A programmable multichannel antialiasing filter for the CUORE experiment

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A R T I C L E   I N F O
Available online 15 September 2009

Keywords:
- Double beta decay
- Bolometers
- CUORE
- Low-pass filter
- Bessel–Thomson
- Optical coupled

A B S T R A C T
The first prototype of antialiasing filter for the CUORE experiment is a board that accommodates 12 independent channels. Each channel is an active six-pole Bessel–Thomson low-pass filter (LPF) with a roll-off of 120 dB/decade. In order to adapt the bandwidth to every detector, the filtering frequency can be selected independently for every channel by a remote control between four possible values (8, 12, 16 or 20 Hz). The board is equipped with an ARM microcontroller which communicates with the on-board peripherals via I2C synchronous serial bus and with the remote control via CAN-bus. Important features are the low-cost, the compact realization and the capability to perform diagnostic routine remotely.

1. Introduction
The cryogenic underground observatory for rare events (CUORE) experiment will be placed in the Hall A of the Gran Sasso Underground Laboratories (LNGS) [1]. The main aim is the search of neutrinoless double beta decay in 130Te, a good candidate isotope as double beta source. The detector will consist of an array of 988 TeO2 bolometers arranged in a cylindrical configuration composed of 19 towers. Each tower will have four columns and each column will be composed by 13 crystals $5 \times 5 \times 5 \text{ cm}^3$ in size. The total mass of the detector will be 741 kg of granular calorimeter, corresponding to 600 kg of Te and to 203 kg of $^{130}$Te. The elementary sensitive element is the bolometer. It is composed of a the crystal (absorber) and by a Ge-NTD (neutron transmutation doped) thermistor (sensor) glued on it. CUORE bolometers are operated at a temperature of about 10 mK inside a $^3$He/$^4$He dilution refrigerator. An energy release in the crystal is converted in a voltage change across the thermistor. The typical amplitude signal variation is in the order of $\Delta V_{\text{TH}} = (100–200) \mu \text{V/MeV}$ with a typical rise and fall time in the range $t_r = (40–80) \text{ ms}$ and $t_f = (130–700) \text{ ms}$ severally.

2. Antialiasing filter board
The signal produced by the bolometer is amplified, digitized and analyzed off-line by optimal filtering algorithms in order to maximize the signal-to-noise ratio. To obtain an adequate frequency response an antialiasing filter placed at the downstream of the analog signal processing. The chosen filter is an active six-pole Thomson (or Bessel) low-pass filter (LPF) which yields a roll-off of 120 dB/decade and a gain, in passband, of 2 V/V. The main features of this filter are the maximally flat amplitude response and the maximally linear phase response in the passband. These features maximize the shape preservation in passband for the filtered pulse, avoiding distortion.

Each CUORE antialiasing filter board accommodates 12 channels. Each channel is composed of a differential input amplifier and by a cascade of three 2-pole voltage-controlled voltage-source (VCVS) filter cells. In order to adapt the bandwidth to every bolometer the cut-off frequency can be set independently to every channel by a remote control between four possible values (8, 12, 16 or 20 Hz). Each board is equipped with an ARM microcontroller (LCP2129) which communicates with the on-board peripherals via I2C synchronous serial bus and with the remote control via optically coupled CAN-bus. Important features are the low-cost realization and the capability to perform diagnostic/monitoring routine remotely. It is possible to monitor the board power supplies, the not filtered and the filtered stages through the internal 10-bit ADC of the LCP2129. An alert is notified at the occurrence of any trouble.

3. Board characterization
In order to characterize the board prototypes built, but also in view of the final production, we designed an automatic setup, based on a 18-bit National Instrument Acquisition System (NIAS) and on a Vtsch Environmental Chamber (EC). This system...

Table 1

<table>
<thead>
<tr>
<th>Board</th>
<th>Ch</th>
<th>( f_{\text{cut}} ) (Hz)</th>
<th>( f_1 ) (Hz)</th>
<th>( f_2 ) (Hz)</th>
<th>( f_3 ) (Hz)</th>
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</table>

The nominal values are the subscript of the table labels.

Table 2

<table>
<thead>
<tr>
<th>Fitted value (Hz)</th>
<th>( \sigma ) (Hz)</th>
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<tr>
<td>( f_{\text{cut}} )</td>
<td>( 0.0816 \pm 0.007 )</td>
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<tr>
<td>( f_1 )</td>
<td>( 1.200 \pm 0.200 )</td>
</tr>
<tr>
<td>( f_2 )</td>
<td>( 0.030 \pm 0.000 )</td>
</tr>
<tr>
<td>( f_3 )</td>
<td>( 0.040 \pm 0.000 )</td>
</tr>
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</table>

Fig. 3. Distribution of the output offset drift (with short-circuited input) as function of the temperature.

Fig. 2. Output offset voltage (with short-circuited input) as function of the temperature.

6-1/2 digits multiplexed multimeter (Keithley® 2700) measured the outputs. Changing the temperature from 0 to 60 °C, with a slope of 0.1 °C/min, it was possible to study the offset as function of the temperature. An example of output offset trend is shown in Fig. 2.

At first order, the dependence can be considered linear (parameter \( c \) of Fig. 2 is always negligible). Even in this case the distribution of the angular coefficient has a normal shape with a mean value of \( \mu_{\text{offset}} = (0.1156 \pm 0.2768) \mu \text{V/°C} \) (Fig. 3).

4. Conclusion

We have designed a board that accommodates 12 Bessel-Thomson six-pole anti-aliasing filters each one with a roll-off of 120 dB/decade, a gain of 2 V/V and four frequency bandwidths remotely selectable. The board also accommodates an ARM μ-controller with a developed firmware that allows to:

- communicate with a remote controller via optically coupled CAN-bus;
- configure the channels through the on board I2C bus;
- perform diagnostic routines in order to check the correct operation of the boards.

We have characterized the boards using an automatic system that will be exploited also for production characterization. The boards developed are fully compliant with the specifications of the CUORE experiment. Final production is under way.

Reference