channels - it is composed of a 64-bit Signaling Not a Number *sNaN* ("Sequence Number *sNaN*") IEEE 754 - double precision floating point. This particular value is composed by two parts: the most significant 32 bits are constant (0xFFF40000**)** and the lower 32 bits indicates the sequence number in hexadecimal format (for example the sequence number 161 is represented as 0x000000A1, so the entire *sNaN* is displayed as 0xFFF40000 000000A1). In order to maintain the format of the transmitted data stream, the *sNaN* value is repeated *k* times, where *k* is the number of active channels and the header is terminated with a custom

"End of Data set" *sNaN* (0xFFF40002 FFFFFFFF) - the same used at the end of single acquisition when ASCII mode is disabled. As an example, the header of a 2-channel acquisition with ASCII mode disabled for a sequence number of 161 is displayed as:

FFF40000000000A1FFF40000000000A1FFF40002FFFFFFFF

"Sequence number *sNaN*" is repeated twice because the number of active channels is 2

sNaN
(End of data set)

The footer appended to the transferred data indicates the end of trigger event. The footer format depends on the ASCII setting:

- ASCII mode enabled: the footer has the following form: "EOTRG\r\n" (End Of TRiGger);
- ASCII mode disabled: the footer is composed by the following fixed *sNaN*, called "End of trigger event *sNaN*" 64-bit sequence 0xFFF4 0001 FFFF FFFF.

Examples:

TRG example with ASCII mode enabled on 2 channels (the following data are represented in string format):

TRG:ON*\r\n* →

← ACK*\r\n*

(pause)

Trigger/Gate pin signal
(positive edge event)

header: ← SEQNR:0000000000*\r\n*

← +1.12345678E-12*\t* +1.12345680E-12*\r\n*

← +1.12345670E-12*\t* +1.12345685E-12*\r\n*

← ....

← +1.12345690E-12*\t* +1.12345684E-12*\r\n*

footer: ← EOTRG*\r\n*

Trigger/Gate pin signal
(positive edge event)

(pause)

Trigger/Gate pin signal
(positive edge event)

header: SEQNR:0000000001\r\n

+1.12345690E-12\t +1.12345680E-12\r\n

+1.12345680E-12\t +1.12345683E-12\r\n

....

+1.12345695E-12\t +1.12345689E-12\r\n

footer: EOTRG\r\n

Trigger/Gate pin signal
(positive edge event)

(pause)

TRG:OFF\r\n

ACK\r\n

TRG example with ASCII mode disabled on 1 channel (the following data are represented in hexadecimal format):

TRG:ON\r\n

ACK\r\n

(pause)

Trigger/Gate pin signal
(positive edge event)

header: FFF4000000000000FFF40002FFFFFFFF

3D73C3997B2D31CBFFF40002FFFFFFFF

3D74D3987B2D31CBFFF40002FFFFFFFF

....

3D75C4005B2D31CBFFF40002FFFFFFFF

footer: EOTRG\r\n

Trigger/Gate pin signal
(positive edge event)

(pause)

Trigger/Gate pin signal
(positive edge event)

header: FFF4000000000001FFF40002FFFFFFFF

3D73C3997B2D31CBFFF40002FFFFFFFF

3D74D3997B2D31CBFFF40002FFFFFFFF

....

3D75C4005B2D31CBFFF40002FFFFFFFF

footer: FFF40001FFFFFFFF

Trigger/Gate pin signal
(positive edge event)

(pause)

TRG:OFF\r\n →

← ACK\r\n

2.2.5 GATE Command

The GATE Command is similar to the TRG Command (see the TRG Command chapter). This command also allows to synchronize acquisition with an external event using the signal on the "Trigger/Gate" input connector (see I/O Connectors chapter) and the only difference respect to the TRG Command is that the start/stop of the acquisition is not triggered by the rising edge of "Trigger/Gate" signal, but it is linked to the "Trigger/Gate" signal level. When the TetrAMM unit is set to "gate mode" it starts to acquire the data on the rising edge of "Trigger/Gate" input signal; data are then continuously handled (a normalized averaging due to the communication limitations) and sent to the host as long as the "Trigger/Gate" signal is kept in its logic high state. Acquisition is then stopped at the falling edge of "Trigger/Gate".

A "GATE:ON\r\n" string needs to be sent to the TetrAMM in order to set it to "gate mode". When the command is received the unit replies with an acknowledgement string ("ACK\r\n"). The command to exit from the "gate mode" is "GATE:OFF\r\n" (*default*). The format and representation of the header, footer and output data stream is the same as for the TRG Command (see TRG Command section).

Examples:

GATE example with ASCII mode enabled on a 2-channel acquisiton (the following data are represented in string format):

GATE:ON\r\n →

← ACK\r\n

(pause)

Trigger/Gate pin signal
(positive edge event)

header: ← SEQNR:0000000000\r\n

← +1.12345678E-12\t +1.12345680E-12\r\n

← +1.12345670E-12\t +1.12345685E-12\r\n

← ....

← +1.12345690E-12\t +1.12345684E-12\r\n

footer: ← EOTRG\r\n

Trigger/Gate pin signal
(negative edge event)

(pause)

Trigger/Gate pin signal
(positive edge event)

header: ← SEQNR:0000000001\r\n

← +1.12345690E-12\t +1.12345680E-12\r\n

← +1.12345680E-12\t +1.12345683E-12\r\n

....

+1.12345695E-12\t +1.12345689E-12\r\n

footer: EOTRG\r\n

Trigger/Gate pin signal
(negative edge event)

(pause)

GATE:OFF\r\n

ACK\r\n

GATE example with ASCII mode disabled on 1-channel acquisition (the following data are represented in hexadecimal format):

GATE:ON\r\n

ACK\r\n

(pause)

Trigger/Gate pin signal
(positive edge event)

header: FFF4000000000000FFF40002FFFFFFFF

3D73C3997B2D31CBFFF40002FFFFFFFF

3D74D3987B2D31CBFFF40002FFFFFFFF

....

3D75C4005B2D31CBFFF40002FFFFFFFF

footer: EOTRG\r\n

Trigger/Gate pin signal
(negative edge event)

(pause)

Trigger/Gate pin signal
(positive edge event)

header: FFF4000000000001FFF40002FFFFFFFF

3D73C3997B2D31CBFFF40002FFFFFFFF

3D74D3997B2D31CBFFF40002FFFFFFFF

....

3D75C4005B2D31CBFFF40002FFFFFFFF

footer: FFF40001FFFFFFFF

Trigger/Gate pin signal
(negative edge event)

(pause)

GATE:OFF\r\n

ACK\r\n

2.2.6 FASTNAQ Command

The FASTNAQ command is used to use the fast acquisition capabilities of the TetrAMM unit – i.e.to acquire a limited number of samples at the maximum sampling frequency of 100 kHz. The acquired samples are stored on the internal memory and they are later transmitted to the host. The maximum number of acquired samples is limited by the internal memory size, so that the window size is larger if the acquisition has to be performed on a smaller number of channels (see CHN Command section) but it is independent from the data format (ASCII or binary data).

Number of Channels	Maximum Number of Samples	Maximum Time-window Size
1	1.048.576	10,48576 seconds
2	699.050	6,99050 seconds
4	419.430	4,19430 seconds

Obviously, the averaging of the acquired samples is not possible using this command so that the NRSAMP setting is ignored (see NRSAMP Command section).

The command to be set in order to start a fast acquisition is "FASTNAQ:*n*\r\n", where *n* is the number of samples to be acquired for each channel. The output data format depends on the setting of the "ASCII mode" (refer to the ASCII Command section) and the number of channels to be acquired (refer to the CHN Command section). To get a more accurate description of the output stream please refer to the ACQ Command section.

Note that, while in the ACQ command procedure the ASCII setting limits the acquisition time, in the FASTNAQ acquisition the ASCII setting does not affect the acquisition speed but it influences only the data transmission speed.

The unit indicates the end of data transfer by sending an acknowledgement reply ("ACK\r\n" in ASCII mode).

Examples:

FASTNAQ example for 4 acquisitions with ASCII mode enabled on 2 channels (the following data are represented in string format):

FASTNAQ:4*\r\n* →

← +1.12345678E-12*\t* +1.12345680E-12*\r\n*
← +1.12345670E-12*\t* +1.12345685E-12*\r\n*
← +1.12345682E-12*\t* +1.12345698E-12*\r\n*
← ACK*\r\n*

FASTNAQ example for 5 acquisitions with ASCII format disabled on 1 channel (note that following data are represented in hexadecimal format, note that the last line

"41434B0D0A" in hex format is equivalent to "ACK\r\n" in string format – see the ASCII table *appendix):*

FASTNAQ:5\r\n →

← 3D73C3997B2D31CBFFF40002FFFFFFFF
← 3D74D3997B2D31CBFFF40002FFFFFFFF
← 3D75C4000B2D31CBFFF40002FFFFFFFF
← 3D75C4005B2D31CBFFF40002FFFFFFFF
← 3D75C4080B2D31CBFFF40002FFFFFFFF
← 41434B0D0A

2.3 Configuration Commands

The commands that can be used to set or to read the TetrAMM device configuration are described in this section.

2.3.1 CHN Command

The purpose of the CHN command is to set the number of active input channels that have to be sampled; the TetrAMM provides the capability to simultaneously sample 1, 2 or 4 channels. The number of sampled channels does not affect the internal sampling frequency (that remains 100 kHz). The default number of sampled channels is four (4).

The sampled channels and the relative CHN command are shown in the following table:

Command	Sampled Channels
CHN:1\r\n	CH1
CHN:2\r\n	CH1, CH2
CHN:4\r\n	CH1, CH2, CH3, CH4

The command used to read the actual CHN setting is: "CHN:?\r\n". The reply to the read command is in the following form: "CHN:*sampled_chn*\r\n", where *sampled_chn* could be '1', '2' or '4'.

Examples:

CHN set example:

CHN:4*\r\n* →

← ACK*\r\n*

CHN set example with incorrect parameter:

CHN:3*\r\n* →

← NAK:02*\r\n*

CHN read example:

CHN:?*\r\n* →

← CHN:4*\r\n*

2.3.2 ASCII Command

The purpose of the ASCII command is to change the format of the digital data stream generated by the TetrAMM unit. There are two possible stream settings that can be configured:

Command	Generated stream
ASCII:ON\r\n	Output values are sent as strings in normalized scientific notation with a fixed length
ASCII:OFF\r\n	Output values are sent as double precision floating point values (IEEE 754 standard – 64 bits)

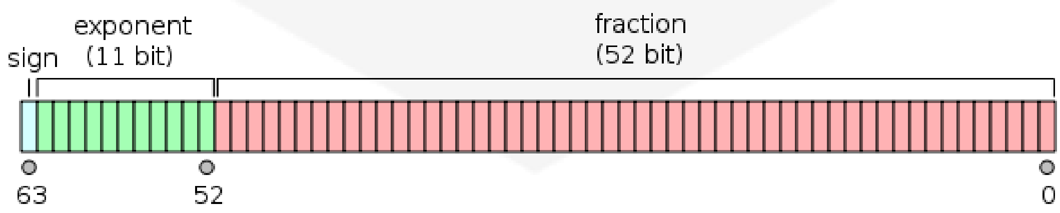
With the "ASCII:ON\r\n" command the ASCII format is enabled and the output values are sent as a string in a normalized scientific notation. An example of used notation is as follow:

$$\underbrace{+1.12345678}_{a}\mathrm{E}\underbrace{-12}_{b}$$

where the exponent *b* is chosen so that the absolute value of *a* is included between one and ten ($1 \leq |a| < 10$). The total length of the string is fixed to 15 characters (15 bytes), so that, as an example, the number -10.1 is displayed as:

$$\underbrace{-1.01000000}_{a}\mathrm{E}\underbrace{+01}_{b}$$

The double precision floating point representation ("ASCII:OFF\r\n" setting) improves the data rate transmission as it avoids the overhead due to the ASCII format conversation and reduces the amount of sent data. The structure of each 64-bit (4 bytes) double precision number is as follows:



so that each number is represented as a combination of the following data fields:

- **bit #63** - "sign" bit;
- **bits #62-52** (11 bits) - "exponent" bits;
- **bits #51–0** (52 bits) - "significant" or "mantissa" bits.

For default the ASCII mode is disabled – data are represented in the double precision floating point format. In order to have some examples on the generated output stream, please see Acquisition Commands section.

The user can use the command "ASCII:?\r\n" in order to read the actual ASCII setting; the replies to the read command are in the format "ASCII:*mode*\r\n", where *mode* could be ON or OFF.

Examples:

ASCII set example:

ASCII:ON*\r\n* →

← ACK*\r\n*

ASCII set example with incorrect parameter:

ASCII:XX*\r\n* →

← NAK:04*\r\n*

ASCII read example:

ASCII:?*\r\n* →

← ASCII:OFF*\r\n*

2.3.3 RNG Command

The purpose of the RNG command is to set the gain and therefore the full scale range of the TetrAMM. The TetrAMM unit can operate in two possible ranges:

	Full Scale	Resolution@24 bit
Range 0	±120 µA	15 pA
Range 1	±120 nA	15 fA

The full scale range can be set to all four channels simultaneously using the command "RNG:*parameter*\r\n", where the *parameter* could be:

- '**0**' to set the range to ±120 µA full-scale value on all 4 channels;
- '**1**' to set the range to ±120 nA full-scale value on all 4 channels;
- '**AUTO**' to enable the automatic range selection (in this case one of the two available ranges is automatically selected evaluating the input values for each individual channel). The active range can be different among channels.

When the automatic range selection is enabled, the TetrAMM unit determines the most suitable range for each individual channel using the following logic:

- if the channel range is set to '**0**' (±120uA full-scale value) and the input current absolute value drops below 90nA for at least a 1-second period, the range is automatically changed to the narrower range '**1**' (±120nA full-scale value);

- if the channel range is set to '**1**' (±120nA full-scale value) and the input current absolute value exceeds 110nA for at least a 100-µs period, the range is automatically changed to the wider range '**0**' (±120uA full-scale value),

Few samples are corrupted during the range change as internal switches are opened/closed; these corrupted samples are not cancelled from the data stream in order to maintain equal period between samples.

At power-up the TetrAMM range is set to its higher current full-scale range (0, *default*) in order to avoid possible damages to the device in case some of its inputs are connected to a high current source/sink at startup.

Ranges could also be set on each channel independently, thus allowing inputs to have different full-scale ranges. The command to set the channel range to a single channel is "RNG:CH*x*:*parameter*\r\n", where *x* is the channel number, ranging from '1' to '4' and *parameter* is the selected range that could be '0', '1' or 'AUTO'. The meaning of the parameter field is the same as previous.

To read the actual RNG setting simultaneously on all 4 channels, it is possible to use the command "RNG:?\r\n". The answer on that read command when all four channels have the same setting is "RNG:*mode*\r\n", where *mode* could be '0', '1' or 'AUTO'. When channels ranges are not equal to each other, the response is slightly different. In that case the TetrAMM unit response with four *mode* fields separated by character ':', representing setting for each individual channel – so the response is in the following form: "RNG:*mode*:*mode*:*mode*:*mode* \r\n".

It is also possible to read the individual channel RNG setting. In that case the read command is: "RNG: CH*x*:?\r\n", where *x* is the number of channel from '1' to '4'. The response on that command is "RNG: CH*x*:*mode*\r\n", always with *x* representing the channel number and *mode* the full range setting.

Examples:

RNG set example (simultaneously sets range '1' (±120 nA) on all 4 channels):

RNG:1\r\n →

← ACK\r\n

RNG set example (simultaneously sets automatic range selection on all 4 channels):

RNG:AUTO\r\n →

← ACK\r\n

RNG set example (sets only channel #3 to range '1'):

RNG:CH3:1\r\n →

← ACK\r\n

RNG read example (all 4 channels are set on automatic range selection):

RNG:?\r\n →

← RNG:AUTO\r\n

RNG read example (channels ranges are not equal to each other, for example range of ch#1 is set to '0', range of ch#2 and ch#3 to '1' and ch#4 to 'AUTO' mode):

RNG:?\r\n →

← RNG:0:1:1AUTO\r\n

RNG read example (reads only the ch#2 range setting):

RNG:CH2:?\r\n →

← RNG:CH2:0\r\n

2.3.4 USRCORR Command

The TetrAMM device is already factory-calibrated during the production process. However, user is allowed to set user-defined linear calibration parameters on each channel in order to obtain the desired response from the unit or to null the application-related offsets.

USRCORR Commands allows to enable/disable or to set/read the user-defined gain and offset corrections. If enabled, output values are computed as:

$$I_{READ} = Gain_{UD} \cdot I_{raw} + Offset_{UD}$$

where:
- I_{READ} is the user-calibrated current readback from the single channel [A];
- $Gain_{UD}$ is the user-defined gain factor [A/A];
- I_{raw} is the normal current read of the device [A];
- $Offset_{UD}$ is the user-defined offset value [A].

If disabled, $Gain_{UD}$ is set to 1 and $Offset_{UD}$ to 0 (*default* setting) – in this case the user-calibrated readback is the same as the nominal current read of the TetrAMM as

$$I_{READ} = I_{raw}$$

The commands shown in the following table needs to be sent to the device in order to enable or disable the user-correction feature respectively:

Command	Setting
USRCORR:ON\r\n	User correction enabled
USRCORR:OFF\r\n	User correction disabled

The device replies with an acknowledgement string if the command is correctly interpreted. The command "USRCORR:?\r\n" is used to read the actual user-correction setting; replies to this read commands are in the format "USRCORR:*mode*\r\n", where *mode* could be 'ON' or 'OFF'.

This command could be also used to set or read the correction gain and offset of each channel and each range - note that the user correction could be different on the two possible ranges and among the various four channels, so there are 8 possible values for gain and 8 possible values for offset.

The command that can be used to set the gain *value* for a specific range *x* of a specific channel *y* is in the format "USRCORR:RNG*x*CH*y*GAIN:*value*\r\n"; please note that *value* is a dimensionless value [A/A].

A similar procedure can be performed in order to set the offset on a specific range of single channel the command "USRCORR:RNG*x*CH*y*OFFS:*value*\r\n"; in this particular case *value* is a current value expressed in [A].

An acknowledgement string is returned if any of the previous commands are correctly interpreted.

The user-defined gain and offset values can be read as follows:

- "USRCORR:RNG*x*CH*y*GAIN:*?*\r\n" in order to read the gain correction value on range *x* and channel *y*. The device replies to this command with "USRCORR:RNG*x*CH*y*GAIN:*value*\r\n", where *value* is the applied gain correction to channel *y* on range *x* ;
- "USRCORR:RNG*x*CH*y*OFFS:*?*\r\n" in order to read the offset correction value on range *x* and channel *y*. The device replies to this command with "USRCORR:RNG*x*CH*y*OFFS:*value*\r\n", where *value* is the applied offset correction to channel *y* on range *x* ;

Examples:

USRCORR *set example (enables user correction):*

USRCORR:ON\r\n →

← ACK\r\n

USRCORR read example:

USRCORR:?\r\n →

← USRCORR:ON\r\n

USRCORR set gain correction on range '0' and channel #2 example:

USRCORR:RNG0CH2GAIN:1.012\r\n →

← ACK\r\n

USRCORR read offset correction on range '1' and channel #4 example:

USRCORR:RNG1CH4OFFS:?\r\n →

← USERCORR:RNG1CH4OFFS:0.0158\r\n

2.3.5 NRSAMP Command

This command allows to select the number of samples on which averaging is computed. The command has the following format: "NRSAMP:*n*\r\n", where *n* indicates the number of acquisitions on which the normalized averaging is done, so every transferred acquisition is calculated on n "real" samples (the internal fixed sampling frequency is 100 kHz). The acquisition frequency f_{data_rate} could be calculated as:

$$f_{data\_rate} = \frac{f_{sampling}}{n} = \frac{100\ kHz}{n}$$

Due to the transferred speed limitations introduced by the communication link it is necessary to limit the data transfer rate for some acquisition modes. The data rate limitations are described in the Acquisition Commands section.

The command format used to read the current setting for averaged samples is "NRSAMP:?\r\n". The reply to the read command is "NRSAMP:*n*\r\n", where *n* represents the number of averaged samples; a maximum number of 100.000 internal samples can be averaged in order to obtain a single data sample ($1 \leq n \leq 100.000$) thus having an equivalent sampling period ranging from 10 µs to 1 s.

Examples:

NRSAMP *set example:*

NRSAMP:500\r\n →

← ACK\r\n

NRSAMP *invalid set example (the number of averaged samples is not sufficient because of the data transfer limitation):*

NRSAMP:1\r\n →

← NAK:17\r\n

NRSAMP *read example:*

NRSAMP:?\r\n →

← NRSAMP:500\r\n

2.3.6 STATUS Command

The internal status register of the TetrAMM shows the status of the unit. The status is composed of 6 bytes – i.e. 48 bits – where each byte cointains a specific type of information (please note that bit 47 is the MSB and bit 0 is the LSB):

Status Register structure			
Byte #5 (*bits 47 - 40*)	*Bytes #4 - #2* (*bits 39 – 16*)	*Byte #1* (*bits 15 – 8*)	*Byte #0* (*bits 7 – 0*)
CONFIGURATION byte	RANGE bytes	FAULTS byte	HIGH VOLTAGE byte

The structure of the CONFIGURATION byte (bits 47 – 40) of the status register is hereafter presented:

Bit #	Cell caption
47-46	*do not care*
45	External interlock enabled (0 – disabled; 1 – enabled)
44-42	Active channels (1,2 or 4 in binary representation)
41	User correction (0 – disabled; 1 – enabled)
40	ASCII representation (0 – disabled; 1 – enabled)

The structure of the RANGE bytes (bits 39 – 16) section of the status register is shown in the following table:

Bit #	Cell caption
39-37	*do not care*
36	CH4 full scale range (0 – RNG 0; 1 – RNG 1)
35-33	*do not care*
32	CH3 full scale range (0 – RNG 0; 1 – RNG 1)
31-29	*do not care*
28	CH2 full scale range (0 – RNG 0; 1 – RNG 1)
27-25	*do not care*
24	CH1 full scale range (0 – RNG 0; 1 – RNG 1)
23-20	*do not care*
19	CH4 auto-range (0 – disabled; 1 – enabled)
18	CH3 auto-range (0 – disabled; 1 – enabled)

17	CH2 auto-range (0 – disabled; 1 – enabled)
16	CH1 auto-range (0 – disabled; 1 – enabled)

The structure of the FAULTS byte (bits 15 – 8) is as follows:

Bit #	Cell caption
15	General fault (logical or of all faults)
14-11	*do not care*
10	HV Over-current fault (latch of a HV overcurrent event)
9	Over-temperature fault (latch of an over-temperature event)
8	External interlock fault (latch of an interlock event)

The last byte of the status register – *HIGH VOLTAGE byte (bits 7 – 0)* are used to signal the status of the High Voltage module and its structure is shown hereafter:

Bit #	Cell caption
7-4	*do not care*
3	HV over-current (module in over-current condition if '1')
2	Ramp down (when high: HV module is ramping down)
1	Ramp up (when high: HV module is ramping up)
0	High voltage module status (0 – OFF; 1 – ON)

A brief description of the binary flags is hereafter presented:

- *External interlock enabled (bit 45):* this bit is set when the external interlock input is enabled (see INTERLOCK Command section);
- *Active channels (bits 44-42):* these bits indicate the number of active input channels in binary format (see CHN Command section); so these bits are configured as:
  - '001', when one channel is activated,
  - '010', when two channels are activated,
  - '100', when all four input channels are activated;
- *User correction (bit 41):* this bit indicates that the user correction function – i.e. user-defined calibration – is enabled (for more information see the USRCORR Command section);
- *ASCII representation (bit 40):* this bit is set when the ASCII output stream representation is enabled while it is cleared if the binary representation is activated (see ASCII Command chapter);

- *Full-scale range (bits:36, 32, 28 and 24):* these bits indicate the ranges on the input channels: the corresponding bit is low when the channel is set to range 0, and it is set when the channel is set to range 1;
- *Auto-range (bits:19, 18, 17 and 16):* these bits are set when the auto-range option is enabled on the corresponding channel (see RNG Command for more information);

- *General fault (bit 15):* this bit is set if the module has experienced a fault – e.g. generated by an external interlock or an internal protection trip (like internal over-temperature or High Voltage module over-current). This bit is a logical 'OR' of all other fault flags and it is latching – i.e. when a fault occurs, this bit is set together with the specific fault bit. When a fault is detected, the module switches off the High Voltage module. A status reset of the device is necessary in order to reset the module (see the following section);
- *HV Over-current fault (bit 10):* this bit is also latching and it is set when a High Voltage over-current event occurs; a status reset is needed in order to reset this bit (see the following section). The maximum output currents for the different high voltage outputs are shown in High Voltage Commands;
- *Over-temperature fault (bit 9):* this bit is also latching and it is set when the internal TetrAMM temperature rises above the 50°C threshold; to reset this flag it is necessary to execute a status reset command (see following section);
- *External interlock fault (bit 8):* this bit is set when the external interlock signal is enabled and the input interlock signal is high (see Interlock and general I/O connector section); to reset the flag the it is necessary to execute a status reset (see the following section);

- *HV over-current (bit 3):* this bit is set when the High Voltage module experience an over-current situation. The maximum output current ratings for the different High Voltage models are shown in the High Voltage section. This bit is non-latching so that it represents only the actual over-current status of the module. This condition triggers the internal fault over-current bit previously described;
- *Ramp up/Ramp down (bit 2 and bit 1):* these bits are set when the High Voltage is ramping up/down in the process of reaching the selected set-point value. The slew rate of the ramp depends on the High Voltage model (see High Voltage description);
- *High voltage module status (bit 0):* this bit is set only when the High Voltage module is enabled and it is cleared in all other cases.

The internal status register can be read with the "STATUS:?\r\n" command. The reply from the TetrAMM unit to this command is in the format "STATUS:*value*\r\n", where *value* is the ASCII representation of the internal status register value, composed by 12 hexadecimal digits – corresponding to the 6-byte wide status register (every byte is represented by two hexadecimal digits).

If at least one of the fault conditions occurs, then the respective bit and the general fault bit are set. The High Voltage module is switched off in this conditions and it is not possible to enable the module until the internal status register is reset. To command to reset the fault condition of the status register is "STATUS:RESET\r\n"; the TetrAMM unit replies to this command with an acknowledgment string.

Example:

STATUS *read example:*

STATUS:?\r\n →

← STATUS:1800000000\r\n

STATUS *reset example:*

STATUS:RESET\r\n →

← ACK\r\n

2.3.7 INTERLOCK Command

The TetrAMM unit is provided with an external interlock connector due to detect an external generated signal, which can be used to trigger the external interlock fault and so to switch off the High Voltage module.

The command to enable or disable the external interlock input is the following: "INTERLOCK:*mode*\r\n", where *mode* could be *"OFF" (default)* to disable the interlock input or *"ON"* to enable it. The unit replies to this kind of command with an Acknowledge ("ACK\r\n").

To read the actual set interlock status it is possible to use the command: "INTERLOCK:?\r\n". The generated reply to this command has the next form: "INTERLOCK:*mode*\r\n", where *mode* could be *"OFF" (default)* if the interlock input is disabled or *"ON"* if interlock input is enabled.

Example:

INTERLOCK set *example:*

INTERLOCK:ON\r\n →

← ACK\r\n

INTERLOCK read *example:*

INTERLOCK:?\r\n →

← INTERLOCK:ON\r\n

2.3.8 TEMP command:

TEMP Command ("TEMP:?\r\n") allows user to read temperature from internal temperature sensor. Temperature value is updated every 10 seconds. If in case temperature rises over 50°C, the over-temperature fault is set and the High Voltage module is turned off. After a fault event it is necessary to reset the internal status register, to be able to reactivate the High Voltage module.

The reply to the TEMP command is in the following format: "TEMP:*value*\r\n", where *value* is the integer read temperature value expressed in °C.

Example:

TEMP *read example:*

TEMP:?\r\n →

← TEMP:28\r\n

2.3.9 VER Command

The "VER\r\n" command returns information about the TetrAMM unit and the currently installed firmware version.

The reply to the "VER\r\n" command is in following format:

VER:*model*:*ver*:*module1*:*module2*\r\n

where:

- *model*: is a string indicating the device (i.e. "TETRAMM");
- *ver*: cointains the string corresponding to the installed firmware version;
- *module1*: the front-end type installed in the device and the two full-scale ranges;
- *module2*: the High Voltage module installed in the device and its voltage rating.

Example:

VER *example:*

VER:?*\r\n* →

← VER:TETRAMM:0.9.81:IV4 120UA 120NA:HV 500V POS*\r\n*

The "TETRAMM" device of the previous example has the "0.9.81" firmware version installed and it has a 4-channel "current-to-voltage" front-end (i.e. "IV4") with the two full-scale ranges rated at 120µA and 120nA. The High Voltage module installed has a 500V output voltage rating.

2.3.10 HWRESET Command

The "HWRESET\r\n" command performs a complete reset of the hardware and firmware on the on-board FPGA, thus re-initializing the entire TetrAMM module control electronics. The unit replies with an acknowledgment string ("ACK\r\n") before resetting the module.

Example:

HWRESET *example:*

HWRESET:?*\r\n* →

← ACK*\r\n*

2.4 High Voltage Commands

The commands that can be used to set and to read the settings of the High Voltage module installed in the TetrAMM are described in this section.

2.4.1 HVS Command

The HVS command let users set and read the High Voltage output status/value. In order to set a voltage value, i.e. send the command "HVS:ON\r\n" it is necessary to enable the High Voltage module first. When the High Voltage module is turned on then the red led "HV ON" on the front panel of the TetrAMM unit turns on too. The command "HVS:OFF\r\n" disables the High Voltage output, putting it into an high impedance state, and turns off the "HV ON" led on the front panel.

When the module is enabled it is possible to set an output voltage value by sending a "HVS:*value*\r\n", where *value* is the desired voltage output expressed in [V] (for example to set an output voltage or 100.5 V the following command has to be sent to the unit: "HVS:*100.5*\r\n"). The output voltage reaches the set-point on a ramping behaviour. The full-scale value and polarity of the High Voltage module depends on the HV module option. This command also allows to check the last sent set-point value by sending the "HVS:*?*\r\n" string. The response to this read command is in the format "HVS:*value*\r\n", where *value* is the last given set-point value expressed in [V] with 2-digit decimal precision.

Examples:

HVS *ON example:*

HVS:ON\r\n →

← ACK\r\n

HVS *OFF example:*

HVS:OFF\r\n →

← ACK\r\n

HVS *set example (for a High Voltage model with positive polarity):*

HVS:490.7\r\n →

← ACK\r\n

HVS *set example (for a High Voltage model with negative polarity):*

HVS:-400.5\r\n →

← ACK\r\n

HVS *read example:*

HVS:?*\r\n* →

← HVS:-400.50*\r\n*

2.4.2 HVV Command

The HVV command allows user to read the output voltage of the High Voltage module by sending the "HVV:?\r\n" command. The reply to this command is in the following format "HVV:*value*\r\n", where *value* is the output voltage readback value expressed in [V] with a 2-digit decimal precision – i.e. with a 10-mV resolution.

Example:

HVV *example:*

HVV:?\r\n →

← HVV:400.69\r\n

2.4.3 HVI Command

The HVI command allows reading the current provided by the High Voltage module. The command to read the current value is "HVI:?\r\n". The reply to this command is in the following format "HVI:*value*\r\n", where *value* is the read output current expressed in microamperes [µA] with 2-digit decimal precision – i.e. with a 10-nA resolution.

Example:

HVI *example:*

HVI:?\r\n →

← HVI:0.54\r\n

2.5 Command Table Summary

Command	Purposes	Parameters
ACQ	Start continuous acquisition	ON
	Stop continuous acquisition	OFF
ASCII	Enable ASCII output stream	ON
	Disable ASCII output stream	OFF
	Query ASCII setup setting	?
CHN	Set number of reading channels	[1 - 4]
	Query channel settings	?
FASTNAQ	Read a fixed number of samples without averaging on 4 channels	[1 - 419.430]
	Read a fixed number of samples without averaging on 2 channels	[1 - 699.050]
	Read a fixed number of samples without averaging on 1 channel	[1 - 1.048.576]
GATE	Enable gate continuous acquisition	ON
	Disable gate continuous acquisition	OFF
GET	Read a single snapshot	?
HVI	Read the output current provided by the High Voltage module	?
HVS	Enable High voltage module	ON
	Disable High voltage module	OFF
	Set the desired High Voltage set point	$[0 – HV_{full\ range}]$
	Query High Voltage set point	?
HVV	Read the output voltage provided by the High Voltage module	?
HWRESET	Perform a hardware and firmware reset	/
INTERLOCK	Enable external interlock input	ON
	Disable external interlock input	OFF
	Query interlock setting	?
NAQ	Read a fixed number of samples	[1 - 2.000.000.000]
NRSAMP	Set number of samples on which averaging is made	[1 – 100.000]
	Query number of averaged samples settings	?
RNG	Set full scale range to ±120 µA to all input channels	0
	Set full scale range to ±120 nA to all input channels	1
	Set full automatic range selection to all input channels	AUTO
	Query range setup status	?

STATUS	Query device status	?
	Reset status fault conditions	RESET
TEMP	Read the devices internal temperature	?
TRG	Enable triggered continuous acquisition	ON
	Disable triggered continuous acquisition	OFF
USRCORR	Enable user-correction	ON
	Disable user-correction	OFF
	Query user-correction status	?
	Set gain correction on range#*y* ch#*x* to *value*	RNG*x*CH*y*GAIN:*value*
	Query gain correction value on range#*x* ch#*y*	RNG*x*CH*y*GAIN :?
	Set offset correction on range#*x* ch#*y* to *value*	RNG*x*CH*y*OFFS:*value*
	Query offset correction value on range#*x* ch#*y*	RNG*x*CH*y*OFFS:?
VER	Query the device firmware version	?

3. Ethernet Communication

The communication with the TetrAMM unit is based on a 10/100/1000 Mbps Ethernet link. The suggested connection speeds are 100 Mbps or 1Gbps since the 10 Mbps connection is limiting the data rate.

The factory network configuration and the "CAENels Device Manager" software are described in the following sections.

3.1 IP Address Assignment:

The device is shipped with default IP address, subnet mask, gateway and TCP-IP communication port:

Parameter	Factory value
IP address	**192.168.0.10**
Subnet mask	**255.255.255.0**
Gateway	**192.168.0.1**
TCP/IP port	**10001**

Even if the TetrAMM device can be connected to a LAN network, a point-to-point Ethernet connection is strongly recommended in order to obtain minimum delay, maximum data rate performance and to avoid possible communication problems – i.e. increasing communication reliability. This implies that the host PC and the TetrAMM should reside on the same Ethernet subnet.

For a point-to-point connection it is not necessary to use a twisted cable because the used Ethernet link has an automatic detection of the communication direction – i.e. auto-sensing.

To change the device network setup it is necessary to use the free *"CAENels Device Manager"* software that can be downloaded from the CAENels website www.caenels.com. A briefly description of this software is given in next section.

3.2 CAENels Device manager

The free software *"CAENels Device manager"* can be used to search for all the TetrAMM devices connected to the local network and to configure them. This software also allows to set the network configuration of the found devices and to update their firmware.

The *"CAENels Device manager"* is available for Windows and Linux platform and the system requirements hereafter listed:

- Windows minimum system requirements:
  - Windows® XP or newer
  - Intel® or equivalent processor
  - 70 MB available HD space
  - Ethernet network card

- Linux minimum system requirements:
  - Linux kernel 2.2.x or newer
  - Intel® or equivalent processor
  - 70 MB available HD space
  - Ethernet network card

3.2.1 Searching for connected devices

Please follow the next steps in order to search for the TetrAMM devices connected to the local network:

- connect the host PC and the TetrAMM directly with an Ethernet cable (or through a network);

- verify that the *"Link LED"* on the RJ45 connector is turned on (amber for a 1 Gbps connection as shown in **Figure 4** or green for a 100 Mbps connection). The LED is turned off if the Ethernet cable is not connected or if the speed of connection is limited to 10 Mbps (in this last case the device is working correctly even if it is not recommended to use a slow connection since the data transfer rate is limited);

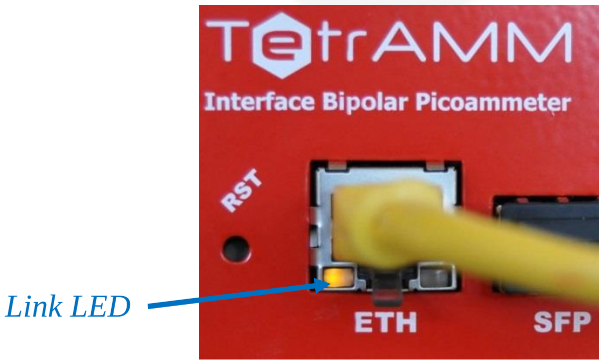


Figure 4: Ethernet Link

- connect the TetrAMM to the AC/DC power supply unit and switch it on;
- install and launch the *"CAENels Device manager"* software;
- perform a scan to discover the connected TetrAMM devices by clicking the *"Scan"* button as indicated in **Figure 5**. If there are multiple available networks it is possible to select the network/networks to be scanned in the *"Selected network interfaces"* window available under the "*Options*" menu. All the information about the selected devices is shown in the right side of the main window.

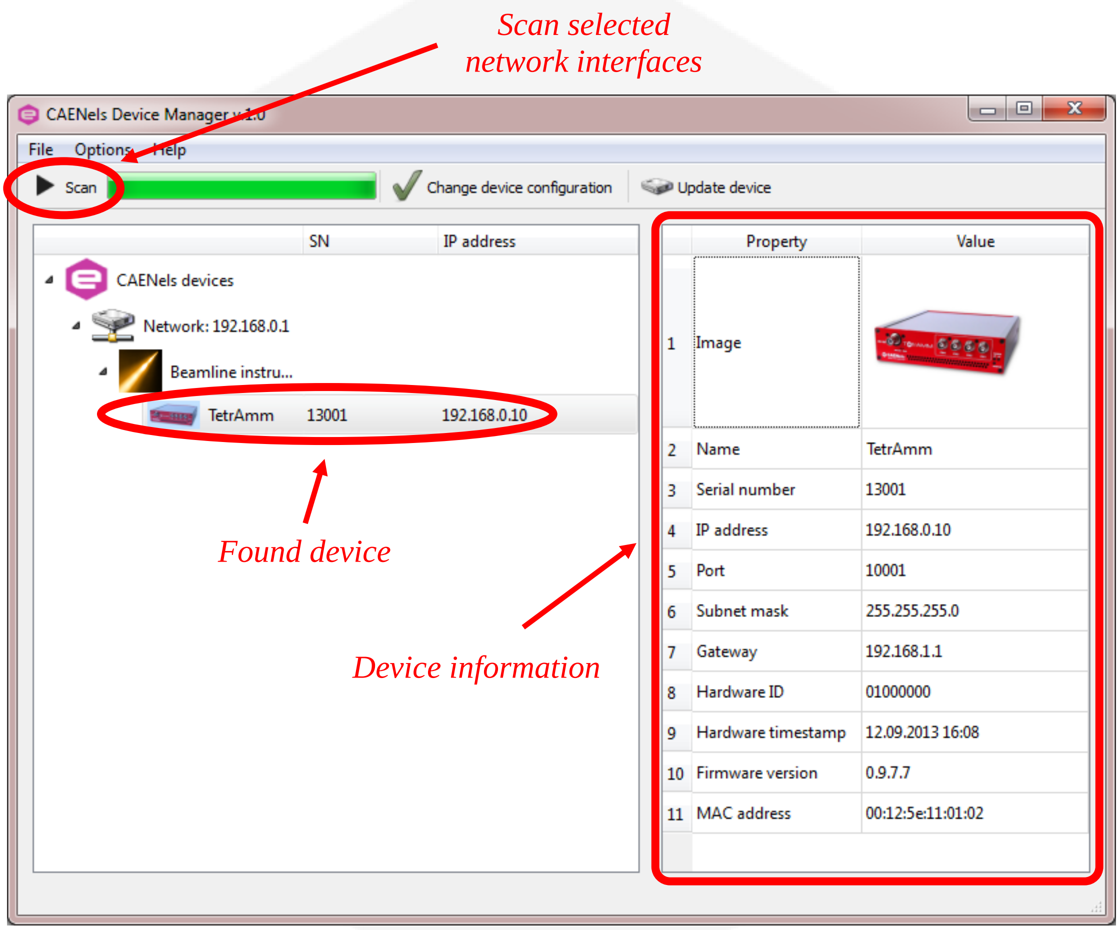


Figure 5: Main interface

If you have a firewall enabled on your router or on your computer, please make sure that the firewall is not preventing communication between your computer and the TetrAMM device.

The "*CAENels Device manager*" uses **<u>UDP port 30719</u>** to find the device, so make sure that the UDP traffic is allowed in both directions on that port.

3.2.2 Device Configuration

It is possible to change the Network configuration of the found devices. In order to set the Network configuration it is necessary to select the desired device and to click on the "*Change device configuration*" button in the main window as shown in **Figure 6**. The configurable Network options are:

- Device IP address;
- TCP/IP communication port;
- Subnet mask;
- Gateway.

To apply the changes on the device configuration it is necessary to edit the corresponding fields and then to click on the "*Save*" button. A screenshot of a sample device configuration is shown in the following picture:

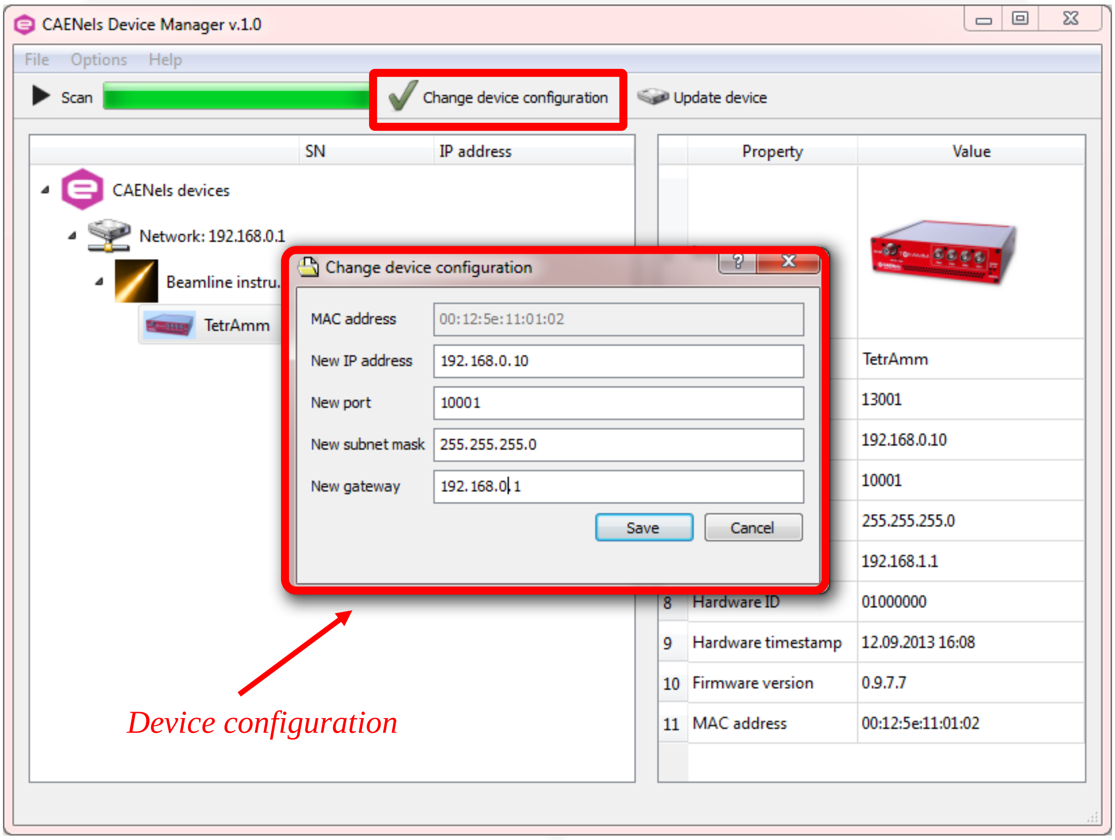


Figure 6: Change device configuration

3.2.3 Firmware Upgrade

The *"CAENels Device manager"* software also allows remotely updating the firmware of the TetrAMM devices. Once the desired device is found, it is possible to perform the firmware update by clicking on the "*Update device*" button as shown **Figure 7**. The new opened window allows to select the new firmware file *(Flash file - *.flash)*.

Once the flash file has been selected it is possible to start the firmware update by clicking the *"Update!"* button. The firmware update task will take a few minutes. A screenshot of the update menu is shown hereafter:

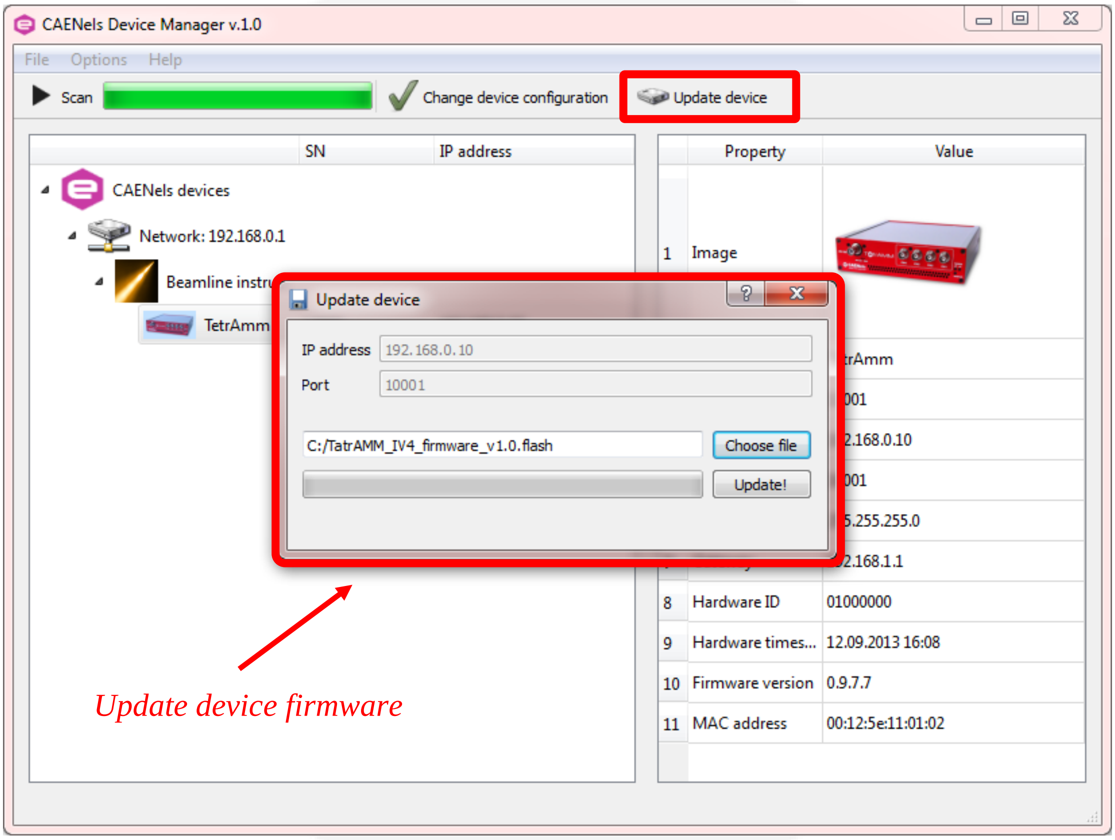


Figure 7: Update device

4. I/O Connectors

This chapter describes the I/O connectors present on the device front and rear panels, their corresponding pinout and each signal functionality.

4.1 Power Connector

The input power connector is a standard male locking jack socket. The input voltage is rated at +12V (±3%) with a maximum input current of 1A.

The input ON/OFF switch is placed above the input power connector which allows turning ON or OFF the device. The used connector is shown in **Figure 8**:

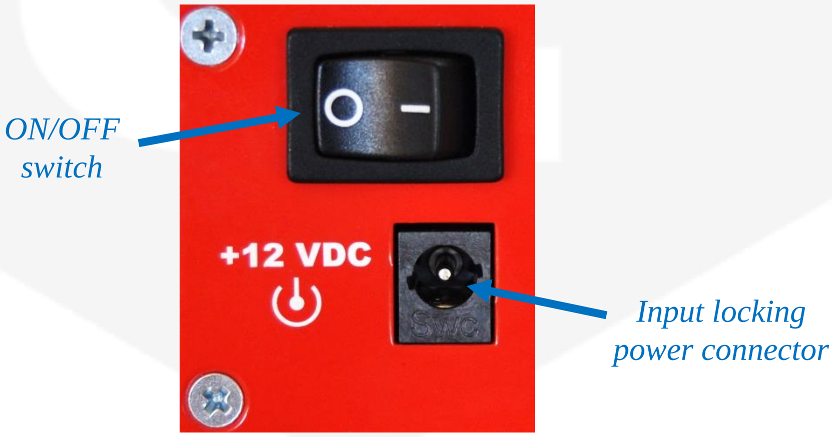


Figure 8: Power connector and switch

4.2 Triggers Connector

The TetrAMM device has two input and one output trigger signals on LEMO coaxial connectors. These input/output connectors are called "*Triggers*" and are placed on the rear panel of the device as shown in **Figure 9**:

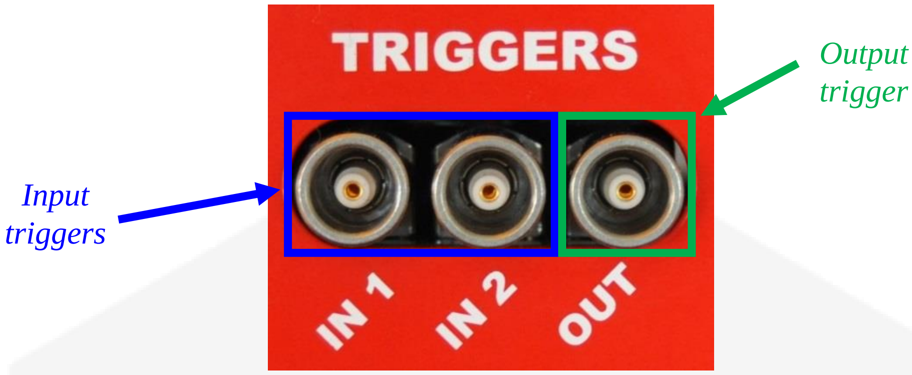


Figure 9: "*Triggers*" connectors on rear panel

Signal levels are TTL, LVTTL and CMOS compatible. The maximum rated output current is 24mA.

The "*IN 1*" input is also called *"**Trigger/Gate**"* signal and it is used to synchronize the acquisition of the device to an external event (for more information please refer to TRG Command and GATE Command sections). The "*IN 2*" and "*OUT*" connectors are reserved for future uses.

4.3 Interlock and general I/O connector

The "Interlocks and general I/O" connector, that has the pinout configuration described in **Figure 10**, is present on the rear panel of the TetrAMM unit:

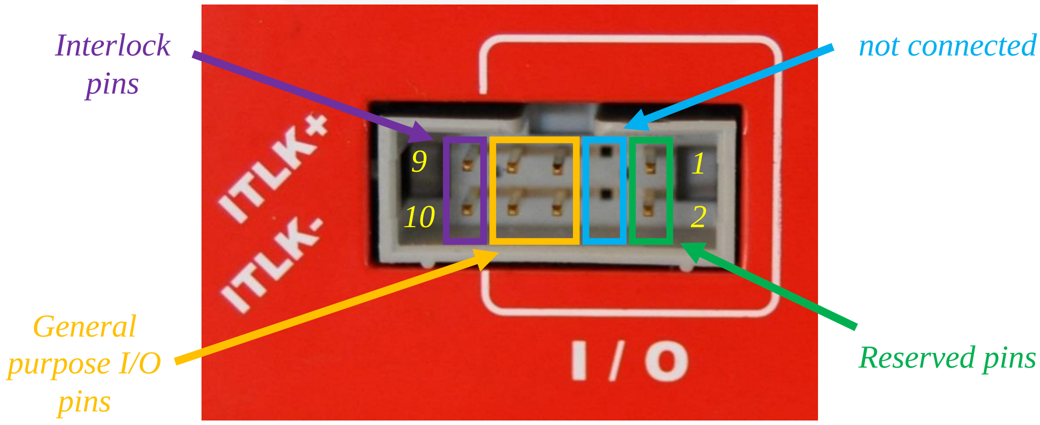


Figure 10: Interlock and I/O connector

The pin functions are summarized in the next table:

Pin #	Function
1-2	Reserved pins
3-4	*not connected*
5-8	General purpose I/O pins
9-10	External interlock pins

The *"External interlock pins"* (pins 9-10) can be used to detect an external signal that can be used to trigger the external interlock fault and to switch off the High Voltage module (see INTERLOCK Command and STATUS Command Commands sections for more information). The interlock pins are galvanically isolated from ground.

The maximum voltage that can be applied to the interlock terminals is rated at **+24V** (the minimum signal that guarantees the tripping of this interlock is rated at +3V); the maximum reverse voltage that this interlock can sustain is rated at -5.5V.

The *"General purpose I/O pins"* (pins 5-8) are connected to the internal digital section and they are reserved for future system updates.

The *"not connected pins"* (pins 3-4) are not present or if present, they are not connected to the internal digital system.

The *"Reserved pins"* (pins 1-2) are connected to the internal digital section and are reserved for internal use, so they must NOT be connected.

4.4 Ethernet and SFP connector

On the rear side of the TetrAMM unit there are also a RJ45 Ethernet connector and a small form-factor pluggable (SFP) slot as indicated in **Figure 11**:

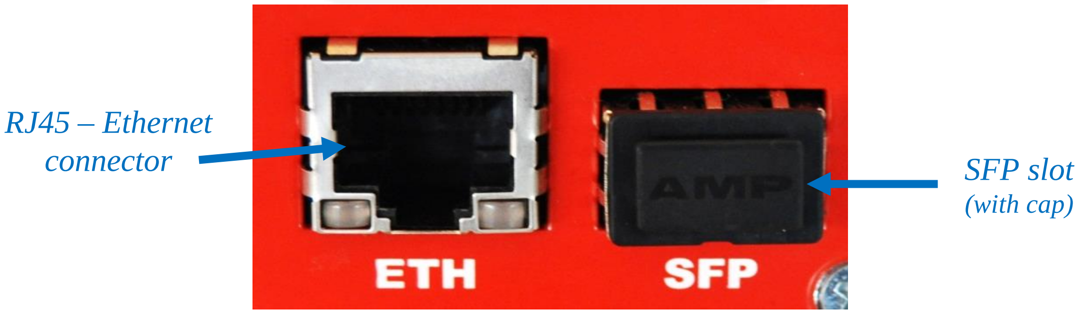


Figure 11: Ethernet and SFP connections

The RJ45 Ethernet slot is used to communicate with TetrAMM unit. The connector is linked to a true 10/100/1000 Mbps physical device. For more information about the Ethernet communication see the Ethernet Communication section.

The SFP slot allows connecting a copper or optic platform to the internal digital system with a fixed speed of 1 Gbps and it is reserved for future system updates – e.g. beamline local feedback system.

4.5 Input BNC connectors

The four BNC connectors (Bayonet Neill-Concelman) on the front panel of the TetrAMM unit are used to measure the input currents. The BNC connectors are miniature quick connect/disconnect RF connectors mainly used for coaxial cables.

Channel incremental numbering, as can be seen in **Figure 12**, is right-to-left (CH1 is the one the right while CH4 is the one on the left):

Figure 12: BNC input connectors

The TetrAMM unit has to be placed next to the current source (e.g. detector) in order to reduce cable lengths – i.e. cable capacitance – and to minimize consequent noise pick-up.

4.6 Output High Voltage connector

The High Voltage SHV output connector is present on the front panel (refer to **Figure 13**) of the device and provides a high voltage bias source for the detecting system connected to the TetrAMM. The connector is similar to the BNC but uses a very thick and protruding insulator.

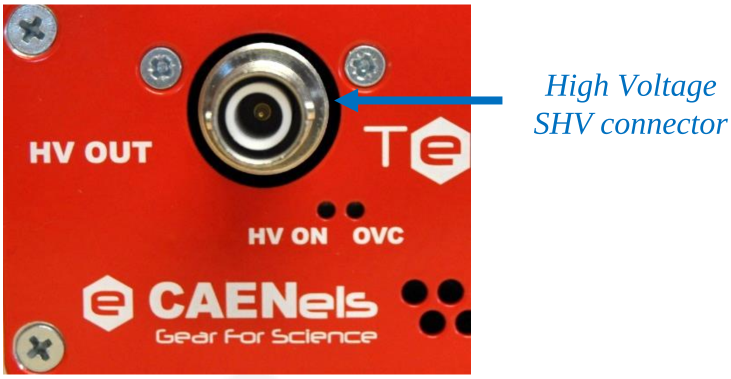


Figure 13: High Voltage SHV connector

The insulation geometry makes SHV connector safe for handling high voltage sources, by preventing accidental contact with the live conductor in an unmated connector or plug.

The HV ON red light indicates that the high-voltage source is present on the SHV connector while the OVC red light is on if the module is experiencing an over-current condition.

5. Technical Specifications

Main technical specifications for the TetrAMM unit are shown in the following table:

Characteristic	Value
Input Channels	4
Current Measuring Ranges	Range 0: up to ±120µA Range 1: up to ±120nA
Current Resolution	Range 0: 15pA Range 1: 15fA
Current Polarity	Bipolar
Sampling Frequency	100 kHz
Sampling bits	24
Analog bandwidth – BW	5 kHz
Equivalent Input Current Noise (@1 ksps)	Range 0: 1ppm/FS Range 1: 6ppm/FS
Equivalent Input Current Noise (@100 ksps)	Range 0: < 6ppm/FS Range 1: < 25ppm/FS
Temperature Coefficient - TC	Range 0: <0.001%/FS/°C Range 1: <0.0012%/FS/°C
Data rate	Up to 100 ksamples/s/ch
Communication	Ethernet 10/100/1000 TCP-IP
Extra Communication interface	SFP – Small form-factor pluggable
External Signals	Configurable Trigger/Gate Trigger Outptut External Interlock
Fault condition	External interlock Internal over-temperature High Voltage Over-Current
High Voltage Source	500V @ 1mA (standard) (configurable up to 4kV upon request)
Nigh Voltage Noise + Ripple – typ.	$< 1\ mV_{RMS}$ $< 3\ mV_{PK-PK}$

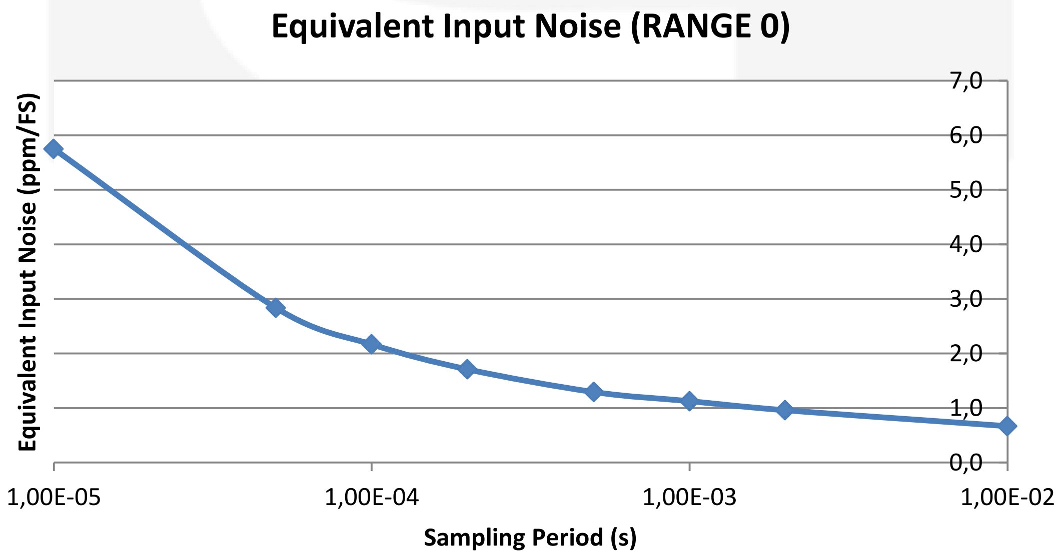
Input connectors	BNC
Output High Voltage connector	SHV
Additional Features	Firmware remote update Sampling Avaraging High Voltage readout High Voltage current readout Ecternal interlock protections High Voltage Over-Current protection
Input Voltage Supply	+12 V
Cooling Method	Blower Fan
Dimensions	195 x 173 x 45
Weight	850 g

5.1 Equivalent Input Noise

The equivalent input noise of the TetrAMM depends both on the data rate (and thus the equivalent bandwidth) and the selected measuring range. A table and a plot with typical values for the equivalent input noise vs. the sampling period for the RANGE 0 (full-scale current of ± 120 µA) is shown hereafter.

RANGE 0 – Full-Scale ± 120µA

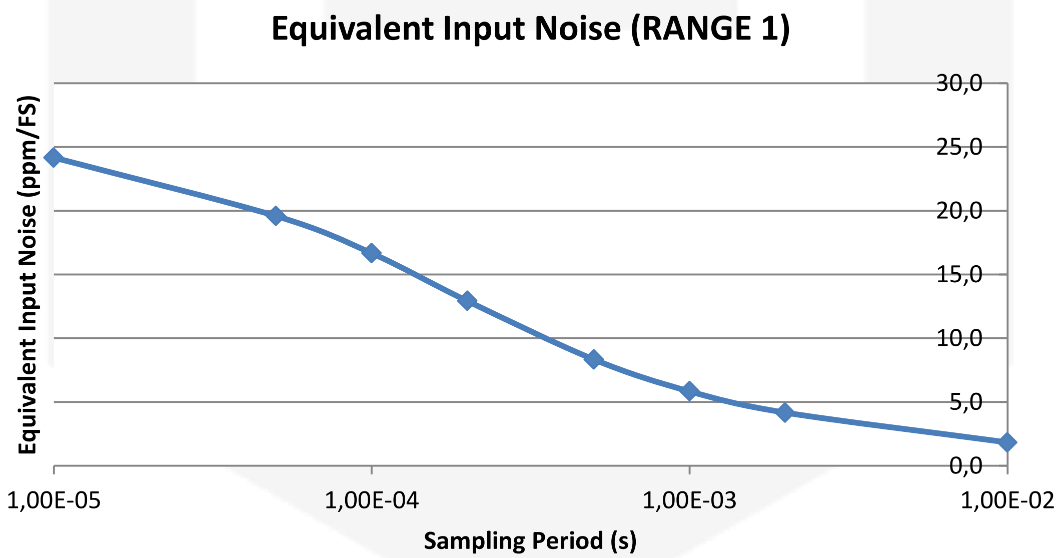
Sampling Period	Data Rate	Equivalent Input Noise (ppm/FS)
10 µs	100 kHz	5.8
50 µs	20 kHz	2.8
100 µs	10 kHz	2.2
200 µs	5 kHz	1.7
500 µs	2 kHz	1.3
1 ms	1 kHz	1.1
2 ms	500 Hz	1.0
10 ms	100 Hz	0.7



The same values for the RANGE 1 (full-scale current of ± 120 nA) are presented in the following table and plot.

RANGE 1 – Full-Scale ± 120nA

Sampling Period	Data Rate	Equivalent Input Noise (ppm/FS)
10 µs	100 kHz	24.2
50 µs	20 kHz	19.6
100 µs	10 kHz	16.7
200 µs	5 kHz	12.9
500 µs	2 kHz	8.3
1 ms	1 kHz	5.8
2 ms	500 Hz	4.2
10 ms	100 Hz	1.8



6. Mechanical Dimensions

The mechanical dimensions of the TetrAMM unit, including connectors, are hereafter presented in **Figure 14**:

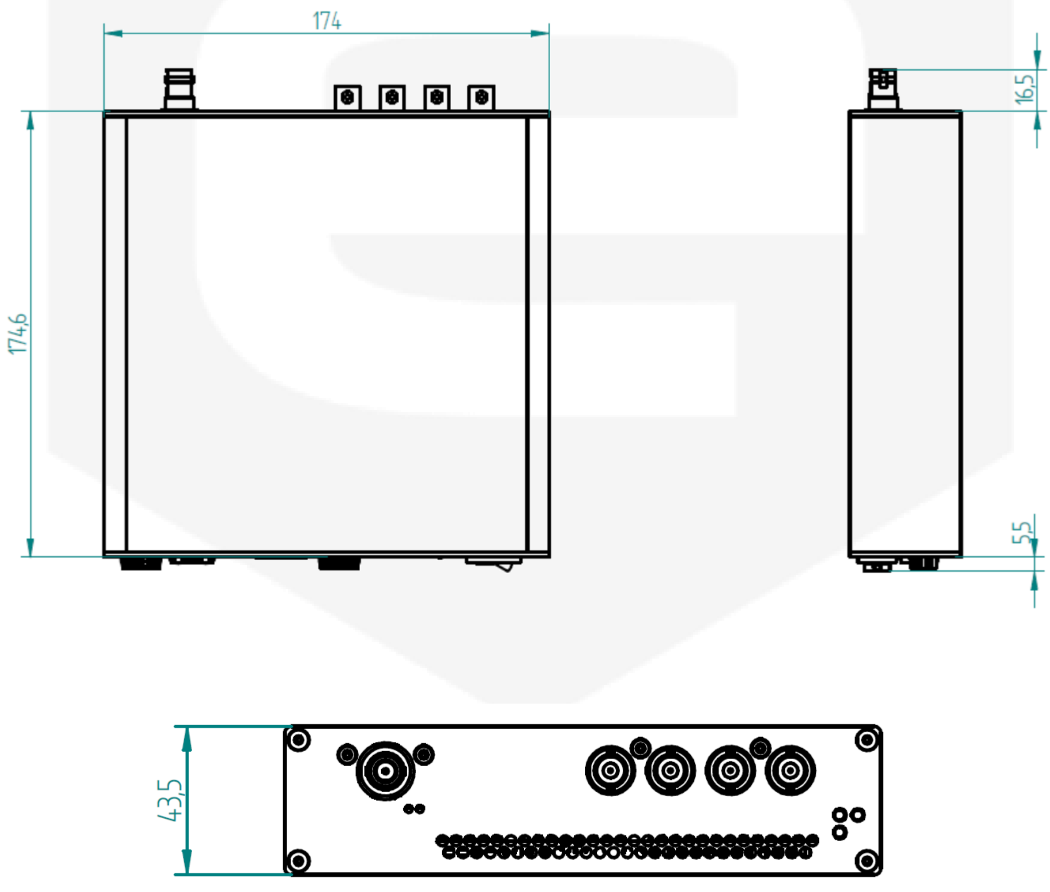


Figure 14: TetrAMM mechanical dimensions

7. TetrAMM Power Supply

This chapter describes the general characteristics and the main features of the TetrAMM linear power supply called PS1112. This power supply is particularly designed for operation with the CAENels TetrAMM picoammeter.

7.1 The PS1112 Linear Power Supply

CAENels PS1112 is a single-output +12V linear power supply designed for low-noise operation and it is especially suited for low power measurement system where switching power supplies could corrupt measuring accuracy, precision and noise.

The power supply is housed in a light, robust and compact plastic box (refer to **Figure 15**) that can be placed next to the supplied device in order to reduce cable lengths and minimize consequent possible noise pick-up.

Figure 15: PS1112 linear power supply

7.2 The PS1112 at a Glance

The PS1112 is an isolated unipolar linear power supply with one output connector. The PS1112, its input, output, indicators and switches are shown in **Figure 16**:

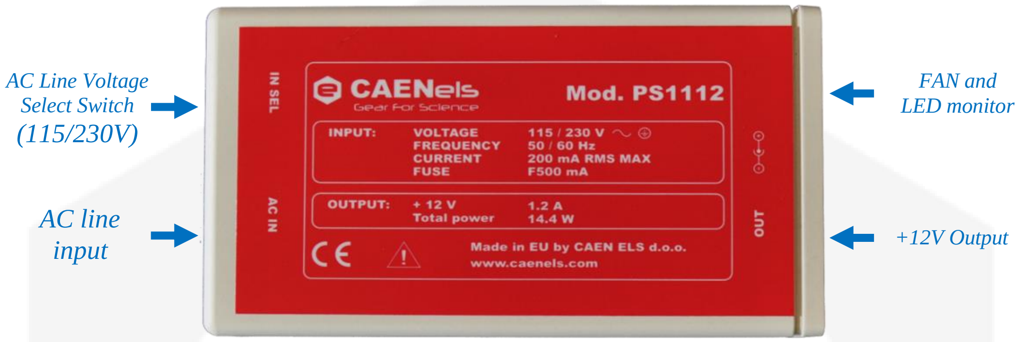


Figure 16: PS1112 connections

The AC Power Line input and the AC Line Voltage selection switch (115/230V) are placed on one side of the box; the output connector, the LED monitor and the air outlet on the other one.

The AC Power Line input is also equipped with an integrated two-slot fuse holder (one active and one as a replacement).

The PS1112 has an isolated output voltage of +12V rated at 1.2A maximum output current.

7.3 I/O Connectors

This chapter describes the I/O connectors and switches, their corresponding pinout and their functionality.

7.3.1 AC Line Input Connector

The AC Line Input connector is in a standard VDE format and it is provided with a two-slot fuse holder for over-current (e.g. short-circuit) protection.

The PS1112 power supply is designed for 115/230V input voltage and for 50-60 Hz input frequency operation: the correct AC input voltage rating **MUST** be selected by the user using the AC Line Voltage Select switch placed next to the VDE plug (i.e. on the left side) before connecting the power supply to the mains. The fuse is housed over the VDE plug as indicated in **Figure 17**:

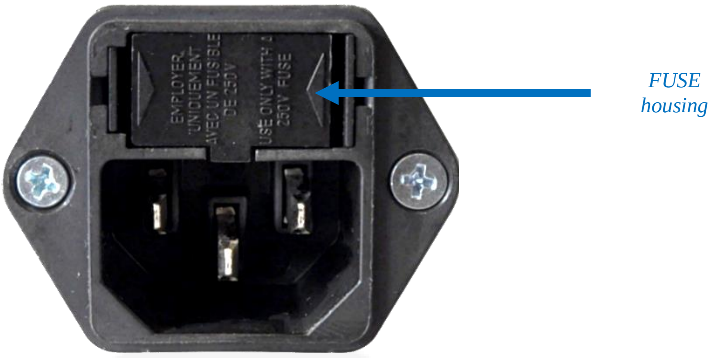


Figure 17: AC input and fuse housing

7.3.2 AC Line Voltage Select Switch

The PS1112 linear power supply can be used either with a 115V – 60Hz AC power line (e.g. United States) or with a 230 V – 50 Hz AC Line (e.g. Europe); be sure to select the correct input voltage rating by switching the AC Line Voltage Select switch placed on one side of the box. Possible switch positions, one for each input voltage rating, are shown in the following **Figure 18** (230V and 115V respectively):

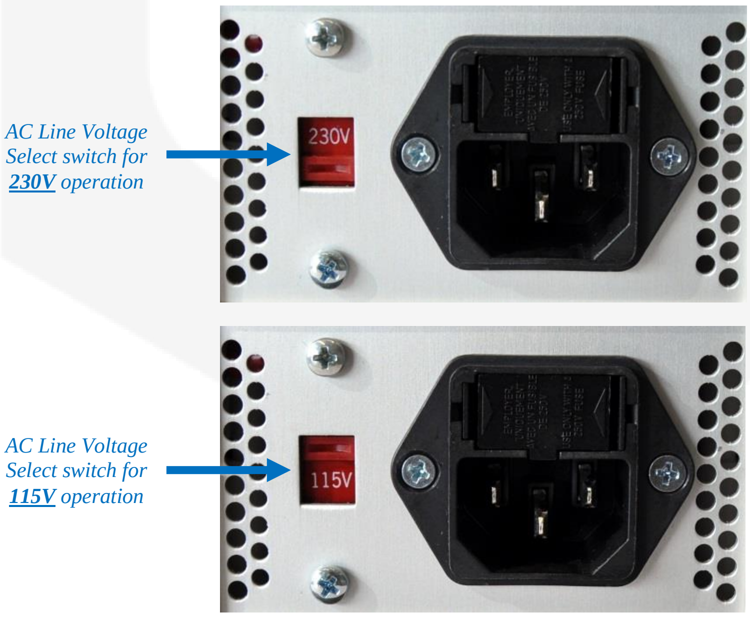


Figure 18: AC line voltage select switch

7.3.3 Output Connectors

The power supply has one locking output connector indicated as "OUT". The central pin corresponds to the positive power supply (+12V) respect to the external conductor that is connected to its ground (refer to **Figure 19**).

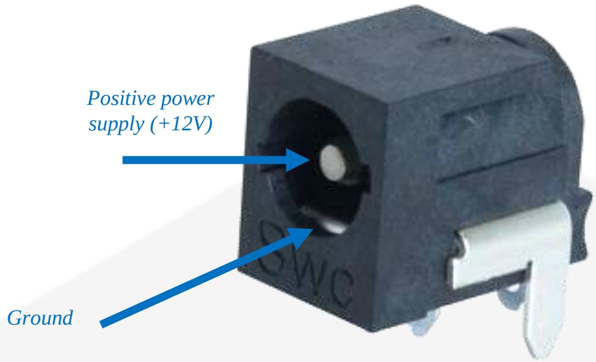


Figure 19: TetrAMM mechanical dimensions

7.3.4 Cabling

The PS1112 linear power supply is equipped with a female to female locking power plug cable in order to handle connections to the CAENels TetrAMM device. The standard cable length is 1.5m (60").

7.4 Technical Specifications

Main technical Specifications for the PS1112 linear power supplies are presented in the following table:

Characteristic	Value
Output Voltage	+12 V
Maximum Output Power	14.4 W
Maximum Output Current	1.2 A
AC Line Voltage Input	115V / 230 V
AC Line Frequency	50 / 60 Hz
Dimensions	115 x 95 x 57 mm
Weight	850 g
Indicators	1 LED (OUT OK)
Cooling	Forced air convection (integrated)
Fuse	F500 mA

8. Appendix

8.1 ASCII table

The first 32 characters in the ASCII-table are called ASCII control characters. They are unprintable control codes and are used to control peripherals such as printers.

Decimal	Hexadecimal	Binary	Symbol	Description
0	00	00000000	**NUL**	Null char
1	01	00000001	**SOH**	Start of Heading
2	02	00000010	**STX**	Start of Text
3	03	00000011	**ETX**	End of Text
4	04	00000100	**EOT**	End of Transmission
5	05	00000101	**ENQ**	Enquiry
6	06	00000110	**ACK**	Acknowledgment
7	07	00000111	**BEL**	Bell
8	08	00001000	**BS**	Back Space
9	09	00001001	**HT**	Horizontal Tab
10	0A	00001010	**LF**	Line Feed
11	0B	00001011	**VT**	Vertical Tab
12	0C	00001100	**FF**	Form Feed
13	0D	00001101	**CR**	Carriage Return
14	0E	00001110	**SO**	Shift Out / X-On
15	0F	00001111	**SI**	Shift In / X-Off
16	10	00010000	**DLE**	Data Line Escape
17	11	00010001	**DC1**	Device Control 1 (oft. XON)
18	12	00010010	**DC2**	Device Control 2
19	13	00010011	**DC3**	Device Control 3 (oft. XOFF)
20	14	00010100	**DC4**	Device Control 4
21	15	00010101	**NAK**	Negative Acknowledgement

22	16	00010110	**SYN**	Synchronous Idle
23	100.00017	00010111	**ETB**	End of Transmit Block
24	18	00011000	**CAN**	Cancel
25	19	00011001	**EM**	End of Medium
26	1A	00011010	**SUB**	Substitute
27	1B	00011011	**ESC**	Escape
28	1C	00011100	**FS**	File Separator
29	1D	00011101	**GS**	Group Separator
30	1E	00011110	**RS**	Record Separator
31	1F	00011111	**US**	Unit Separator

Codes 32-127 are called printable characters, represent letters, digits, punctuation marks, and a few miscellaneous symbols. You will find almost every character on your keyboard. Character 127 represents the command DEL.

Decimal	Hexadecimal	Binary	Symbol	Description
32	20	00100000		Space
33	21	00100001	!	Exclamation mark
34	22	00100010	"	Double quotes
35	23	00100011	#	Number
36	24	00100100	$	Dollar
37	25	00100101	%	Procenttecken
38	26	00100110	&	Ampersand
39	27	00100111	'	Single quote
40	28	00101000	(	Open parenthesis
41	29	00101001	)	Close parenthesis
42	2A	00101010	*	Asterisk
43	2B	00101011	+	Plus
44	2C	00101100	,	Comma
45	2D	00101101	-	Hyphen
46	2E	00101110	.	Period, dot or full stop
47	2F	00101111	/	Slash or divide
48	30	00110000	0	Zero
49	31	00110001	1	One
50	32	00110010	2	Two
51	33	00110011	3	Three
52	34	00110100	4	Four
53	35	00110101	5	Five
54	36	00110110	6	Six
55	37	00110111	7	Seven

56	38	00111000	8	Eight
57	39	00111001	9	Nine
58	3A	00111010	:	Colon
59	3B	00111011	;	Semicolon
60	3C	00111100	<	Less
61	3D	00111101	=	Equals
62	3E	00111110	>	Greater than
63	3F	00111111	?	Question mark
64	40	01000000	@	At symbol
65	41	01000001	A	Uppercase A
66	42	01000010	B	Uppercase B
67	43	01000011	C	Uppercase C
68	44	01000100	D	Uppercase D
69	45	01000101	E	Uppercase E
70	46	01000110	F	Uppercase F
71	47	01000111	G	Uppercase G
72	48	01001000	H	Uppercase H
73	49	01001001	I	Uppercase I
74	4A	01001010	J	Uppercase J
75	4B	01001011	K	Uppercase K
76	4C	01001100	L	Uppercase L
77	4D	01001101	M	Uppercase M
78	4E	01001110	N	Uppercase N
79	4F	01001111	O	Uppercase O
80	50	01010000	P	Uppercase P
81	51	01010001	Q	Uppercase Q
82	52	01010010	R	Uppercase R
83	53	01010011	S	Uppercase S
84	54	01010100	T	Uppercase T
85	55	01010101	U	Uppercase U
86	56	01010110	V	Uppercase V
87	57	01010111	W	Uppercase W
88	58	01011000	X	Uppercase X
89	59	01011001	Y	Uppercase Y
90	5A	01011010	Z	Uppercase Z
91	5B	01011011	[	Opening bracket
92	5C	01011100	\	Backslash
93	5D	01011101	]	Closing bracket
94	5E	01011110	^	Caret - circumflex

95	5F	01011111	_	Underscore
96	60	01100000	`	Grave accent
97	61	01100001	a	Lowercase a
98	62	01100010	b	Lowercase b
99	63	01100011	c	Lowercase c
100	64	01100100	d	Lowercase d
101	65	01100101	e	Lowercase e
102	66	01100110	f	Lowercase f
103	67	01100111	g	Lowercase g
104	68	01101000	h	Lowercase h
105	69	01101001	i	Lowercase i
106	6A	01101010	j	Lowercase j
107	6B	01101011	k	Lowercase k
108	6C	01101100	l	Lowercase l
109	6D	01101101	m	Lowercase m
110	6E	01101110	n	Lowercase n
111	6F	01101111	o	Lowercase o
112	70	01110000	p	Lowercase p
113	71	01110001	q	Lowercase q
114	72	01110010	r	Lowercase r
115	73	01110011	s	Lowercase s
116	74	01110100	t	Lowercase t
117	75	01110101	u	Lowercase u
118	76	01110110	v	Lowercase v
119	77	01110111	w	Lowercase w
120	78	01111000	x	Lowercase x
121	79	01111001	y	Lowercase y
122	7A	01111010	z	Lowercase z
123	7B	01111011	{	Opening brace
124	7C	01111100	|	Vertical bar
125	7D	01111101	}	Closing brace
126	7E	01111110	~	Equivalency sign - tilde
127	7F	01111111		Delete

Codes 128-255 are called extended ASCII codes. There are several different variations of the 8-bit ASCII table. The table below is according to ISO 8859-1, also called ISO Latin-1. Codes 129-159 contain the Microsoft® Windows Latin-1 extended characters.

Decimal	Hexadecimal	Binary	Symbol	Description
128	80	10000000	**€**	Euro sign
129	81	10000001		

130	82	10000010	‚	Single low-9 quotation mark
131	83	10000011	ƒ	Latin small letter f with hook
132	84	10000100	„	Double low-9 quotation mark
133	85	10000101	…	Horizontal ellipsis
134	86	10000110	†	Dagger
135	87	10000111	‡	Double dagger
136	88	10001000	ˆ	Modifier letter circumflex accent
137	89	10001001	‰	Per mille sign
138	8A	10001010	Š	Latin capital letter S with caron
139	8B	10001011	‹	Single left-pointing angle quotation
140	8C	10001100	Œ	Latin capital ligature OE
141	8D	10001101		
142	8E	10001110	Ž	Latin captial letter Z with caron
143	8F	10001111		
144	90	10010000		
145	91	10010001	‘	Left single quotation mark
146	92	10010010	’	Right single quotation mark
147	93	10010011	“	Left double quotation mark
148	94	10010100	”	Right double quotation mark
149	95	10010101	•	Bullet
150	96	10010110	–	En dash
151	97	10010111	—	Em dash
152	98	10011000	˜	Small tilde
153	99	10011001	™	Trade mark sign
154	9A	10011010	š	Latin small letter S with caron
155	9B	10011011	›	Single right-pointing angle quotation mark
156	9C	10011100	œ	Latin small ligature oe
157	9D	10011101		
158	9E	10011110	ž	Latin small letter z with caron
159	9F	10011111	Ÿ	Latin capital letter Y with diaeresis
160	A0	10100000		Non-breaking space
161	A1	10100001	¡	Inverted exclamation mark
162	A2	10100010	¢	Cent sign
163	A3	10100011	£	Pound sign
164	A4	10100100	¤	Currency sign
165	A5	10100101	¥	Yen sign
166	A6	10100110	¦	Pipe, Broken vertical bar

167	A7	10100111	§	Section sign
168	A8	10101000	¨	Spacing diaeresis - umlaut
169	A9	10101001	©	Copyright sign
170	AA	10101010	ª	Feminine ordinal indicator
171	AB	10101011	«	Left double angle quotes
172	AC	10101100	¬	Not sign
173	AD	10101101		Soft hyphen
174	AE	10101110	®	Registered trade mark sign
175	AF	10101111	¯	Spacing macron - overline
176	B0	10110000	°	Degree sign
177	B1	10110001	±	Plus-or-minus sign
178	B2	10110010	²	Superscript two - squared
179	B3	10110011	³	Superscript three - cubed
180	B4	10110100	´	Acute accent - spacing acute
181	B5	10110101	µ	Micro sign
182	B6	10110110	¶	Pilcrow sign - paragraph sign
183	B7	10110111	·	Middle dot - Georgian comma
184	B8	10111000	¸	Spacing cedilla
185	B9	10111001	¹	Superscript one
186	BA	10111010	º	Masculine ordinal indicator
187	BB	10111011	»	Right double angle quotes
188	BC	10111100	¼	Fraction one quarter
189	BD	10111101	½	Fraction one half
190	BE	10111110	¾	Fraction three quarters
191	BF	10111111	¿	Inverted question mark
192	C0	11000000	À	Latin capital letter A with grave
193	C1	11000001	Á	Latin capital letter A with acute
194	C2	11000010	Â	Latin capital letter A with circumflex
195	C3	11000011	Ã	Latin capital letter A with tilde
196	C4	11000100	Ä	Latin capital letter A with diaeresis
197	C5	11000101	Å	Latin capital letter A with ring above
198	C6	11000110	Æ	Latin capital letter AE
199	C7	11000111	Ç	Latin capital letter C with cedilla
200	C8	11001000	È	Latin capital letter E with grave
201	C9	11001001	É	Latin capital letter E with acute
202	CA	11001010	Ê	Latin capital letter E with circumflex
203	CB	11001011	Ë	Latin capital letter E with

				diaeresis
204	CC	11001100	Ì	Latin capital letter I with grave
205	CD	11001101	Í	Latin capital letter I with acute
206	CE	11001110	Î	Latin capital letter I with circumflex
207	CF	11001111	Ï	Latin capital letter I with diaeresis
208	D0	11010000	Ð	Latin capital letter ETH
209	D1	11010001	Ñ	Latin capital letter N with tilde
210	D2	11010010	Ò	Latin capital letter O with grave
211	D3	11010011	Ó	Latin capital letter O with acute
212	D4	11010100	Ô	Latin capital letter O with circumflex
213	D5	11010101	Õ	Latin capital letter O with tilde
214	D6	11010110	Ö	Latin capital letter O with diaeresis
215	D7	11010111	×	Multiplication sign
216	D8	11011000	Ø	Latin capital letter O with slash
217	D9	11011001	Ù	Latin capital letter U with grave
218	DA	11011010	Ú	Latin capital letter U with acute
219	DB	11011011	Û	Latin capital letter U with circumflex
220	DC	11011100	Ü	Latin capital letter U with diaeresis
221	DD	11011101	Ý	Latin capital letter Y with acute
222	DE	11011110	Þ	Latin capital letter THORN
223	DF	11011111	ß	Latin small letter sharp s - ess-zed
224	E0	11100000	à	Latin small letter a with grave
225	E1	11100001	á	Latin small letter a with acute
226	E2	11100010	â	Latin small letter a with circumflex
227	E3	11100011	ã	Latin small letter a with tilde
228	E4	11100100	ä	Latin small letter a with diaeresis
229	E5	11100101	å	Latin small letter a with ring above
230	E6	11100110	æ	Latin small letter ae
231	E7	11100111	ç	Latin small letter c with cedilla
232	E8	11101000	è	Latin small letter e with grave
233	E9	11101001	é	Latin small letter e with acute
234	EA	11101010	ê	Latin small letter e with circumflex

235	EB	11101011	ë	Latin small letter e with diaeresis
236	EC	11101100	ì	Latin small letter i with grave
237	ED	11101101	í	Latin small letter i with acute
238	EE	11101110	î	Latin small letter i with circumflex
239	EF	11101111	ï	Latin small letter i with diaeresis
240	F0	11110000	ð	Latin small letter eth
241	F1	11110001	ñ	Latin small letter n with tilde
242	F2	11110010	ò	Latin small letter o with grave
243	F3	11110011	ó	Latin small letter o with acute
244	F4	11110100	ô	Latin small letter o with circumflex
245	F5	11110101	õ	Latin small letter o with tilde
246	F6	11110110	ö	Latin small letter o with diaeresis
247	F7	11110111	÷	Division sign
248	F8	11111000	ø	Latin small letter o with slash
249	F9	11111001	ù	Latin small letter u with grave
250	FA	11111010	ú	Latin small letter u with acute
251	FB	11111011	û	Latin small letter u with circumflex
252	FC	11111100	ü	Latin small letter u with diaeresis
253	FD	11111101	ý	Latin small letter y with acute
254	FE	11111110	þ	Latin small letter thorn
255	FF	11111111	ÿ	Latin small letter y with diaeresis

8.2 List of the Error Codes

The TetrAMM unit replies with a **N**ot **A**c**K**nowledge ("NAK") if the received command is not correct or it is not accepted. This "NAK" reply is followed by a two digit *"error code"* field, which indicates the error cause and/or type. The list of the possible error codes is hereafter presented:

Error Code	Error name	Brief description of error
00	**Invalid command**	*Command field is not valid; the list of valid commands is shown in the* Command Table Summary *section*
10	**Wrong ACQ acquisition parameter**	*Given parameter is not allowed ACQ setting (see* ACQ Command*)*
11	**Wrong GET acquisition parameter**	*Given parameter is not allowed GET setting (see* GET Command*)*
12	**Wrong NAQ acquisition parameter**	*Given parameter is out of allowed values for NAQ setting (see* NAQ Command*)*
13	**Wrong TRG acquisition parameter**	*Given parameter is out of allowed values for trigger setting (see* TRG Command*)*
14	**Wrong GATE acquisition parameter**	*Given parameter is out of allowed values for trigger setting (see* GATE Command*)*
15	**Wrong FASTNAQ acquisition parameter**	*Given parameter is out of allowed values for FASTNAQ setting (see* FASTNAQ Command*)*
20	**Wrong number of channels parameter**	*Given parameter is out of allowed values for channels setting (see* CHN Command*)*
21	**Wrong ASCII parameter**	*Given parameter is not allowed ASCII setting (see* ASCII Command*)*
22	**Wrong range parameter**	*Given parameter is out of allowed values for range setting (see* RNG Command*)*
23	**Wrong user correction parameter**	*Given parameter is not allowed user correction setting (see* USRCORR Command*)*
24	**Wrong number of samples parameter**	*Given parameter is not allowed number of samples setting (see* NRSAMP Command*)*
25	**Wrong status parameter**	*Given parameter is not allowed for user correction setting (see* STATUS Command*)*
26	**Wrong interlock parameter**	*Given parameter is not allowed for interlock setting (see* INTERLOCK Command*)*

27	**Wrong High Voltage parameter**	*Given parameter is not allowed for High voltage setting (see* HVS Command*)*
30	**Interlock active**	*High Voltage module cannot be turned ON, because a faults condition occurs. Solve the fault cause and reset the status register (see* STATUS Command*)*