The Power Supply System for the CMS-ECAL APDs

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Abstract

This paper describes the power supply system that will be used to bias the Avalanche Photo Diodes (APD) used in the barrel part of the CMS Electromagnetic Calorimeter detector (ECAL).

This part is composed by 61200 $PbWO_4$ crystals each equipped with 2 APDs that need a bias voltage in the order of 300 Volts with high stability and ultra low noise figures (40mV peak-peak).

This system, that will be located in the CMS control room 150 meters far from the APDs, is currently in development under the responsibility of the INFN-ROMA department.

Prototypes tests showing the system feasibility and reliability are also discussed in the following

I. INTRODUCTION

The barrel part of the CMS–ECAL detector is composed by 61200 $PbWO_4$ crystals each equipped with 2 APDs developed for the CMS collaboration by the Hamamatsu corporation and whose electrical characteristics are summarized in Table 1.

Table 1: Expected APD Characteristics and numbers

Parameter	
Maximum Operating Voltage	500 V
Minimum Operating Voltage	200 V
Leakage Current (start of experiment)	< 0.01 µA
Leakage Current (end of experiment)	< 20 µA
dM/dV Gain Sensitivity (at gain M = 50)	3 %/V
APDs used in the ECAL	122400

The APDs have to be reverse biased below the breakdown voltage at an operating gain (M) of 50 that will produces the necessary current value to be processed by the front-end electronics. For this a bias voltage between 200 and 500 Volts is required (the expected value at the moment is around 380 V). The stability of the voltage bias seen by the APD directly affects the ECAL resolution through the gain sensitivity, as a constant contribution to $\sigma(E)/E$. The design goal for the constant term is 0.5%. Other expected contributions to the constant term (intercalibration, light collection uniformity, energy leakage) are estimated of the order of 0.2% or less each. To preserve the resolution, the contribution from the gain stability must be of the same order. As a consequence, considering a safety factor of 2, gain fluctuations due to the APD (and its bias supply) should be limited to the ±0.1% (RMS) level.

A 3 %/V (the typical dM/dV value for the selected APD at M=50) gain sensitivity means that ±0.1% corresponds to ±33 mV (66 mV p-p) and as consequence for the power supply source electrical characteristics (Noise, Ripple, Stability, Regulation) maximum values.

Another issue of the system is its location that will be in the CMS control room due to the high radiation dose expected close to the detector (up to 1 MRad along with a neutron fluence of 2×10^{13} n/cm^2 over the entire life of the experiment). The power supply system will be connected to the detector by cables approximately 150 m long.

This approach leads to the choice of a modular power supply system organized in 144 High Voltage Boards (HVB) each containing 9 High Voltage Channels (HVCh) used to supply 900 APDs (100 per channel). The boards will be hosted in crates (HVCRATE), and the HVCRATEs in standard CMS control room racks.

The system will takes care also of the variations of the APD leakage current (I_{dark}) due to the radiation. Measurements made on this subject allow to evaluate that the I_{dark} from a starting value of 10 nA will increase up to 20 µA during an LHC running time of 10 years.

A leakage current monitor integrated into the system will measure continuously the surged current from APDs on each channel.

Finally the whole system needs to be remote controlled and monitored as well as to be integrated in the LHC Detector Control System (DCS).

In this paper is presented the activity started in the 1999 by the CMS collaboration (under responsibility of the INFN-ROMA department) in order to specify and build the power supply for the APDs.

After a series of tests performed to understand the feasibility and the critical points of the final system some prototypes, based on the system specification, of the HVCh and HVB was designed and produced by two different firms (Italian C.A.E.N. and German ISEG Spezialelektronik GmbH). The prototyping phase was organized in the following two steps:

- The first (named HVPROTO-0) to show the firm capability to implement an HVCh with the required electrical characteristics

- The second (HVPROTO-1) to produce the HVCRATE and HVB to use in the detector.

These prototypes were tested in Rome on a test-bed reproducing the detector load condition through the use of APDs arrays, programmable electronic load and resistors boxes.

At the moment laboratory qualification of the final system components (1 HVCRATE hosting 2 HVB) is going on, qualification on a real system using 1 or more crystals submodule (each submodule use 20 APDs) and the relative front-end electronics is expected in next months.

The rest of this paper is organized as follows. Section II reviews the system specifications. Section III describes the types of test performed on the prototypes and the test bed used. Section IV presents the HVB and HVCRATE developed by the two firm . Section V shows the result of the prototypes tests. Section VI contains the concluding remarks and the expected future works.

II. SYSTEM SPECIFICATION

In specifying the power supply system the starting point was the need to locate the HVCh sources in a site without high radiation dose and so outside the ECAL; this with the number of APDs used (122400) implies the impossibility to have a separated HV channel for each APD or APD capsule (the 2 APD used on the same crystal are assembled in a capsule) due to the space required on the ECAL patch panel for cabling (other than for the cables cost).

The number of APDs capsule sharing the same HVCh, was then fixed to 50 cause this is a good trade off between the following arguments:

- Space and cost for cabling
- Capability to select groups of APDs with the same operating voltage
- Homogeneous exposition to radiation

Last issue come from the voltage drop that the APD dark current produce on the resistors used in the scheme chosen to distribute the bias voltage to the APDs capsule (see figure 1). Each capsule receive the bias voltage through an RC filter network and a protection resistor (Rp) used to avoid to loose all the APDs sharing the same HVCh due of the short circuit between APD cathode and the HV ground (HV-).

In such scheme the voltage drop on the resistors due to the I_{dark} affects the APD bias voltage value and so its important that there will be an homogeneous increase in the current due to radiation and that close APD will share the same HVCh (at the moment the resistors value is fixed at 120Kohm corresponding to a starting voltage drop of 1.2 mV expected to increase to 60 mV after 500 days of running experiment and up to 2.4 V after 10 years).

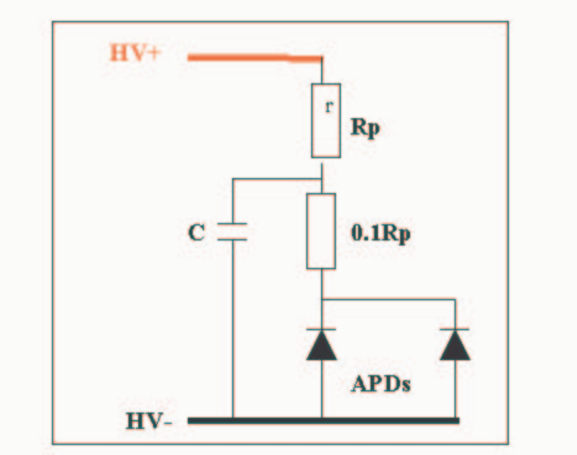

Figure 1: APDs electrical scheme in CMS-ECAL

For similar reason the maximum current value was fixed to 15mA (instead of the required 2 mA = 100 x 20 µA), so that when a short circuit happens on a capsule the HVCh could continue to drive properly the other APDs (supposing the Rp=120KOhm and HV=500 V in case of short circuit the current surged by the capsule will be order of 4 mA).

The HVCh has to be floating (no connection between the HV- and the system ground) and with sense line.(see figure 2) The former issue will allow a great flexibility in designing the detector grounding scheme while the latter improves the regulating abilities and will recover the voltage drop on the leads. This, negligible at the beginning of the experiment, could rise up to the value of 60 mV as time goes by due to the increase of the dark current (it is supposed to use 300m for leads of 100 Ohm/Km resistance).

For the system specification all the electrical system characteristics (Noise, Ripple, Stability, Regulation) have then been fixed to the conservative value of ±20 mV (±33 mV required) as maximum as reported in Table 2.

Table 2: Electrical Specification

Parameter	
Output voltage range	0 to 500 V
Programmable setting step	20 mV
DC regulation at load	< ±20 mV
DC stability at load (over 90 days)	< ±20 mV
Low freq. noise at load (f <100 kHz)	< ± 20 mVpp
High freq. noise at load (f >100 kHz)	< ± 2 mVpp
Operating temperature at supply	15 to 40 C°
Current limit per APD ($I_{MAX/APD}$)	15 mA
On and off maximum ramp rate	50 V/sec.
Absolute voltage precision Or **External Calibration**	< ±20 mV < 500 V

To implement remote control and monitor was specified a system controller (see Table 3) that will also permits to easily integrate the power supply system in the LHC CERN DCS.

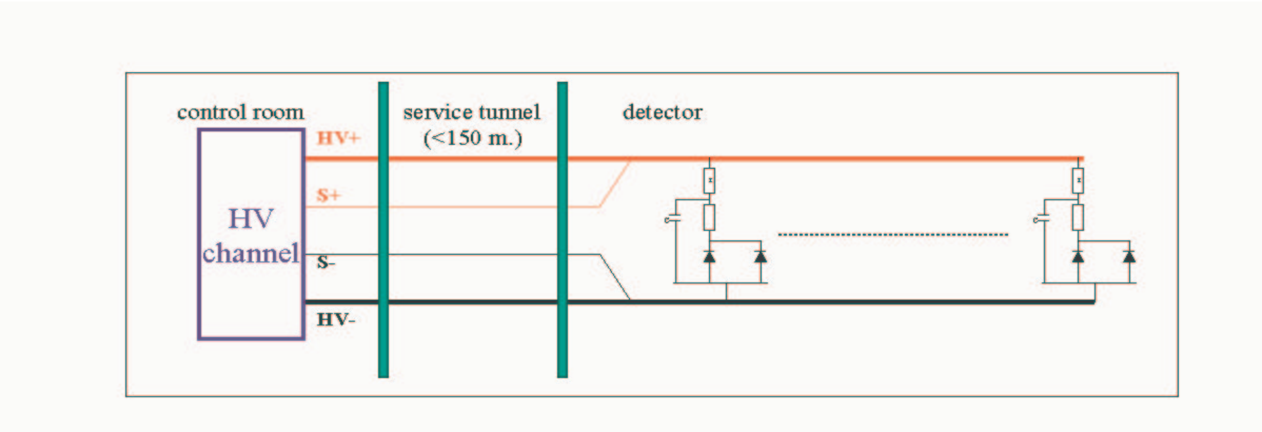

Figure 2: CMS-ECAL APDs power supply architecture

Table 3: Controller Specification

Parameter	
Interface	Ethernet or CERN recognized field bus
Scan Rate	1 ch/s to 1 ch/min
Internal buffer	> 1 000 samples
Sample data	Unit ID Channel ID Voltage Current
Voltage measurement range	0 to 500.00 V
Voltage measurement precision	± 20 mV
Current measurement range	0 to 15 mA
Current measurement resolution	500 nA
Current measurement precision	1%

Further programmable alarms and warnings must be generated in case of over and under current and voltage. Warnings shall generate periodic, “maskable” interrupt requests. Alarms shall generate “non-maskable” interrupt requests. Under program option, alarms shall initiate ramp down for the affected channels.

For complete system specification see[1].

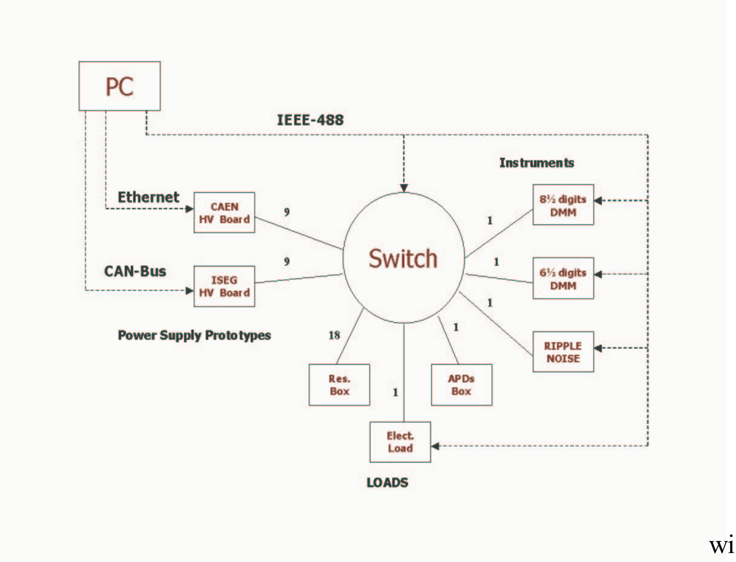

Figure 3: Power Supply Test Bed

III. TESTBED & TESTS

In order to perform system feasibility studies and prototypes test a suited test bed was build in Rome.(see figure 3). The system is based on a PC controlling through the IEEE-488 bus (the monitor software is written using the HP-VEE environment) most of equipments and a switch used to connect the power source under test with a series of “Loads” and measurement instruments. Through the use of a switch it is possible to automatically make measures on more than 72 HVCh (a complete HVCRATE).

The Loads used to test the power supply sources are:

- resistors surging the maximum current from all the HVChs simultaneously
- a programmable electronic load from CHROMA corporation capable to generate different load waveform and to operate in constant current , constant resistance and constant voltage modes
- an APD box containing 50 APDs connected as in figure 2 and installed inside a thermostatic chamber in order to obtain the necessary thermal stabilization (± .05 C°)

Among the measurement instruments used I want to remark the following :

- HP3458A digital multi-meter with 8½ digits resolution that due to an internal calibration capability allows (under software control) the necessary accuracy in temperature and time for long term stability measurements. (at 300Volts presents 1.9mV over 90 days accuracy and 55mV/C° thermal stability)
- a ripple and noise meter from Keisoku Giken corporation that automatically make the measurement of the different components of noise :
    - AC ripple (low freq.)
    - DC ripple (high freq.)
    - Noise

Among others, tests on the full voltage and current range will be performed to measure the following characteristics:

- Short term stability (< 24 hours)
- Short term reproducibility

- Ripple
- Noise
- Load Regulation (No-Load/Full-Load)
- Current measurement precision
- Voltage measurement precision

Test on the APD bias voltage (at the expected average value of 380 V) will be performed to measure the following system characteristics:

- Calibration procedure
- Long term stability (> 10 days)
- Thermal stability in the 15 to 40 C° range
- Long term reproducibility

IV. PROTOTYPES

Both firm developed the HVCh using the same architecture; a DC-DC converter generate the High Voltage (about 500 V) from an intermediate voltage (48 V for CAEN and 24 V for ISEG) and then a linear regulation it is used to obtain the programmable output voltage with the high stability and ultra low noise figures required from the specification. Also for the controller both firm decide to use the same approach integrating on each HVBOARD a micro-controller integrated circuit that take care to control and monitor, as specified, all the channel hosted on the board and providing a link for communication at higher level to a PC.

The CAEN system is based on the existing SY1527 mainframe (HVCRATE) which allow to host up 8 HVBOARD named by CAEN A1520E. The board design is based on a modular concept so that each HVCh is implemented on a separate module and up to 12 channel can be hosted on a single HVBOARD PCB (in our case just 9 module per board are used) thus permitting a major flexibility in case of channel failure. At the crate level the SY1527 integrate a PC capable to communicate with the board controller via an internal bus and different interfaces are available to integrate the SY1527 system on the LHC DCS (Ethernet, RS232, CAENET ,..).

The ISEG system is based on the ECH-228 crate which allow to host up to 8 HVBOARD named by ISEG EQH900p. The board design is based on compact size board using a single PCB integrating the controller electronic and up to 8 HVCh. (in our case two are used for each board) Communication between the board controller and the PC, not integrated on the crate, is made through a CANBUS interface.

V. TEST RESULT

Test results on the HVPROTO-0 and HVPROTO-1 are summarized in the following tables (see tables 4, 5, 6, 7) where for each test are specified the channel setting voltage, the type of load used (DCL = Electronic Load , RBOX = Resistor Box APD = APD Box), the current surged and the test duration in hours. Test shows that all the electrical specification was satisfied by the prototypes and long term stability test (up to 1 month) proved the high reliability of both systems.

Table 4: CAEN HVCh test result

Stability	
APD, 200nA, 318V, 40h	6 mV pp
DCL. 0.25mA, 318V, 63h	7 mV pp
Load Regulation	
DCL 0.25 to 14 mA, 318V	5 mV pp
Repeatability	
DCL 1 mA, 318V	10 mV pp
Ripple & Noise < 20Mhz	12 mV pp
Ripple & Noise < 100Mhz	14 mV pp

Table 5: ISEG HVCh test result

Stability	
APD, 200nA, 318V, 40h	30 mV pp
DCL. 0.25mA, 318V, 63h	30 mV pp
Load Regulation	
DCL 0.25 to 14 mA, 318V	25 mV pp
Repeatability	
DCL 1 mA, 318V	20 mV pp
Ripple & Noise < 20Mhz	2 mV pp
Ripple & Noise < 100Mhz	4 mV pp

The same result was confirmed in the HVBOARD produced by the firms during the following prototyping phase (HVPROTO-1) in this case also the ripple and noise was measured.

A test performed on the HVBOARD for more than 1 month showed the high stability on time of all the channels while all the variations observed was related to temperature changes in the laboratory.

Thermal stability was also verified for both systems in the expected environment temperature range of the power supply rack location (15 to 40 C°) using a thermostatic chamber.

Results showed values in excess of the desired 20 mV pp and a solution based on more stable components (1ppm accuracy) and/or temperature drift compensation setting can be implemented to improve the boards performance.

Table 6: CAEN HVPROTO-1 HVBOARD test result

	Stability Test (mV) (35 days) (13mA, 300V)	**Thermal Stability (mV) (ΔV for 15÷40 C°)** (13mA, 300V)
CH0	± 15	28
CH1	± 20	39
CH2	± 12	33
CH3	± 15	25
CH4	± 15	8
CH5	± 15	35
CH6	± 24	39
CH7	± 11	32
CH8	± 10	26

Temperature drift compensation is possible due to presence on the crate of temperature probes that can be used to monitor the environment temperature and consequently to regulate the channels voltage setting.

VI. CONCLUSION AND FUTURE WORK

In this paper is described the activity to specify, build and test the power supply system for the avalanche photodiode used in the readout electronics of the CMS-ECAL detector.

At the moment all the system building blocks (HVCRATE, HVBOARD) have been produced and tested in laboratory in Rome. Test shows the compliance with the electrical and system specification.

Table 7: ISEG HVPROTO-1 HVBOARD test result

	Stability Test (mV) (35 days) (13mA, 300V)	**Thermal Stability (mV) (ΔV for 15÷40 C°)** (13mA, 300V)
CH0	± 13	27
CH1	± 19	62
CH2	± 50	92
CH3	± 21	36
CH4	± 16	25
CH5	± 11	31
CH6	± 27	82
CH7	± 16	63
CH8	± 10	28

Further activity has to be done in order to validate the HVBOARD and the HVCRATE on real readout system (crystals, APDs, readout electronics) before to proceed with the mass production (144 HVBOARD and 18 HVCRATE).

System integration into the LHC DCS using the PVSII SCADA software is then mandatory for use in to the CMS experiment.

REFERENCES.

[1] – "Specification for a prototype of a modular power supply system for avalanche photodiodes to be used in the electromagnetic calorimeter of the CMS experiment", CMS-EB-CS-0001, 1-7-99