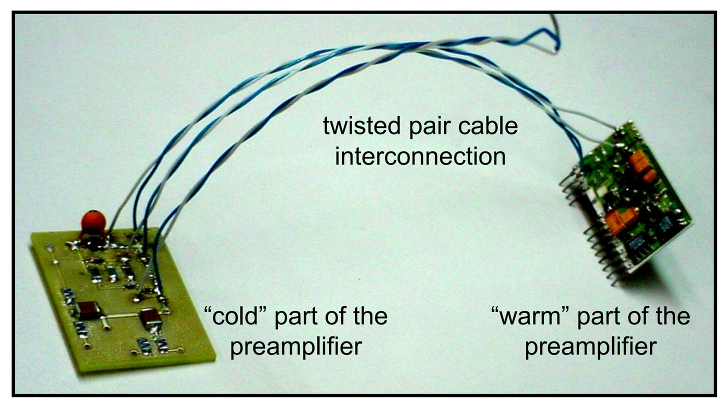
A Cold Low Noise Preamplifier for Use in Liquid Xenon

A. Pullia [1], F. Zocca [1], U. Oberlack [2], C. Olsen [2], P. Shagin[2]

[1] University of Milano and INFN Milano, Italy
[2] Rice University, Houston, TX 77005, US

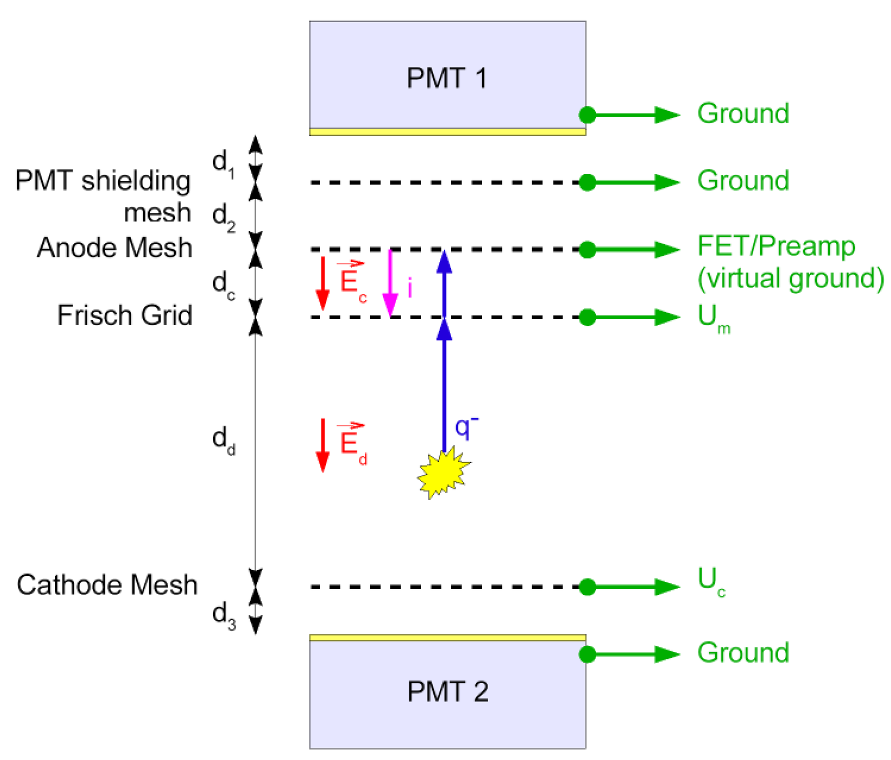
In the context of R&D for a Liquid Xenon Time Projection Chamber (LXeTPC) as a Compton telescope for MeV gamma-rays, we have developed a low noise preamplifier with cold front-end inside liquid xenon. The LXeTPC approach exploits the excellent scintillation and ionization properties of ultrapure liquid xenon, in a temperature range of about 165-180K. With a W-value of 15.6 eV, LXe is an efficient ionization medium and provides more charge than other noble liquids. Yet, the charge signals of ~1 fC/100 keV are also significantly smaller than in semiconductor detectors. Operation as a Compton telescope requires both excellent energy resolution and low thresholds. Since the LXeTPC uses a cryogenic liquid as detector medium, it is usually made of a detector vessel and a cryostat. As a result, any measured charge signals must pass feed-throughs and typically substantial cable length before reaching a charge-sensitive amplifier (CSA). Placing a first amplification stage inside the xenon liquid has several potential benefits: it places the amplification stage in immediate proximity to the sensing electrodes, removing the input capacitance of long leads, and reducing the potential for noise pick-up. Furthermore, the operating temperature of the LXeTPC is near the noise optimum for Si-based electronics, hence reducing thermal noise in the preamplification without otherwise impeding the device performance. On the other hand, the location inside an LXeTPC also imposes significant constraints on this first amplification stage: insertion of electronegative impurities into the xenon liquid must not exceed the ppb level; the electronics and connections must withstand thermal cycling from a mild `baking' temperature of ~400K under vacuum to the low operating temperature inside LXe; and the introduction of excess heat must be reduced to a minimum, in order to avoid local formation of gas bubbles and to reduce heat load in general.

We present an approach that places the first-stage Junction Field Effect Transistor (JFET, Philips BF862) of an ultra-low noise charge sensitive amplifier on a board next to the sensing electrode inside LXe, together with the surface-mount resistor and capacitor feedback elements, as well as a capacitor for charge calibration with a testpulse. This "cold stage" is connected with the remainder of the CSA through twisted pair cables: one pair each for feed-back, source/drain of the JFET, and the testpulse input. The main CSA stage is placed in a box directly connected to a detector feed-through. The Milan group developed a custom CSA to match the requirements of an LXe detector. In particular, the gain was brought to a level of 77 mV/fC into a differential (100 Ω) output, to match the ~1 V differential input range of an FADC board sampling the signal. The Rice group designed the cold stage.



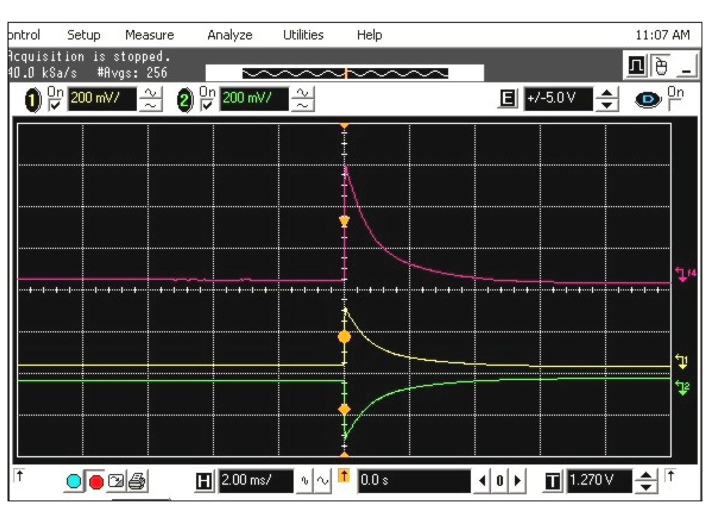
The front-end electronics setup has been realized and characterized at room temperature. In these benchtop tests with the front-end JFET and feed-back elements mounted 15 cm far away from the preamp board and with a capacitance of 33 pF connected to the input, the CSA showed an excellent noise performance with a minimum of ~110 electrons achieved for a shaping time of 6 µs. The front-end electronics is now ready for installation in the LXe test detector.

Detector scheme

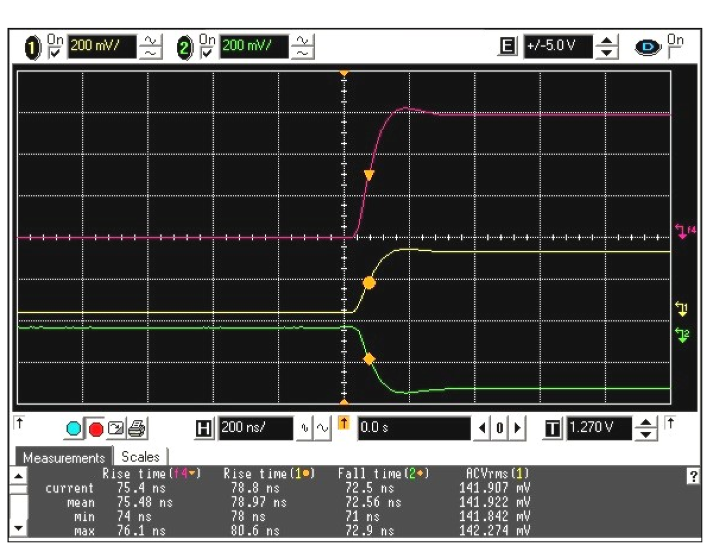


Preamplifier response

The preamplifier response to a test pulse of 10 mV (10fC of equivalent input signal charge) is shown here. The inverting/non-inverting signals are read out through two terminated 50-Ω cables, which means a 100-Ω equivalent load at each output. A gain of ~75 mV/fC is obtained for the differential signal, including half splitting on the termination resistances. A clean waveform shape is observed. The risetime of ~75 ns is fast enough for the considered application.



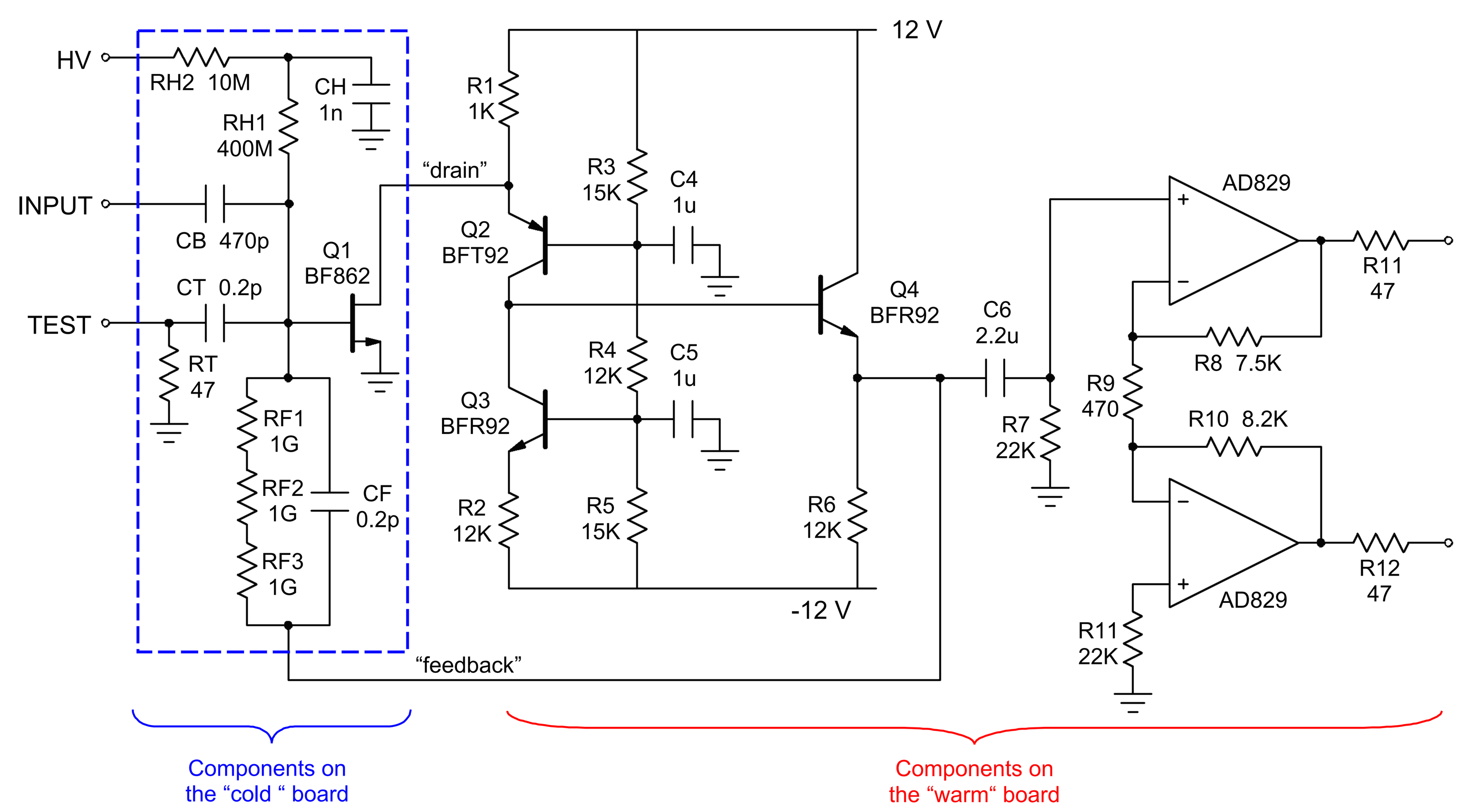
X-axis: 2 ms / div. – Y-axis: 200 mV / div



X-axis: 200 ns / div. – Y-axis: 200mV / div

Schematic diagram

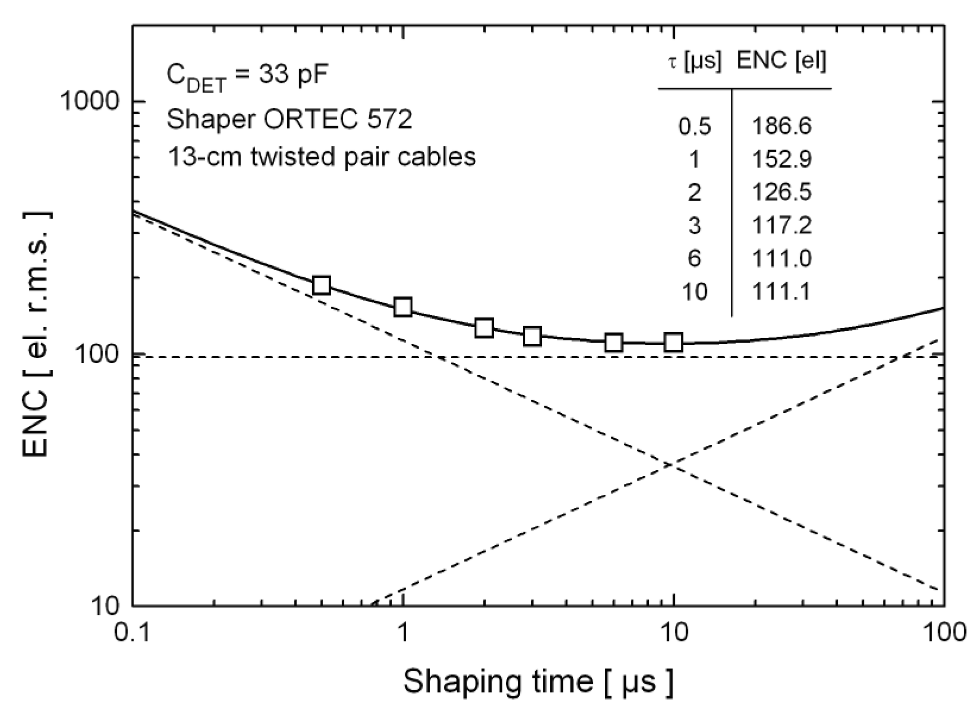
In order to implement the large required gain of 77mV/fC a low-value feedback capacitance of 0.2pF has been used, and a large gain of 17.4 has been implemented in the differential output stage. With such a high overall gain a substantial DC offset at the preamplifier output is envisaged. The DC offset has been reduced by AC coupling the output buffer (C6, R7) and by using resistance R11 for compensating the bias currents of the AD829 operationl amplifiers.



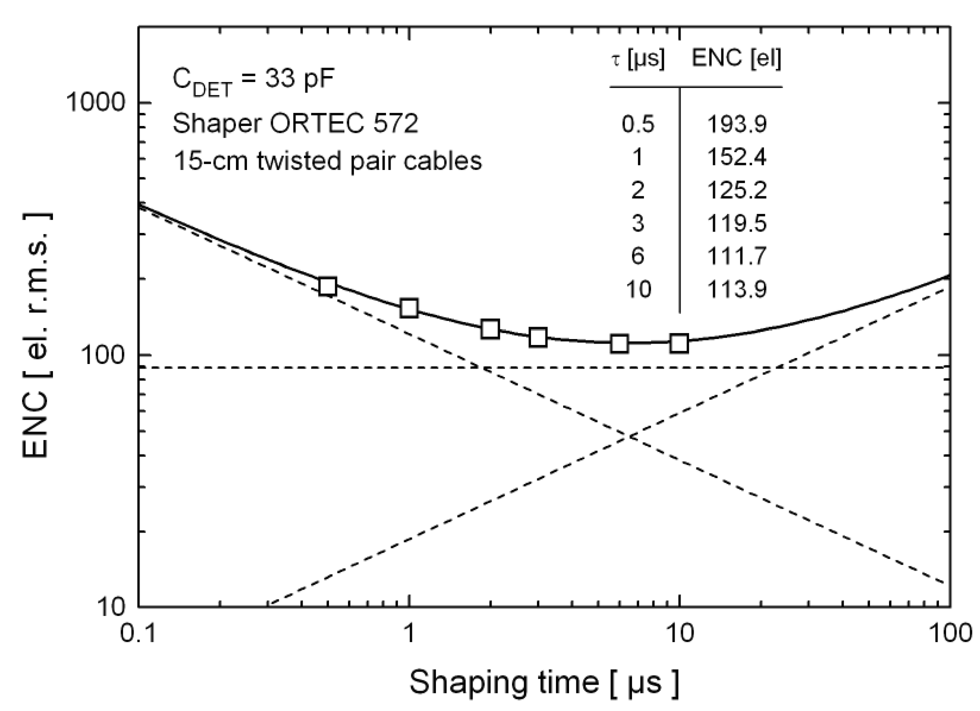
The connection between the "cold" and "warm" parts is realized through two 15-cm twisted-pair cables. Each pair consists of a signal and a ground wire. The latter provides a local path for the return current, which reduces the EMI and helps stabilize the circuit. Such signal wires are labeled in the figure as "drain" and "feedback". The ground wires are not shown.

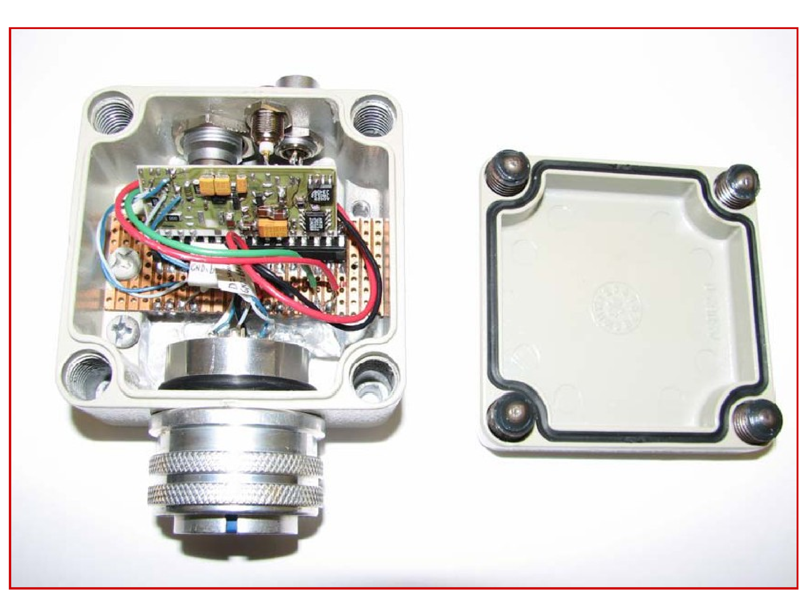
Noise measurements

"Cold" preamplifier board with no ground plane.
Low noise but high microphonism.
Test performed at room T



"Cold" preamplifier board with a ground-plane strip.
Microphonism is strongly reduced.
Test performed at room T





"Warm" part of the preamplifier as mounted in its hermetic shielded box. The two twisted pair cables used to connect the warm to the cold part pass through the big cylindrical connector.

"Cold" part of the preamplifier placed 15-cm far away from the "warm" part.