# HIGH-VOLTAGE POWER SUPPLY FOR GEM DETECTORS*

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This paper presents a brief description of a design of a high-voltage power supply for GEM detectors designed by the Research Team.

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## 1. Introduction

GEM detector [1] is constructed with a few layers of thin conductive foil. To fulfill their task, each of the layers of foil must be polarized by wide ranges of high voltage. In a WEST experiment, a GEM detector with 8 layers of foils is used and the polarized voltage changes from 350 V to 1400 V. To provide a wide range of voltage regulation at 8 channels and to meet security requirements [2] for the GEM detector, a high-voltage power supply was developed.

## 2. HV power supply

This high-voltage power supply was made in an industrial 2U standard case with integrated mounting plates. Its aluminum case provides sufficient isolation and is equipped with EMI isolation features. The power supply has a modular structure wherein the high-voltage area is separated from the

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management area. Additionally, each high-voltage channel was designed as a distinct isolated module. Thanks to the modular structure of this HV power supply, it can be easily expanded with additional modules. In addition, repair is facilitated by simply replacing the unwanted module.

### *2.1. Management part*

The task of the management module is primarily to send control commands to the HV modules and read the status data they return. The management module is also responsible for supporting the user's interface, which consist of an alphanumeric display providing a $40 \times 4$ characters and a numeric keypad with a rotary encoder. The management module also provides Ethernet and USB communication through which commands that control the HV power supply can be sent. Control commands adhering to SCPI standards ensure remote access to all of the controlling and measuring functions of this HV power supply. The management module is based on the atmega1280 AVR microcontroller. Communication between eight high-voltage modules takes place via the USART interface. The selected microcontroller is not equipped with a sufficient number of USART interfaces. Therefore, to ensure communication with each HV module, interface multiplexing is used. The TX transmission line is directly connected to each HV module, while the RX receiving line is switched. The control algorithm is based on addressing, with each HV module having its own unique address. The control algorithm sends two types of messages to the modules: update request and status request. The update request saves new configuration data into the HV module and the status request command causes the reading of the current module configuration. Each message is sent in the form of a string consisting of a preamble, a module address, and the command code to be executed. The main controller sends a message with a specific address to all modules and then switches the RX line multiplexer to receiving data from the addressed module. Only the module with the correct address will respond.

### *2.2. High-voltage part*

A single HV module provides regulated voltage in the range from 10 V to 1450 V with 0.1 V step. Each high-voltage module is equipped with galvanic isolation. Both the lines transmitting the control signals and the power supply of the modules are isolated. The high-voltage module is equipped with an isolated LLC power converter. The LLC converter is based on changing the resonant frequency of two coils and a capacitor. As the transformer of the LLC converter, two coils from wireless chargers were used. The coils are placed on different sides of the PCB, which separates them by a layer of

FR4 laminate. This design of the power supply provides a stable voltage of 12 V with a current efficiency of 500 mA and this is sufficient to supply the HV part of the module.

The atxmega128A3U microcontroller is used to control the HV module. The part of the module responsible for generating high voltage is based on the UC3872M. The feedback loop has been modified so that the output voltage of the converter can be smoothly adjusted from 10 V to 1450 V using the DAC built into the microcontroller. The high-voltage transformer can work upto a maximum voltage of 1400 V. To achieve an output voltage above 1400 V, a voltage multiplier is placed behind the transformer.

The GEM detector is very sensitive to overvoltages. Therefore, each high-voltage module is equipped with a number of protective features to safeguard the detector. High output voltage and output current are constantly monitored by the microcontroller. If the output voltage increases beyond the set margin, the high voltage converter is switched off. The output current is monitored using a fast analog comparator built into the microcontroller. The internal DAC converter is connected to the positive input of the internal comparator and the output of the operational amplifier that amplifies the drop voltage on the shunt resistor is connected to the negative input. If the consumed current increases above the set value, the output of the comparator changes the state. The microcontroller reacts on the change of the edge of comparator output signal by entering into the interruption in which the HV inverter is switched off. Unfortunately, in output capacitors and in coaxial cables supplying voltage to the detector, there is still some electrical charge which can cause a discharge in the area of the GEM detector foil and, consequently, its damage. Therefore, a discharging system built from the MOS transistor and a resistor was used. After switching off the HV converter, the MOS transistor switches on the 100R resistor in parallel to the outputs and this discharges the electric charge in the output area.

Additionally, to increase the safety features of the HV power supply, each high-voltage module is equipped with an additional MOS transistor used to disconnect the output voltage. The transistor is controlled by a microcontroller in the HV module and by a switch located on the front panel of the HV power supply. A switch featuring protection from accidental switching was used. The user can flip the switch at any time, causing immediate disconnection of the high output voltage on all of the channels.

## 3. Issues with sparks

Sparks were encountered in the high voltage generating part of the module. Above the 1200 V voltage, sparks were detected in some HV modules. Sparking was not directly visible but it was clearly audible. Two reasons for sparking were established.

The first reason was the error in the PCB design consisting of placing a transistor gate control line under the high-voltage transformer in the place where the winding wire of one of the transformer coils adheres to the PCB.

The second reason was that in the process of automatically assembling the HV modules, overly aggressive chemical agents were used that slightly damaged the insulation of the transformer coil wire at the stage of washing the PCB. This insignificant damage with the insulation caused sparking for voltages above 1300 V.

These problems were solved by placing a high voltage transformer several mm above the PCB and by replacing the transformers with new ones mounted by hand. No sparking was observed after applying these corrections.

## 4. Tests in laboratory

During the tests, long-term stability was tested and the stability of the output voltage was determined at $\pm 1$ V for the whole range. Reaction time was measured during the testing of the mechanism for overload detection and discharging the output capacitance. Reaction time for overcurrent is about a few microsecond. The next tests will be performed with the GEM detector.

## 5. Summary

Designed power supply has the following features:

- Output voltage range 10–1450 V, 0–10 uA;
- Modular construction — number of channels can be customised;
- Isolated inputs and outputs — the outputs can be connected in series or in parallel;
- Very fast current limiter — critical to operation of GEM detectors. It enables protection of detector in case of arching. It is crucial in the case of high gain detectors because it can reduce the value of the series protection resistor and significantly improve linearity of the detector;
- Transient recorder on each channel — currents and voltages can be recorded thanks to an embedded scope function. When arching occurs, one can observe signals before and after the event;
- Voltage and current measurement in each channel. One can selectively measure current consumed by each GEM foil;
- Ethernet and USB interfaces;
- User interface with keyboard and LCD display.

High-voltage power supply which has been built (Fig. 1), has a modified eighth channel to work as a non-isolated 5 V DC power supply.


Fig. 1. High-voltage power supply for WEST experiment.

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