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

B. Betev[3], S. Dhawan[2], L. Djambazov[3], M. Dröge[3],
W. Lustermann[3], A. Nardulli[3], M. Pestalozzi[3], P. Sharp[1]

[1]CERN, CH-1211 Geneva 23, Switzerland.
[2]Yale University, New Haven, CT 06511, USA
[3]Eidgenössische Technische Hochschule, ETH-Zürich, CH-8093 Zürich, Switzerland.

Werner.Lustermann@cern.ch

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Abstract

The CMS electromagnetic calorimeter requires about 113 kW at 2.5 V to power the custom designed readout chips in 0.25 μm technology. The power is converted to low voltage DC at the periphery of the CMS magnet and distributed by copper buses over ~ 25 m to the detector. Low voltage regulator cards using radiation hard low voltage regulators from CERN/ST microelectronics provide the power to the readout cards. The power is delivered floating and is grounded at the detector end. Several regulator cards were produced and tested.

1 Introduction

The CMS[1] electromagnetic calorimeter consists of a lead tungstate crystal calorimeter divided in a barrel (EB) and an end-cap (EE) part and a silicon pre-shower detector in the end-cap region. This article describes the power supply system of the crystal calorimeter only.

The EB is composed of 61200 lead-tungstate crystals arranged in 36 super modules (SM) housing 1700 crystals each [2]. The 2 end-caps consist of 14648 crystals arranged in 4 so called Dee's with 3662 crystals each. The scintillation light of the crystals is converted into an electrical signal, by an avalanche photo-diode in the EB and a vacuum photo-tube in the EE. A multi-gain pre-amplifier (MGPA) amplifies and shapes the signal with 3 different gains and sends it to an ADC chip with 4 parallel 12 bit 40 MHz ADC's and a digital selection logic (AD41240) to choose the optimal gain range. Five such readout channels are implemented into a single very front-end (VFE) card.

The obtained digital data are processed in the front-end (FE) card. It uses 7 FENIX ASIC's, which perform different tasks. Five of them buffer the data of five VFE cards for the level 1 trigger latency and estimate the energy sum of the five channels in ϕ. Another FENIX generates the trigger tower energy, identifies the associated bunch crossing and sends the information to the readout system using an optical link system with a Gigabit optical link (GOL) chip. The last FENIX collects the data out of the buffers and sends them via a second identical optical link to the data acquisition system, in case of a level 1 accept signal. As the outputs of the AD41240 are low voltage differential signals (LVDS) and the inputs of the FENIX are single ended a signal adaptation is necessary. This will be done by special input pads on the FENIX or by an additional radiation hard buffer. In order to be conservative we suppose the necessity of 16 channel buffers with 100 mA at 2.5 V.

Clock distribution and the control of the system is performed by using the clock and control unit (CCU) and detector control unit (DCU) ASIC's developed for the CMS tracker project.

For the readout of 25 crystals, corresponding to a trigger tower (TT) in the barrel, five VFE and one FE board are used. In addition there is one mother-board, which distributes the high voltage, the analogue low voltages and re-routes the signals from the photo-detectors to the VFE cards.

The power needed for 25 readout channels is conditioned in a separate low voltage regulator card.

1.1 Power requirements for the on-detector electronics

All used integrated circuits are developed in the same 0.25 μm technology which requires a supply voltage of

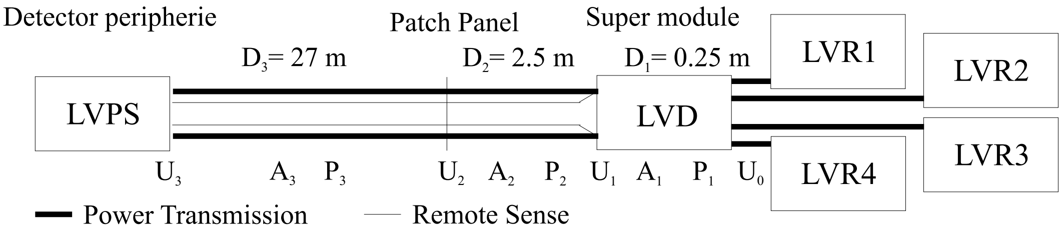

Figure 1: ECAL low voltage distribution system.

2.5 V. While an under-voltage will not harm the circuit an over-voltage of 7% for more than 300 ms may already damage it. The analogue and the digital part of the electronics will be powered from a single power supply. As the analogue signals from the photo-detectors are very small and sensitive to any perturbations and all the digital electronics runs at 40 MHz clock frequency we provide isolation of the power supplies for the analogue and the digital part of the system by using separate low voltage regulators.

Chip	N / TT	I_{ana} in mA	I_{dig} in mA
MGPA	25	232	
ADC	25	101.6	110.8
Buffer	25		100
FENIX	7		120
GOL	2		120
CCU	2		140
DCU	6		10

Table 1: Components currents at 2.5 V.

The different power consumptions of the active components are summarized in table 1.

In addition to the power required at the load there is a significant power loss in the low voltage regulators due to the drop-out voltage which is assumed to be 1.8 V, including a 20% margin compared to the regulators specification. The regulators require about 7% of the load current as bias current. From this the total current and power consumption for a trigger tower are calculated to be $\sim$ 16 A and $\sim$ 68.5 W respectively. Thus the power consumption per channel is 2.7 W. About 46% of this power is dissipated in the low voltage regulators. The detailed numbers are summarized in table 2.

The power consumption of the ECAL is summarized in table 3, where a low voltage channel (LVCH) consists of 4 TT and the EE power is scaled from the EB power by the number of channels.

U in V	+2.5 Vana	+2.5 Vdig	Sum
I_{load} in A	8.34	6.55	14.89
I_{LVR} in A	0.58	0.46	1.04
I_{tot} in A	8.92	7.01	15.93
P_{load} in W	20.85	16.38	37.23
P_{LVR} in W	17.52	13.76	31.28
P_{tot} in W	38.37	30.14	68.51

Table 2: Power consumption of a trigger tower.

Unit	I in A	P in W
LVCH	63.7	274
EB SM	1083	4658
EB	39002	167710
EE	9335	40141
EB+EE	48337	207850

Table 3: ECAL power consumption.

2 CMS Low Voltage System

The CMS experiment will use a common low voltage (LV) distribution system to provide DC power to the periphery of the detector. Each sub-detector is further distributing this power and adapting it to its specific requirements.

In the first step the 3-phase 50 Hz AC power is converted to 3-phase, 400 V, 400 Hz at the surface area of the CMS experimental site. This can be done by motor generators or static power converters. In either case the stored energy in the conversion system will remove power glitches of several 100 ms of the AC distribution network, providing thus a more stable power to the CMS detector.

The 400 Hz power is transferred via cables into the service cavern. There, isolation transformers provide a separation for different parts of the system and enable an adaptation of the output voltage if needed. The output power of the transformer is distributed to AC-DC conversion boxes at the periphery of the detector. For each of this boxes there is a separate power cable with a circuit breaker and a computer controllable switch in the service cavern, such that each box is individually controllable and secured. The boxes have to operate in a magnetic field of about 0.1 Tesla and in a radiation environment with about $6\times10^{10}\,\mathrm{N/cm^2}$ and a total dose of 0.1 Gy for the integrated luminosity of $5\times10^5\,\mathrm{pb}^{-1}$. They use a simple transformer plus rectifier plus filter capacitors configuration. The reason for using 400 Hz as a frequency for the supply voltage was the possibility to built reasonably sized transformers which will operate in the magnetic stray field. The boxes have no specific line or load regulation capabilities and their output voltage will be adapted for the needs of the sub-detector systems.

3 ECAL Low Voltage System

The ECAL uses commercial switching mode low voltage power supplies (LVPS) located at the periphery of the detector close to the AC-DC conversion boxes. The power is delivered floating with remote sensing to local voltage regulators for groups of 4 TT, i.e. 100 readout channels, over a distance of about 27 m. A low voltage distribution panel (LVD) provides the sensing of the voltages, an additional filtering if necessary and distributes the power to 4 low voltage regulator cards (LVR) serving one TT each. See figure 1.

The LVPS will supply a single voltage for each LVCH. The split between the analogue and the digital part of the electronics is achieved by using separate regulators and proper filtering.

3.1 Power losses

In table 4 the cable cross sections (A), drop-out voltages (U) and the power losses (P) in the low voltage cables are summarized. The power loss in the cables for a single LVCH is 99.1 W hence about 1 W per readout channel. Thus the total power loss for the EB is ∼ 61000 W. Assuming the same configuration for the EE the power loss there is ∼ 15000 W. About 85% of this is dissipated in the cable trays between the LVPS and the detector patch panels.

Index	0	1	2	3
$U_{0,1,2,3}$ in V	4.30	4.33	4.53	5.86
$N_{1,2,3}$ wires		2×2	2×2	1×2
$A_{1,2,3}$ in mm^2		2.5	16	50
$l_{1,2,3}$ in m		0.25	2.5	27
$P_{1,2,3}$ in W		0.51	12.3	84.7

Table 4: Distribution wires and power losses. The symbols U, N, A, l and P are voltage at this point, number of wires, wire cross section, wire length and power loss respectively. The row "index" refers to the index of the quantities, as they are given in figure 1.

The total power required by EB and EE from the LVPS is ∼ 283 kW of which ∼ 113 kW corresponding to 35% are used in the readout electronics and the rest is lost in the distribution system.

3.2 LVPS requirements

The power supplies are attached to the periphery of the detector. They have to operate in a magnetic field of about 0.1 Tesla and in a radiation environment of about $6\times10^{10}\,\mathrm{N/cm^2}$ and a total dose of 0.1 Gy, like the AC-DC conversion boxes, as given in section 2. There are at least two manufacturers which have proven to be able to built power supplies operating reliably under this conditions. In particular DC-DC supplies are required with the following properties:

- output voltage: nominal ∼ 5.8 V; range 2 V to 7 V
- output current: nominal ∼ 64 A; maximum 77 A
- floating supply voltage
- remote sensing capabilities for a line voltage drop of up to 2 V and a sense wire resistance of up to 10 Ω
- ripple and noise of less than 5 mV pk-pk and less then 0.5 mV RMS after 25 m of cables and a load capacitance larger than 300 μF.
- load and line regulation less than 0.5%
- Temperature stability better than 0.5%
- output voltage adjustment by means of a potentiometer or a 10bit DAC
- 4 software controllable TTL compatible, optically isolated output signals including status monitoring of them
- absolute maximum output voltage of the power supply is 10 V.
- over current protection by hardware and software limits
- monitoring of output current, output voltage, remote sense voltage and supply temperature with 0.2% precision
- compliance with European electromagnetic interference (EMI) and safety standards

The EB consists of 36 super modules with 17 low voltage channels each. Hence, 612 LVPS are required. The EB uses about 160 LVPS. Therefore, the total number of LVPS required is about 772.

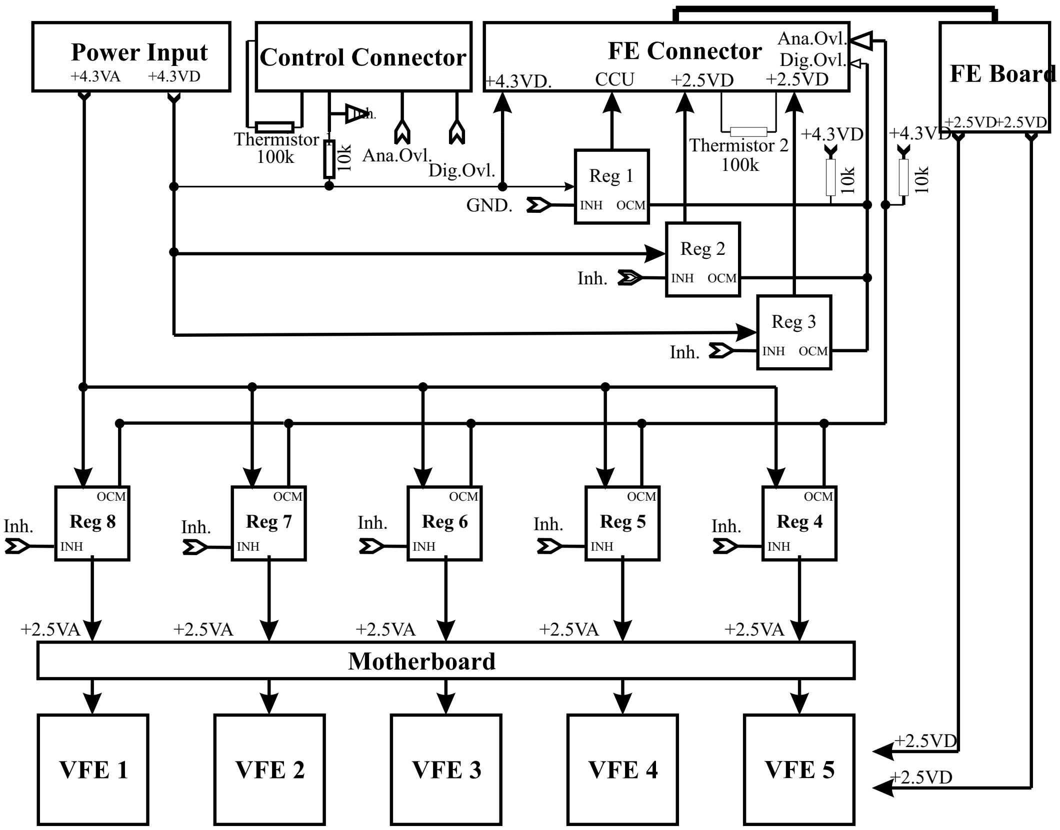

Figure 2: Schematic view of the LVR card.

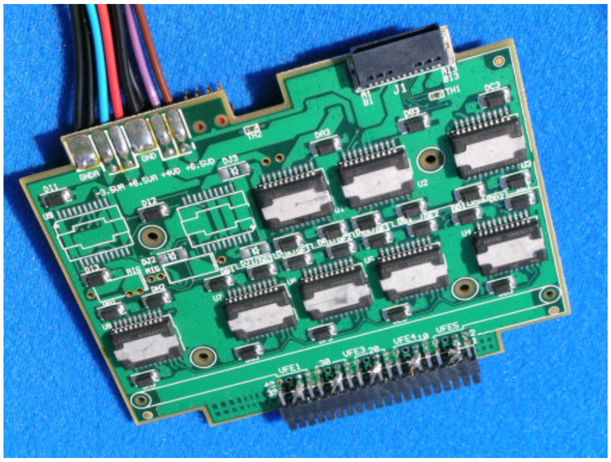

Figure 3: Schematic view of the LVR card.

4 Low Voltage Regulators

The low voltage regulators are embedded in the detector and have to operate in a radiation environment of up to 30 kGy and $3 \times 10^{14}\,\mathrm{N/cm^2}$, in the case of the EE. The only regulator known to us is the LHC4913 [4], developed by ST-microelectronics and CERN. It is a positive voltage regulator with maximum output current of 3 A and a load dependent drop-out voltage of 0.5 V per ampere of output current (see specifications). The regulator has an adjustable output current limitation, over-current protection, over-temperature protection and provides a TTL output signal in case of an output short circuit.

One of its important features is the TTL compatible active “high” INHIBIT input, which allows its output to be turned ON and OFF.

The line regulation of the regulator was measured (see figure 4) to be 0.07% for a load current of 2.0 A. This is in good agreement with the 0.1% given in the specfications.

The load regulation was measured to be 0.5% (see figure 5) confirming the specified value of 0.4%.

An output voltage of the MGPA of 400 μV corresponds to the least significant bit of the ADC. In order to have a constant pedestal it is required to limit the contribution of the low voltage power supply to the noise at the ADC input to about 40 μV. With a power supply rejection ratio of the MGPA better than a factor 10 the supply voltage to the MGPA has to be stable within 400 μV. As the current of the MGPA is stable, the load regulation of the LVR has no influence. Its line regulation of 0.1% requires an input voltage stability better than 400 mV. Hence the required stability of 0.5% of the output voltage of the the LVPS leaves about a factor 10 safety margin.

The requirement of less than 0.5 mV RMS noise together

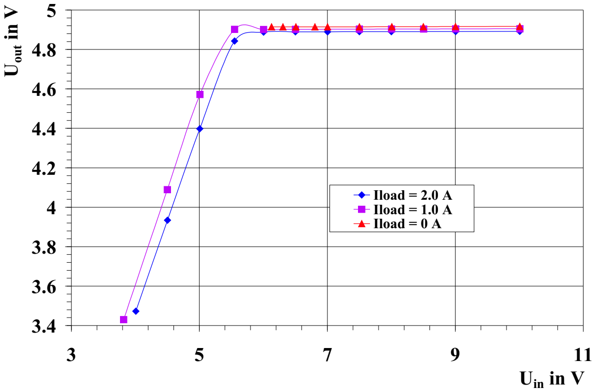

Figure 4: Measured line regulation of the LHC4913 for different load currents. The line is only to guide the eyes.

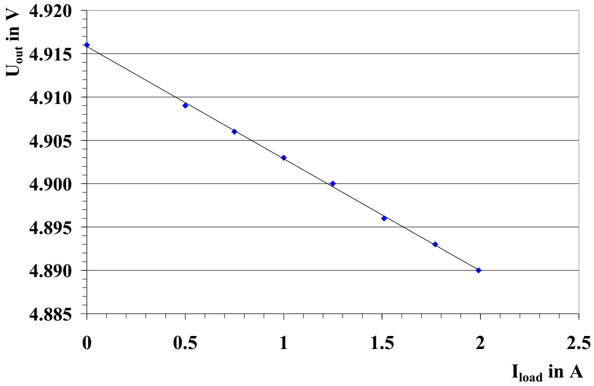

Figure 5: Measured load regulation of the LHC4913 with a fitted line.

with the power supply rejection ration of 0.1 guaranties that the contribution of the power supply to the MGPA noise is less than 50 μV and hence negligible.

A prototype of the regulator card had been designed and built for the previous version of the ECAL electronics. The card uses 8 LHC4913 positive regulators and one LHC7913 negative regulator. Four of those cards have been used during the ECAL test beam period in summer 2003. We did not encounter any problem with the positive regulators.

Five of the regulator cards (see fig. 2) were modified to power the new, 0.25 μm ECAL electronics, described above. The schematic view of the card is shown in figure 2. There are 5 regulators which provide the analogue power for one VFE card each. Two regulators provide the digital power for the VFE and FE cards and one powers the clock and control system including the token ring board. This regulator has its INHIBIT connected to ground such that whenever input power is provided, it is turned on. The INHIBIT of all other regulators are connected together and will be controlled by the the LVPS (see section 3.2). At power on, the LVPS will disable all regulators by setting the INHIBIT signals to “high”, it will then turn on the output power which will in turn start the CCU on the FE card. Now the power for each TT can be switched on and off individually by the LVPS. In this way, a single TT can be switched off in case of problems without affecting other TT’s connected to the same power supply.

One of the low voltage regulator cards was used to power the first complete trigger tower of readout electronics. Since the FENIX chips were not yet available, we used a prototype FE card equipped with XILINX FPGAs instead. As buffer, a non radiation hard device operating at 3.3 V was used. The current for the +2.5 V analogue was measured to be 8.91 A, which is in perfect agreement with the calculated value of 8.92 A. The current consumption of the FE card was measured in stand alone mode for different numbers of GOH’s (see table 5). The results indicate a current for the GOH of 104 mA which is about 10% less than the expected value of 120 mA.

GOH	0	1	2	1 and 2
I in mA	462	564	565	656

Table 5: Current consumption of FE card.

For the complete TT the current of the 2.5 V digital power was measured to be 2.92 A. Subtracting the current used by the FE card, we obtain a current of 2.36 A for the 25 ADC’s resulting in a current of 94 mA per ADC instead of the expected 110.8 mA from individual ADC tests. The bulk part of this difference can be explained by the usage of different termination resistances in the differential output lines of the ADC, 110 Ω compared to 100 Ω for the individual ADC tests. The current of the 25 differential buffers was measured to be 2.1 A, indicating that the estimated value of 100 mA is reasonable.

References

[1] CMS Collaboration, G.L. Bayatian *et al.*, **Technical Proposal**, CERN Report No. CERN/LHCC 94-38, LHCC/P1, 15. Dec. 1994.

[2] CMS Collaboration, G.L. Bayatian *et al.*, **The Electromagnetic Calorimeter Project Technical Design Report**, CERN Report No. CERN/LHCC 97-33, CMS TDR 4, 15. Dec. 1997.

[3] CMS Collaboration, G. Acquistapace *et al.*, **The Magnet Project Technical Design Report**, CERN Report No. CERN/LHCC 97-10, CMS TDR 1, 2. May. 1997.

[4] CERN Web Services, **ST Microelectronics LHC Radiation Hardened Voltage Regulator** http://lhc-voltage-regulator.web.cern.ch/lhc-voltage-regulator/