MEASAR: A Measurement System for CEM-Arrays

1. Description

MEASAR is a modular electronic instrument to operate systems with multiple channel electron multipliers (CEMs) or photomultipliers (PMTs) and evaluate all output signals simultaneously by pulse counting as well as current and integral charge measuring. One important application is isotope ratio determination with CEM-arrays.
It consists of a mechanical housing in 19"-subrack technology, with modules MS0X for high voltage generation, pulse counting, and current and charge monitoring, and one system controller module COM0X with an RS 232-interface (which may easily be translated to USB by means of an external bridging circuit, e.g. NI USB-232 from National Instruments) to connect the system to a host computer.
High voltage, discriminator threshold, and measurement time are set by the computer, measurements can be run once per start command or automatically repeated.
All modules are housed in shielded plug-in units with front panels 3 HE / 7 TE (i.e. 133.4 mm height, 35.6 mm width). Subracks are provided for one controller and 3, 5, 8, or 11 MS0X modules when fully equipped. An example with 5 channels is shown in fig.1. The controller has to be placed in the most left position 00, the MS0X-modules can be placed in any slot, they are addressed with the slot number.
Operation is performed exclusively via the RS232 interface, the only direct mechanical control is a safety switch to turn off the high voltage.
For interface details and protocol see document *MEASAR RS232 Interface Protocol_rev E.pdf* .
Software to operate MEASAR is available.

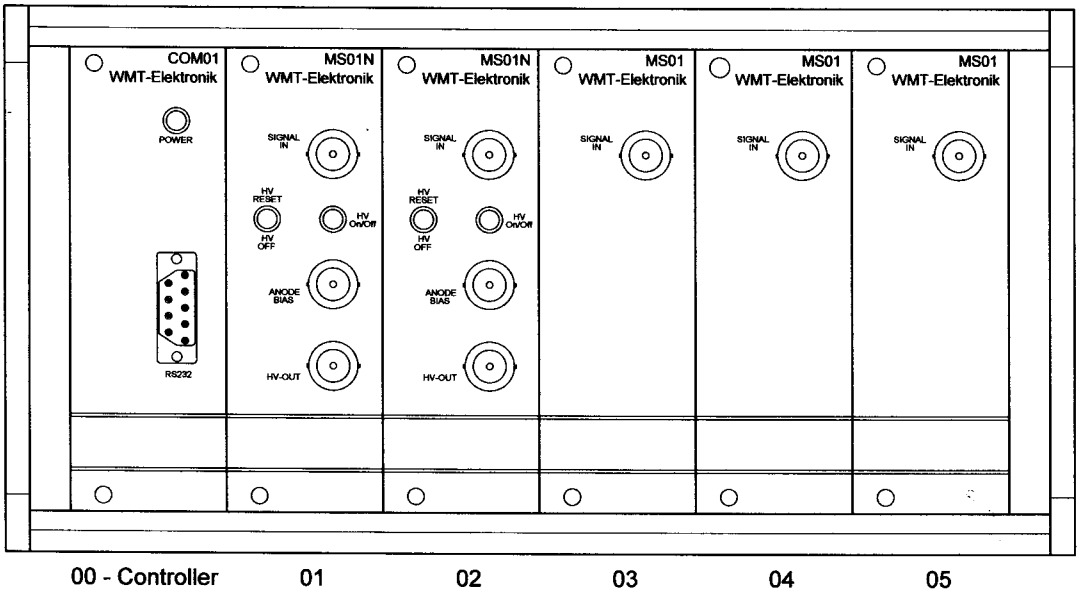

Fig. 1: Front view of MEASAR with controller and five channels.

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CEM arrays have common high voltage and anode bias inputs. One plug-in with high voltage supply and counter is sufficient, the remaining (n-1) channels can be operated with plug-ins without HV supply. For redundancy a second high voltage plug-in is recommended. The unused high voltage must be turned off for safety.

CEMs are operated in ultra-high-vacuum, HV-throughputs (BNC-HT, SHV, or equivalent, MEASAR is equipped with BNC-HT), are necessary for High Voltage and -with positive HV- for ANODE BIAS. For SIGNAL a BNC throughput is sufficient.
The signal cables must be coaxial 50 Ω type, e.g. RG 58/U or -preferably because of its double shield- RG 223/U.

2. Programmable Measurement Parameters

High Voltage:

HV(11:0)	12 bit binary for high voltage = 128 V to 4095 V (MS0X-P), - 128 V to - 4095 V (MS0X-N), step size = 1 V, max. output power = 1.0 W. Voltages with absolute value < 128 V are internally set to zero.
HV-slope	1 bit for high voltage slope = ± 100 V/s or ± 800 V/s

Pulse Detection:

THR(7:0)	8 bit binary for discriminator threshold = 3 mV to 130.5 mV input referred, step size = 0.5 mV. For a typical pulse width of 8 ns (FWHM) this is equivalent to CEM output charge 0.48 to 20.9 pC.
DTIM(1:0)	2 bit binary for dead time = 15 - 30 - 60 - 100 ns

Measurement Time Interval:

MEAST(15:0)	16 bit binary to determine the measurement time interval: MEAST(15:0) = 0000_{hex} : unlimited, stop by command MEAST(15:0) = 0001_{hex} to $FFFF_{hex}$ for intervals 10 ms to 655.35 s with auto-stop
AUTO(7:0)	8 bit binary for single or automatically repeated measurement: $00_{hex} \Rightarrow$ unlimited number of measurements to be ended by command, $01_{hex} \div FF_{hex} \Rightarrow 1 \div 255$ measurements. In AUTO mode uninterrupted counting is provided and the counter data are transferred periodically without read command to the host computer, if parameter F is asserted.

CEM Overload Protection:

COP (3:0)	4 bit binary determine the maximum allowable anode current, averaged over one second. Step size is 1.024 µA (or 204,800 counts/sec in modules without the current measurement feature). COP(3:0) = 0000 disables this overload protection.

Counter Readout:

F_i	One bit for each MS0X determines, whether the counter result of module (i) is read out automatically after the measurement ends ($F_i = 1$), or not ($F_i = 0$).

3. Controllers

3.1. Function

The controller is the link between the modules MS0X and the host computer. Commands and data sent from the computer via the RS232 interface to the MEASAR controller are transferred to the MS0X plug-ins via an internal bus and vice versa.

3.2. Types

Two different types of controller plug-ins are available:

- COM01 with length 220 mm for use with MS01.
- COM04 with length 160 mm for use with MS02 and MS04.

An older Version COM02 for use with MS02 only is obsolete.

3.3. Commands

The command index (n) is the number of the slot, where the MS0X-module is placed. For n = 0 all modules are addressed.

SET HV(n)	Determines high voltage value and slope of module n.
READ HV(n)	Reads the actual high voltage and slope of module n.
SET THRSH(n)	Determines the discriminator threshold and dead time of module n.
READ THRSH(n)	Reads the discriminator threshold and dead time of module n.
SET MEASTIM(n)	Determines duration of measurement interval of module n.
READ MEASTIM(n)	Reads duration of measurement interval of module n.
SET AUTO(n)	Determines number of automatically repeated measurements.
READ AUTO(n)	Reads number of automatically repeated measurements.
SET COP(n)	Determines CEM overload threshold of module n.
READ COP(n)	Reads CEM overload threshold of module n.
SET F(n)	Determines auto-read mode of module n.
READ F(n)	Reads read-mode of module n.
START(n)	Enables counter in module n, starts measurement.
STOPIM(n)	Ends measurement in module n immediately.
STOP(n)	Ends measurement in module n after the end of the present measurement interval.
READ I(n)	Reads actual current of CEM n, 16 bit binary.
READ Q(n)	Reads integral charge of last measurement interval of module n, 16 bit binary.
READ CNT(n)	Reads the counter result of module n, 32 bit binary.

NOTE: The ADC to measure the current, the integrator to calculate the the integral charge, and the counter all have saturation characteristics, i. e. they do not overflow. Readings of I, Q, or CNT with all "1s" shall be rated as overflow.

For a detailed listing of the software protocol refer to *CEM COM 01_RS232 Interface_revE.pdf* .

3.4. Front Panel Elements

LED "CONNECTED" :	green:	controller is connected to host computer
	red:	no connection
	off:	controller is not powered
LED "MEAS ON" :	red:	a measurement is running
	off:	system is idle or not powered
Sub-D9:	RS232 connector, null-modem cable is required	

4. Measurement Plug-Ins MS0X

4.1. Types

Three different types of measurement plug-ins are available:

- **MS01** with 220 mm length, requires the deep mainframe MSF-D and works in combination with COM01 only. Can be equipped with only negative high voltage power supply and has circuitry for both pulse counting and current measurement. The overload protection is implemented on the basis of current measurement.
  Options: MS01-N with negative high voltage supply,
  MS01 without high voltage supply.

- **MS02** is for pulse counting only and is not capable of anode current measurement and charge accumulation like MS01. Therefore the overload protection is implemented on count rate basis instead of current measurement. Length is 160 mm for use with the standard mainframe MSF-S and controller COM 02 or COM 04.
  Options: MS02-N with negative high voltage power supply
  MS02-P with positive high voltage power supply
  MS02 without high voltage power supply

- **MS04** is a four channel plug-in for counting purposes only. MS04 has no high voltage supply and is not capable of anode current measurement and charge accumulation like MS01. Therefore the overload protection is implemented on count rate basis instead of current measurement. Plug-in length is 160 mm for use with the standard mainframe MSF-S and controller COM 04 only.

All MS0X modules have direct coupled inputs with 50 Ω input resistance. If capacitive coupling is applied, the capacitor must be placed inside the vacuum chamber if possible or directly at the vacuum throughput. The connection cable must not carry high voltage, because leakage in the cable dielectric creates false counts. The capacitance value depends on the pulse risetime and width; for CEMs 220 pF to 470 pF is suited.

4.2. High voltage generator:

Output Voltage:	128 V to 4095 V, programmable in 1 V steps. High voltage is positive in MS02-P, negative in MS01-N, MS02-N
Max Output Power:	1.0 W, overload and short-circuit protected
Anode Bias Output:	MS01-P, MS02-P: +HV - 120 V MS01-N, MS02-N: - 120 V

Slew Rate: ± 100 V/s or ± 800 V/s, programmable
An emergency switch for immediate turn-off is provided on the front panel. HV-reset is manually by pressing a frontpanel button or by reprogramming the HV value.

LED "High Voltage": red: HV is Off,
green: HV has programmed value,
orange: HV is ramping up or down to a new value.

4.3. Preamplifier/Discriminator

Input Impedance: 50 Ω dc-coupled
Threshold: Programmable: 3 mV to 130.5 mV input referred.
For a typical pulse width of 8 ns (FWHM) this is equivalent to CEM output charge 0.48 to 20.9 pC.
Note: With CEM gain = 10^8 a single electron at the CEM input produces 16 pC output charge in the average.
Dead Time: Programmable: 15 - 30 - 60 - 100 ns.

4.4. Transimpedance Amplifier

A transimpedance amplifier with 16-bit-ADC is included in MS01 and MS01-N.
Full scale is 16.38375 µA, the quantization step is 250 pA, bandwidth is 1 kHz (- 3 dB), the ADC`s conversion rate is 51.2 kHz. The momentary current can be read by the computer at any time.
A programmable overload threshold for the anode current is set by the computer. Exceeding the threshold in any channel turns off the high voltage in all modules in the subrack to protect the CEMs. In addition a fixed hardware threshold is implemented, the high voltage is turned off, if the anode current exceeds 25 µA.
Furthermore the current is digitally integrated over the measurement time interval and the accumulated charge can be read after the measurement is completed. Resolution for the charge is 16 bit, quantisation step size is 5.12 nC, full scale is 335.5392 µC.

4.5. Front Panel Elements

SIGNAL IN: BNC-Connector for the signal

ANODE BIAS: BNC-connector with -120V (MS01-N, MS02-N)
or BNC-HT connector with HV - 120V (MS02-P)

HV-OUT: BNC-HT connector for high voltage output

HV RESET: Switch with two settling positions and one touch contact:

bottom position:	HV OFF, overrides host setting of HV
middle position:	HV ON. After switchoff, the high voltage is not yet on, but can be activated by host command.
top touch contact:	HV is reset to the previous set value

5. Mainframes

Mainframes are equipped with backplane and power supply for mains voltage 90 Vac to 250 Vac. They are available in deep version MSF-D for MS01, COM01 with width for 6, 9, or 12 plug-ins and short version MSF-S for MS02, MS04, COM02, COM04, with width for 4, 6, 9, or 12 plug-ins.

Examples:	MSF-D6:	Deep version for 1 COM01 and 5 MS01 plug-ins (= Fig. 1.).
	MSF-S12:	Short version for 1 COM04 and 11 MS02 or MS04 plug-ins.

6. Specifications

6.1. General

Ambient Temperature:	Operating:	0 °C ÷ +50 °C
	Storage:	-20 °C ÷ +80 °C
Humidity (non condensing):	80 % max.	
Electromagnetic Compatibility (EMC):	Emissions EN 55022, level B	

6.2. Mainframe

Mainframes are equipped with backplane and AC/DC-converters, power is sufficient for full population with modules COM0X and MS0X. Forced cooling not required.

Input Mains Voltage:	90 to 250 V_{AC} , 47 to 63 Hz, fuse: 1 A slow blow
AC/DC-Converter Efficency:	70 % to 80 %, depending on load

6.3. Measurement Accuracy

Measurement time interval:	$\pm 10^{-4}$
High Voltage:	setting: $\pm 1\ \% \pm 2$ V for 200 V ≤ HV ≤ 3800 V
	reading: $\pm 10^{-3} \pm 2$ V for 200 V ≤ HV ≤ 3800 V
Anode Bias:	HV - (120 ± 10)V for positive HV, - (120 ± 10)V for negative HV
Discriminator Threshold:	$\pm 1\ \% \pm 0.2$ mV
Dead Time:	$\pm 3\ \% \pm 1$ ns
Current Measurement:	± 2 %
Charge Accumulation:	± 2 %

Final test protocol with measured values is delivered with each module.

7. Measurement Setup for Positive or Negative High Voltage

Connection scheme for negative high voltage:

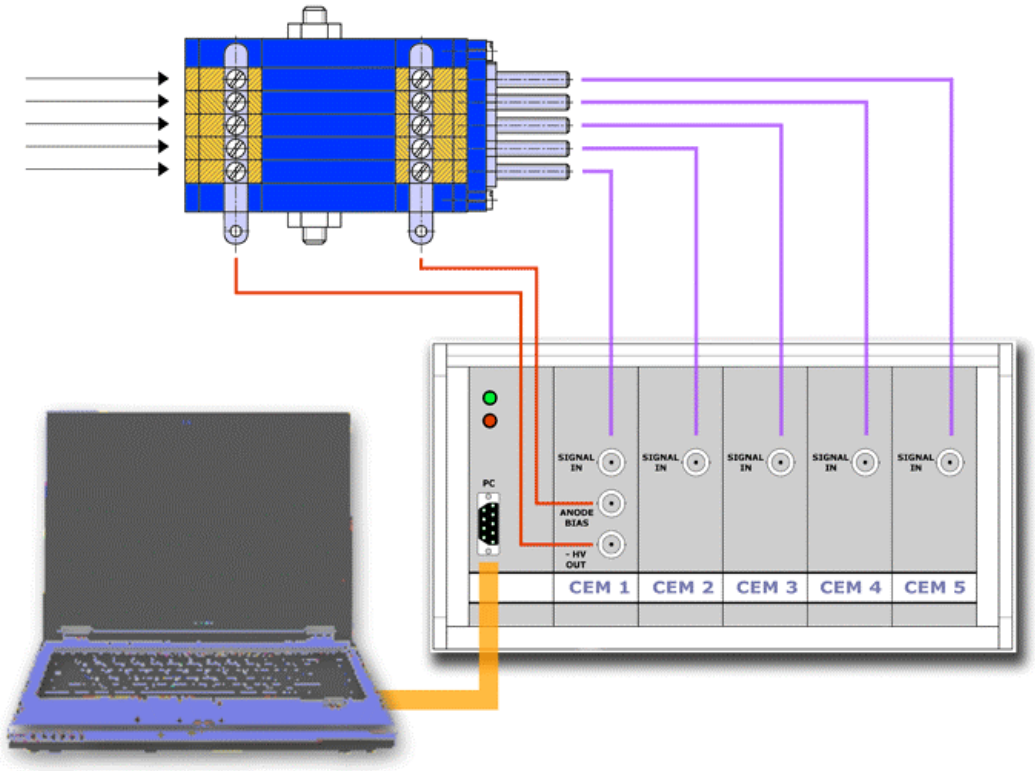

Fig. 2: CEM-array with negative high voltage

The collection plates are grounded in the plug-ins through the 50 Ω input resistance, the CEM channel voltage is:

$$V_{channel} = - HV - ANODE\ BIAS = - (HV - 120\ V)$$

For positive high voltage supply the collection electrodes must be biased to high voltage with a resistor, typically 1 MΩ, and connected to the signal inputs of the counting plug-ins via a high voltage capacitor, typically 220 pF to 470 pF.
The resistors and coupling capacitors are best placed within the vacuum chamber directly at the CEMs.
If this is not possible, they have to be placed directly at the throughputs. The signal cable (coaxial 50 Ω type) must not carry high voltage, because the dielectricum is not a perfect insulator. Free charge carriers are moved by high voltage, and these current pulses are detected in the counter and will be interpreted as dark current pulses, although not created in the CEM.

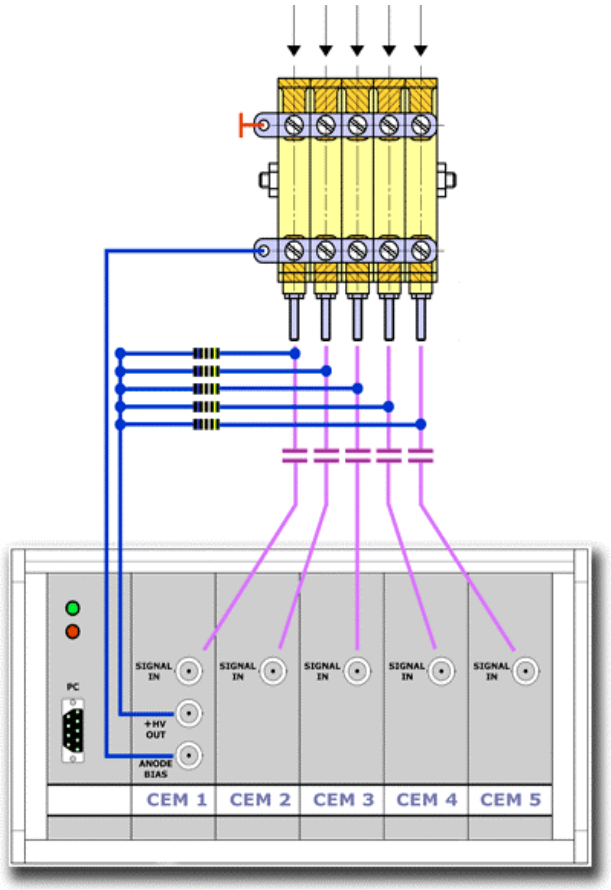

Fig. 3: CEM-array with positive high voltage

The CEM channels are grounded at the inputs and biased to ANODE BIAS, the collection electrodes are biased to HV. The CEM channel voltage is:

$$V_{channel} = \text{ANODE BIAS} = \text{HV} - 120\ \text{V}$$