Test of a Fully Integrated CMOS Preamplifier for HPGe Detectors

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***Abstract*– A CMOS fully integrated charge preamplifier for nuclear physics spectroscopy measurements, designed to work with HPGe detectors in the Gerda experiment is tested. The electronics is composed of two distinct circuits: a low noise charge sensitive preamplifier (CSA) and a fully differential low impedance coaxial cable driver (FDA).**

A couple of passive elements (few resistors and the feedback capacitor) are not yet integrated, in order to make the debug process easier and to fit their values to the specific needs of different set-up configurations. The preamplifier operates with +2.5 v / -2.5 v power supplies, 50 mW power consumption and 8 v differential output bipolar dynamic range at the driver side of the 50 ohm impedance cable.

Up to now, we tested it within an experimental set-up consisting of an encapsulated p-type germanium detector, operated at liquid nitrogen temperature by means of a custom Dewar container.

Reliability and robustness of the CMOS electronics and mounting set-up have been verified, e.g. in terms of immunity to normal operation of the detector high voltage power supply and integrity of IC bonding wires in contact with liquid nitrogen.

Long term stability of the preamplifier gain, although operating at almost constant temperature, has also been verified by overnight measurements.

Overall noise performance is worse than expected from previous set-ups with simulated detector capacitance, due to relatively larger detector capacitance and leakage current contributions previously not completely taken into account.

I. Introduction

ANALYSIS, design and testing of front-end readout electronics for γ rays spectroscopy with HPGe detectors has been investigated since the early years of nuclear electronics and many important results have been achieved, in terms of reliable preamplifiers with e.g. very low noise [1], large bandwidth and dynamic input range [2], part of which have already been manufactured to suit the needs of international experiments/collaborations.

In nearly all cases, the entire front-end electronics have been designed and implemented by means of discrete active and passive devices (J-FETs, BJTs, resistors, capacitors) and/or some "off-the-shelf" high performance operational amplifiers.

As the availability of segmented HPGe detectors increases with time, higher number of readout channels are being required by nuclear physics experiments. Moreover, in a few cases, additional needs related to specific applications must also be taken into account, e.g. the Gerda experiment [3].

Gerda is an experiment that searches for neutrino-less double beta decay (DBD) of Ge-76 deploying an array of germanium diodes enriched up to 87% in the isotope Ge-76. In GERDA both the diodes and the front end charge preamplifier are operated immersed in LAr without any encapsulation; LAr acts at the same time as cooling agent and shielding material against external radioactive radiation. The pulses produced by the cryogenic CSA are then processed by 14-bit, 100 MHz Flash ADCs: therefore the output stage must drive ~10 m long cables. As a direct consequence, the Gerda experiment also requires: i) very low power consumption per channel, ii) very small front-end electronics volume, iii) operation at cryogenic (77 k) temperature.

II. Method

This novel front-end electronics [4] has been designed in the AMS HV CMOS 0.8 um CZX technology. CMOS technology was chosen instead of more versatile BiCMOS processes because the front-end electronics has to operate also at cryogenic (77 k) temperature. The front-end electronics mainly consists of two separate parts: a very low noise preamplifier (CSA) followed by a low noise fully differential amplifier (FDA). The entire FDA and the inner section of the CSA designs are based on fully differential circuits. Specific care has been taken in order to increase the reliability of the front-end electronics with respect to electrostatic discharge (ESD) effects and leakage current spikes from the detector, by adding proper series clamping devices (trans-diode connected

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MOS and bipolar junctions) with different sizes and capabilities.

In order to test the electronics within a set-up as close as possible to the one of the Gerda experiment, we used a specifically designed Dewar container filled up with liquid nitrogen (Fig. 1-2) to cool down an encapsulated p-type HPGe detector; we connected the preamplifier to the crystal electrodes on the bottom side of the cryogenic capsule (Fig. 3) and acquired the preamplifier output signals on: i) a large bandwidth oscilloscope and ii) a standard nuclear spectroscopy electronics (amplifier, multi-channel analyzer, PC).

Fig. 1. Set-up of the energy resolution measurement test in Milan. The encapsulated germanium detector, Dewar container, mechanical holders and vacuum pump have been provided by the Gerda experiment.

Fig. 2. The Dewar container and the associated mechanical holder allow relatively easy handling of the HPGe detector both inside and outside of liquid nitrogen.

Fig. 3. The encapsulated HPGe detector just removed from the Dewar container. Special care has been taken to avoid excessive ice deposition on the electrodes and the electronics.

III. Application

The most important results of the test are summarized in Table I. Rise time and power consumption (less than 50 mW, 20 mW of which are because of voltage and current reference circuits that don't need to be replicated in case of multi-channel circuits) suit the need of the Gerda experiment. The relatively large output dynamic range suggests the possibility of using a preamplifier feedback capacitor of lower value, in order to increase the sensitivity and still maintain the required range. Energy resolution on 1.32 Mev 60Co peak is 3.03 Kev FWHM and energy resolution on pulser line (≈ 1 Mev) is 2.4 Kev FWHM, with 8 us shaping time. These results are worse than expected from previous measurements with spectroscopy pulsers and simulated detector capacitance (1.2 Kev @ 12 us shaping time).

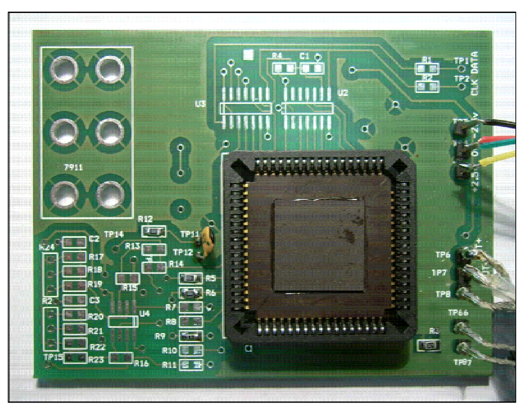

Fig. 4. The two layers prototype printed circuit board to test the integrated circuit. The six mounting holes on the upper right side of the board are specifically designed to suspend the electronics in the liquid nitrogen tank of the Gerda experiment. Size of board and integrated circuit ceramic carrier are optimized for functionality and not for area.

This may be seen as a result of: i) encapsulated detector capacitance (indirectly estimated to be 60/70 pF during high voltage ramping) larger than the expected value of 33 pF; ii) detector leakage current larger than expected and feedback resistor (300 MOhm) lower than before (1 GOhm resistor produced too much pile-upped pulses for the analog MCA), which didn't allow operation at longer shaping times; iii) stray capacitance on the preamplifier input node due to parasitic effects of the bonding wires and PCB traces (5/10 pF).

A much smaller printed circuit board (see Fig. 7) with 0.5 pF feedback capacitor, 600 MOhm feedback resistor and a different bonding wire scheme has been designed, in order to make it possible to test the preamplifier also with lower capacitance n-type HPGe detectors and hopefully improve the energy resolution.

TABLE I
MAIN RESULTS

Cf = 1 pF, Rf = 300 MOhm, Rout = 50 Ohm, Power supplies = ± 2.5 v, FDA gain = 2.4	
BW (CSA+FDA)	≈14 MHz
Rise time (CSA+FDA)	25 ns
Idle bias current	9 mA
Output voltage swing (before 50 Ohm series res.)	± 2 v

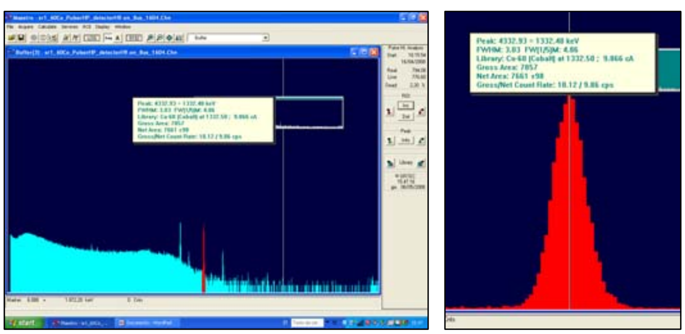

Fig. 5. ^{60}Co spectrum obtained at relatively high counting rate (4k/s) Energy resolution on 1.32 Mev 60Co peak is 3.03 Kev FWHM and energy resolution on pulser line (≈ 1 Mev) is 2.4 Kev FWHM, both at 8us shaping time.

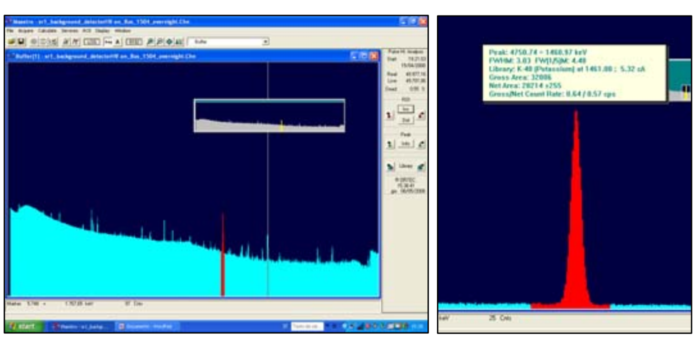

Fig. 6. Natural background spectrum acquired overnight (16 hours) at very low counting rate. Energy resolution on 1.46 Mev peak of ^{40}K is 3.03 Kev FWHM, with no noticeable evidence of peak shifts.

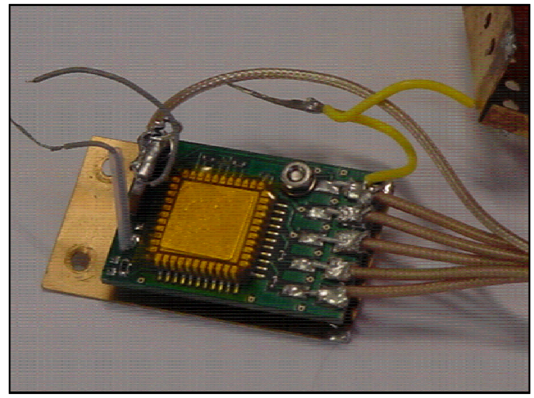

Fig. 7. The new prototype printed circuit board to test the integrated circuit. Board size (25 x 40 mm) is much less than the previous one, in order be able to test the circuit inside small volume cryostats. Connection to the detector are provided by the two single wires on the left. The high voltage capacitor is also visible on the left of the board. On the right of the board five coaxial cables provide connections for power supply, test signal and output signals

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