Electrical characterization of the Cu-PEN low radioactivity links of the CUORE experiment

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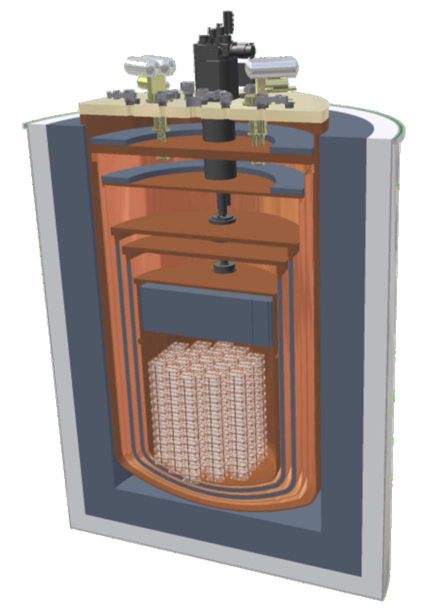
CUORE and CUORE-0

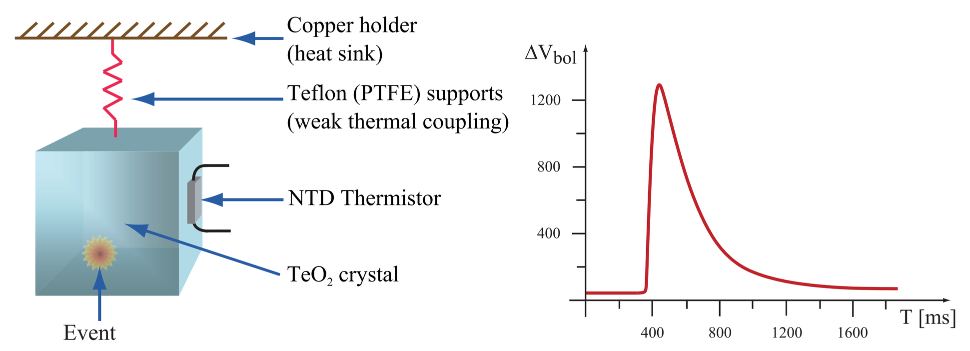
CUORE is a rare event search experiment under construction at LNGS (Gran Sasso), designed for a sensitivity to the half life of the neutrinoless double beta decay (0vDBD) of ^{130}Te of 1.6×10^{26} years at 1σ after five years of data taking.

The experiment makes use of the bolometric technique:

- Crystals of TeO_2 are held at a T ~ 10 mK in a dilution cryostat.
- Particle interactions cause measurable thermal signals, detected by the NTD thermistors glued on each crystal.
- The slow thermal signals (~ 100 Hz bandwidth) from the high impedance sensors (~ GΩ thermistors) are read out by low noise amplifiers at room temperature: there is a long (~ 5 m) differential connecting link from the thermistors to the outside.



Sketch of the CUORE cryostat



A sketch illustrating the bolometric technique, and a typical CUORE signal

The construction of CUORE is expected to be completed in 2014. It will be composed of 19 towers of 52 detectors each.

To test the CUORE construction and assembly techniques, a single CUORE tower, named CUORE-0, was assembled, and will soon start data taking.
The sensitivity of CUORE-0 to the half life of the 0vDBD of ^{130}Te is expected to be of nearly 10^{25} years at 1σ after two years of data taking.

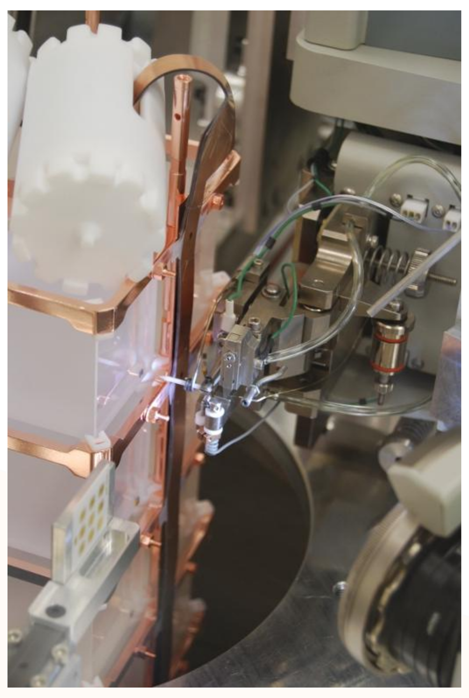
Assembly of the CUORE-0 tower

The Cu-PEN Tapes

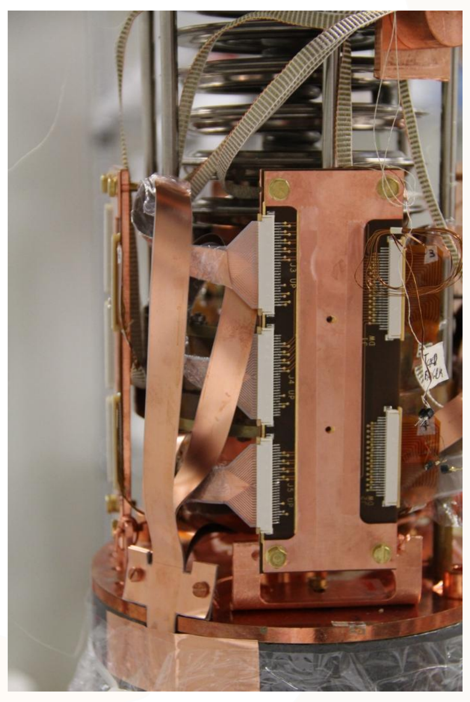
The first and most critical part of the electrical links from the thermistors to the outside consists of the Cu-PEN tapes, connecting the detectors to the first thermalization stage.

PEN was selected for the highest radiopurity, as the tapes run parallel to the towers, very close to the detectors. The Cu-PEN tapes are ~ 1.5 m long for CUORE-0 (will be ~ 2.4 m long in the final design for CUORE). Each tape has 29 traces, carrying 10 differential signals (and grounds to shield the channels from each other).

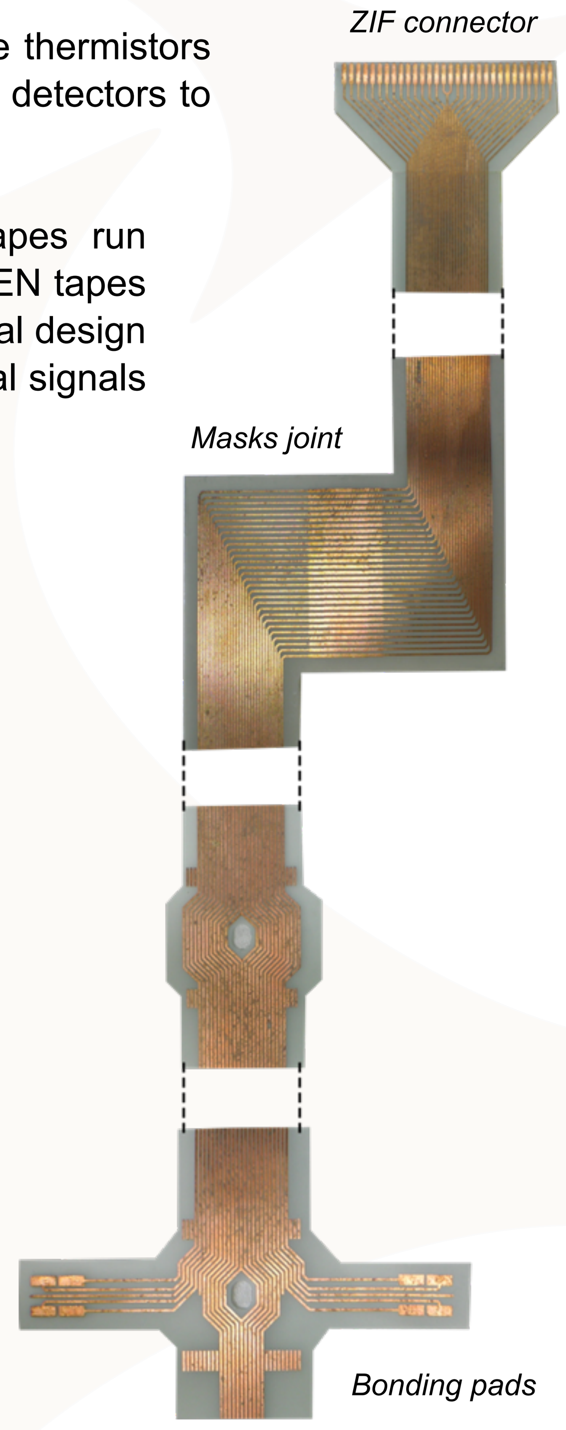
- On the detector side, the thermistors are directly bonded to copper pads on the tapes.
- On the other side, the tapes are plugged into ZIF connectors on a Kapton board.



Bonding of the pads of the Cu-PEN tapes to the thermistors in the CUORE-0 tower



The Cu-PEN tapes plugged into the ZIF connectors in the first thermalization stage in CUORE-0



Time Domain Reflectometry (TDR)

Measurement method:

- A differential pair of traces is connected to a fast sampling scope (Agilent DCA-X 86100D, 18 GHz bandwidth)
- The traces are left open at the far end
- A fast differential voltage step (t_r ~ 20 ps) is sent on the pair of traces
- The reflected signal is acquired, and gives information on the characteristics of the line (dielectric constant, characteristic impedance, ...) as well as detecting broken or shorted traces

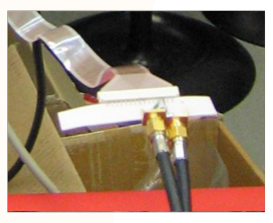
Main advantages:

- The method gives information on the position of possible problems, with a resolution of $\varepsilon^{-1/2} c t_r$ ~ 5 cm
- Electrical continuity can be tested without contacting the bonding pads (good for radiopurity issues)

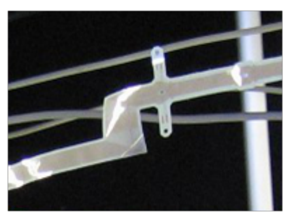
Results:

- Characteristic impedance Z_0 = 150 Ω (differential)
- Propagation delay t_p = 3 ns (one way)
- Capacitance = t_p / Z_0 = 20 pF
- Relative dielectric constant ε = 1.72

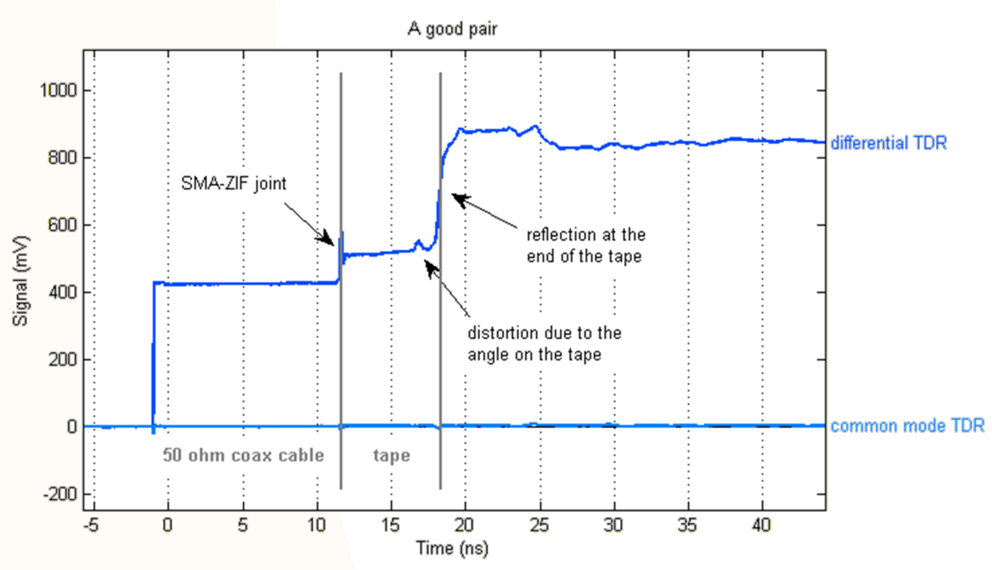
A good tape:
The 'differential TDR' shows the characteristics of the differential pair of traces.
The 'common mode TDR' is zero, because of the symmetry.



SMA-ZIF joint

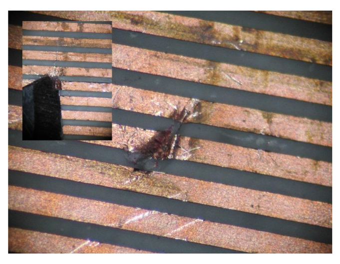


Angle on the tape (masks joint)

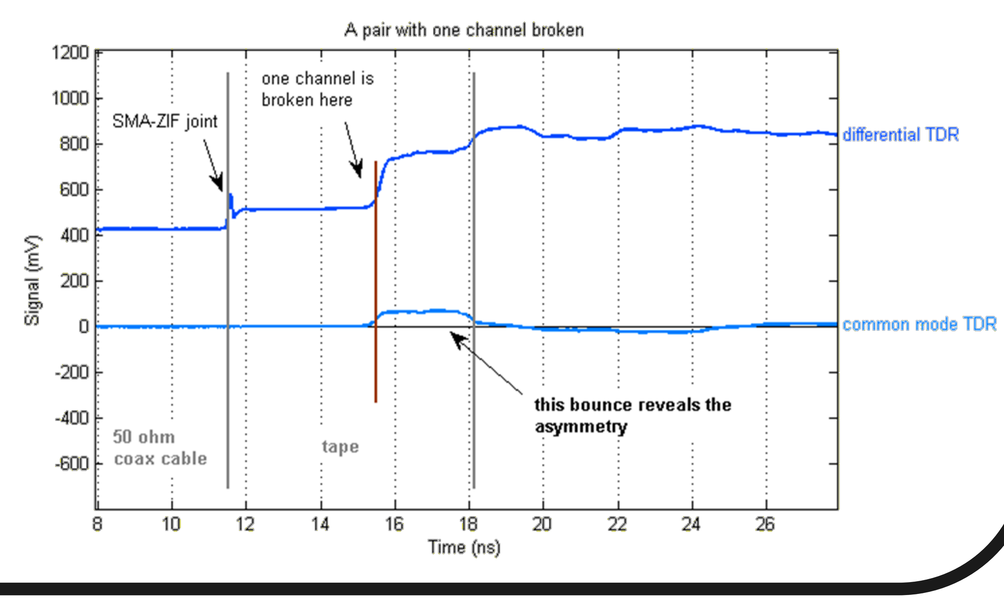


A broken tape:
One trace was intentionally cut with a scalpel to simulate a defect. The cut width was ~ 200 μm (could not be seen with naked eye).

The 'differential TDR' shows an impedance change due to the trace cut.
The 'common mode TDR' clearly reveals the asymmetry, being not zero for all the part of the tape after the cut.



The cut on the tape



Electrical Insulation

Measurement method:

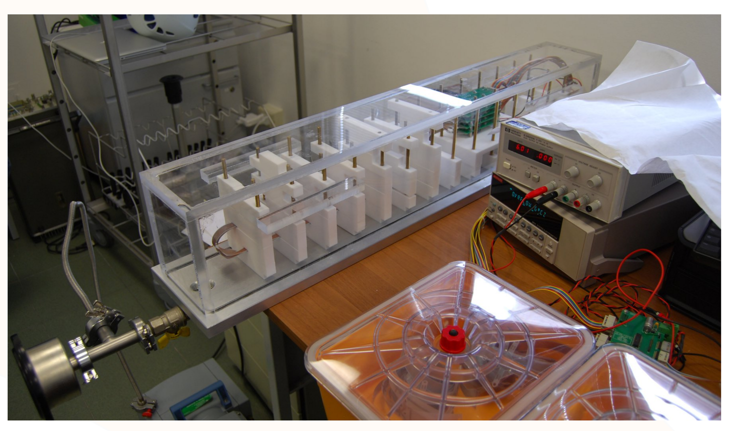
- All the 10 pairs of traces are put in parallel and connected to a Keithley 6514 electrometer (~200 GΩ sensitivity)
- The tracks are left open at the far end
- The parasitic resistance between the traces can be measured with a sensitivity of 10 x 200 GΩ = 2 TΩ (in other words, the parasitic conductance between the traces can be measured to less than 1 pA/V)

This method is complementary to the TDR. It cannot detect broken traces, but it gives the fundamental information about the parasitic conductance, which cannot be obtained with the TDR.

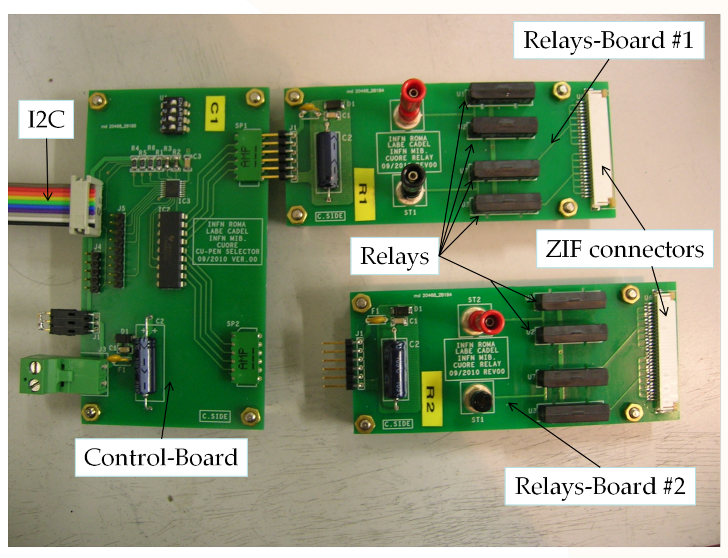
Electrical insulation depends much on environmental conditions. The measurement is performed in vacuum, to remove the air humidity and to simulate the conditions in the CUORE cryostat.

A set of boards was designed and built to control remotely (via I2C) a set of relays, connected to a group of tapes. In this way, the electrical connections between each tape and the electrometer can be set after the vacuum is made.

(Thanks to M. Capodiferro, F. Cidronelli, from INFN Roma 1, for the accurate PCB layout.)

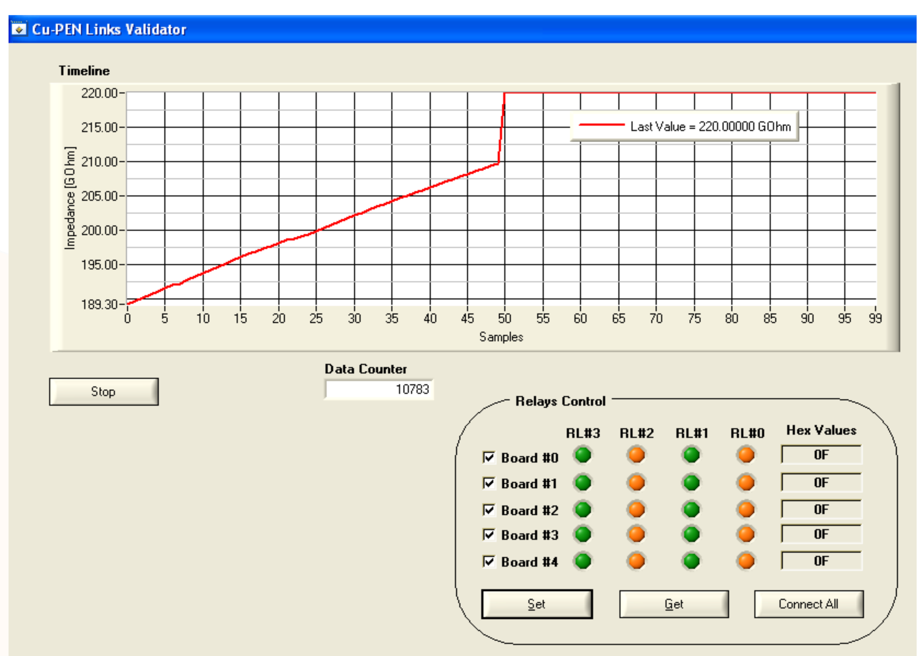


A group of Cu-PEN tapes under test; the measurement is performed in the vacuum



The PCBs designed and used for the tests

A software was written in CVI to control the tape connections throught the relays, and to read, display and acquire the data from the electrometer. The figure shows a good tape, with a mean parasitic conductance between traces of less than 1 pA/V. The tape capacitance is charged by the electrometer with a constant current of 0.9 nA, until the value falls out of the range of the instrument.



The graphical user interface for insulation measurement; the plot shows the impedance value versus time