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

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ABSTRACT

In the CUORE experiment, under construction at LNGS (Gran Sasso National Laboratory), Cu-PEN tapes are the first part of the connecting links between the detector and the front-end electronics. Deep electrical characterization on each tape is to be performed, to ascertain that they comply with the requirements of the experiment. The characterization method is presented here. The first part is based on the time domain reflectometry (TDR) technique, to check the integrity of the electrical link while touching only one end of the tape, to avoid any possible damage to the bonding pads. The TDR measurement allows to locate possible defects on the tapes with a resolution of about 5 cm. The second part of the characterization is focused on the parasitic impedance between neighboring links. For this characterization, a commercial electrometer is used; custom boards with remote control capability were built, in order to be able to check the links in vacuum and reach sensitivities on the parasitic conductance of the order of 1 pA/V.

1. Introduction

CUORE, the Cryogenic Underground Observatory for Rare Events [1], is a neutrinoless double beta decay ($0\nu\beta\beta$) search experiment under construction at LNGS (Gran Sasso National Laboratory), in central Italy. The detector will be composed of 988 TeO_2 crystals of 5 cm side, arranged in 19 towers of 52 crystals each. The TeO_2 crystals are bolometers, held at a temperature of about 10 mK inside a cryostat. The energy released in the crystals by interacting particles causes measurable temperature variations, detected by neutron transmutation doped (NTD) Germanium thermistors directly glued to the crystals. The thermistors are biased and read out by the front-end amplifiers located at room temperature outside the cryostat [2,3].

The connecting link between the thermistors and the front-end amplifiers is composed of three main parts. The first part is made of flexible tapes of Cu-PEN (Copper on a Polyethylene 2.6 Naphthalate substrate). The thermistors are directly bonded to the pads at one end of the tapes. The other end plugs into ZIF connectors mounted on Kapton boards at the first thermalization stage. The second part of the connecting links is made of twisted NbTi-NOMEX wires, from the first thermalization stage to the multipole connectors at the top of the cryostat. The third and last part are the twisted cables from the top of the cryostat to the front-end crates. Since the resistance value of the thermistors is in the GΩ range, the connecting links must guarantee a negligible parallel parasitic conductance to neighboring connecting links. The Cu-PEN tapes are the most critical part: aside from electrical behavior, their contribution to the radioactive background of the experiment must be negligible [4].

Fig. 1 shows the main details of a CUORE Cu-PEN tape. The tape has 29 traces of 0.2 mm width and spacing, carrying 10 differential signals, and nine grounded traces needed to prevent crosstalk. Different kinds of tapes were designed to be stacked together to serve groups of 26 crystals. The length of the tapes from end to end is about 2.3 m.

After fabrication, and before the cleaning and assembly procedure, each tape must be tested for production defects. The time domain reflectometry technique allows to test the tapes for defects (broken traces or shorts) without contacting the bonding pads, to avoid any possible damage. The tapes which pass this test are then checked with an electrometer, to measure the electrical insulation between neighboring traces.

2. Time domain reflectometry

In the time domain reflectometry (TDR), the tape under test is seen at high frequency as a transmission line. The measurement method consists of using the reflections of a fast voltage step

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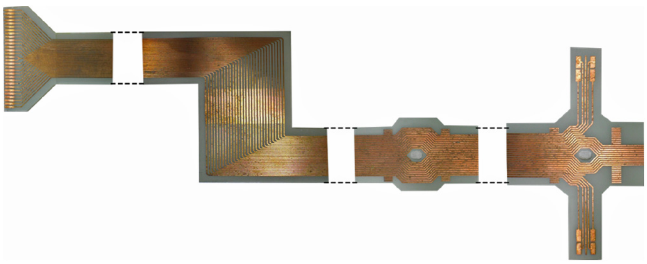

Fig. 1. The main details of a CUORE Cu-PEN tape. On the left side the end to be plugged in the ZIF connector; on the right side the thermistor bonding pads. The double bend in the middle with the larger trace spacing is needed to allow the alignment of the different masks used in the fabrication process.

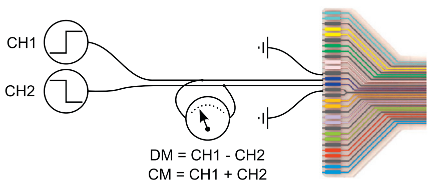

Fig. 2. Setup for time domain reflectometry (TDR) measurement. In this sketch, different colors are used to denote the 10 differential pairs. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

produced at one end of the tape to gather information on the characteristics of the tape. The concept is illustrated in Fig. 2.

For this measurement, a Agilent DCA-X 86100-D fast sampling oscilloscope was used. The instrument is connected to the ZIF end of the tape, and sends a differential voltage step of t_R=20 ps rise time down a differential pair of traces. The pad end of the tape is left open, untouched, preventing any possible damage to the bonding pads. At the ZIF side, the voltage is sampled with a bandwidth of 18 GHz. From the amount of reflected signal at the beginning of the tape, the differential characteristic impedance of the tape as a transmission line can be estimated to be $Z_0 = 150\Omega$. From this value, and from the value of the propagation delay, which is $t_{pd} = 4.6$ ns/m, the capacitance of the differential pair can be estimated to be $C = t_{pd}/Z_0 = 30$ pF/m. The measured value is found to be consistent with the value reported in previous measurements [4]. The speed of propagation of the voltage step on the tape is $c/\sqrt{\epsilon}$, where ϵ is the relative dielectric constant of the traces on the tape. Knowing the tape length, ϵ can be measured to be 1.9.

This setup allows to locate defects with a spatial resolution of t_R/t_{pd}=5 cm. Fig. 3 shows the typical TDR results in the case of a good pair and of typical defects. The "differential mode" (DM) reflects the behavior of the differential pair of traces. The "common mode" (CM) exposes any possible asymmetry between the two traces in the pair, which would indicate a defect in one of the two traces. The tapes which are indicated by the TDR to be good can be accepted, and are tested for electrical insulation between traces.

3. Electrical insulation

To test the electrical insulation between traces on the tape, all the odd and even traces are connected in parallel forming two

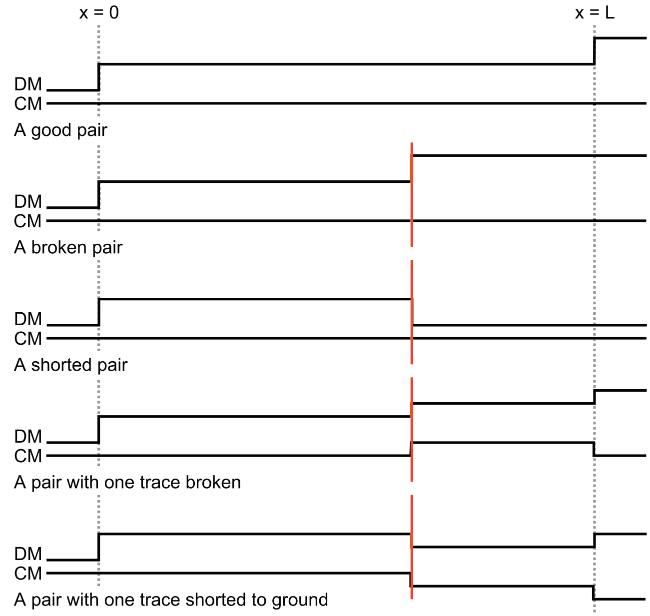

Fig. 3. Schematic representation of the results of a TDR measurement for a differential pair of traces of length *L*, showing the differential mode (DM) and the common mode (CM) reflected waveforms for the case of a good pair (top) and of typical defects.

groups, which are connected to a Keithley 6514 Electrometer with a full scale of 200 GΩ. Thanks to the parallel connection, the maximum measurable impedance per pair is increased by a factor of ten, obtaining a sensitivity of 0.5 pA/V for the mean parasitic conductance of the pairs on the tape.

As previously reported [4], the measurement must be performed in vacuum to avoid parasitic effects due to air humidity. A set of boards equipped with relays were realized to switch the electrometer inputs on different tapes. The relays are remotely controlled from a PC through a I2C protocol. This setup allows to test several tapes held together in vacuum. The tapes which pass also the electrical insulation test can be considered compliant with the electrical requirements of the CUORE experiment.

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