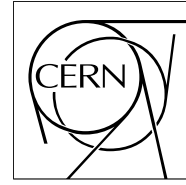


The Compact Muon Solenoid Experiment

CMS Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland



High Voltage System for the CMS Forward Calorimeter

N. Akchurin¹, O. Atramentov³, L. Dimitrov², J. Hauptman³, H. Kim¹, S. Los⁴, S. Sergeev^{4,5}, I. Vankov²

¹*Texas Tech University, Department of Physics, Lubbock, TX, USA*

²*Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria*

³*Iowa State University, Department of Physics, Ames, IA, USA*

⁴*Fermi National Accelerator Laboratory, Batavia, IL, USA*

⁵*Joint Institute for Nuclear Research, Dubna, Russia*

Abstract

The high voltage system for the CMS forward calorimeters (HF) is described and the measurements of the critical parameters are tabulated.

1 Introduction

The Compact Muon Solenoid (CMS) is a general purpose detector for precision detection of gammas, leptons, hadrons and jets at the Large Hadron Collider (LHC) at CERN [1]. The hadronic calorimeters [2] consist of three subsystems: Hadronic Barrel (HB), Hadronic Endcap (HE), and Hadronic Forward (HF), as shown in Figure 1. There are two identical forward calorimeters (HF+ and HF-) located at ± 11 meters from the interaction point. The absorber structure is composed of 5-mm-thick stacked grooved iron plates. The active medium consists of fused-silica core optical fibers inserted into these grooves. The signal is generated when charged shower particles above the Cherenkov threshold ($E \geq 190$ keV for electrons) generate Cherenkov light, thereby rendering the calorimeter mostly sensitive to the electromagnetic core of hadronic showers. The absorber structure is azimuthally subdivided into 20-degree modular wedges (18 on either side of the interaction point). The fibers run parallel to the beam line and are bundled to form 0.175×0.175 in $\Delta\eta \times \Delta\phi$ towers. Each calorimeter is functionally subdivided into two longitudinal depth segments. Half of the fibers run over the full depth of the absorber (165 cm) while the other half starts at a depth of 22 cm from the front of the detector. These two sets of fibers are read out separately by Hamamatsu R7525 photomultipliers (PMTs). This arrangement makes it possible to distinguish showers generated by electrons and photons, which deposit a large fraction of their energy in the first 22 cm, from those generated by hadrons, which produce signals in both segments.

Each calorimeter is housed in a hermetic radiation shielding consisting of layers of 40 cm thick steel, 40 cm of concrete, and 5 cm of polyethylene. A large plug structure in the back of the detector provides additional shielding (Figure 2).

In this paper, we describe our design for supplying high voltage to 1728 PMTs, maintaining economy and ease of use without sacrificing performance. In Section 2, we elaborate on the design considerations. In Sections 3 and 4, we concentrate on the design of the power supply and high voltage units. The description of the controller and monitoring is in Section 5. The software system is discussed in the following section, Section 6. After a brief presentation of critical system parameters in Section 7, we summarize in Section 8.

2 Design Considerations

2.1 Parallel Dynode High Voltage

The principle of a parallel dynode high voltage (HV) system is to use a common resistive divider to supply the dynodes of a set of PMTs that are nearly identical in gain. This approach reduces the number of high voltage channels, the dissipated power in the dividers, and the cost of the overall system. Individual PMT gain adjustments are not possible, but this is easily addressed by selecting PMTs with similar gains.

We chose to bias 8 PMTs with one printed circuit board (PCB) as depicted in Figure 3. The first six dynodes are supplied from one HV channel (U_K) by means of a common resistive divider since there is relatively low current through the first six dynodes. Two separate channels (U_{D7} and U_{D8}) are used to supply dynodes $D7$ and $D8$. This arrangement makes it possible to provide the highest dynode currents directly from the corresponding high voltage channels for $D7$ and $D8$, ensuring voltage stability and drastically decreasing the power losses in the intermediate resistors. To decrease the total number of HV channels, the cluster of three HV channels required per PCB is designed to supply nine PCBs with similar PMTs in gain.

2.2 Photomultiplier PCB Distribution

One of the concerns in a calorimeter system of this kind is the PMT lifetime at high luminosity. The criterion is that the gain degradation should not exceed 20% over 10 years of LHC operation. We estimate that approximately 1 kC of charge would be accumulated during this time. In order to remain under 1 kC, the PMT gain must be about 5×10^4 for the region nearest to the beam (high rapidity), 1.5×10^5 for the middle region, and 5×10^5 for the outer region (low rapidity).

The 24 PMTs are mounted in a readout box, and two readout boxes are needed per wedge (see Figure 4). In order to provide three groups of eight PMTs with different gains, the three PCBs in each readout box must use three different HV clusters. For this reason, nine PCBs supplied by each cluster are distributed among the nine readout boxes of one quadrant (a 90-degree section of the calorimeter).

The three HV sets required for each quadrant are provided by one HV module. One 21-wire 165 m long cable (three extra wires are added for both LED control and Interlock circuits, and several spares are available) feeds the HV module output to a HV distributor, from which the nine readout boxes (through about 15 m cables) are powered. Thus, in the case of HF, eight HV power supply modules and eight cables (eight quadrants) are needed for the entire system.

3 Power Supply System

Four high voltage power supply modules for each calorimeter are housed in a 19 6U Eurostandard crate. A crate controller, a crate power supply module, and a monitoring and control unit also reside in the same crate (Figure 5). The operation of this crate is similar to that of the crates of the CMS hadron barrel and endcap calorimeter [3].

Four trimmer potentiometers are installed in the monitor and control unit for presetting the upper limit values:

1. One potentiometer for the output voltages of all channels: only the upper limit $U_{K,lim}$ for U_K of all three clusters (A, B, C) is adjusted, while the voltage limits for the remaining six channels are derived from $U_{K,lim}$ as $(0, 4)U_{K,lim}$ for U_{D7} channels and $(0, 2)U_{K,lim}$ for U_{D8} channels.
2. Three potentiometers for the current limits in each three subsequent channels ($I_{lim1}, I_{lim2}, I_{lim3}$).

These settings are common for all HV modules in the crate and are distributed by four analog lines in the backplane of the crate.

The crate controller provides data and instructions transfer between the host computer and the crate via an RS-485 interface. The internal interface with the HV power supply modules is implemented by the crate local bus using a custom protocol [4].

The crate power supply module generates all voltages required for normal operation of the modules, $+5, \pm 8$ and $+40$ V. They are read out by the crate controller and displayed on the main monitoring window of the host computer (see Figure 9). An alarm is generated if any of the supply voltages exceed the preset limits. A photograph of the power supply crate is shown in Figure 6.

4 High Voltage Power Supply Module

The block diagram of the HV module is shown in Figure 7. As already mentioned, it contains three clusters (A, B, and C) of three channels. The output voltage of the first channel in each cluster (A1, B1, and C1) is intended to supply the resistive dividers in the PCBs and can be regulated from 0 to -2000 V. The second channel produces the voltage for the $D7$ dynodes and can be varied from 0 to -800 V. The third channel generates the $D8$ voltage, and it ranges from 0 to -400 V. Each high voltage channel includes one 12-bit serial digital-to-analog converter (DAC), a DC-DC converter [4], and two comparators (CMPs) for overvoltage and overcurrent protection.

A LOCAL CONTROL block in the module [4] receives all the output voltage set values from the crate local bus in a serial mode sent by the crate controller. This block transfers them to the DACs that provide the reference voltages for each output. The data are stored only in the DAC output register of the corresponding channel.

All analog signals corresponding to the output voltage and load current values are fed consecutively through a multiplexer (MUX) to a 12-bit analog-to-digital converter (ADC) to be read (in serial mode) by the local control block. These signals are also sent to the individual channel comparators (CMPs), where they are compared with the corresponding voltage or current limit values received by the crate local bus. In case of overvoltage or overcurrent in any channel, the corresponding comparator sends a signal to the local control block, which immediately clears the DACs in all three channels of this cluster, dropping the output voltage to zero. An alarm signal is also sent to the crate controller.

In order to maintain the integrity of all HV lines, a daisy chained interlock circuit is added in all cables distributing the high voltage from the module to the readout boxes. In case of interruption of the interlock

circuit, the local control block immediately disables all HV channels, activates the module front panel LED (INTERLOCK), and communicates the interlock error condition to the crate controller.

Ten LEDs (one in the HV distributor and nine in the readout boxes) indicate that at least one group of HV channels is on and that readout boxes are powered.

A photograph of the HV power supply module is shown in Figure 8. All high voltage circuits are protected by an aluminum shielding.

5 Crate Controller Module and Monitor and Control Unit

The internal structure and the principle of operation of the crate controller module and the monitor and control unit (Figure 9) are the same as in the HCAL power supply system [3]: a standard RS-485 interface is used for the link with the host computer; the same control logic block performs the data exchange with the HV modules and the monitor and control unit; and the unit displays the status of the system using seven front panel LEDs. The main difference between the HV system for HB/HE and HF is that the former subsystems use hybrid photodiodes (HPD) for light detection whereas HF uses PMTs

Firmware is capable of controlling both HPD and PMT power supply systems while recognizing the different types of modules by their unique ID numbers.

6 System Software

Essentially the same software package as in the HB/HE power supply system [3] is used. The main difference is in the client program which controls and monitors the entire system. The program is adopted to monitor and display the parameters of nine channels, as shown in Figure 10.

7 Technical Parameters

The technical parameters of the system are shown in Table 1. The performance values marked with an asterisk have been verified by measurements.

Table 1: The specifications of the high voltage system for the HF are summarized below. The asterisks indicate tested values.

Parameter	Channels A1, B1, C1	Channels A2, B2, C2	Channels A3, B3, C3
Max. Operating Voltage (V)	-2000	-800	-400
Voltage Adjust Step (V)	0.5	0.2	0.1
Ramp Rate (V/s)	5 – 500	2 – 200	1 – 100
Voltage Ripple (mV _{pp})	< 100*	< 40*	< 20*
Voltage Monitor Precision (%)	< 0.1*	< 0.1*	< 0.1*
Long Term Stability (%)	< 0.1*	< 0.1*	< 0.1*
Max. Current Out (mA)	0.8	0.8	0.8
Current Monitor Precision (%)	< 1*	< 1*	< 1*

8 Conclusions and Summary

An economical, robust, and reliable multi-channel power supply system is developed, based on a custom power supply module and containing three clusters of three high voltage outputs for the CMS hadronic forward calorimeter photomultipliers. The long term and beam tests confirm the stable operation of the system and the reliability of its user interface.

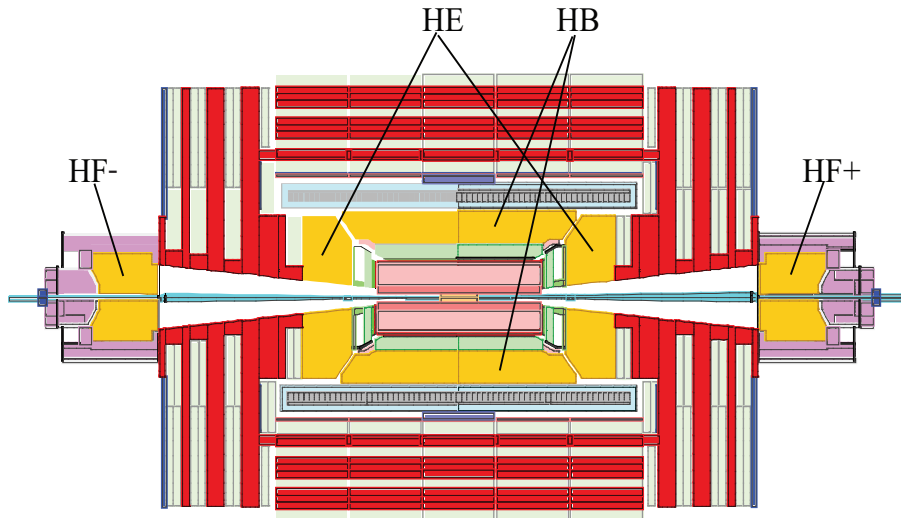


Figure 1: Three subdetectors make up the hadronic calorimeter system in CMS, hadronic barrel (HB), hadronic endcap (HE) and hadronic forward (HF).

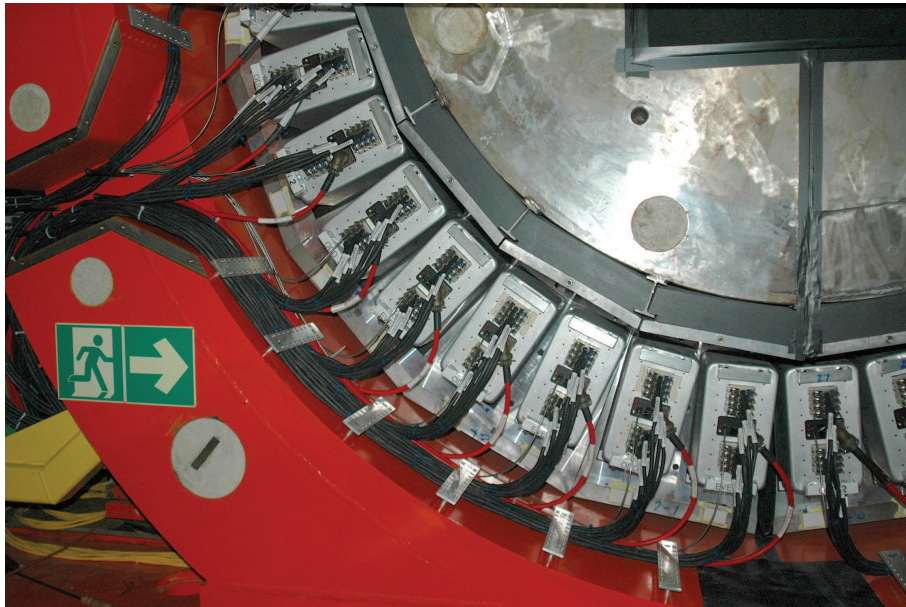


Figure 2: The back view of the quarter of the CMS hadron forward calorimeter (HF) is shown during assembly. Nine readoutboxes are installed per one quarter of the detector. The high voltage cables are in red and the signal cables are in black.

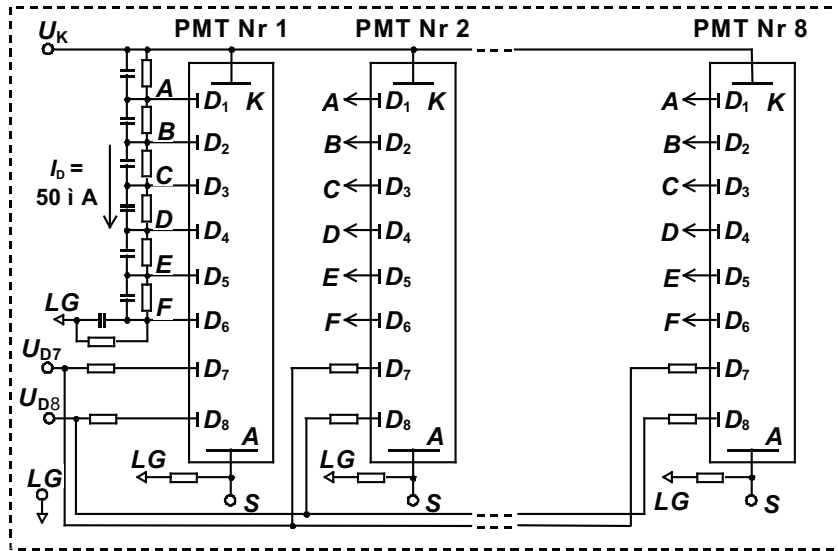


Figure 3: The electrical diagram of the PMT voltage distribution shows that there are three voltages provided to PMTs in a group of eight in addition to ground. The photocathode voltage is set at U_K and the seventh and the eighth dynodes are set at U_{D7} and U_{D8} , respectively.

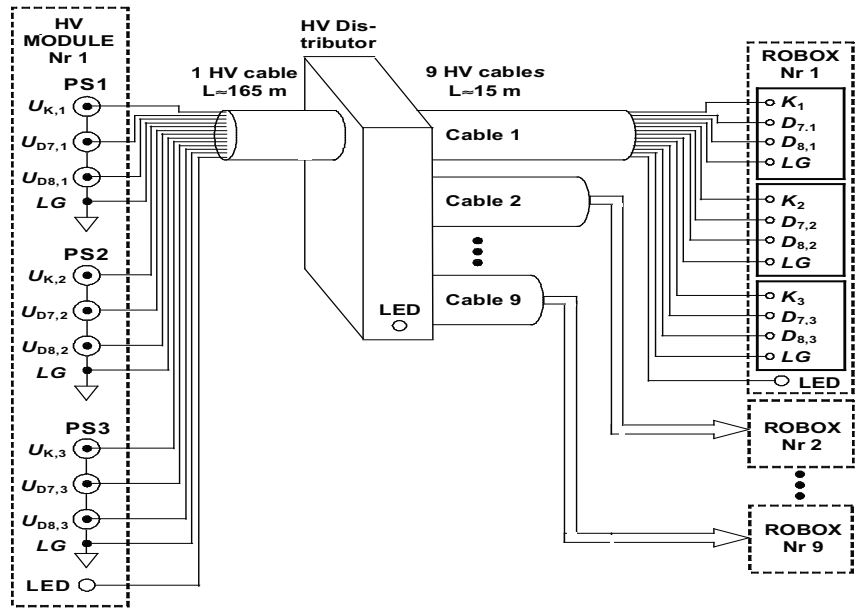


Figure 4: One quadrant high voltage distribution 9 readout boxes are biased using one high voltage module. For the voltages delivered to individual PMT dynodes see also Figure 3.

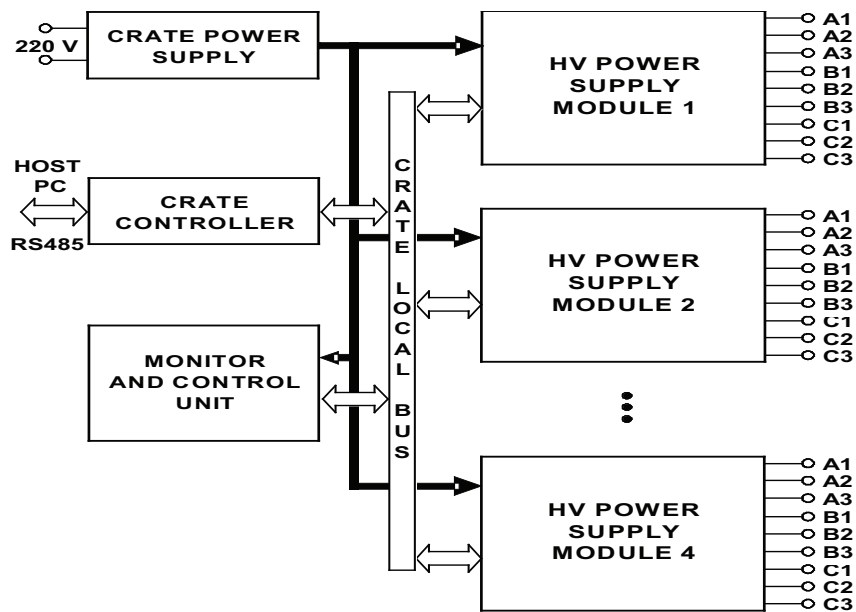


Figure 5: The block diagram of the high voltage supply module is depicted above.



Figure 6: The high voltage crate normally houses 4 power supply modules, one per HF quadrant.

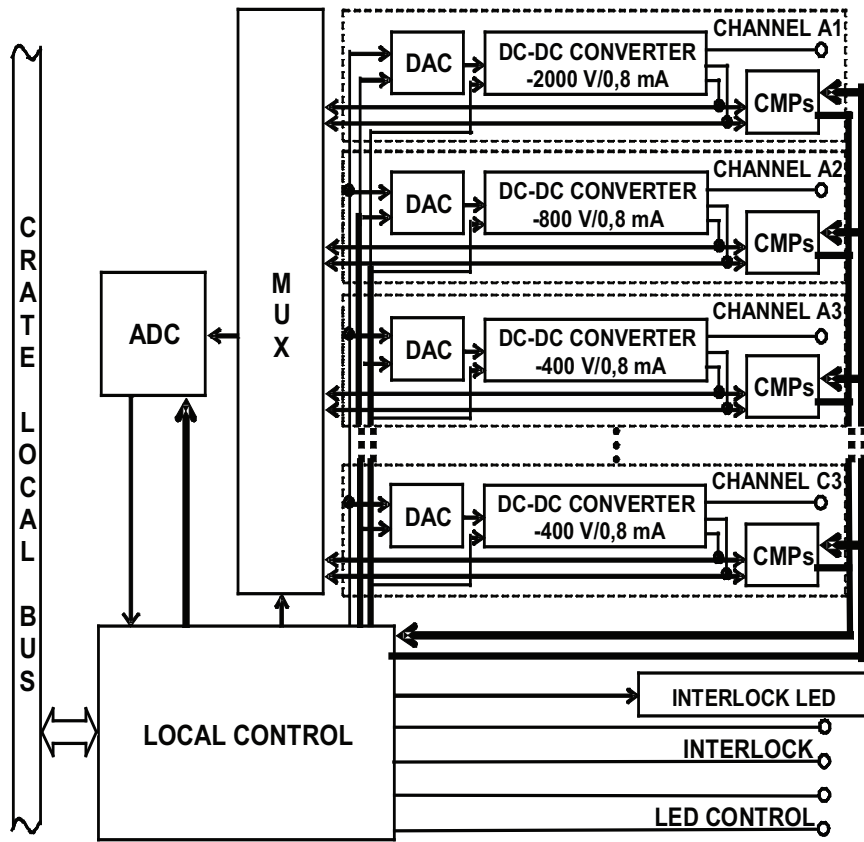


Figure 7: The block diagram of the high voltage module (see Figure 8).



Figure 8: The high voltage supply module is shown above and it is housed in the HV crate (see Figure 6). The high voltage output is through the connector shown on the panel.

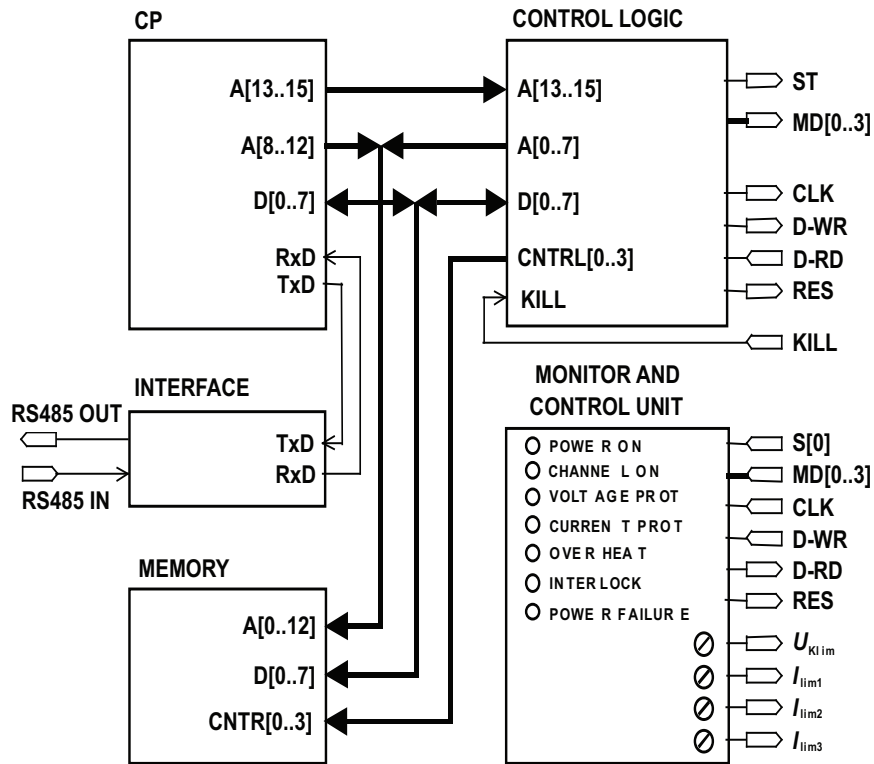


Figure 9: The block diagram of the crate controller module with the monitoring and control unit shows the fundamental elements of the system. The communication to the computing system is through the RS-485 interface.

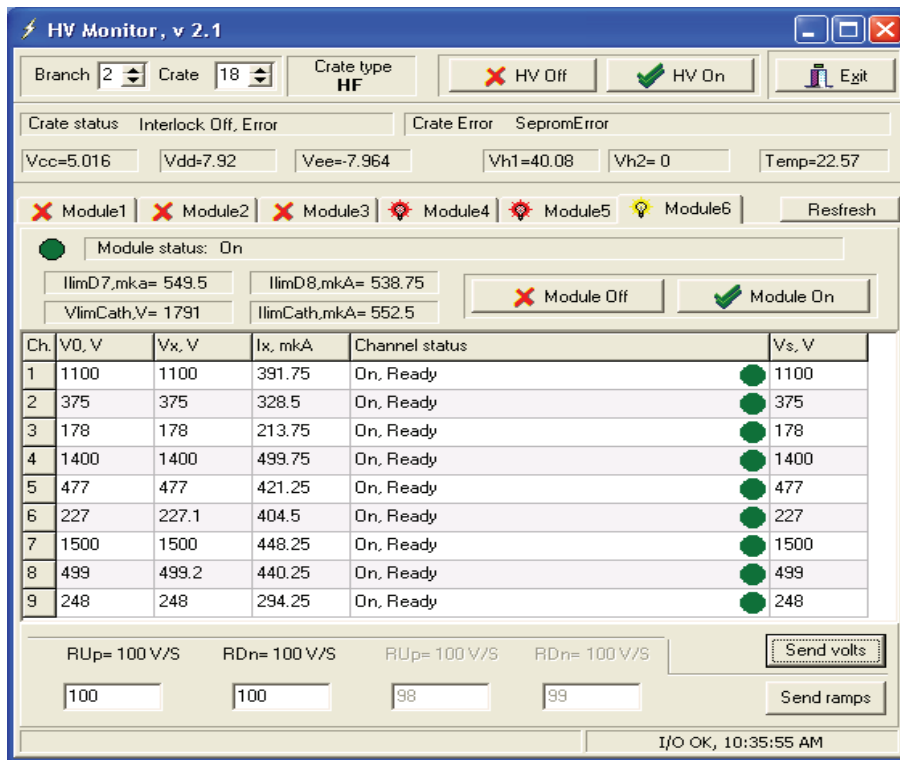


Figure 10: Control and the monitoring functions for the high voltage are carried out through a graphical user interface. The monitoring system reports back the actual voltages and currents in all nine outputs for a given HF quadrant.

References

- [1] CMS Collaboration, *CMS Technical Proposal*, CERN/LHCC 94-38, LHCC/ P1, 15 December 1994.
- [2] CMS Collaboration, *The Hadron Calorimeter Project*, Technical Design Report. CERN/LHCC 97-31, CMS TDR 2, 20 June 2003.
- [3] L. Dimitrov, J. E. Elias, B. Kunov, S. Sergueev, A. Ronzhin and I. Vankov, *Photodetector Power Supply System for the CMS Hadron Calorimeter*, Nucl. Instr. Meth. **A** 2005 (in print).
- [4] L. Dimitrov and I. Vankov, *High Voltage Module for the Photomultiplier Power Supply System of the CMS Forward Hadron Calorimeter*, Proc. of the 14-th Int. Conf. ELECTRONICS ET2005, Sept. 2005, Sozopol, Bulgaria, Book 2, p. 179.