The cold preamplifier set-up of CUORICINO: Towards 1000 channels

C. Arnaboldi, G. Pessina, S. Pirro*

Dipartimento di Fisica dell’Università di Milano-Bicocca and INFN, Sezione di Milano, I-20126 Milano, Italy
Available online 18 January 2006

Abstract

We present the characterization of the cold preamplifier set-up of the CUORICINO Experiment. It consists of two single boxes located inside the cryostat, linked to the 4.2 K stage. Each box has 12 independent differential buffer channels, composed of 12 pairs of Silicon JFET transistors in source follower configuration and 48 pairs of load resistors (6.8 GΩ × 5 units/channel) for thermistor biasing. The operating temperature of the JFETs is ~110 K. The figure of merit of the set-up is a series input noise of about 35 nV_RMS in the 0–12 Hz detector bandwidth. Parallel noise is limited only by the load resistors (54 GΩ) to be about 1.2 fA_RMS. In order to build a 1000 channels bolometric array a further progress in the performances of the cold stage has been studied.
© 2006 Elsevier B.V. All rights reserved.

PACS: 07.20.Mc; 07.50.—e; 07.57.K; 84.30.Le

Keywords: Cold amplifier; Cryogenic detectors; Low noise JFET

1. Introduction

Thermal bolometer are cryogenic detectors with very high-energy resolution. Their output signal is in the low-frequency region so, to exploit their potential the front-end electronics must show very low series voltage noise as well as very low parallel current noise at low frequency. The Si JFET is a candidate transistor which can satisfy both these stringent requirements. There are two classes of bolometric detectors: large mass bolometers (macrobolometers) and very small mass bolometers (microbolometers). Both are characterized by a dynamic output impedance in the tenth to hundred of MΩ range. The first class has its signal bandwidth limited to around 10 Hz. In principle, they can be read out by a JFET located far from them, at room temperature, since they do not suffer from signal integration by the capacitance of the long connecting wires. In this operating condition, care must be taken for the room temperature operated JFET since its noise current may become a limiting factor. Due to the long connecting cables between the detectors and front-end, microphonic noise from wires vibration plays an undesired role in the low energy region. The work presented here is in support of the CUORE [1] experiment that will consist of 1000 macrobolometer (750 g each) for the search of neutrinoless Double Beta Decay and Dark Matter.

2. Experimental details

The single cold buffer stage used in CUORICINO [2] consists of 2 Printed Circuit Boards (PCB) made with woven fiberglass (15%/PTFE composite material which has shown a limited amount of radioactive contamination); each of them consists of six independent differential channels, composed of six pairs of silicon JFET transistors in source follower configuration and 48 load resistors for thermistor biasing (each channel has 4 + 4, series connected, surface mounted thick-film 6.8 GΩ resistors). The series connection of many resistors minimizes the electric field in each device, to which the low frequency noise is proportional [5]. The differential configuration of the bolometer read out helps in performing a strong rejection of the noise coming from wires vibrations. In fact, in this case the pair of read out wires generates similar, common, disturbances that are cancelled out at the cold buffer output. The dimension of the PCB is 104 × 32 × 0.5 mm³. The two PCBs are mounted “front-to-back” in order to

*Corresponding author.
E-mail address: Stefano.Pirro@mib.infn.it (S. Pirro).

0168-9002/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
minimize the occupied volume, as shown in Fig. 1. The distance between the two PCBs is 8 mm. The operating temperature of about 110 K is achieved by means of 0.4 mm diameter nylon wires that thermally decouple the two PCBs from the copper box in which they are enclosed. The box is gold-plated in order to minimize irradiation. The connecting wires between PCB and cold box are 25 \( \mu \)m diameter insulated Constantan wires. In order to minimize the thermal conductance to the cold box they are arranged in order to maximize their length, as shown in Fig. 1. The electrical connections to every differential channel consist of 2 Sources and one Drain (common to both transistors) contacts. Two additional wires serve to bias, through the load resistors, the bolometer. Within the PCB all the Drain contacts are connected together. The temperature of the PCB can be monitored by a surface mounted PT100 thermometer read out with the classical 4-wire set-up. To warm up the board two metal film resistors of 15 k\( \Omega \) are used. The source of every JFET is biased to the \(-10 V\) power supply through a 35 k\( \Omega \) resistor. The resulting working current is therefore 0.29 mA (~0.6 mA for each differential pair). Due to the large value of the source resistor, there is a very small spread in the working current of any JFET. The complete scheme of a single channel [3,4] is shown in Fig. 2.

3. Noise measurements

Once the cryostat is cooled down, the heaters of the PCBs are powered to warm up the cold electronics. Once the temperature is \( \sim 60 K \) the JFETs are biased. In normal operation the PCB is heated only through the power dissipated by the JFETs themselves. The working temperature is then set by trimming the common voltage \( V_{\text{drain}} \). We can exploit this method since the gain of the buffer stage was studied to be independent, within the used range, from \( V_{\text{drain}} \).

In order to measure the intrinsic noise of the cold stage, the CUORICINO bolometers were heated so that their resistance value becomes negligible.

A room temperature operated second stage amplifies the differential voltage present at the cold buffer stage output. An antialiasing filter is the last element of the chain, located close to the acquisition system. The whole front-end set-up has all its parameters remotely programmable [6].

We selected five temperatures for the noise characterization of the complete front-end. The measured noise from the various channels was found almost uniform. The mean standard deviation from the average of the noise spectra, 30\% at most, was observed only at low frequency. The noise spectra measured at different temperatures and mediated over all the measured samples are shown in Fig. 3. The main parameters of each measurement are summarized in Table 1. It has to be remarked that the smaller RMS noise of the detectors in the running CUORICINO is 340 nV\(_{\text{RMS}}\), one order of magnitude larger than the intrinsic noise of the described cold stages.
4. Future developments

For the future experiment CUORE we have to satisfy the stringent requirement to readout ~1000 channels. Power dissipation per unit volume inside the fridge must be smaller than the present one. To face this requirement, we have designed a new prototype cold stage. It is based on the use of a new JFET that has improved the noise and the power dissipation characteristics [7]. In addition the JFET are packaged in SMD, package SOIC8. These allow to reduce the space occupation. We have designed a new PCB based on these small size JFETs. We will use 25 µm diameter NiCr wires instead of Constantan, aiming therefore a reduction of a factor ~3 in the power flow from PCB to the copper box. The total volume occupied by a single channel decreased by a factor 2 with respect to the CUORICINO cold stage resulting in 3.3 cm³/channel. A very important characteristic when dealing with low background measurements is represented by the natural radioactive contaminations. The new PCB woven fiberglass (8% PTFE) shows a factor ~5 lower radioactive contaminations/channel with respect to the one of CUORICINO.

5. Conclusions

The cold stage developed for CUORICINO shows a noise performance (30 nV_{RMS} in the 0–12 Hz signal bandwidth) that is 1/10 of the mean noise of the 62 detectors and 1/5 of the noise of the best detector. The new prototype cold stage has been already developed having noise and power dissipation further improved.

References