EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN–ECP/95–30
21 December 1995

MC-128: A CURRENT COMMUTATOR FOR SILICON-STRIP DETECTOR TESTS

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Abstract

The MC-128 is a CAMAC module designed to simplify routine tests of multichannel semiconductor detectors. The module provides sequential measurement of the currents flowing from 128 channels, corresponding to 128 strips of a detector, to a grounded Common Bus. As an option, the MC-128 allows the measurement of the capacitance between each strip and the common (high-voltage) electrode of the detector at 10 kHz frequency.

The first practical tests of MC-128 in measurements with ATLAS prototype strip detectors produced by the MSU (Moscow) group within the framework of the RD-2 Collaboration showed results well within the specifications. The plans for the development of a CAMAC single-element detector test station STS-1 and of a standalone module UTS-1 both providing a bias voltage of any polarity are also presented.

1 INTRODUCTION

The MC-128 is a CAMAC module designed to simplify routine tests of multichannel semiconductor detectors. It was developed at the Budker Institute of Nuclear Physics (BINP), Novosibirsk, in collaboration with the RD2 group, as part of the ATLAS SCT development programme.

The module provides 128 channels, offering sequential measurement of the currents flowing from detector strips to a grounded Common Bus. Each input stays virtually connected to the Common Bus independently of whether its current is measured or not. Eight inputs are permanently connected to the Common Bus, allowing the connection of additional elements such as guard ring structures. The total detector current can be measured as the current flowing through the Common Bus. Measurements are accessible via a CAMAC bus and in analog form via a front panel connector. As an option, the MC-128 allows the measurement of the capacitance between each strip and the common (high-voltage) electrode of the detector at a frequency of 10 kHz.

2 MC-128 SPECIFICATION

The specifications of the MC-128 are presented in Tables 1–3 below.

Table 1
Main parameters of the MC-128

Number of switching channels	128
Number of permanently connected channels	8
Output CAMAC code	24 bits
Single channel measurement rate	10–100 Hz
Switching channel measurement rate	1.5–15 Hz

Table 2
Current measurements

Current measurement range for a switching channel	±10 μA
Current measurement range for the Common Bus	±10 mA
Maximum allowable current in each channel	±5 mA
Maximum allowable Common Bus current	±100 mA
Peak-to-peak noise for switching-channel current	±50 pA
Peak-to-peak noise for Common Bus current	±50 nA
Offset error	±50 pA
Gain and nonlinearity error	±1.0%
Maximum input voltage drop for a 10 μA current in a switching channel	±0.1 V
Maximum input voltage drop for a 10 mA Common Bus current	±0.1 V

Table 3

Capacitance measurements in switching channels (optional)

Test AC frequency	10 kHz
Amplitude	0.5 V
Full-scale range	100 pF
r.m.s. noise	±0.1 pF
Offset errors	±0.1 pF
Gain and nonlinearity errors (not including cable errors)	±5%

3 MC-128 FUNCTIONAL DESCRIPTION

The MC-128 can be divided into an analog and a digital part (Fig. 1). The analog part consists of: an analog multiplexer, low-pass filters, and an ADC. The digital part of consists of: a microprocessor, a CAMAC interface, a LED indicator, and manual control keys.

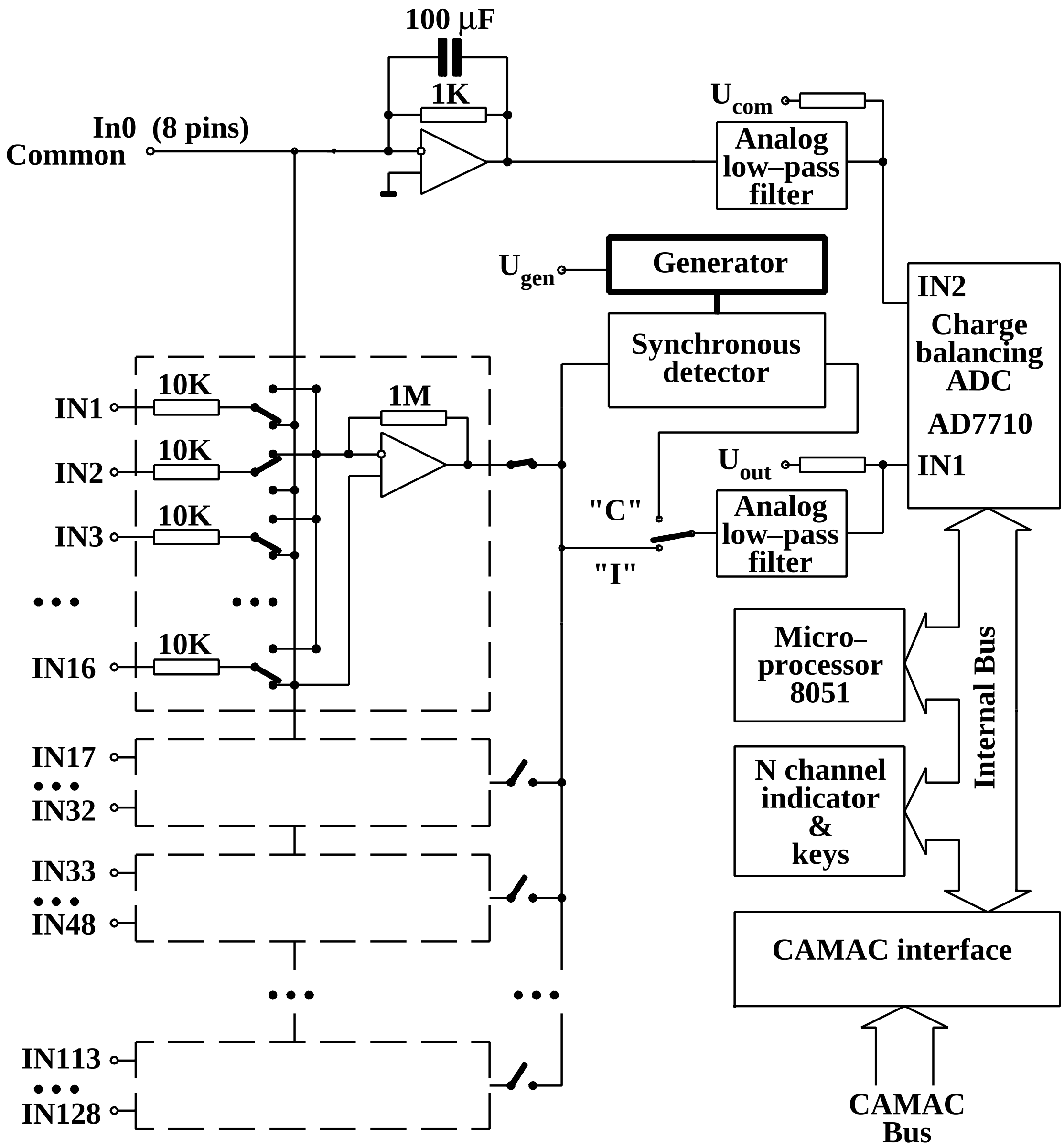

Fig. 1 MC-128 functional diagram.

3.1 Analog part

3.1.1 Multiplexer

The analog multiplexer is separated in two stages. The first consists of eight identical 16 $\rightarrow$ 1 sections operating simultaneously. Each section contains 16 switches and one amplifier. For single-channel measurement only one channel is connected to the amplifier input, all others being connected to the Common Bus. For Common Bus current measurement or for a measurement of amplifier offsets all channels are connected to the Common Bus.

The switch functionality is illustrated in Fig. 2. The input current is converted to voltage using the current amplifier (1) while the potential at the input is kept at ground by the feedback resistor (2). The advantage of switching channels at ground potential is that, since no recharge of input capacitance is required, the set-up time after each channel switching can be reduced. Another advantage is the reduction of leakage current, since all signal lines and the grounded guard rings have the same potential. Each input switch consists of two field-effect transistors especially selected for low leakage currents. The first one (4) is an n-channel FET that connects the current of an 'off' switch directly to the Common Bus, which is also at ground potential. The other (5) is a p-MOS that connects the input to the amplifier. The use of different transistors allows the gates of both transistors to be connected together, so that one is opened when the other is closed. This switch provides a good electrical shock protection. The input resistor (3) of each channel provides negligible voltage drop for normal input current, but reduces the input current in case of electric shock. Excess positive voltage will open the diode between the channel and the substrate of the p-MOS transistor and a current will be drained to the Common Bus. Excess negative voltage will be drained through the gate of the n-channel transistor to a protection circuit at a control line.

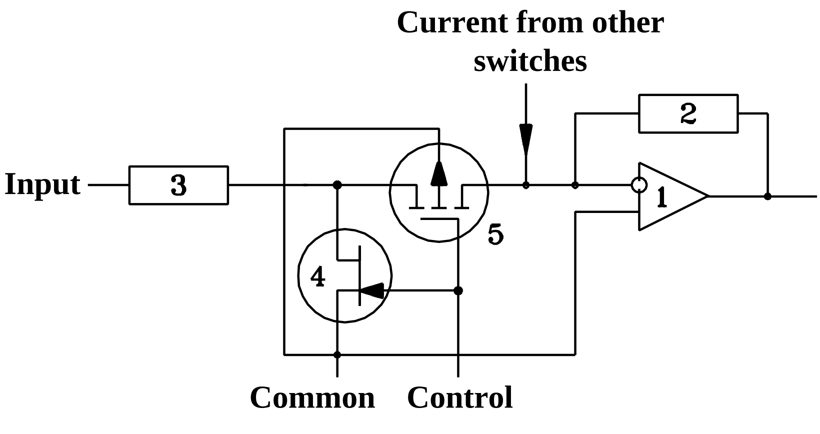

Fig. 2 Schematics of the switch.

The second multiplexing stage is a single 8 $\rightarrow$ 1 multiplexer. It has an analog low-pass filter at its output. The filter's output is also accessible at the front panel as:

$$U_{out} = 1\ M\Omega * I_{inp}\ .$$

The Common Bus amplifier converts the Common Bus current to a voltage, which is also available at the front panel as:

$$U_{com} = 1\ K\Omega * I_{com}\ .$$

Note that a connection of an external voltmeter to the control connector can increase the conversion noise of the MC-128.

3.1.2 The AD7710 ADC

Both U_{out} and U_{com} are connected to the AD7710 ADC. The AD7710 consists of an input commutator, an internal reference, a charge-balancing ADC, and an output digital filter.

The first notch of the digital filter can be programmed via the on-chip control register. The data rate of the ADC is equal to the first notch frequency of the digital filter. This data rate can be obtained by one-channel measurements. In case of sequential channel measurements the data rate is reduced by a factor 6. One period of data rate is used for synchronization, four periods for a filter setting time and one period for a measurement. The AD7710 can execute a calibration sequence that allows the subtraction of the input amplifiers' offsets. The microprocessor of the MC-128 automatically forces this calibration sequence when the input amplifier offset changes. The calibration sequence also requires some time.

The AD7710 provides up to 24 bits of no missing codes performance. The effective resolution, defined as the magnitude of the output r.m.s. noise with respect to full-scale input at 10 Hz first notch frequency, is 21.5 bits. It means that at the ±10 μA range of the module the internal ADC convention r.m.s. noise is less than 7 pA. It corresponds approximately to 40 pA peak-to-peak noise. The full noise, including switches, amplifiers, and ADC, is less than

±50 pA. Note that this noise included in an amplifier's offset during the calibration sequence can give an offset error up to ±50 pA for a group of measurements.

3.1.3 Capacitance measurement

In the capacitance measurement option, a built-in generator and a synchronous detector are added. A front panel switch allows the choice between current and capacitance measurements.

The generator provides a 0.5 V sinusoidal signal at a 10 kHz frequency. This signal is added to the bias voltage applied to the detector. The AC component of the current of each channel is detected by a synchronous detector which can be connected between the second step of the multiplexer and the analog low-pass filter (Fig. 1). The synchronous detector selects the reactive current component and suppresses the active AC component, allowing the measurement of the capacitance current only. The full-scale range for capacitance measurement is 100 pF with a resolution of better than 0.1 pF.

The gain error, mainly due to a slow drift of the generator amplitude and phase, is not more than 5%. Because of the low input impedance to ground of the MC-128, practically all input current flows directly to the input amplifier, and only a small part of the AC current flows to the ground through the cable capacitance. A 100 pF cable capacitance at frequency of 10 kHz has a 150 kΩ impedance to ground, compared with the 10 kΩ input impedance to ground of the MC-128. So only 7% of AC current will be lost, limiting the error due the cable capacitance. Using a sample capacitor for calibration procedures in one of the channels, both the slow drift and cable errors can be reduced to 0.1–0.2%.

3.2 Digital part

The digital part consists of an Intel 8051 microprocessor, a CAMAC interface, a LED indicator, and manual control keys.

3.2.1 The 8051 microprocessor

Most CAMAC functions are interpreted by the microprocessor. One of its main functions is ADC and commutator control. It also provides a proper measurement sequence: switch the commutator to the next channel, invoke the calibration sequence when the amplifier offset changes, wait for the filter setting time, get the data, and transfer the data to CAMAC interface.

The microprocessor allows the easy addition of new CAMAC functions to the MC-128 module. For example, to operate the module via a Macintosh computer with a Micron card and a MAC-CC crate controller working only with 16 bits of CAMAC bus, a new CAMAC function was added, which allows one to read bits 24–17 of the data through the R8–R1 lines. To implement the new function it was sufficient to reprogram the ROM chip that contains the program executed by the microprocessor.

The microprocessor also supports manual operations, with the MC-128 used as a commutator and current amplifier. The commutator can be switched to any channel by pressing the front panel keys, and doesn't require any computer control.

3.2.2 Calibration

There are two different calibration modes, mode 0 and mode 1, differing in the way the amplifier offsets are treated.

In mode 0 a calibration is performed during the setting of a new channel, switching to the next section of the commutator or switching to the Common Bus channel. In this case the calibration routine will include the amplifier offsets, so that the measured data do not contain the offsets.

In mode 1 a calibration is performed only when the ADC input is switched and the ADC inputs shorted, so that the measured data will include amplifier offsets. The offsets can be measured separately and subtracted by software.

3.2.3 CAMAC interface

The CAMAC interface consists of an input register, an output register, and a logic which decodes CAMAC functions. It can execute the simplest standard CAMAC functions such as F8, F24, F26. All other functions only reset the Module Ready Trigger of the CAMAC interface and then these functions can be executed by the microprocessor. After finishing the execution the processor sets the Ready Trigger up. The Ready Trigger of the CAMAC interface affects the Q and LAM signals. When the module is not ready there is no LAM or Q.

3.3 Front panel

At the front panel there are two 68-pin input connectors. Each connector contains 4 pins connected directly to the Common Bus and 64 input pins (see Appendix A).

It also contains:

- U_{out} LEMO connector — output of analog multiplexer;
- U_{com} LEMO connector — output of common bus current amplifier. The signals from these two connectors always contain amplifier offsets, which should be measured separately;
- LED indicator of channel number;
- Two keys ‘<’ and ‘>’ for manual control of the analog multiplexer. Pressing one key decreases or increases the channel number. By pressing both keys simultaneously, all switches are turned OFF in the first step of the analog multiplexer, and a measurement of the amplifier offset is performed;
- Switch for toggling between a current and a capacitance measurements;
- U_{gen} LEMO connector — AC generator output.

3.4 MC-128 CAMAC functions

There are two groups of CAMAC functions. The first group consists of functions that can be executed at any time by a CAMAC interface:

- F24, A0
  Disables LAM. Returns X = 1, Q = 1.
- F26, A0
  Enables LAM. Returns X = 1, Q = 1.
- F8, A0
  Tests LAM. Returns X = 1, Q = LAM.
- F9, A0
  Program Reset. Returns X = 1, Q = 1. It provides internal reset for the microprocessor. Sets LAM = 1 after finishing the reset sequence.

The second group of CAMAC functions includes F16 and F0 commands, which are interpreted by the microprocessor and therefore always require a testing of LAM before execution. F16 and F0 commands return X = 1 and Q = 1 if the MC-128 is ready (LAM = 1) to execute the command. If the module is not ready (LAM = 0) it returns Q = 0, and does not accept a command. If the LAM state is changed during the NAF cycle, unpredictable results can follow. It is therefore necessary always to wait for LAM = 1 before performing F16 or F0 commands. All these commands reset LAM to 0 and then set it to 1 when NAF is executed.

- F16, A0, N_{ch}
  Writes the channel number = N_{ch}, resets LAM, starts the calibration and measurement. When data is ready it sets LAM = 1. Valid values are:
  - $N_{ch} = 0$ – Common bus current
  - $N_{ch} = 1 \ldots 128$ – Input channels' current
  - $N_{ch} = 129$ – Commutator offset for ch. 1–16
  - $N_{ch} = 130$ – Commutator offset for ch. 17–32

....

N_{ch} = 136 – Commutator offset for ch. 113–128

- F16, A1, F_{n1}
  Writes first notch frequency in Hz. Valid values of F_{n1} = 10 ... 100 Hz.
- F16, A2, C_{mode}
  Writes calibration mode. Calibration mode affects channels 1–128 only and not channel 0.
  C_{mode} = 0. When the calibration sequence is started, the commutator zero offset will be included. Output data does not contain commutator offset. An F0, A2 command forces recalibration including commutator zero offset when commutator is switched to a next input amplifier and the zero offset changes. It also forces recalibration when the commutator switches the ADC inputs.
  C_{mode} = 1. Recalibration (always with shorted ADC inputs) will be executed only when the ADC inputs are switched.
  Note: calibration of channel 0 will always be executed with a shorted ADC input.
- F16, A3, N_{ch}
  Writes channel number, resets LAM, starts calibration only if channel number = 0, starts measurement. When data is ready, sets LAM = 1. This is recommended only with calibration mode = 1, otherwise unpredictable results may follow. Switching of a commutator from channel 0 to any other channel always requires recalibration, so this command can't be used in that case. Instead use of F16, A0, N_{ch} is recommended.
- F0, A0, data
  Reads data from output register.
- F0, A1, data
  Reads data from output registers and starts measurement in same channel.
- F0, A2, data
  Reads data from output register and starts next channel measurement. See also F16, A2.
- F0, A3, data
  Reads data from output register and starts repackaging of data so that bits 24–17 can be read after that command through lines R1–R8.

Data is a result of measurement in a form of 24-bit word. To obtain the actual current the following formula should be used:

$$I\ [nA] = 10250.0 \times (0 \times 800\ 000\text{-data})/0 \times 800\ 000 \text{ for channels 1–136 .}$$

The same formula gives a current in microamperes for channel 0.

4 PROGRAMMING FOR MC-128

The following example shows how to measure current in all channels:

```
F9 Initial reset
F26 Enable LAM
Wait for LAM
F16,A1,10 Set notch freq 10 Hz
```

```
Wait for LAM
F16,A2,0 Set calibration mode 0
Wait for LAM
F16,A0,0 Set starting channel number = 0 and start measurement
for (i = 0; i < 129; i++) {
    Wait for LAM
    F0,A2,data   Read  24  bit  data  and  start  next  channel
    measurement
    /* alternative for 16 bit CAMAC controller           */
    /*F0,A3,lowdata      read low 16 bits                */
    /*F0,A2,highdata     read high 8 bits and start next */
    /* data = ldata+highdata<<16                         */
    I[i]=10250.0*(0x800000-data)/0x800000
}
```

5 FIRST PRACTICAL RESULTS

The first practical tests of the MC-128 were performed at CERN in March–April 1995 in measurements of the ATLAS prototype strip detectors produced by the MSU (Moscow) group within the framework of the RD2 Collaboration. The connection diagram between the detector, high-voltage source, and external voltmeters are shown in Fig. 3. The system was connected to a Macintosh through a Micron card and MAC-CC crate controller. The software was developed under LabView 3.10. Some of the results obtained are illustrated in Figs. 4 and 5.

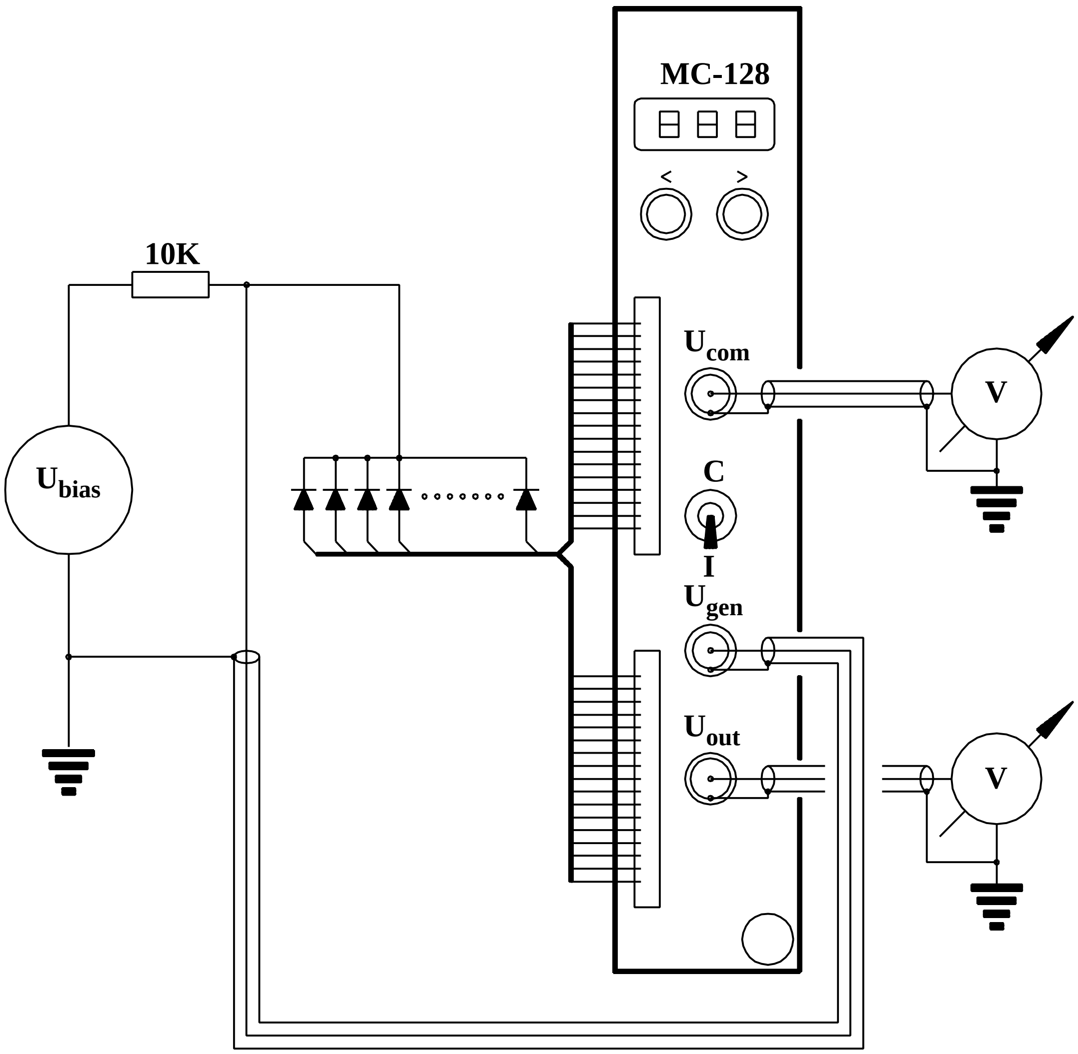

Fig. 3 MC-128 connection.

The tests confirmed the specifications of the MC-128. The module operation was stable and robust. The use of 1.5 m unscreened flat cable for the connection between the MC-128 and the detector did not significantly increase the noise level.

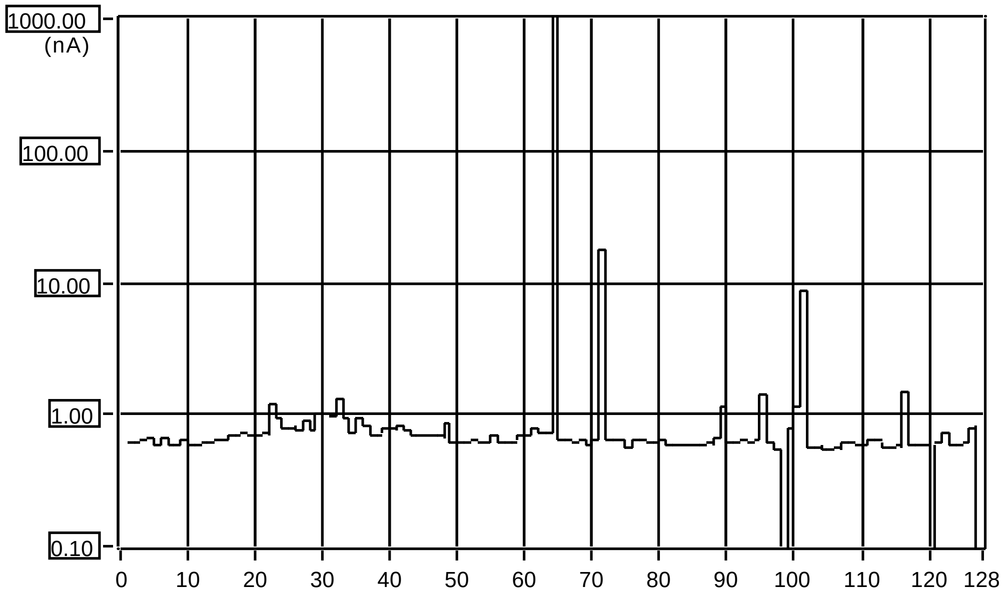

Fig. 4 Current distribution for 128 strips of a real detector measured at the depletion voltage 40 V. The typical current is slightly below 1 nA. Note the reliable measurement of the current at this level.

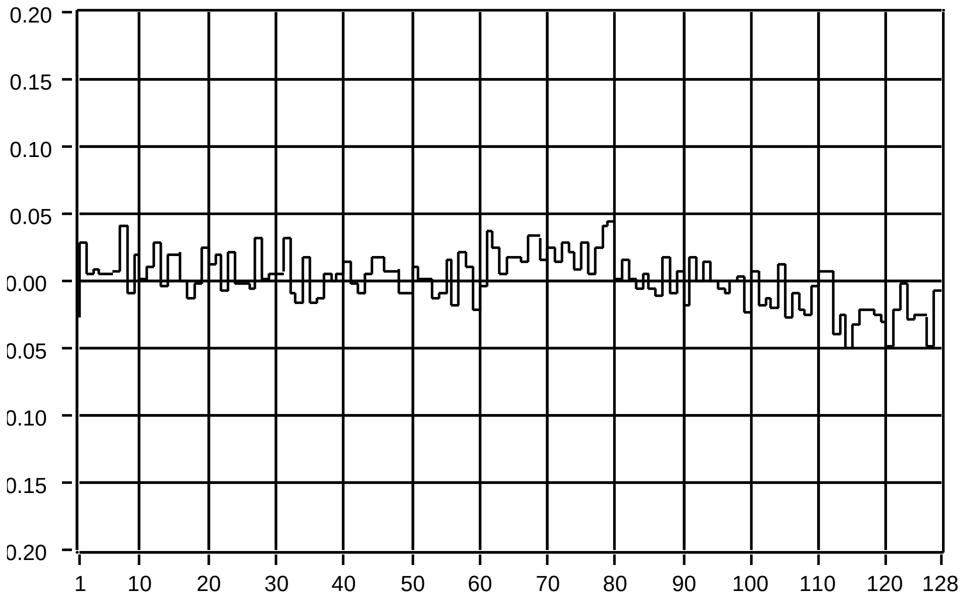

Fig. 5 Output current (in nA) vs. channel number measured with all 128 inputs floating. This distribution illustrates the intrinsic noise of the device.

6 PLANS FOR FURTHER DEVELOPMENTS

One natural direction for the further development is to supplement the MC-128 by a compact Detector Power Supply Unit in CAMAC that will be able to change programmatically a bias voltage in a range 0 – ±1000 V. This module will allow also a measurement of the total output current and of the temperature near the detector. Such a module, associated with an MC-128, makes up a fairly complete system for standard I-V, C-V measurements. As a stand-alone device it can be used as a compact programmable Power Supply Unit for semiconductor detectors allowing I-V measurements for a single element detector.

Another possible development is a creation of a powerful stand-alone Detector Test Station with a GPIB interface and a wide range of abilities for I-V and C-V measurements.

Both these options are now under discussion. The preliminary specifications for the above-mentioned devices can be found in Appendices B and C.

Acknowledgements

The authors are pleased to express their sincere gratitude to A.G. Clark for the stimulating discussion and support for this project. They are also very grateful to B. Lisowski and M. Merkin for their help in performing tests at CERN.

APPENDIX A

INPUT PIN-OUT FRONT VIEW

Table A1
Top connector

common	common
96	128
95	127
...	....
...	...
66	98
65	97
common	common

Table A2
Bottom connector

common	common
32	64
31	63
...	...
...	...
2	34
1	33
common	common

APPENDIX B

PRELIMINARY SPECIFICATIONS FOR THE FUTURE SINGLE-ELEMENT DETECTOR TEST STATION STS-1

The STS-1 is housed in a 3M CAMAC module. The voltage is set and controlled via a computer and is indicated on the front panel. An additional control on the front panel allows manual change of the voltage in a simple up-down mode in 1 V steps. A special button on the front panel allows manual switch-off of the voltage. Another button allows restoration of the previously set voltage. The voltage growth rate is about 100 V/s.

The output current is measured via computer and is indicated on the front panel. A temperature sensor situated on a cable which cannot exceed 5 m length is connected to the module via a connector on the front panel. Temperature is measured via computer and is also indicated on the front panel. Optionally STS-1 may provide a measurement of capacitance between the high voltage and the ground electrodes of the biased device. The capacitance value is available via computer with simultaneous indication at the front panel.

The characteristics of the STS-1 are summarized in Table B1.

Table B1
Characteristics of the STS-1

Output DC voltage	
Output voltage	0–1000 V (any polarity)
Voltage setting accuracy	0.1 V in the range 0–100 V 1.0 V in the range 100–1000 V
Voltage oscillations	< 0.1% and < 0.1 V
Temperature stability	Better than 0.01 V/°C
Output DC current	
Maximum output current	10 mA
Measurement accuracy:	$0.01 \times (I_{out} + 1\ \text{nA})$
Temperature measurements	
Measurement range	–40°C – +60°C
Accuracy	0.1°C
Capacitance measurement	
Frequency	0.1–1000 kHz (variable by factor 10)
Amplitude of the AC signal	0.5 V
Range	0–200 pF
Accuracy	0.2 pF

APPENDIX C

UNIVERSAL TEST STATION UTS-1

The UTS-1 is a stand-alone module with a built-in power supply from the mains. It is fully controlled manually and via a GPIB (IEEE-488 Standard) interface. It provides bias voltage of any polarity with indication at the front panel.

After being set up, a voltage can be switched off ('killed') and then switched on ('restored') to the previously set value by special <Kill> and <Restore> buttons (and corresponding GPIB commands). The voltage growth rate is 100 V/s. Output current is measured at the high-voltage side of the detector. In all operation modes the total output current is always indicated at the front panel and is available via the GPIB.

There are 128 switching channels allowing sequential measurement of the current in these channels at the ground side of the detector. (For a specification of these measurements see Section 2 of the main text.) The switching of the measuring channels can be made manually in a simple 'up-down' way or via GPIB in an arbitrary way. In all cases the channel under measurement and the current in it are indicated at the front panel and are available via GPIB. For simplicity of a single-element detector connection the channel 1 input is duplicated by a separate connector at the front panel.

In another operation mode a capacitance to a common (high-voltage) electrode of the detector can be measured for any channel as well as for any subgroup of them belonging to the same first step commutator amplifier (see Section 3.1.1 in the main text). By manual selection any single channel can be chosen for a capacitance measurement. A more complex group composition may be achieved via computer. A value of capacitance is indicated at the front panel and is available via GPIB.

The switch between the I-mode and C-mode can be done either manually or by computer. There is a temperature sensor situated on a cable of up to 5 m length connected at the front panel. A temperature reading is available at the front panel indicator and via GPIB.

The characteristics of UTS-1 are summarized in Table C1.

Table C1
Characteristics of the UTS-1

Dimensions	(to be specified later)
Output DC voltage	
Output voltage	0–1000 V (any polarity)
Voltage setting accuracy	0.1 V in the range 0–100 V 1.0 V in the range 100–1000 V
Voltage oscillations	< 0.1% AND < 0.1 V
Temperature stability	better than 0.01 V/°C
Output DC current	
Maximum output current	10 mA
Measurement accuracy:	$0.001 \times (I_{out} + 1 \text{ nA})$
Temperature measurements	
Measurement range	–40°C – +60°C
Accuracy	0.1°C
Capacitance measurement	
Frequency	100 Hz, 1 kHz, 10 kHz, 100 kHz, 1000 kHz. A 20 Hz measurement is possible with 5 times worse accuracy.
Amplitude of the AC signal	0.5 V
Range	0–1000 pF
Accuracy	Up to 100 pF: $0.01 \times C + 0.1$ pF Above 100 pF: $0.01 \times C + 1.0$ pF