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The Upgraded CMS Preshower High Voltage System

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Abstract

In March 2012 the high voltage system of the silicon-sensor-based CMS Preshower detector underwent a significant upgrade. In order to increase the granularity of the bias distribution lines, the number of power supplies was doubled and fully configurable distribution boards were developed and installed. These new boards provide much improved flexibility in the powering, necessary to cope with the expected evolution of the 4288 silicon sensors with radiation damage. They also provide measurement of the 2200 bias-voltage lines that go to the detector, enabling fast identification/diagnosis of any anomalous currents and providing detailed knowledge of the sensor current evolution over time.

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The Upgraded CMS Preshower High Voltage System

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ABSTRACT: In March 2012 the high voltage system of the silicon-sensor-based CMS Preshower detector underwent a significant upgrade. In order to increase the granularity of the bias distribution lines, the number of power supplies was doubled and fully configurable distribution boards were developed and installed. These new boards provide much improved flexibility in the powering, necessary to cope with the expected evolution of the 4288 silicon sensors with radiation damage. They also provide measurement of the ~2200 bias-voltage lines that go to the detector, enabling fast identification/diagnosis of any anomalous currents and providing detailed knowledge of the sensor current evolution over time.

KEYWORDS: Voltage distributions; Radiation monitoring.

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1. Introduction and motivation

The CMS Preshower is part of the CMS Electromagnetic Calorimeter (ECAL) system [1]. It is a sampling calorimeter comprising two layers of lead per endcap, each followed by a layer of silicon strip sensors. There are a total of 4288 sensors. From 2009-2011 the sensors were biased by 192 commercial bias-voltage (BV) power supply channels through 16 custom 9U distribution boards (4 types, with 7 different types of plug-in mezzanine). The distribution boards were used to fan out the 192 voltages to around 2200 BV lines which power either two sensors in parallel or, in a few cases, a single sensor. The sensors, provided by 6 manufacturers, present specific characteristics and have a large spread in voltage required for full depletion (V_{fd}) – from 50V up to 300V. The sensors were grouped on the detector such that a single BV channel powered between 12 and 30 sensors with similar V_{fd} .

The V_{fd} changes with accumulated neutron fluence (strongly dependent on distance of the sensor from the beam axis) and is predicted to decrease to a value below 50V before increasing to values up to 500V. The leakage currents of the sensors were of the order of a microampere at installation time, but increase with radiation, mainly due to damage to the bulk silicon from neutrons. Figure 1 shows the Preshower silicon sensor volume leakage currents as a function of the sensor position from the beam axis, at the end of 2011 after an integrated luminosity of 6.17 fb^{-1} , corresponding to a fluence of around $4.5 \times 10^{11} \text{ n/cm}^2$ closest to the beam axis. The optimum BV grouping of the sensors will change with time due to their different locations. The initial high-voltage system was not flexible enough to deal with these expected changes. In addition, in 2010 & 2011, 2% of the sensors exhibited anomalously high leakage currents (the extreme outliers in Fig. 1), requiring them to be disconnected (via jumpers) at the BV distribution boards. Identification of the sensors responsible for the high currents was difficult since the granularity of the current monitoring was only at the BV power supply channel level. Following the evolution of the currents on individual BV lines was only possible between LHC operating periods, by disconnecting cables and performing measurements by hand – a lengthy and cumbersome process.

To address these issues, the Preshower group decided to purchase an additional 192 BV power supply channels and upgrade the distribution boards to include additional flexibility and functionality (requiring a full re-design).

Figure 1: Volume leakage current measured as a function of the distance from the beam, after an integrated luminosity of 6.17 fb^{-1} . The solid line indicates the expected values based on Fluka simulations and calculations of the Hamburg model for 0°C . The measurements were carried out at 18.9°C , but the data are converted to the equivalent currents at 0°C . Points far from the blue line are due to sensors with excess surface currents.

Figure 2: The situation in all four planes of the CMS Preshower in 2011 (before the upgrade). Operating sensors shown in green. Disconnected sensors due to high current are shown in red. Sensors not being read out due to other (low-voltage and optical connection) problems are shown in yellow and black, respectively.

Figure 2 illustrates Data Quality Monitoring (DQM) plots showing the situation in 2011 in all four planes of the CMS Preshower before the upgrade. The two planes at each end are ES+F, ES+R and ES-F, ES-R, respectively.

2. Implementation

The new distribution boards have been designed to provide increased flexibility and continuous in-situ current monitoring of individual BV lines. The new design comprises a single multilayer PCB that distributes up to 24 BV power supply channels to 200 individual BV lines through 5 connectors each serving 40 lines.

The boards can be configured for any powering scheme through a pin matrix that is fully configurable by jumpers. The board has one sub-matrix per output connector, consisting of two stages: the first is essentially a multiplexer while the second one is a fan-out. The multiplexing stage selects up to 10 of the 24 available BV power supply channels. The fan-out stage independently assigns each of the 40 BV lines of the output cable connector to one of the 10 selected BV power channels. The constraint of selecting from only 10 BV power supply channels, when assigning the BV lines of one output cable connector, is due to space limitations on the PCB. Figure 3 shows an example of a BV line assignment through the pin matrix.

The BV currents are read out by Embedded Local Monitoring Boards (ELMB) [2] through voltage divider networks. Each board carries 5 ELMBs, which are interconnected and interfaced to the ECAL Detector Control System (DCS) [3] through a Controller Area Network (CAN) bus. The distribution boards have the possibility to be daisy-chained externally in order to reduce the total number of CAN bus channels needed for their readout. Figure 4 shows a picture of a distribution board already configured for part of the CMS Preshower sub-detector.

For the assembly of the large pin arrays, which cover half the board's surface, press-fit pins were used instead of solderable ones. This choice was made for reliability reasons, since soldering was found to be extremely difficult and unreliable due to the very high thermal mass of the pin arrays.

The new system – consisting of 32 12-channel power supplies and 16 distribution boards – was installed in March 2012. The 16 distribution boards are organised in 4 groups of 4 corresponding to the 4 CMS Preshower planes. Additionally, the boards of each group are daisy-chained in order to be read-out by a single CAN bus channel. Figure 5 shows front and rear views of a crate equipped with the new distribution boards.

Figure 3: BV line assignment example. In this example, the BV line 5 is assigned to BV power supply channel 3. The two jumpers used are shown in yellow.

Figure 4: Picture of the new distribution board indicating its external connections, configured for a part of the ES-F plane. In the close-up of the top jumper array we see how the BV lines 2-3, 4-5, 6-10 and 11-15 are assigned through jumpers to BV power supply channels 1, 2, 3 and 4, respectively.

Figure 5: Front view (on the left) and rear view (on the right) of a production crate.

3. Current Monitoring

The high voltage monitoring electronics is based on a passive design to condition the signal for the ELMB readout, shown in Figure 6. A resistor is placed in series with each BV line to the detector, with the resistance being carefully calculated to ensure a negligible voltage drop and consequently negligible change to the detector bias level. The voltages on either side of this series resistor are stepped down to appropriate levels for the ELMB input using simple voltage dividers. The voltages from both dividers are then connected to the ELMB, which is able to measure the differential voltage, enabling the current through the series resistor to be determined.

Figure 6: Readout circuit.

A total of 80 ELMBs are used to read all Preshower BV lines. By design, the ELMBs of the 16 distribution boards are grouped into 4 CAN branches, with 4 distribution boards (20 ELMBs) per branch. The low-voltage powering scheme required by the ELMBs (3 x 12V for CAN, Analog and Digital electronics) is duplicated 4 times according to the distribution of the CAN buses. This means that the 4 groups are completely independent, avoiding a loss of the whole BV current monitoring system in the case of single failures. Figure 7 shows the ELMB power distribution in a production crate at the CMS site.

Figure 7: ELMB power distribution.

The CAN buses are connected to a CMS ECAL DCS computer through CAN-USB converters. The Open Platform Communications Data Access (OPC DA) server delivered with the ELMBs is used to manage the CAN bus communication and make the data available on the computer. The CMS ECAL DCS software is developed using a Supervisory Control and Data Acquisition (SCADA) system called WinCC Open Architecture (WinCC OA) [4] and makes wide use of the Joint Controls Project Framework (JCOP FW) [5]. Developed on top of the ELMB JCOP FW

component, the Preshower BV monitoring application was deployed into production at the beginning of 2012 and provides readout of all BV line currents every 30 seconds. Standard data smoothing algorithms of WinCC OA are used to reduce the data quantity before it is archived in an Oracle database.

Due to time constraints, a complete calibration of all readout channels was not possible and therefore, until the first LHC Long Shutdown (LS1) in 2013 and 2014, only raw differential voltage values are being archived and analysed (Figures 8 and 9). A calibration setup has been prepared in the CMS ECAL DCS laboratory to provide a complete understanding of the readout characteristics and to allow a precise correlation between the distributed BV lines and the power supply channel. When all channels are calibrated, it will be possible to follow the evolution of the sensor currents in real time as well as to quickly identify any problematic sensors.

ESBV_Monitoring (cms_es_dcs_03 - P5_Support_Tools; #1)									
32106 32107	CAEN/ES_HV2/board03/channel010	259.74	95.05	33308 33309	CAEN/ES_HV2/board03/channel009	160.10	41.88		
32306 32307	CAEN/ES_HV2/board03/channel010	14.55	28.97	33608 33609	CAEN/ES_HV2/board03/channel009	99.99	33.78		
32206 32207	CAEN/ES_HV2/board03/channel010	-114.04	33.50	33508 33509	CAEN/ES_HV2/board03/channel009	93.44	47.56		
32506 32507	CAEN/ES_HV2/board03/channel010	267.11	29.31	32202 32203	CAEN/ES_HV2/board03/channel011	-235.01	27.96		
32406 32407	CAEN/ES_HV2/board03/channel010	-117.70	43.62	32102 32103	CAEN/ES_HV2/board03/channel011	155.05	36.45		
32606 32607	CAEN/ES_HV2/board03/channel009	76.05	13.80	32402 32403	CAEN/ES_HV2/board03/channel011	224.43	58.86		
32806 32807	CAEN/ES_HV2/board03/channel009	-193.28	10.01	32302 32303	CAEN/ES_HV2/board03/channel011	-85.57	27.21		
32706 32707	CAEN/ES_HV2/board03/channel009	21.68	10.44	32602 32603	CAEN/ES_HV2/board03/channel011	-7.76	5.80		
33006 33007	CAEN/ES_HV2/board03/channel009	10.81	17.38	32502 32503	CAEN/ES_HV2/board03/channel011	-292.15	20.01		
32906 32907	CAEN/ES_HV2/board03/channel009	-171.01	32.28	32803 NC	CAEN/ES_HV2/board03/channel011	342.52	208.36		
33206 33207	CAEN/ES_HV2/board03/channel009	-244.74	17.58	32703 NC	CAEN/ES_HV2/board03/channel011	177.78	59.61		
33106 33107	CAEN/ES_HV2/board03/channel009	5.97	22.35	32204 32205	CAEN/ES_HV2/board03/channel010	-221.99	29.18		
33407 NC	CAEN/ES_HV2/board03/channel009	-19.32	20.63	32104 32105	CAEN/ES_HV2/board03/channel010	241.52	67.37		
33306 33307	CAEN/ES_HV2/board03/channel009	40.46	10.68	32404 32405	CAEN/ES_HV2/board03/channel010	28.90	17.64		
32208 32209	CAEN/ES_HV2/board03/channel007	53.47	64.60	32304 32305	CAEN/ES_HV2/board03/channel010	249.99	76.61		
32108 32109	CAEN/ES_HV2/board03/channel007	51.83	53.79	32604 32605	CAEN/ES_HV2/board03/channel011	242.98	7.54		
32408 32409	CAEN/ES_HV2/board03/channel007	204.94	81.01	32504 32505	CAEN/ES_HV2/board03/channel011	340.03	66.57		
32308 32309	CAEN/ES_HV2/board03/channel007	153.93	55.57	32804 32805	CAEN/ES_HV2/board03/channel011	-42.01	32.75		
32608 32609	CAEN/ES_HV2/board03/channel008	-14.03	49.58	32704 32705	CAEN/ES_HV2/board03/channel011	-511.06	89.01		
32508 32509	CAEN/ES_HV2/board03/channel008	72.68	72.03	33004 33005	CAEN/ES_HV2/board03/channel011	-81.40	61.07		
32808 32809	CAEN/ES_HV2/board03/channel008	80.74	30.26	32904 32905	CAEN/ES_HV2/board03/channel011	-249.68	74.29		
32708 32709	CAEN/ES_HV2/board03/channel008	-23.79	10.29	33205 NC	CAEN/ES_HV2/board03/channel011	23.98	73.06		
33008 33009	CAEN/ES_HV2/board03/channel008	81.01	38.40	33104 33105	CAEN/ES_HV2/board03/channel011	-137.68	6.60		
32908 32909	CAEN/ES_HV2/board03/channel008	-43.86	47.94						
33208 33209	CAEN/ES_HV2/board03/channel008	58.06	47.58						
33108 33109	CAEN/ES_HV2/board03/channel008	133.90	33.57						
33408 33409	CAEN/ES_HV2/board03/channel009	-26.45	16.83						
ESM_CR09 50									

Figure 8: WinCC OA panel displaying ELMB readings for one Preshower partition.

Figure 9: Example of current measurements for one power supply channel (CAEN) and one BV line connected to that channel (ELMB).

4. Results

A large part of the effort in the commissioning of the new system was the optimization of the BV grouping. The definition of the optimum configuration has been done taking into account two parameters: the recovery of the disconnected sensors due to high-leakage currents and the equalization of the current consumption in order to be able to withstand the expected silicon radiation damage due to the neutron fluence until the end of the 2012 physics run.

The configurability of the new system has made it possible to repair and restore the previously "unplugged" sensors. They have been connected to individual BV channels, thus restoring to operation the part of the detector that was missing in 2010/2011. Figure 10 illustrates DQM plots showing the situation in 2012 in all four planes of the CMS Preshower after the upgrade.

Figure 10: The situation in all four planes of the CMS Preshower in 2012 (after the upgrade). Operating sensors shown in green. Sensors not readout due to other (low-voltage and optical connection) problems are shown in yellow and black, respectively.

Already, a few months after the commissioning of the new system, the flexibility of the distribution boards has proven very useful. In mid 2012, the LHC management decided to extend the 2012 physics run as well as to increase its luminosity such that the accumulated neutron fluence at the end of 2012 is expected to be twice as high as originally foreseen. In order to withstand these significantly increased levels of radiation, the BV grouping implemented in March 2012 had to be changed in the middle of the 2012 physics run. A new BV grouping was defined and applied successfully during the technical stop of September 2012, demonstrating the rapid reconfiguration that is now possible with the newly designed distribution boards.

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