AMC-PICO-8

8-channel 20 bit Bipolar Floating Picoammeter with MTCA.4 REAR I/O

CAENels
Gear For Science

User's Manual

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MTCA.4 – MicroTCA for Physics

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Document Revisions

Document Revision	Date	Comment
1.0	June 24th, 2015	First Release
1.0.1	November 24th, 2017	Minor errors fixed
1.1	July 7th, 2018	AMC-PICO-8-C2 information added
1.2	June 26th, 2019	Format changed
2	August 8th 2024	Updated address and revision numbering

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 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 50°C
Operating Humidity	30% to 85% RH (non-condensing)
Storage Temperature	-10°C to 60°C
Storage Humidity	5% to 90% RH (non-condensing)

This manual refers to the following boards:

- **AMCPICO8XAAA** - AMC-PICO8 - 8-channel AMC – MTCA.4 Bipolar Floating Picoammeter Board;
- **AMCPICO8C1XA** - AMC-PICO8-C1 - 8-channel AMC-MTCA.4 Bipolar Dual-Range Floating Picoammeter Board;
- **AMCPICO8C2XA** - AMC-PICO-8-C2 - 8-channel AMC-MTCA Bipolar Float. Picoammeter (±10 mA, ±500 uA, BW=300 kHz)

1. Introduction

This chapter describes the general characteristics and main features of the AMC-PICO-8 board.

1.1 AMC-PICO-8 Overview

The CAEN ELS AMC-PICO-8 is an eighth channel picoammeter AMC board in MTCA.4 format. The analog front-end allows measuring bipolar currents up to 1 mA with maximum sampling rate of 1 MSPS.

The analog front-end 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. The 20-bit resolution is obtained from independent, simultaneous sampling and low-delay SAR (Successive Approximation Register) Analog to Digital Converters (ADCs).

Each channel has two full-scale measuring ranges, up to ±1 mA and ±1 µA respectively and the current source can be floating up to ±300 V respect to the chassis ground. The floating capability of the inputs is perfectly suitable for applications where the detector or current source needs to be biased.

The analog front end is designed in order to achieve low noise, low temperature dependence and very small unbalance between channels. The analog characteristics are further improved with calibration. Calibration data are stored in the on-board EEPROM memory and are loaded in the signal-processing logic on power-up.

The on board Virtex-5 FPGA performs the conversion from "raw" values acquired from ADCs to a single-precision floating point numbers, representing the measured current in amperes. The floating point format is highly suitable for additional post-processing. The signal-processing logic can also be configured to capture the signal on certain trigger condition. Additionally, the internal memory can also be programmed to store data before trigger condition happens, providing a valuable data to user.

The communication with Virtex-5 FPGA is performed with the PCI express bus. All system parameters (e.g. analog front-end range, sampling frequency) can be achieved by writing to appropriate registers from PCI express. The FPGA also embeds a Scatter-Gather DMA which can be used to transfer data to PCI express root port (e.g. CPU).

The start-of-conversion signal for ADCs can be generated internally in the FPGA or it can be provided to board from various external interfaces, taking the full advantage of mTCA.4 connectivity.

1.2 Installation Instructions

The AMC-PICO-8 picoammeter is an AMC (Advanced Mezzanine Card) specifically designed to comply with all MTCA.4 (MicroTCA for physics) requirements and as such shall be installed in a MTCA.4 compliant chassis. Many chassis variants are available from different vendors with possibly different backplane arrangements for connections on ports 2 and 3. The CAEN ELS AMC-Pico-8 does not rely on vendor specific implementations of the backplane allowing the board to be mounted on a broad range of chassis; the only mandatory requirement is the ability of the crate to host Double-Width Full-Size AMC boards.

1.2.1 Installation Procedure

1. Locate an available free AMC slot in the MTCA sub-rack;

2. Make sure that the ESD contact on the card guide of the MTCA chassis sub-rack is in properly working conditions and that the AMC-Pico-8 ESD Strip is not covered and that provides a clean surface for contact;

3. Pull the AMC module Hot-Swap Handle until it is in the unlocked position;

4. Insert the AMC-Pico-8 board in the top and bottom card guides of the AMC slot and slide the card fully in until the edge connector is fully mated to the MTCA backplane connector (see Figures 2.1 and 2.2);

5. If the board is correctly inserted into the MTCA chassis the extended face plate of the AMC front panel shall be almost in contact with the sub-rack retention interface and allow the front panel screws to be locked to the chassis.

Do not force the AMC card in the chassis as this may result in damage to the board. If difficulty arises in fully inserting the board into the chassis make sure it is correctly inserted in both the card guides of the sub-rack, if so remove it from the slot and check for any possible obstruction coming from the card guides or nearby struts.

1.2.1 Ground Connections

For safety and performance reasons the MTCA standard requires the presence of two separate ground connections, a Logic GND that is the reference potential for the Payload Power and the Management Power and a Chassis GND that is connected to the MTCA chassis and all the AMCs front panels.

The triaxial connectors are used for the measurement current inlet. The measured current path is through the center wire and the inner shield of the triaxial cable (see **Figure 1**). By convention the current that flows from the source into the AMC-PICO-8 board through the center wire is measured as positive, on the contrary the current that is sinked by the current source and flows from the AMC-PICO-8 board through the center wire is measured as negative. The return current path is always established through the inner cable shield.

Figure 1: Measured current path

There can be large potential difference between the inner and the outer triaxial cable shield because of the front end isolation. Therefore the outer shield of the triaxial cable must be grounded (see **Figure 2**). The voltage between both shields must be limited as breakdown may occur so the maximum value of the isolation voltage is given in the specifications section.

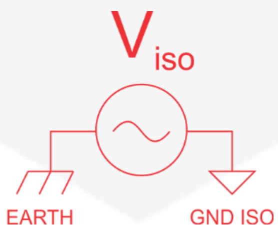

Figure 2: Definition of isolation voltage

The default ground connection is done on the FMC board side through the FMC bezel which is connected to the grounded chassis (see **Figure 3**).

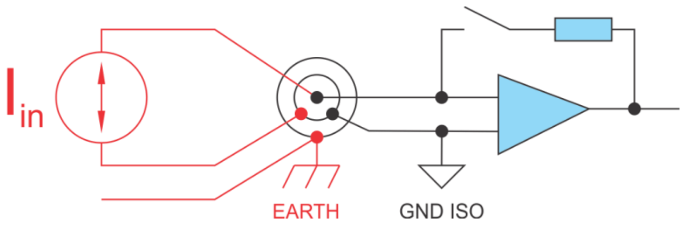

Figure 3: Grounding at the FMC board side

2. AMC-PICO-8 Oscilloscope

The CAEN ELS AMC-Pico-8 Oscilloscope is an application which offers a graphical environment for easy interfacing with AMC-Pico-8 board. The main window of AMC-Pico-8 oscilloscope is shown in **Figure 4** . There are two plots, a field showing signal statistics, the range selection box and the box with display, acquisition and trigger options.

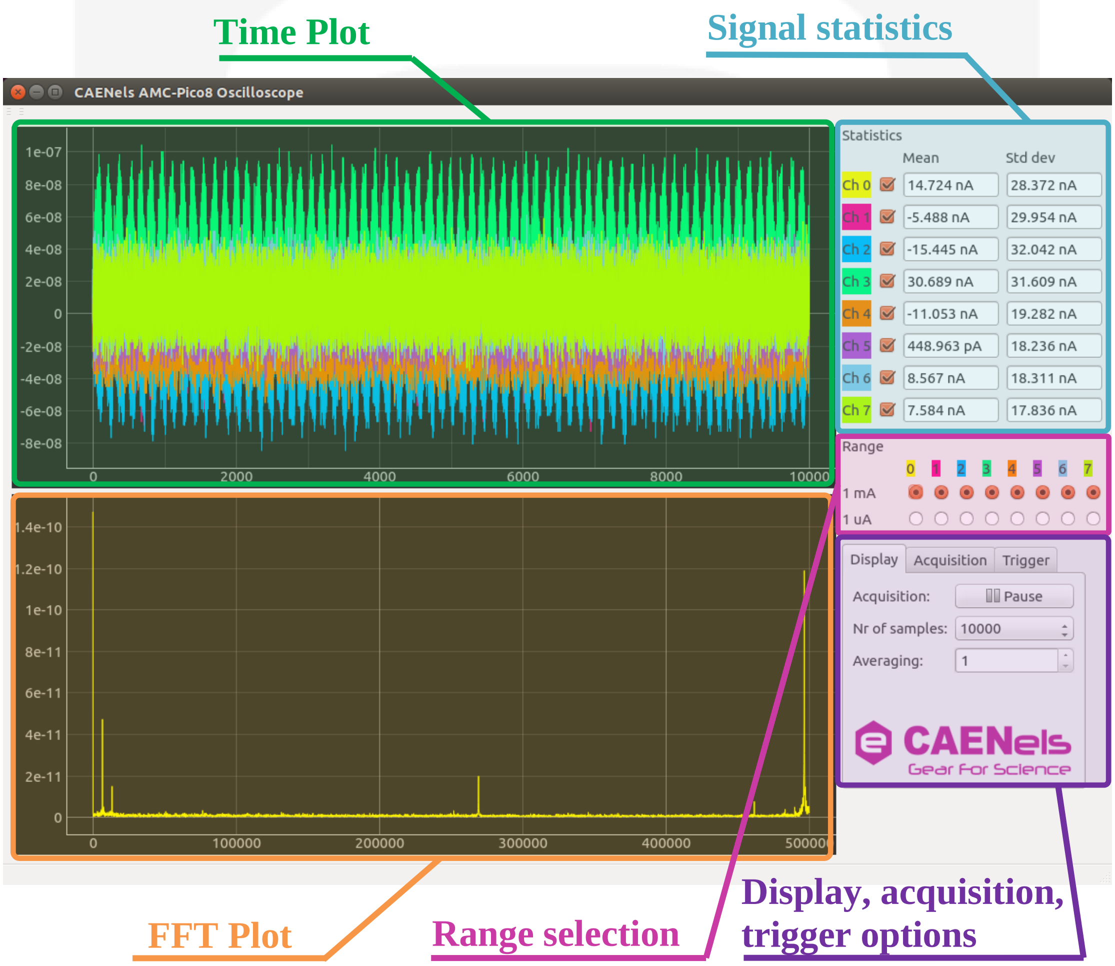

Figure 4: CAENels AMC-Pico8 Oscilloscope

2.1 Time and FFT Plots

The two plots present the captured signals in time (time plot) and frequency domain (FFT plot). The settings regarding the plots are accessible with right-click on the plot area and from "Display" tab on the lower left part of the main window. Plots also support zooming with dragging, as indicated on **Figure 5**.

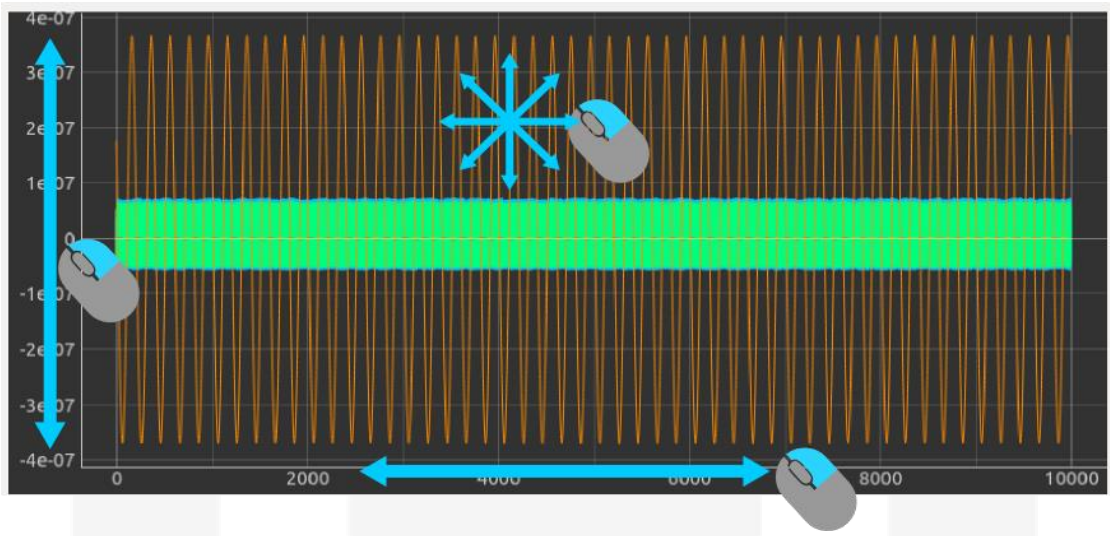

Figure 5: AMC-Pico-8 Oscilloscope zooming possibilities

When the user uses zoom on the plot, an auto-ranging feature is disabled. The button with a letter "A" (shown on **Figure 6**) in the lower right corner of the plot re-enables the auto-ranging functionality.

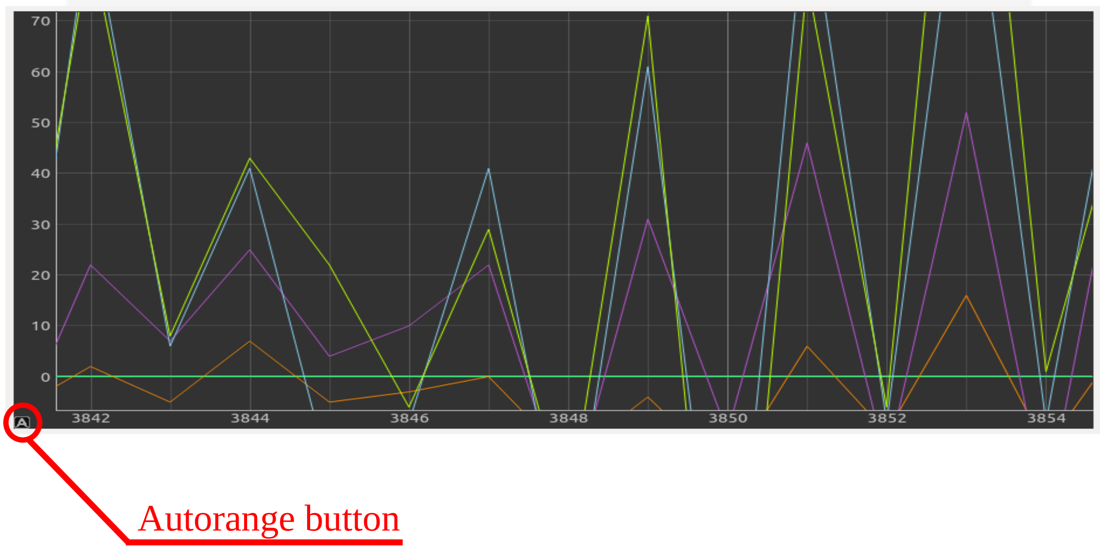

Figure 6: AMC-Pico-8 Oscilloscope autorange button

2.2 Channel Statistics

At each update of the oscilloscope window, the channel statistics are calculated for all enabled channels. The calculated values are mean value and standard deviation of signals. The checkboxes next to the channel numbers can be used to enable and disable plotting of certain channels. These are shown in **Figure 7**.

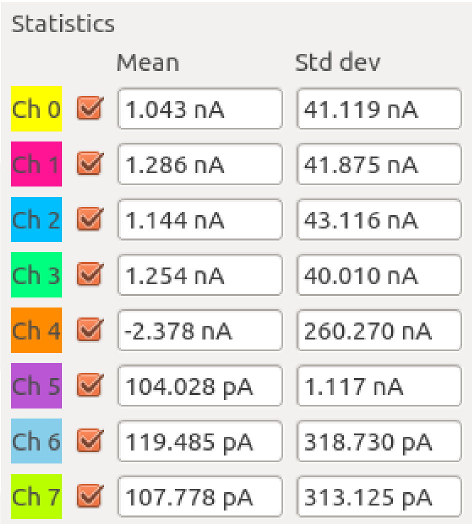

Figure 7: AMC-Pico-8 Oscilloscope channel statistics

2.3 Measuring Ranges

The oscilloscope allows user to change the analog front-end range of each input channel independently. The example of the configuration is shown in **Figure 8**.

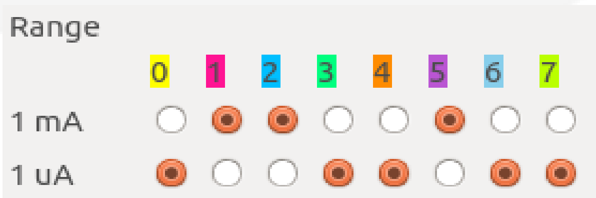

Figure 8: AMC-Pico-8 Oscilloscope ranges buttons

2.4 Display Settings

The display settings allow user to set how many samples are being read each cycle. The plotting can become quite slow with large buffers, for this case the Averaging can be used to reduce the number of samples displayed on the plots. The "Pause" button pauses the acquisition and enables user to inspect the currently displayed buffer. An example is shown in **Figure 9**.

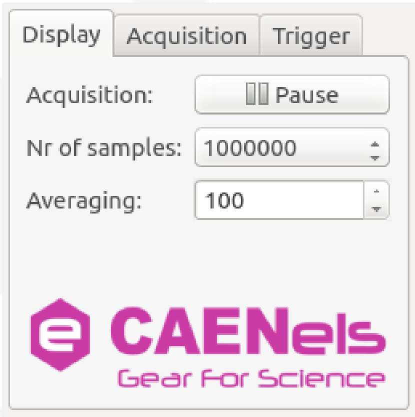

Figure 9: AMC-Pico-8 Oscilloscope display settings

2.5 Acquisition Settings

The acquisition settings tab allows setting the acquisition frequency and also to select various sources for gate and start-of-conversion signal. The gate and start-of-conversion signals can be feed to AMC-PICO-8 from various interfaces, taking the full advantage of mTCA.4 connectivity. The acquisition settings are shown in **Figure 10**.

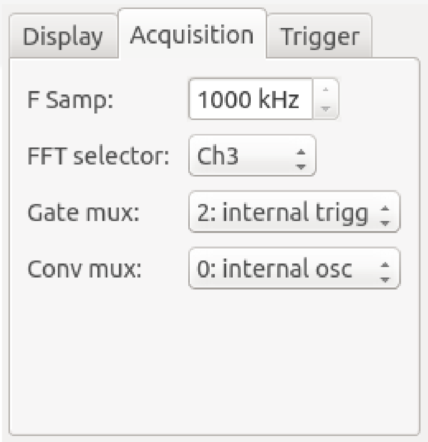

Figure 10: AMC-Pico-8 Oscilloscope acquisition settings

2.6 Trigger Settings

The AMC-PICO-8 has the internal module which can generate a gate signal based on the desired trigger condition. The settings which control this module are shown on

Figure 11.

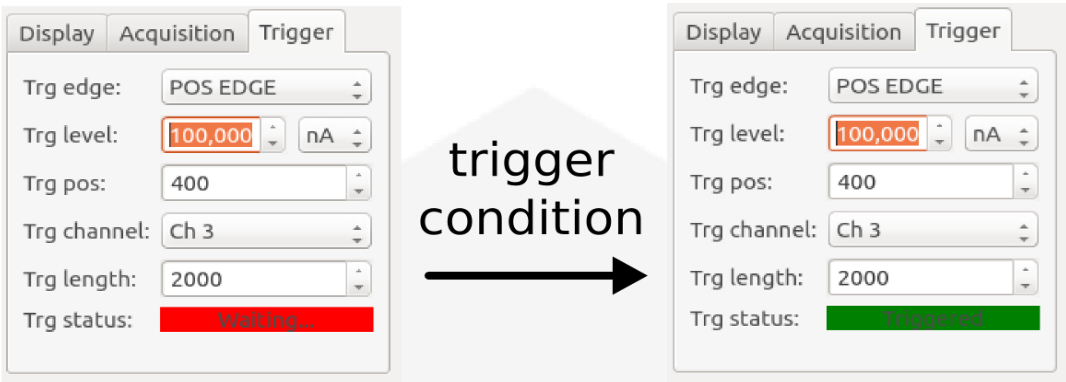

Figure 11: AMC-Pico-8 Oscilloscope trigger settings

The trigger edge select whether the signal must be rising or falling at the desired trigger level to generate the trigger condition. Trigger channel selects which input channel is considered when evaluating the trigger condition. The trigger length selects the number of samples which are captured at each trigger event. When the trigger condition is met, the new data is displayed on plot and the trigger status is changed from *"Waiting..."* to *"Triggered"* for a brief period.

The trigger level and trigger position can also be set from time plot by dragging the red lines, as shown on **Figure 12**.

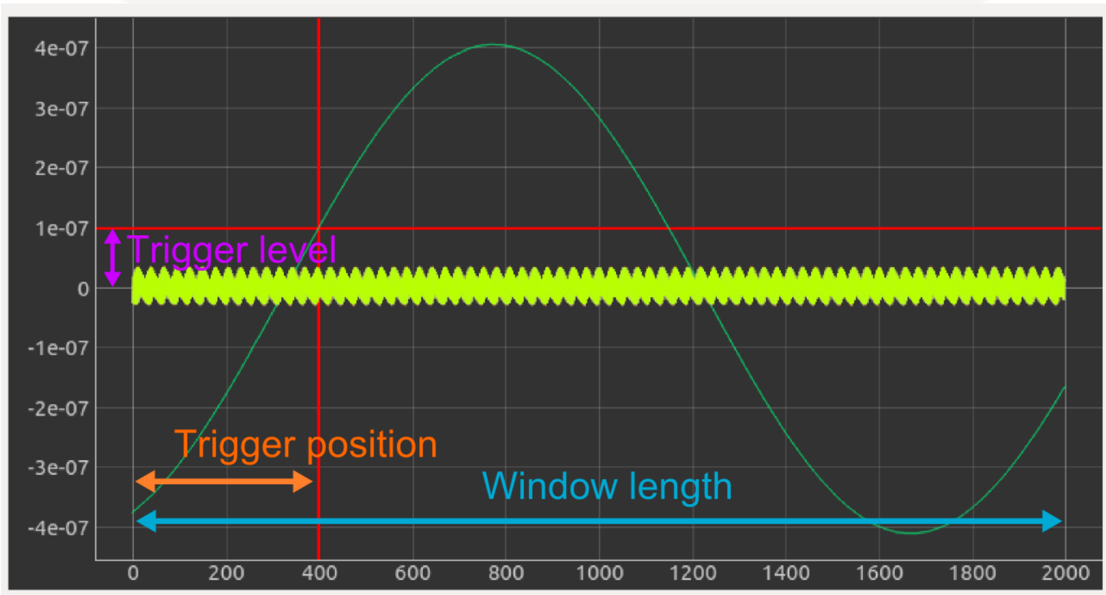

Figure 12: Trigger level, position and windows length explained

3. System Overview

The AMC-Pico8 is an 8-channel picoammeter, composed by the AMC carrier board DAMC-FMC25 and two picoammeter FMC plug-ins, called FMC-Pico-1M4 (and variants). The core of the system is a Virtex-5 FPGA, mounted on the AMC carrier. The FPGA takes care of the picoammeter channel readings, data calibration and communication with the PCI Express BUS. The system structure is illustrated in **Figure 13** and described in the following sections.

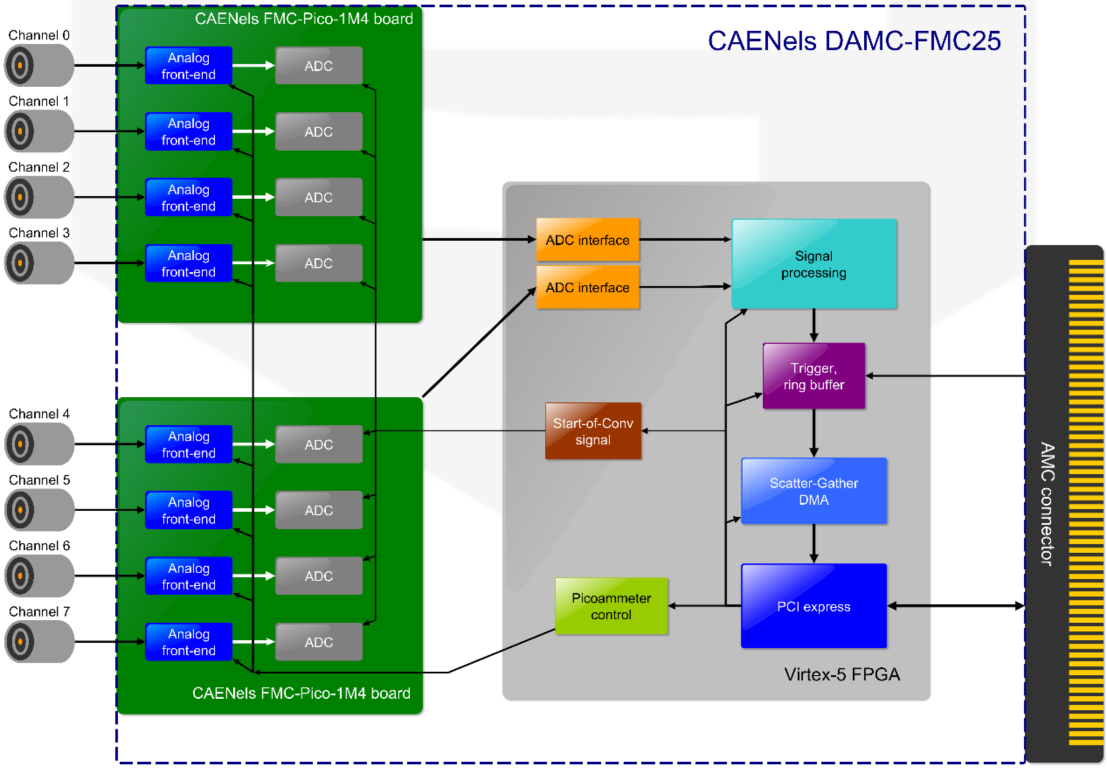

Figure 13: AMC-PICO-8 System Overview

➢ Analog front-end

The analog front-end converts current to voltage and also limits the signal bandwidth to prevent undesired effect (aliasing caused by sampling). The input range can be selected between ±1 mA and ±1 µA (in the standard version).

➢ Analog-to-digital converters

The analog-to-digital converters convert analog input voltage to digital representation, which is suitable to be used processed by FPGA and CPU.

➢ Picoammeter control module

The picoammeter control module provides start-of-conversion signal for ADCs and selects the input range independently for each input channel.

➢ ADC interface module

The ADC interface module communicates with ADC converters to obtain the measured data. The data is then forwarded to Signal processing module.

➢ Signal processing module

The signal processing module takes the "raw" measurement from the ADCs and converts them to amperes [A], considering the input channel characteristics. The module performs also a calibration of the acquired data. The calibration parameters are stored on the on-board EEPROM memory present on the FMC-Pico-1M4 boards. The data representation used during the signal processing is IEEE-754 floating point, which are easy usable and by CPUs and offers a good quantization-error performance. The data transfer is performed using a DMA module.

➢ DMA module

The DMA (Direct Memory Access) module enables transfer of data from signal processing module to PCIe Root Port (e.g CPU Root Complex or another FPGA). This particular implementation of DMA converts stream of data (such as picoammeter measurements) to memory-mapped writes. The most common use is to perform bulk data transfer from picoammeter to a determined space in a computer RAM.

The signals used by the DMA module are: the control port, data input port and data output port. The data input port is connected to signal processing module and the data output port is connected to PCI Express module. The control port is used to control the DMA module.

The DMA module is composed of 4 sub-parts (**Figure 14**):

- Control slave
- Command queue
- Response queue
- DMA engine

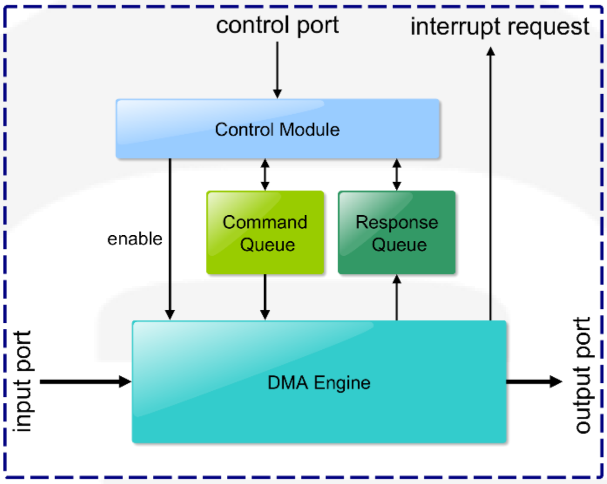

Figure 14: DMA Module Overview

The DMA engine performs the data transfer. The control slave is responsible for preparing and en-queuing DMA commands to command queue, for de-queueing the DMA responses from response queue and to present the response data to user. The DMA engine performs the data transfer.

To start a DMA transfer user should provide the write (destination) address and number of bytes to transfer. When both values are written to control slave registers, the user should write 1 to bit GO in CONTROL register. The DMA engine can also generate interrupt request when it finished with transfer, the user should set also set bit IRQ_EN (Interrupt Request Enable). Both bits should be set in a single write.

The DMA engine starts with a transfer when the command queue is not empty. It reads stream of data from data input port and performs memory-mapped write on data output port. The DMA finishes with a transfer when the specified number of bytes was transferred or when the signal processing module signaled that this is the last sample it should be stored (e.g. at the end of a gate window). When the DMA finishes with the transfer, a response is en-queued in the response queue. The response contains the starting address of DMA transfer and the number of bytes transferred. If the IRQ_EN bit was set high, an interrupt request is signaled to PCIe module.

The response queue shows the first element of the queue on the registers RESP_TRANS_LEN and RESP_TRANS_ADDR. The number of elements in both queues can be obtained from STATUS register. User should de-queue the response after it has been read and processed. To de-queue the response, a write to RESP_TRANS_LEN should be performed.

- **Internal trigger module**

The internal trigger module can be configured to generate the gate signal, which enables the acquisition of the input signals at desired trigger condition.

- **PCI Express module**

The PCI Express module manages read and write requests and provides the high-throughput data transfer to the PCI Express bus using a dedicated port for bus mastering (i.e. an ability to emit PCIe request on bus).

4. Module Management Controller

The Module Management Controller (MMC) is a management subsystem of AMC-Pico8 board. It interfaces with MCH and negotiation the communications, monitors the board voltages, temperatures and board status and allows remote update of FPGA configuration memories using IPMI HPM.1 protocol.

4.1 USB Interface

The MMC (Module Management Controller) is accessible from USB connector from the front panel. The USB interface exports two COM ports, the one with the lower number is connected to Spartan-6 FPGA and the one with higher number is connected to the MMC. The settings are: **115200 baud, 8 bits, 1 stop bit, no parity**.

The MMC presents a command prompt on the USB interface. The interface allows user to check the current version of the system with command version as shown on **Figure 15**.

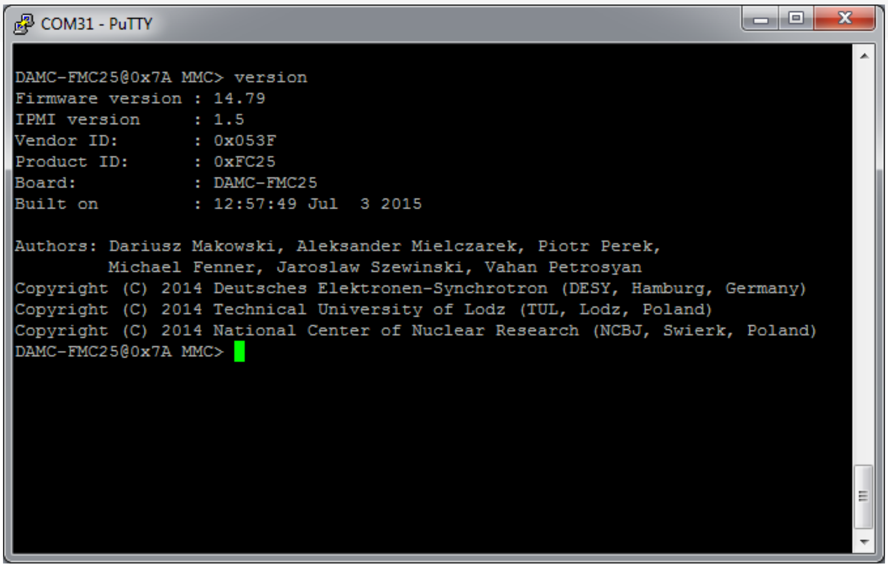

Figure 15: Version of the MMC firmware

The status of the system can be examined with command **status** as show on **Figure 16**. This command displays the voltage values, temperature values and FPGA configuration status.

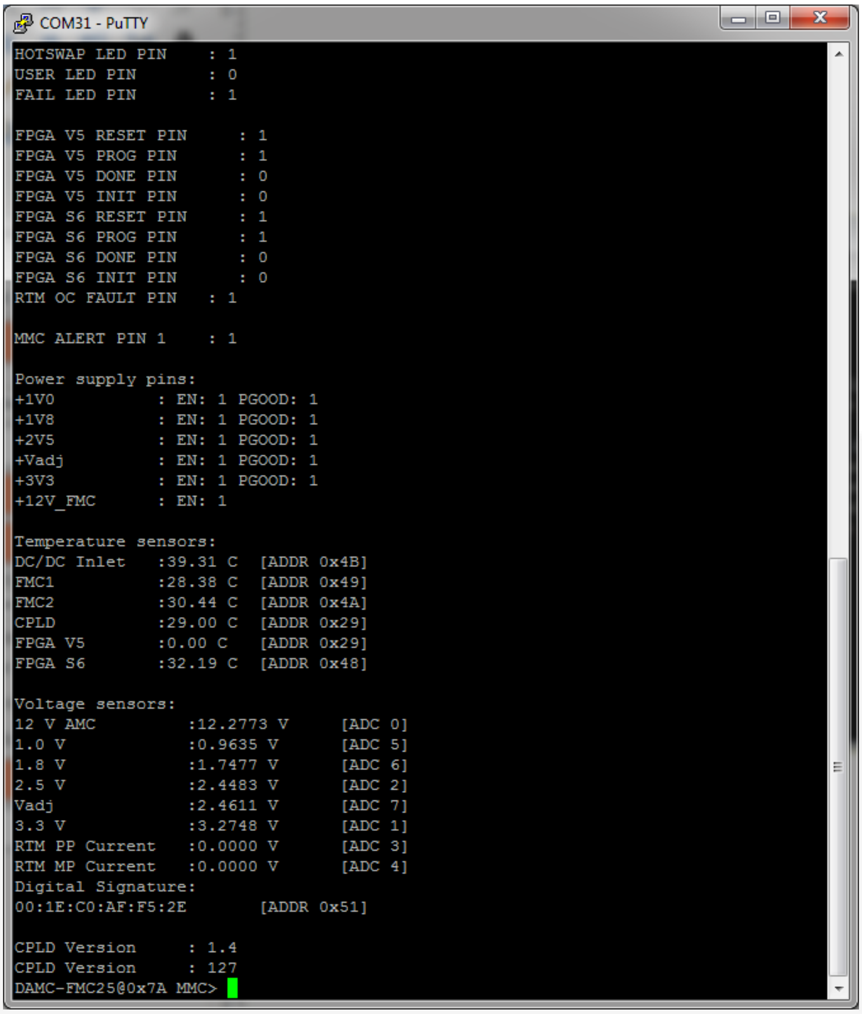

Figure 16: Board status

4.2 IPMI Interface

The remote update of the system can be performed using the *IPMI HPM.1* protocol. The *ipmitool* is a command line tool to interface with IPMI devices. The user is invited to check the man page for *ipmitool* for detailed explanation of all arguments and possible commands.

The general *ipmitool* syntax is:

```
ipmitool -H [MCH IP ADDR] -P "" -B 0 -b 7 -T 0x82 -t 0 [0x72 + 2xslot] [commands]
```

The command used to download a new version of the FPGA configuration file is:

```
ipmitool -H 192.168.1.41 -P "" -B 0 -b 7 -T 0x82 -t 0x7A hpm upgrade damc25_virtex_v1.02_3.rle.hpm
```

5. Linux Driver

The Linux driver for AMC-PICO8 enables interfacing to AMC-PICO8 FPGA with a standard POSIX system calls, such as *read()* or *ioctl()*.

The applications calls *read()* on AMC-PICO8 driver device node (e.g. /dev/amc_pico) with desired number of bytes. One sample, composed from 8 channels is 256 bytes long. It is recommended to perform reads with the same granularity.

Under the hood, the driver prepares a buffer in memory and starts the DMA transfer. The task which called the *read()* is then put to sleep until all the data is available. The timer is also set in place to wake up the task if the DMA transfer is not finished within 500 ms. The *read()* function always returns the number of bytes requested, even in cases where there were less data available. The application should check the number of bytes transferred with the *ioctl(GET_B_TRANS)* system call, which returns the number of bytes transferred. The number of bytes transferred can be different of the bytes requested in case there is a trigger or gate signal, which terminates the transfer early.

The driver can take advantage of Scatter-Gather mechanism in DMA to create chain of DMA transfers when a single buffer cannot accommodate all the data to be transferred.

The control of various system parameters can be achieved by issuing the following *ioctl()* requests:

SET_RANGE

Defined as:

```
#define SET_RANGE   _IOW(AMC_PICO_MAGIC, 11, uint8_t*)
```

The argument is a pointer to *uint8_t* word in which every bits represents the range selection for each channel. The LSB bit controls the Ch0. If the bit is cleared, the range is set to wider range (e.g. 1mA on standard AMC-PICO-8). If the bit is set, the range is set to narrower range (e.g. 1uA on standard AMC-PICO-8).

GET_RANGE

Defined as:
```
#define GET_RANGE   _IOR(AMC_PICO_MAGIC, 11, uint8_t*)
```

As the argument it takes a pointer to *uint8_t* word into which the current range selection is copied.

SET_FSAMP

Defined as:
```
#define SET_FSAMP   _IOW(AMC_PICO_MAGIC, 12, uint32_t*)
```

This sets the sampling frequency of the internal convert signal generator. The maximum sampling frequency is 1 MHz and the minimum is 150 kHz.

GET_FSAMP

Defined as:
```
#define GET_FSAMP   _IOR(AMC_PICO_MAGIC, 12, uint32_t*)
```

Gets the sampling frequency.

GET_B_TRANS

Defined as:
```
#define GET_B_TRANS _IOR(AMC_PICO_MAGIC, 40, uint32_t*)
```

Gets the number of bits that last read call successfully transferred.

SET_TRG

Defined as:
```
#define SET_TRG     _IOW(AMC_PICO_MAGIC, 50, struct trg_ctrl *)
```

Set the trigger control using the trigger control structure (*trg_ctrl*) shown hereafter:

```
struct __attribute__((__packed__)) trg_ctrl {
       float limit;
       uint32_t nr_samp;
       uint32_t ch_sel;
       enum {DISABLED, POS_EDGE, NEG_EDGE, BOTH_EDGE} mode;
};
```

SET_RING_BUF

Defined as:
`#define SET_RING_BUF    _IOW(AMC_PICO_MAGIC, 60,  uint32_t*)`

Set the number of samples that are acquired before the trigger event and stored in the ring buffer. The max size of the ring buffer is 1023.

SET_GATE_MUX

Defined as:
`#define SET_GATE_MUX    _IOW(AMC_PICO_MAGIC, 70,  uint32_t*)`

Set the source of the gate signal. The gate signal enables the data acquisition. The possible gate source settings are:

Value	*Description*
0	Fixed at 1 (always enabled)
1	Fixed at 0 (always disabled)
2	Internal trigger (see SET_TRG command)
3	Reserved
4	AMC port #17 RX
5	AMC port #18 RX
6	AMC port #19 RX
7	AMC port #20 RX

Table 1: Gate source settings

SET_CONV_MUX

Defined as:
`#define SET_CONV_MUX    _IOW(AMC_PICO_MAGIC, 80,  uint32_t*)`

Set the source of the start-of-conversion signal for the ADCs. The possible source settings are:

Value	Description
0	Internal oscillator (see SET_FSAMP)
1	AMC TCLKA
2	AMC TCLKB
3	Reserved
4	AMC port #17 RX
5	AMC port #18 RX
6	AMC port #19 RX
7	AMC port #20 RX

Table 2: Start-of-conversion sources

6. Technical Specifications

Technical Specifications for the **AMC-PICO-8** are presented in the following table:

Characteristic	Value
Input Channels	8
Input Connector Type	Triaxial - LEMO 00.650 Series (EPL.00.650)
Current Polarity	Bipolar
Full-Scale Current	RNG0: ± 1 mA RNG1: ± 1 µA (configurable upon request)
Maximum Sampling Rate	1 MSPS (per channel)
Equivalent Signal-to-Noise	RNG0: > 100 dB RNG1: > 90 dB
Current Resolution	RNG0: 2 nA RNG1: 2 pA [20 bit]
Bandwidth (-3dB)	> 10 kHz
Temperature Coefficient - TC	10 ppm/°C
Differential TC	< 25 ppm/°C
Front End Isolation Voltage	± 300 V
Board Size	Double-Width, Mid-Size
Standard	MicroTCA.4: AMC.0, AMC.1 Module Management: IPMI Version 1.5, MMC v1.0
Trigger inputs	Internal, AMC port #17 RX AMC port #18 RX AMC port #19 RX AMC port #20 RX

Table 3: Technical Specifications – **AMC-PICO-8**

Technical Specifications for the **AMC-PICO-8-C1** are presented in the following table:

Characteristic	Value
Input Channels	8
Input Connector Type	Triaxial - LEMO 00.650 Series (EPL.00.650)
Current Polarity	Bipolar
Full-Scale Current	RNG0: ± 130 µA RNG1: ± 16 µA (configurable upon request)
Maximum Sampling Rate	1 MSPS (per channel)
Equivalent Signal-to-Noise	RNG0: > 100 dB RNG1: > 90 dB
Current Resolution	RNG0: 250 pA RNG1: 30 pA [20 bit]
Bandwidth (-3dB)	35 kHz ± 10 %
Temperature Coefficient - TC	< 50 ppm/°C
Differential TC	< 25 ppm/°C
Front End Isolation Voltage	± 300 V
Board Size	Double-Width, Mid-Size
Standard	MicroTCA.4: AMC.0, AMC.1 Module Management: IPMI Version 1.5, MMC v1.0
Trigger inputs	Internal, AMC port #17 RX AMC port #18 RX AMC port #19 RX AMC port #20 RX

Table 4: Technical Specifications – **AMC-PICO-8-C1**

Technical Specifications for the **AMC-PICO-8-C2** are presented in the following table:

Characteristic	Value
Input Channels	8
Input Connector Type	Triaxial - LEMO 00.650 Series (EPL.00.650)
Current Polarity	Bipolar
Full-Scale Current	RNG0: ± 10 mA RNG1: ± 500 µA (configurable upon request)
Maximum Sampling Rate	1 MSPS (per channel)
Equivalent Input Noise	RNG0: < 230 nA RNG1: < 15 nA
Equivalent Input Noise (with 3-nF input capacitance)	RNG0: < 230 nA RNG1: < 25 nA
Current Resolution	RNG0: 20 nA RNG1: 1 nA [20 bit]
Bandwidth (-3dB)	300 kHz ± 10 %
Temperature Coefficient - TC	< 50 ppm/°C
Differential TC	< 25 ppm/°C
Front End Isolation Voltage	± 300 V
Board Size	Double-Width, Mid-Size
Standard	MicroTCA.4: AMC.0, AMC.1 Module Management: IPMI Version 1.5, MMC v1.0
Trigger inputs	Internal, AMC port #17 RX AMC port #18 RX AMC port #19 RX AMC port #20 RX

Table 5: Technical Specifications – **AMC-PICO-8-C2**