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An instrument for low-level measurements of the leakage current from high-voltage biased detectors

C. Arnaboldi, R. Bertoni, A. Delucia, G. Pessina*, N. Redaelli, T. Tabarelli

INFN Istituto Nazionale di Fisica Nucleare, Sez. di Milano-Bicocca and Facoltà di Fisica di Milano-Bicocca, P.za della Scienza 3, 20126 Milano, Italy

Abstract

Resistive Plates Chambers (RPC) are detectors biased at High-Voltage (HV) in excess of 4 kV. When fired by a particle, they develop a large signal current that can be read across a small resistance, 100 Ω or so. A characterization has been made of their ageing as a function of the behaviour of their leakage current with time. An array of 10 detectors has been developed for this purpose. We present the instrument designed and built to perform a continuous and automatic monitoring of the leakage current from each detector of the array, while the system is taking data. For the particular biasing set-up adopted, the current has been measured in series to the terminal connected to the HV of every channel. Since the small value of the currents, order of tens of nA, a special circuit solution and special precautions have been adopted.

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Keywords: Low-Level current measurements; High-Voltage Monitoring; Resistive Plate Chambers (RPC); Detectors

The monitoring of the leakage current from detectors while they are running is useful for having a diagnosis of the operating conditions. A typical application example is the study of the ageing of Resistive Plate Chambers (RPC) [1,2], strictly related to their leakage current, that can range from a few nA to μA, at the end of their useful life. The instrument to be dedicated to this role must be capable of measuring the detector currents starting from such small levels, switching between different channels without adding any disturbances to the acquisition system. Some solutions have been already implemented for larger range of currents [3]. In this paper, we introduce our system that is able to guarantee the requirements for an array of 10 RPCs.

The principle of operation of the developed instrument is shown in Fig. 1. The biasing of the array of detectors was chosen using only one High-Voltage (HV) supply (4.5 kV in our experiment). A first voltage attenuator composed of R_A, R_B and R_S allows to read and monitor the HV only, at the node V_{COM}. The value of R_A is 30 GΩ, while that of R_B and R_S are 40 MΩ and 2.2 MΩ, respectively. Therefore, the attenuator reduces the HV supply by a factor of 750 V/V at the measuring node. In Fig. 1 beside the divider R_A, R_B and R_S, the layout connection for the readout of the *i*th detector is shown. The detector is connected to the HV through the sensing resistor R_{Si} ($R_{Si} = R_S$ in value), across which its leakage current develops a voltage. The node connected at the smaller potential of R_{Si} is probed by means of the voltage attenuator R_{Ai}, R_{Bi} ($R_{Ai} = R_A$ and $R_{Bi} = R_B$ in value), at the node V_i.

A system consisting of an array of relays (of which SW_r and SW_i are two examples) allows selecting the node to be measured. The difference between V_{COM} and V_i results proportional to the leakage current I_{Li} of the *i*th detector according to:

$$V_{COM} - V_i = \frac{R_B}{R_A + R_B + R_{Si}} R_{Si} I_{Li} = \frac{R_{Si}}{750} I_{Li}. \tag{1}$$

Voltages V_{COM} and V_i have a large common mode, of about 7 V in our experiment. It is cancelled at the Instrumentation Amplifier (IA) input by proper setting of a 12 bits DAC (Analog DAC8043) whose output is V_{REF}. A dedicated value of V_{REF} is determined for every individual channel at the start up of the measurement

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*Corresponding author. Tel.: +39 02 64482825; fax: +39 02 64482463.
E-mail address: Ganluigi.Pessina@mib.infn.it (G. Pessina).

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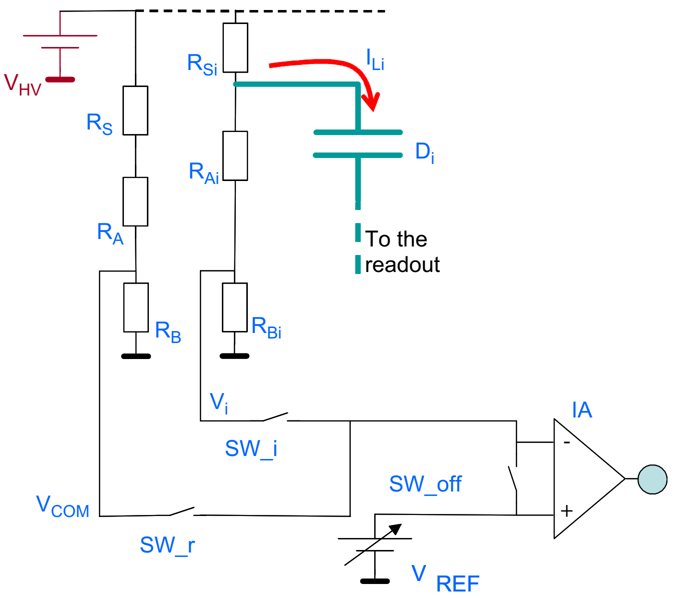

Fig. 1. Schematic diagram of the system to measure the leakage current of a single channel. $R_A = R_{Ai} = 30\,\text{G}\Omega$, $R_B = R_{Bi} = 40\,\text{M}\Omega$ and $R_S = R_{Si} = 2.2\,\text{M}\Omega$.

and settled anytime the corresponding channel is to be monitored.

This large common mode voltage can also generate an offset at the IA output, although the selected IA was chosen having a very large common mode rejection ratio (Burr-Brown INA116). To account for this error, the relay switch SW_off of Fig. 1, is actuated after every measurement. This way, the offsets generated by the common mode signals at the IA output, can be measured and subtracted from the values found previously for the corresponding V_i and V_{COM} voltages.

In a very long and continuous operated experimental run, the temperature of the environment may change. If a very precise measurement is required, the suppression of the temperature drift of any part of the measuring instrument should be made. For this reason, our instrument probes in separate steps the voltages V_{COM} and V_i to determine the current that flows in R_{Si}. A differential coefficient is obtain from V_{COM} that regards both the drift of the HV supply and the voltage attenuator itself, that otherwise are expected to give a constant reference signal. The same coefficient may be used with the other attenuators for the determination of the final V_{COM}-V_i. Since the other attenuators are made with the same technology, using the same temperature coefficient allows to obtain a rejection of the drift larger than 20 dB. Much larger drift suppression is obtained if every voltage V_i's is read, for a proper period of time, when the detectors are not connected to the measurement instrument and the temperature is also monitored at the same time (National Semiconductor LM50), since in this way the temperature dependence law for every channel will be fully available. We have adopted this last strategy in our experiment.

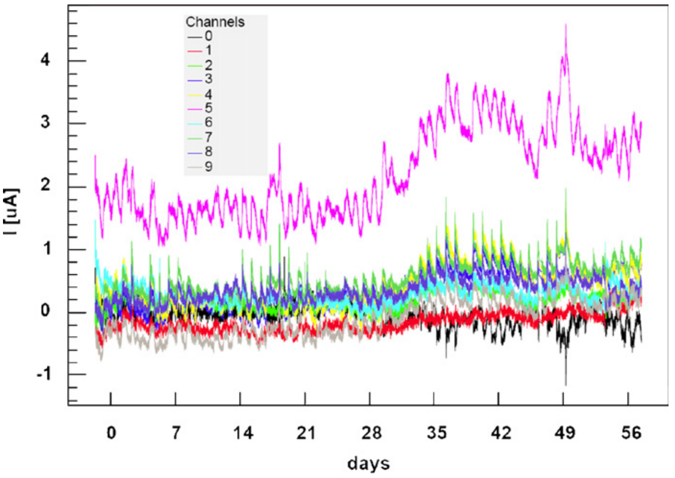

Fig. 2. Current from 10 channels of RPC taken across 2 months of running time.

The complete instrument consists of an analog board that is interfaced by a computer by means of a commercial PCI analog acquisition card, DAQ, put inside. It provides both the capability to read analog signals and also to manage digital I/O lines for the relays and DAC settling. The resolution of the DAQ is 16 bits. The present version of our set up has a voltage gain of 10 V/V for the IA. The voltage range that is compliant to our common mode signal is 10 V. Considering Eq. (1) and the values of the resistors used the Less Significant Bit (LSB) is equivalent to a leakage current of about 5.2 nA. Better sensitivity can be obviously obtained if the DAQ has a larger number of bits and/or the IA has larger gain and/or R_S is increased. The noise of the system is not a stringent limitation because the signals to be measured is static and can be filtered down to low frequencies.

Fig. 2 shows the monitoring of the leakage current of a 2 months run of an array of 10 RPCs, after the temperature compensation method has been applied (the drift of the set-up was characterized with a 4 days pre-run without the RPCs connected). As can be seen, the trend of the increase of the leakage current is common to all the detectors of the array, but one, that has shown a leakage greater than that of all the other during the whole experimental run.

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