Low Voltage Supply System for the Very Front End Readout Electronics of the CMS Electromagnetic Calorimeter

B. Betev[3], P. Denes[1]. L. Djambazov[3], M. Dröge[3], J.-L. Faure[3], B. Iliev[2], W. Lustermann[3], I. Nanov[2], P. Raykov[2], N. Shivarov[2]

[1]Princeton University, Princeton, NJ 08544, USA.

[2]Bulgarian Academy of Sciences, Central Laboratory of Mechatronics and Instrumentation, BG-1113 Sofia, Bulgaria.

[3]Eidgenössische Technische Hochschule, ETH-Zürich, CH-8093 Zürich, Switzerland.

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Abstract

We use a two stages low voltage power supply system with remote sensing. Linear low voltage power supplies outside the cavern feed local voltage regulators housed in water cooled boxes inside the detector with significant power losses over around 120 m of therefore cooled cables. All voltages are floating and provided independently to groups of 50 crystals, two trigger towers. They are grounded at the detector end. Controls, overvoltage and overcurrent protection and fuses are integrated into the power supplies. Radiation tests on the low voltage regulator components were performed. A low voltage regulator has been built and tested.

1 Introduction

The barrel part of the CMS [1] Electromagnetic Calorimeter (ECAL) is composed of 61200 lead-tungstate crystals arranged in 36 super modules (SM) housing 1700 crystals each [2]. There are two end caps composed of 16000 crystals. After the crystal's scintillation light is converted into an electrical signal, the readout electronics in the barrel and the end cap region are identical. Throughout this article mainly the barrel region is considered supposing a low voltage system (LVS) for the end caps will be derived from the barrel one at a later stage.

Groups of 5×2 crystals in $\eta \times \phi$ form a submodule read out by a Very Front End (VFE) module. A trigger tower consists of 5×5 crystals. Their energy is summed to provide first level trigger information. The LVS will be subdivided into independent Low Voltage Channels (LVCH). Each of them will power groups of 50 crystals corresponding to 2 trigger towers, corresponding to 5 VFE modules.

1.1 Requirements for the Very Front End Electronics

The VFE electronics requires four independent low voltages, +5 V and −2 V for the analog part and +5 V and +2 V for the digital part. Their expected currents (I) and the resulting power consumptions (P) are summarized in the following table:

Voltage [V]	+5	−2	+5	+2
I_{LVCH} [A]	7.8	1.3	1.5	3.3
I_{SM} [A]	264	43	51	111
I_{Barrel} [A]	9486	1530	1836	3978
P_{LVCH} [W]	38.8	2.5	7.5	6.5
P_{SM} [W]	1318	85	255	221
P_{Barrel} [W]	47430	3060	9180	7956

The VFE electronics will be very sensitive to noise, especially to correlated noise as introduced by the power supplies because the energy of 25 crystals is summed as the trigger towers energy. Therefore linear power supplies are proposed in order to avoid all potential problems arising from the use of switching mode ones.

1.2 Environmental Constraints

The ECAL barrel is located inside the 4 Tesla superconducting magnet [3]. Behind the crystals an integrated dose up to 2 Mrad and up to $5 \times 10^{13}\,\mathrm{n/cm^2}$ are expected at an integrated luminosity of $5 \times 10^5\,\mathrm{pb^{-1}}$. In addition the available space inside the detector is very limited. There is no space for the low voltage power supplies inside the SM's and only about $(800 \times 500 \times 150)\,\mathrm{mm^3}$ per SM about 4 m away from

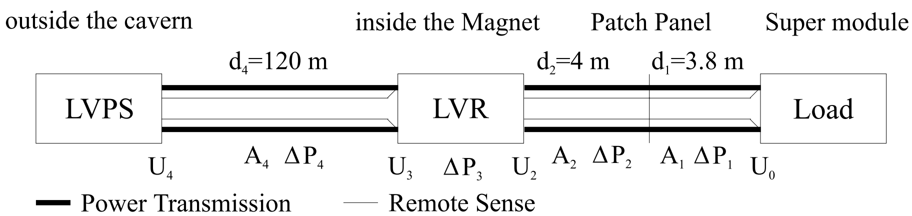

Figure 1: Two stage power supply system with remote sensing.

the SM's but still in the CMS magnet. Outside the detector radiation levels and the magnetic stray field are strongly depending on the location. There is sufficient space at the galleries but still in a radiation environment of 100 rad absorbed dose and in a moderate magnetic field of 0.05 T. An important point is also the accessibility of the system. To access the electronics inside the detector, the entire end caps have to be removed. Also the access to the electronics in the cavern is limited to the shutdown periods of the accelerator. In contrary there is always access to the counting house, where radiation and magnetic field are negligible.

U_0[V]	5	-2	5	2
$A_1[\text{mm}]^2$	1.0	1.0	1.0	1.0
$A_2[\text{mm}]^2$	1.5	1.5	1.5	1.5
$A_4[\text{mm}]^2$	8.0	4.0	4.0	8.0
U_2[V]	6.4	-2.2	5.3	2.6
U_3[V]	7.9	-3.7	6.8	4.1
U_4[V]	11.9	5.0	8.3	5.8
ΔP_1[W]	4.9	0.13	0.18	0.9
ΔP_2[W]	5.7	0.15	0.21	1.0
ΔP_3[W]	11.6	1.9	2.3	4.9
ΔP_4[W]	31.0	1.6	2.3	5.5

Table 1: Cable cross sections, voltages and power losses in the low voltage system.

2 Low Voltage System Layout

The LVS is very complex taking into account the large number of channels, 1224 for the barrel, the total required power of ~74 kW for the ECAL barrel only and the problems of radiation and magnetic field. So any chosen solution includes advantages and disadvantages. In addition the final LVS performance strongly depends on its behavior in the CMS environment including the interference with other parts of the detector and not only on single blocks specifications.

We propose a two stage power supply system with floating voltages and remote sensing in both stages, as sketched in Figure 1. In the first stage linear low voltage power supplies (LVPS) located outside the cavern feed low voltage regulators inside the detector over ~ 120 m long cables. The LVR's regulate the voltage at the load in a distance of ~7 m, constituting the second stage. This configuration is identical for all four voltages required by the VFE modules. The grounding will be performed at the detector end.

The major disadvantage of this solution is the huge power loss in the system. In order to minimize this loss the cables cross sections are increased in three steps from the load back to the LVPS. A minimal power loss at the LVR is achieved by regulating its input voltage. But still the power losses in the cables and the LVR's are significant.

In table 1 the different cross sections (A) of the copper cables and the resulting voltages (U) and power losses (ΔP) for a single LVCH are summarized, with the variables as defined in Figure 1. With 34 LVCH's in a SM this leads to power losses of ~ 200 W in the cables inside the SM, ~ 240 W between the SM patch panel and the LVR box, ~ 700 W in the LVR box and ~ 1400 W from the LVR box to the LVPS. Assuming an efficiency of 50 % for the linear LVPS's the total power consumption of the ECAL barrel will be ~ 350 kW, leading to an overall efficiency of ~ 25 %.

It is obvious that the entire system, including the cables and the LVR's requires water cooling. The cooling system of the SM's will remove the additional energy lost in the cables inside the SM's themselves. The LVR's will be housed in water cooled boxes and the cables are placed into water cooled channels. We are investigating the possibility to use the return flow of the SM cooling system for this purpose.

3 The Low Voltage Regulators

3.1 Radiation Test

As the low voltage regulators will be located inside the detector it is mandatory that they survive radiation doses up to 1 Mrad. Therefore a set of commercial components was tested using the PSI Optis beam [4] with 1.25×10^9 protons/(cm^2 s) of 64 MeV. This simulates at the same time ionizing and nonionizing

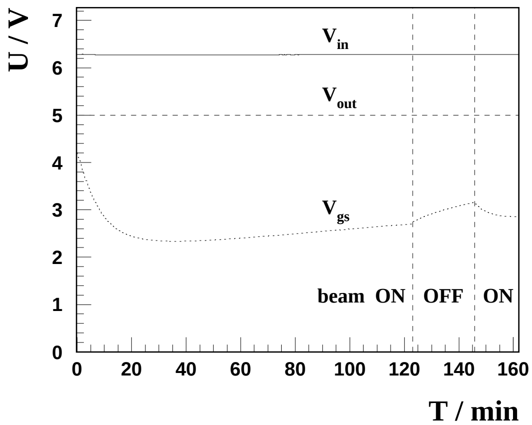

Figure 2: Irradiation test: SIPMOS SPP30N03L.

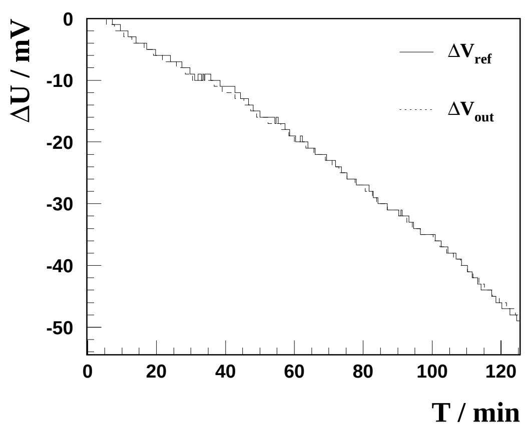

Figure 3: Irradiation test: MC1723CP.

irradiation. About 2 hours operation at Optis beam correspond to 10 years of the expected irradiation for the ECAL VFE electronics at LHC. In particular we tested a SGR117A three terminal type, positive, adjustable voltage regulator from Linfinity, a TLE4270 fixed voltage regulator from Siemens, a MC1723CP type regulator from Motorola, a SIPMOS-SPP30N03L power transistor from Siemens, a BTS640S2 [5] semiconductor smart switch from Siemens and a IRFZ24N-HEXFET transistor from International Rectifierer.

The components were tested on experimental setups under working conditions equivalent to their future use. All of them but the BTS640S2 switch survived a minimum of 2 hours of irradiation. In Figure 2 the behavior of the SPP30N03L during ~ 140 minutes of irradiation is drawn for an output current of $I_{out} = 8\,\mathrm{A}$ and an output voltage of $+5\,\mathrm{V}$, for an input voltage voltage of $U_{in} = 6.28\,\mathrm{V}$. The shift of the gate-source voltage, V_{gs}, is tolerable as it enables always a safe operation of the pass transistor. The output voltage was constant at $(5.001 \pm 0.001)\,\mathrm{V}$. Figure 3 presents the results for the MC1723CP low voltage regulator from Motorola during ~ 120 minutes of irradiation. The output voltage decreased nearly linearly with the irradiation by about $50\,\mathrm{mV}$. This change is clearly correlated with the change in the reference voltage V_{ref}.

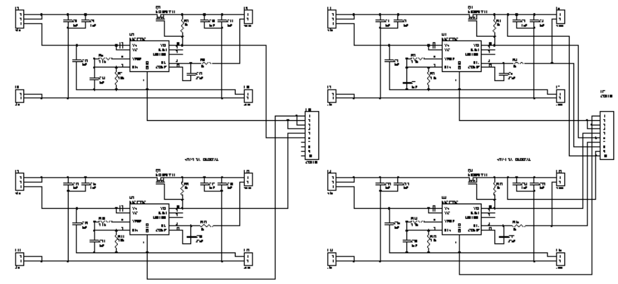

Figure 4: LVR prototype layout for one LVCH.

3.2 Prototype Layout

The failure of the BTS640S2 switch, which also includes fault protection features, in the irradiation test lead to a very simple design of the LVR. All additional functionality like switching of the output voltages, overvoltage and overcurrent protection and output current measurement were moved into the LVPS. The LVR serves one LV channel with a single PCB of $104 \times 77\,\mathrm{mm}^2$ containing four independent voltage regulators based on the MC1723CP type regulator and the Siemens-SIPMOS SPP30N03L pass transistor. The schematic layout is given in Figure 4.

It is forseen to add some means to measure the sensed voltage at the load and the V_{gs} and to transfer them to the LVPS rack controllers.

3.3 Prototype Test Results

The LVR's frequency response was studied at the prototype board and with a SPICE model. Therefore the input to output transfer functions, the $+15\,\mathrm{V}$ to output transfer functions, the output dynamic impedances, the output noise and the cross talk between the different channels for all four independent voltages were measured.

The LVR unity gain cross over frequency is about a few kHz depending on the gain of the MOSFET. The input to output transfer functions showed two maxima one just above the unity cross over frequency and the second one around $(100 - 500)\,\mathrm{kHz}$ due to the self resonance of the regulator. The output noise was found to be around a few $\mu\mathrm{V}/3\,\mathrm{kHz}$. The cross talk increased with the frequency.

3.4 LVR housing

For one ECAL super module 34 of the above described LVR boards are needed. As they will be located inside the cryostat it is mandatory that they are water cooled in order to remove the energy of 800 W per SM. Therefore a special housing, the LVR box, is constructed. It

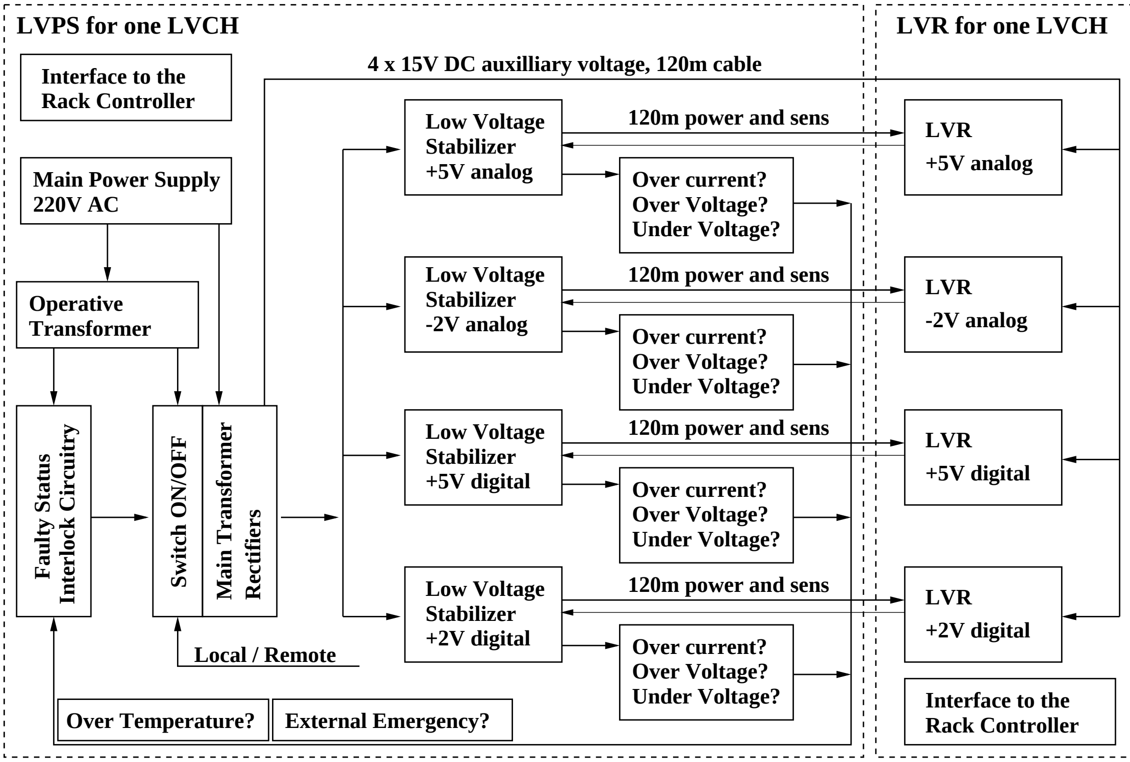

Figure 5: Block diagram of the low voltage system for one LVCH.

is based on two aluminum plates, sandwiching a cooling pipe. Two rows of up to 9 LVR boards can be mounted on each side of the cooling plate. The pass transistors are directly screwed onto it. The box has a size of $800 \times 500 \times 150\,\mathrm{mm}^3$ and the two smallest side panels serve as input and output patch panels.

4 Low Voltage Power Supplies

4.1 General Layout

The LVPS's have to match the modularity of the LVCH's, in order to enable an individual control of the voltages and a measurement of their output currents. Thus the LVPS has to provide 4 voltages corresponding to +5 V, −2 V, +5 V and +2 V at the load. One transformer is feeding 4 independent channels composed of rectifier, filter and low voltage regulator with a pass transistor. Four additional windings with following rectifiers and stabilizers provide four +15 V auxilliary voltages for the LVR. The system performs overvoltage, undervoltage and overcurrent protection and reacts on the over-temperature and other emergency signals. A block diagram is sketched in Figure 5.

The current and voltage protection functionality is based on the BTS640S2 smart power switch. It has ground referenced input for switch ON/OFF, a diagnostic feedback status output and a sense voltage output proportional to the output current.

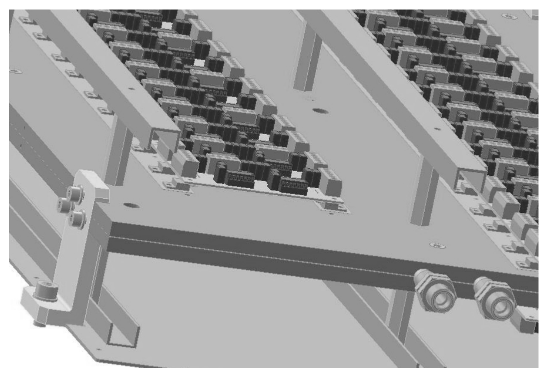

Figure 6: LVR box with LVR modules and cooling plate.

4.2 Technical Specifications

Each LVCH as described above provides the following main voltages: $(+8.0 \pm 1.0)$ V, (-3.9 ± 0.5) V, $(+7.5 \pm 0.9)$ V and $(+4.1 \pm 0.5)$ V, with the following maximal currents respectively: 12.0 A, 2.0 A, 2.3 A and 5.0 A. The input is standard AC 220 V. The line regulation for +10 % and −20 % of the AC input voltage has to stay below 0.5 % and the load regulation below 1 % of the output voltage. A maximum ripple and noise of 3 mV RMS and 30 mV peak to peak at the power supply output is tolerable. The supply provides adjustable overvoltage and undervoltage protection, a thermal shutdown at 85°C, soft turn on 0.5 s, fast turn

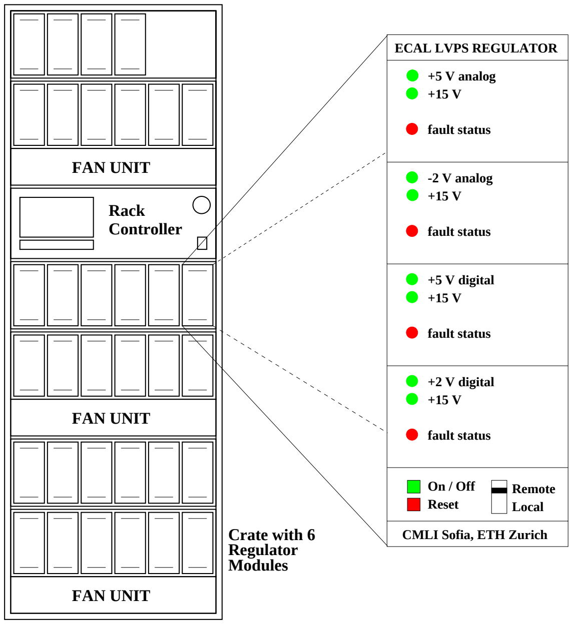

Figure 7: LVPS rack layout (left) and regulator module front panel (right).

off ($< 100\,$ms) and a hardware interlock circuitry sensitive to overvoltage, overcurrent and undervoltage signals for all main voltages, to over-temperature conditions and to an external emergency signal. In addition 4 auxilliary voltages of $+15\,$V, $100\,$mA are provided with 0.2% line regulation 0.4% load regulation, $0.2\,$mV RMS and $2\,$mV peak to peak ripple and noise. All power supplies in one rack are connected to a LVPS rack controller which measures and displays all main and auxilliary voltages, the sensed voltages at the LVR inputs and the currents of the main voltages. It reads the status information of the interlock circuitry and measures the temperature in the rack. It receives the voltages and currents from the corresponding LVR's and displays them. The rack controller is accessible via a front panel connector. It connects the rack to a main LVS controller in a local network. The power supply can be operated in local or remote mode. In remote mode the rack controller can turn ON or OFF individual channels while in local mode a front panel button is used. It provides means to dispatch the ON, OFF and RESET signals from single front panel buttons to all LVPS voltages in all regulator modules. The output voltage status is controlled by switching the input AC voltage of the main transformer exclusively, thus all outputs are always switched in parallel.

An additional transformer provides power to the AC input switch and to the interlock circuitry in order to allow the startup of the system.

4.3 LVPS housing

Each ECAL barrel SM requires 34 of the above specified LVPS's. They will be mounted into a 19" rack together with the rack controller. Having in mind the sizes of the main transformers and of the electrolytic capacitors it is possible to house six LVPS's in one 19" 4 to 5 units high crate. Hence 6 crates per rack allow the installation of 36 LVPS's. Their total power loss will be below the admissible $8\,$kW. Each crate consists of a mechanical support structure with a connector backplane and built in AC/DC conversion units for 6 LVCH's in the back part. In the front up to 6 Regulator modules can be inserted, serving one LVCH each. The front panel of them provides a status information via LED's and contains all necessary switches and buttons. In addition the rack will contain the required fan units. The rack controller will be housed in a 4 to 5 units high crate. It includes a front panel display with control buttons, a rack ON/OFF button, a rack reset button and power and reset switches for the auxilliary voltages and the controller itself. A possible layout of the LVPS rack and the regulator module front panel is given in Figure 7.

5 Conclusion

The system design of a linear low voltage system for the CMS ECAL has been shown. Active components for the LVR withstanding the radiation have been identified. A prototype of the LVR board has been built and tested. The LVPS specifications are basically known and its design is in progress. We conclude that a linear LVS is feasable with the known dissadvantages of large power losses and thus a huge amount of cables.

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