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The front-end readout for CUORICINO, an array of macro-bolometers and MIBETA, an array of μ-bolometers

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Abstract

The front-end approach for the readout of two arrays of bolometric detectors is described. The first front-end is for an array of μ-bolometers, while the second is for an array of macro-bolometers. Analogies and differences in the adopted strategies are put into evidence.

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1. The front-end of MIBETA

MIBETA and CUORICINO are two arrays of bolometers. The MIBETA array is composed of 10 very small mass detectors, or μ-bolometers, each 260 μg on average. CUORICINO, by contrast, contains 62 channels and is the prototype of an array consisting of very large mass detectors, 760 g each. The MIBETA experiment, just stopped, was realized to study the electron anti-neutrino mass in the β decay of ^{187}Re [1]. The main system requirements for this experiment were good energy resolution and fast detector speed. We met both conditions by utilizing bolometers of small mass.

The dynamic impedance of a bolometer has both resistive and inductive components. To obtain high speed, 5–10 kHz bandwidth, the front-end input capacitance must be very small, to minimize signal integration.

In Fig. 1, we show the schematic diagram of the front-end of every channel of the MIBETA array. The bolometer, with impedance Z_B, is operated at about 90 mK, while its load resistor, R_L (1 GΩ), is held at about 20 mK. The signal is readout, through a short, high impedance link, using a Si JFET (Q_1), which works at its optimum temperature of about 110 K in a source–follower configuration. A room temperature differential voltage preamplifier (1000 V/V gain), PA, subtracts from the signal at the source of Q_1 any common mode disturbance present at the ground lead of the bolometer. A programmable amplifier (2–26 V/V

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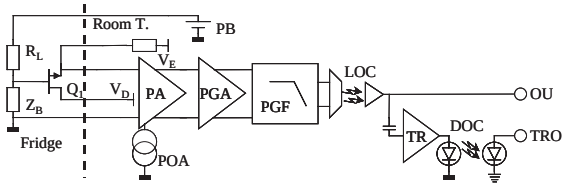

Fig. 1. Schematic diagram of the front-end set up for the array of μ-bolometers MIBETA.

gain), PGA, followed by the a 4-pole, active, antialiazing programmable Bessel filter PGF (500–12 800 Hz bandwidth), completes the second stage. The second stage has been made fully programmable to allow for compensation of the different characteristics typical of individual bolometers. In this way the full range of the acquisition system, DAQ, connected to the analog output OU can be exploited. The offset present at OU is auto-adjusted, when fired, by the programmable current source, POA, which injects a proper static current in a node of PA. In the set-up of Fig. 1 the coupling of PA to the JFET is not fully AC, and a small DC gain is left that allows the possibility to characterize the detectors at any time, for monitoring purposes, by varying the programmable detector bias PB.

Ground loops (GL) are minimized by the use of the specially designed analog linear optical buffer amplifier LOC.

The trigger circuit (TR) generates a digital pulse that is optically coupled to the DAQ. The realized circuit has been designed to suppress any possible re-triggering effect that may be generated by those large signals presenting an undershot, resulting from the coupling of the inductive component of the bolometric impedance with the shunting capacitance of the connecting link. Since the trigger circuit is AC coupled, the rising edge of the undershoot would be seen as a spurious signal if not rejected.

The white, or high frequency, voltage noise at the input of PA is about $1\,\mathrm{nV}/\sqrt{\mathrm{Hz}}$; the low-frequency component leads it to $2\,\mathrm{nV}/\sqrt{\mathrm{Hz}}$ at 1 Hz. The cold JFET has a white voltage noise of about $4\,\mathrm{nV}/\sqrt{\mathrm{Hz}}$. At 1 Hz it becomes $15\,\mathrm{nV}/\sqrt{\mathrm{Hz}}$ due to the low-frequency contribution. Parallel noise is totally negligible, since the vanishing value of the gate current. The cold JFETs are biased to minimize their power consumption: $V_{DS} = 1\,\mathrm{V}$, $I_{DS} \approx 0.3\,\mathrm{mA}$. The present version of the cold front-end gives a negligible contribution to the energy resolution when the array is operated at 60 mK, where the signal-to-noise ratio is a maximum. At the chosen operating condition of 90 mK, a trade-off between high speed and adequate energy resolution, the detector noise lowers and the front-end noise rises its contribution to a factor of about $\sqrt{2}$.

2. The front-end of CUORICINO

The aim of CUORICINO is to study the neutrinoless double β decay of ^{130}Te [2]. Each detector of the array is composed of a 760 g TeO_2 crystal to which a Ge NTD thermistor is glued.

The very slow signal bandwidth is the main feature of a massive bolometer. For CUORICINO it is 8 Hz, on average. As a consequence, the front-end electronics must contribute very little noise at small frequencies. It must also has very little drift, since the readout must be DC coupled to the detector.

As a result we have adopted the strategy shown in Fig. 2. A differential, cold, buffer stage that works at about 100 K, is located closed to the bolometer, Z_B, which is operated at about 10 mK. The load resistors R_L (each 27 GΩ) are located near the buffer stage, at 100 K. The link that connects Z_B to Q_1 and Q_2 is a twisted cable that minimizes signal cross–talk, microphonics of the link itself, and electromagnetic interference.

The differential voltage preamplifier, PAC, (220 V/V gain) reads the signal at the sources of

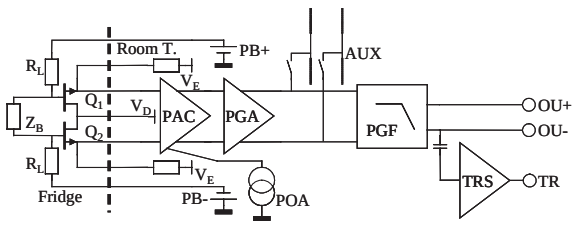

Fig. 2. Schematic diagram of the front-end set up for the array of macro-bolometers CUORICINO.

Q_1 and Q_2. The second stage PGA and PGF are similar to the ones described in the previous section, except the range of the gain, 1–45 V/V, and the filtering bandwidth, 8–20 Hz with 6 poles of roll-of. Since the frequency bandwidth is small, and the roll-off of the filter is steep, it was not necessary to use a linear buffer optocoupler to suppress GL.

The current source POA auto-adjusts the output offset. The trigger circuit TRS is an AC coupled (2–10 V/V gain) amplifier with the same re-triggering suppression circuit as for MIBETA.

The cold stage for CUORICINO has been used to read-out 24 detector channels. Two metallic boxes, anchored at the 4.2 K plate of the refrigerator, each contain two boards with 6 differential buffer channels and the load resistor pair. The remaining 38 channels of the array do not make use of the cold buffer stage, Q_1 and Q_2 of Fig. 2, and the detectors are directly connected with a twisted cable to the preamplifier PAC. In this case the load resistors (R_L, each 27 GΩ) are at room temperature. An additional bus, AUX, can be connected to any output channel independently from the DAQ. This bus is used for the DC characterization of the bolometers and monitoring.

The cold buffer stage has the JFET operated at $V_{DS} = 0.5$ V and $I_{DS} = 0.3$ mA. The resulting voltage noise is about $10\,\mathrm{nV}/\sqrt{\mathrm{Hz}}$ at 1 Hz, while $2\,\mathrm{nV}/\sqrt{\mathrm{Hz}}$ is its white term. Current noise is totally negligible. The voltage noise of PAC is $4\,\mathrm{nV}/\sqrt{\mathrm{Hz}}$ at 1 Hz; $3\,\mathrm{nV}/\sqrt{\mathrm{Hz}}$ white. The current noise is about $4\,\mathrm{fA}/\sqrt{\mathrm{Hz}}$. A special circuit has been introduced in PAC that allows reducing the input drift to $\leqslant 0.2\,\mu\mathrm{V}/^\circ\mathrm{C}$. The electronics circuit described above adds negligible noise to the CUORICINO array.

The programmability of all the described features, for both MIBETA and CUORICINO, can be set remotely, via a fiber-optical link.

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