A Low-Noise Charge Sensitive Preamplifier for Ge Spectroscopy operating at Cryogenic Temperature in the GERDA Experiment

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Abstract—Front-end electronics for ionizing radiation detectors signal read-out must sometimes operate at cryogenic temperatures. The classical solution based on cold input transistor and subsequent warm electronics is sometimes not suitable due to the physical constraints of the experimental setup, so the entire front-end circuit has to operate at cryogenic temperature. The proposed multi-channel charge sensitive preamplifiers (“CC2”) have been tested in the framework of the GERDA experiment (GERmanium Detector Array), in connection to High-Purity Germanium (HPGe) detectors and are able to operate at cryogenic (liquid Nitrogen) temperature.

The results obtained during preliminary tests with an encapsulated Germanium detector and subsequently with naked Germanium detectors are all within the specifications of the GERDA experiment for Phase-I.

I. INTRODUCTION

The GERDA experiment [1] has been proposed in 2004 as a new $^{76}$Ge double-beta decay experiment at LNGS (Gran Sasso National Laboratory) of INFN (National Institute of Nuclear Physics). It consists of a facility where Germanium detectors made out of isotopically enriched material are operated inside a cryogenic fluid shield. The facility will serve a triple purpose: i) prove the Majorana nature by searching for the Onbb of $^{76}$Ge with a sensitivity of $T_{1/2} > 10^{25}$ y; ii) probe the neutrino mass at the level of 300 meV, in a couple of years of data taking and iii) demonstrate as a pioneering low order of magnitudes below the current state-of-the-art.

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From the viewpoint of the front-end electronics connected to the detectors, the general requirement of a low radioactivity level experimental set-up and the need for cryogenic operation impose very stringent conditions on the design and manufacturing of the charge sensitive preamplifiers. A few circuits have been designed and tested as the front-end electronics of the GERDA experiment, e.g. the “PZ0” charge sensitive preamplifier [2, 3].

Preamplifier signals are driven out of the cryostat by means of low-impedance coaxial cables, up to a dedicated digital acquisition system based on free running ADCs.

This paper focuses on the characteristics, design, manufacturing and performances of the “CC2” Charge Sensitive Preamplifier (CSP) in terms of spectroscopic energy resolution, linearity, inter-channel cross-talk, power consumption, size, cost and radio-purity).

II. THE CC2 CHARGE SENSITIVE PREAMPLIFIER

The CC2 is a low-noise hybrid CSP, based on two main active components: the BF862 n-channel JFET (NXP Semiconductors) as the front-end device and a subsequent CMOS operational amplifier. We tested different commercially available operational amplifiers and eventually selected the AD8651 (Analog Devices) as the most satisfactory candidate. Specific design attention has been dedicated to both the circuit schematic and the printed circuit board layout in order to achieve high immunity to the electrical disturbances conducted by the low voltage power supply cables. As the GERDA experimental set-up currently consists of very thin and resistive coaxial cables connecting the Germanium detector to the room temperature area outside of the cryostat (in order to minimize the radioactive background level), this feature has proved to significantly contain the amount of the inter-channel cross-talk and the CSP susceptibility to conducted noise.

Additional benefits of the proposed CSP design are also robustness, affordability, reduced manufacturing efforts and time.

We coupled the CC2 charge sensitive preamplifier to a Germanium encapsulated detector (“SUB”) in Milano and obtained the satisfactory results reported in Sec. II. At LNGS we have recently connected the CSP to non-encapsulated Germanium detectors of both low capacitance (BEGe type) and intermediate capacitance value (coaxial type); all of them are operated in cryostats filled with liquid Argon and results are reported in Sec. III.

In all the experimental conditions the output signals of the CC2 CSP have been acquired using both standard analog
electronics (shaping amplifiers, MCA) and dedicated digital systems based on free running ADCs (100 MHz, 14 bits).

![Image](image1)

**Fig. 1:** Front and back side of the 3 channels CC2 CSP (printed circuit board size is 38 mm x 45 mm).

### III. Tests with the “SUB” Ge Detector

We coupled the CC2 charge sensitive preamplifier to a Germanium encapsulated detector in Milano (the “SUB” detector, manufactured by MPIK Heidelberg) and during two weeks of continuous operation we obtained the following results. The CSP intrinsic best energy resolution at liquid Nitrogen temperature (with no added input capacitance) was 0.7 keV, with 22 eV/ pF noise slope (all values are FWHM, for 12 us shaping time, in Ge detectors); the best measured energy resolution was of 1.96 keV for 22Na.

The guaranteed energy dynamic range was 15 MeV (for 0.5 pF feedback capacitor and ±2.5V power supplies for the CMOS OpAmp); the CSA could drive 50 Ohms loads associated with at least 10 meters long coaxial cables, providing signal rise time less than 55 ns for terminated, long cables and energy of incoming events up to 15 MeV.

The measured inter-channel cross-talk was less than 0.1%; the estimated linearity better than 1/1000 and the power consumption less than 45 mW/channel.

![Image](image2)

**Fig. 2:** Schematic drawing of the electrical connections between the CSP, the SUB detector and the warm electronics outside the cryostat.

![Image](image3)

**Fig. 3:** The measured energy resolution (keV, FWHM) for 33 pF simulated Ge detector capacitance as a function of the spectroscopy amplifier shaping, time for two different JFET power supply voltage levels (triangles: 6 V; circles: 12 V).

![Image](image4)

**Fig. 4:** One of the experimental energy spectra acquired with the SUB detector, for a low activity 232Th source (2.75 keV FWHM energy resolution) and the radioactive natural background.

### IV. Tests at the LNGS Underground Facility

At LNGS we connected the CSP to non-encapsulated Germanium detectors of both low capacitance (≈ 1-2 pF, BEGe type, in the LArGe set-up, see Fig. 5) and subsequently to a string of 3 coaxial detectors with intermediate capacitance (≈ 30 pF). All detectors and CSPs have been operated inside cryostats filled with liquid Argon.

As a specific requirement of the GERDA experiment, the charge sensitive preamplifiers must be extremely low in radioactivity, so that a dedicated design and the corresponding printed circuit board layout have been carried out. The total amount of measured radioactivity from the PCB (excluding pins) is ≈ 170 μBq for 232Th.

Among the key points to achieve this results (to be separately reported in the future) are: manufacturing of the CSP board on a specifically selected low-radioactivity substrate; minimization of the number of tantalum power-supply decoupling capacitors and integration of the low value capacitors, e.g. for input-to-output feedback of the CSP.
directly on the printed circuit board in order to eliminate the corresponding NP0 ceramic devices.

The energy resolutions obtained within the LArGe experimental set-up were: 3.0 keV FWHM @ 2.6 MeV ($^{228}$Th line); 2.3 keV FWHM @ 1.3 MeV ($^{60}$Co line); 1.6 keV FWHM @ 3 MeV (pulser line).

![Fig. 5: The LArGe experimental set-up at LNGS inside which naked Germanium detectors can be operated in liquid Argon.](image)

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![Fig. 6: A "Broad Energy" Ge (BEGe) detector and the associated CC2 charge sensitive preamplifier inside a copper box.](image)

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The preliminary energy resolution obtained within the GERDA experimental set-up (see Fig. 7) was 4.2 keV FWHM @ 2.6 MeV ($^{208}$Tl line). Electro-magnetic disturbances, conducted and/or irradiated to the string of Ge detectors inside the cryostat still limited the obtainable energy resolution. By optimizing the electrical connections from the CSP inside the cryostat, the power supplies and the DAQ system, better energy resolution should be achieved.

![Fig. 7: External view of the GERDA experimental apparatus at LNGS, showing the water tank containing the cryostat.](image)

V. CONCLUSIONS

The CC2 CSP has been extensively tested for performance and reliability and satisfactorily operates at cryogenic temperature in connection to Germanium detectors within framework of the GERDA experiment. Further reduction of picked-up disturbances will improve the energy resolution in spectroscopy measurements.

![Fig. 8: The string of three natural Germanium naked coaxial detectors.](image)

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![Fig. 9: Signal pulses as acquired by the DAQ system based on free running ADCs (100 MHz, 14 bits) and the superimposed electro-magnetic disturbances.](image)

![Graph](image)

REFERENCES


[2]: "Spectroscopy Performances of the GERDA Cryogenic Charge Sensitive Amplifier Based on JFET-CMOS ASIC Coupled to Germanium Detectors", A D'Andragora et al., IEEE-Nuclear Science Symposium, Orlando, 2009