The supply voltage apparatus of the CUORE experiment

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A B S T R A C T

The Electronics system of experiments for the study of rare decays, such as the neutrino-less double beta decay, must be very stable over very long expected runs. We introduce our solution for the power supply of such an experiment, CUORE. In this case the power supply chain consists of a series of ACDCs, followed by DCDCs and then Linear Regulators. We emphasize here our approach to the DCDC regulation system that was designed with a complete rejection of the switching noise, across 100 MHz bandwidth. In the experimental layout the DCDC will be located far from the very front-end, with long connecting cables (10 m). We introduced our very simple and safe solution to prevent huge over-voltages, due to the energy stored in the inductance of the cables, generated after the release of accidental short circuits, so avoiding destructive effects. Some micro-controllers are present on every board and take care of the DCDC operation. These micro-controllers are managed from the control room, via CAN BUS protocol coupled via optical fibres. CUORE is an array of 1000 cryogenic detectors that will need 30 of our DCDCs.

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1. Introduction

Detectors featuring a large number of readout channels demand dedicated power supply systems. Target requirements can be very stringent for those experiments which are performed on very long runs because the stability must be guaranteed. CUORE [1], the Cryogenic Underground Observatory for Rare Events, is one of the experiments for which the present instrument was developed; it is composed by 1000 bolometric channels working at 10 mK temperature in order to study the neutrino-less double $\beta$ decay of $^{130}$Te. CUORE is expected to measure for years in a highly stable set-up. The power supply system of CUORE must guarantee a high stability and also low noise. LUCIFER, Low-background Underground Cryogenic Installation For Elusive Rates, [2], is the second experiment for which the present power supply set-up was developed. It is based on an array of cryogenic detectors which is simultaneously sensitive to both heat and light to reject background from alpha particles, to improve the study of the double beta decay of $^{82}$Se and $^{100}$Mo.

Although designed for the 2 above cited experiments, the power supply system considered in this paper has a quite general application and can be used in several other applications.

2. The DCDC concept

The power supply system takes energy from the main line to produce, at the end of its path, the DC voltages for the electronics system. The scheme we have adopted for that is in Fig. 1. A commercial ACDC generates a 48 V DC voltage. Its location is adequately far from the next DCDC stage, about 10 m. We introduced our very simple and safe solution to prevent huge over-voltages, due to the energy stored in the inductance of the cables, generated after the release of accidental short circuits, so avoiding destructive effects. Some micro-controllers are present on every board and take care of the DCDC operation. These micro-controllers are managed from the control room, via CAN BUS protocol coupled via optical fibres. CUORE is an array of 1000 cryogenic detectors that will need 30 of our DCDCs.

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Regulators, again to minimize residual EMI interferences. The distance from the DCDCs and the linear regulators is 10 m. As Fig. 1 shows, between the DCDCs and the final Linear Regulator stages there are passive filters designed to eliminate the residual switching noise. Each filter consists of a common mode choke and a capacitance with a very low ESR (Equivalent Series Resistance) and parasitic inductance, that implements the second function of protection against the recovery from accidental short circuits [5]. The Linear Regulator is the last element of the chain and is a revised version of [6].

The DCDCs have 3 output voltages, 2 of them used for the analogue circuitry, the last for the digital circuitry of the electronics system. Every DCDC feeds a pair of Linear Regulators. Each Linear Regulator generates a pair of bipolar voltages for the analogue circuitry, while the supply voltages for the digital circuitry come directly from the DCDC. Each voltage line is foreseen to work at 6 A of maximum and/or rated current. This means that every DCDC will drive a maximum of 18 A with its 3 outputs lines. This allows the DCDCs to work at less than 30% of their maximum power capability, increasing their MTBF (Mean Time Between Failures) considerably.

The combination of the ripple rejection filter from Vicor* and our low pass filter resulted in a very low noise of the DCDC converters. Fig. 2 shows the output noise in the bandwidth 10–100 MHz of any of the 3 DCDC outputs of a unit, when loaded at 7 A. As it can be seen the noise becomes close to the amplifier noise (used to attenuate the spectrum analyser noise contribution), 4 nV/√Hz, after a few kHz. Switching noise is missing and the low frequency noise is about 500 nV/√Hz, at 10 Hz. In the picture the noise floor of the amplifier is shown for comparison. The measured RMS noise is below 3 μV RMS in the 10–10 kHz frequency range, and about 13 μV RMS in the 10–50 MHz frequency range (the latter was obtained by quadratically subtracting the amplifier RMS noise from the total measured RMS noise and is a very worst case estimate). This is an outstanding result as a noise of less than 20 μV pp and less than 80 μV pp, estimated from the quoted RMS noise in the 10 kHz and 50 MHz bandwidths respectively, are rarely found even in commercial linear regulators.

The DCDC picture. The 3 light-blue rectangles superimposed to the picture mark the 3 units covered with the respective heat sink. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

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Fig. 3 shows the photograph of a single DCDC unit in which the 3 regulators with their heat sinks are marked with 3 light-blue rectangles. Each unit is remotely programmable via CAN BUS interface. Several parameters are settable such as ON/OFF condition, output voltage level, and others are readable such as temperature, output voltage monitoring and output current absorption. The 3 outputs are completely independent and floating. Each regulator has a micro-controller dedicated to its supervision and the 3 micro-controllers are connected to a fourth main micro-controller (on board) which communicates with the control room. The 3 micro-controllers communicate with an optically coupled intra-board CAN BUS with the main micro-controller, preserving the ground isolation. The main micro-controller has also its outgoing CAN BUS optically coupled with that of the control room.
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