Photo-multiplier power supplies for the GEM calorimeter

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Abstract
The Gamma Electron Muon detector at the Superconducting Super Collider requires special power supplies for the photo-multipliers of the calorimeter. We describe the research and development of these power supplies and the corresponding Data Acquisition System.

Resumen
El detector GEM en el colisionador de protones SSC requiere fuentes de poder especiales para los fotomultiplicadores del calorímetro. Describimos la investigación y desarrollo de estas fuentes de porder y del correspondiente sistema de tele-control y tele-medida.

1 Introduction

The Gamma-Electron-Muon (GEM) detector will record proton-proton collisions at a center of mass energy of 40TeV at the Superconducting Super Collider (SSC)[1]. The GEM detector consists of a central tracker, a calorimeter, and muon chambers in the magnetic field of a large air-core super conducting solenoid. The calorimeter consists of three layers: an electromagnetic section, a fine hadronic section (both using liquid krypton or argon), and a coarse hadronic section with copper absorber and scintillating fibers. The scintillating fibers are read out by photo-multiplier tubes (PMT's). In this article we report the research and development of the power supplies for these PMT's, and of the control and data acquisition system for these power supplies. At the time this work was carried out it was believed that of order 7000 PMT's would be required.

Consider a PMT operating at a photo cathode potential of -2400V. Assume that the last dynode draws 1mA at -500V (1mA corresponds to an average of 10 photo-electrons per bunch crossing at a gain of 10^7). Then the power drawn by the PMT is approximately 1mA*500V = 0.5W. The standard PMT base contains a resistive divider (possibly with capacitors and zener diodes). The current drawn by this divider is chosen to be approximately 10 times the current of the last dynode to avoid significant voltage droop. In our example 10mA would be required, which corresponds to a power dissipation of 10mA*2400V = 24W! For the GEM calorimeter with 5000 - 10000 PMT's this presents a problem of dissipation and power supply cost. The PMT photo cathode surface resistance, dark current, chemical balance, spectral response and responsivity are all sensitive to temperature[2].

The alternative that we consider is a Cockcroft-Walton charge pump that chops and multiplies a regulated voltage of order 300 - 400V up to 2 - 3KV via a capacitor - diode network. This approach was suggested to us by Uriel Nauenberg and has been successfully developed for the ZEUS experiment at DESY[3,4]. With this approach the power dissipated is reduced to the power drawn by the PMT divided by the charge pump efficiency of about 30%, corresponding to 1.5W in our example. This approach has other advantages as well. Voltage droop at high current can be effectively controlled, and thousands of expensive and bulky high voltage cables are avoided reducing the chance of breakdowns and the corresponding fire hazard.

The ZEUS design contains a ferrite transformer that would saturate in the GEM magnetic field. We have therefore developed an alternative design with no magnetic components. This design is still preliminary since we do not yet have a data sheet on the PMT's being developed for GEM (how many dynodes?, what voltages?, what admissible dissipation?, what gain?) nor do we have a final PMT count. A final design and tests with the GEM PMT's will have to wait until a device becomes available.

2 Charge pump

The preliminary design of the charge pump is shown in Figure 1. The input is a regulated remotely controlled voltage in the range 0 to 350V. This voltage is switched at about 25KHz (in synchronism with the SSC super bunch to reduce switching noise) and multiplied and rectified by a capacitor diode network. The dynodes and photo cathode of the PMT are connected to appropriate voltage taps of this network. A sample of the 25KHz square wave is added to the PMT signal output (by a network that depends on the PMT and is not yet designed) in order to cancel pick-up (as in ZEUS). One charge pump (as shown in Figure 1) is mounted directly on the base of each PMT (and replaces the usual resistive divider).

The circuit of Figure 1 was tested with a load of 3mA on the last (8th) dynode, and a load of $3\text{mA}/7^{8-n}$ on the n'th dynode. The ideal operating frequency is a compromise between low switching losses and low ripple. We have evaluated three transistor sets: a) ECG396, ECG175 and two ECG38, b) Two ECG397 and two ECG396, and c) ECG396, ECG397, and ECG2381 and ECG2385 MOS-FET's. For set a) at 25KHz and 370V in, the current drawn is 16mA, and the output voltage is 2.8KV. The corresponding efficiency is 27%. The measured peak to peak ripple voltage is 10Vpp on the first dynode and 2Vpp on the last dynode. For set b) at 25KHz and 320V in, the current drawn is 12mA, the output voltage is 2.4KV and the ripples are 5Vpp and 1.2Vpp respectively. The corresponding efficiency is 31%. At 50KHz the current increased to 18mA, and the ripple voltages dropped to 3Vpp and 0.7Vpp respectively. For set c) we obtained similar results.

3 Regulator

The input voltage to the charge pump is obtained from the regulator shown in Figure 2. These regulators (one per PMT) are installed in racks outside the collision hall. The regulators provide a computer controlled output voltage in the range 0 to 350V and have a current limit set at 12mA to protect the PMT's. The regulators also have precision voltage and current readouts that interface to the computer Data Acquisition System. (Optionally the current limit may be controlled by computer, and a high voltage monitor can be added.) We have chosen a series regulator since the normal operating voltage will be within 20% of the maximum voltage. The power dissipation in the series transistor is therefore less than 360V*20%*12mA = 0.9W even at the highest current. The open loop gains are nominally 130 and 50 for the voltage and current limit loops respectively. The voltage stability is therefore determined by the stability of the voltage divider resistors (and not by the stability of active components). The design of both voltage and current loops are unconditionally stable.

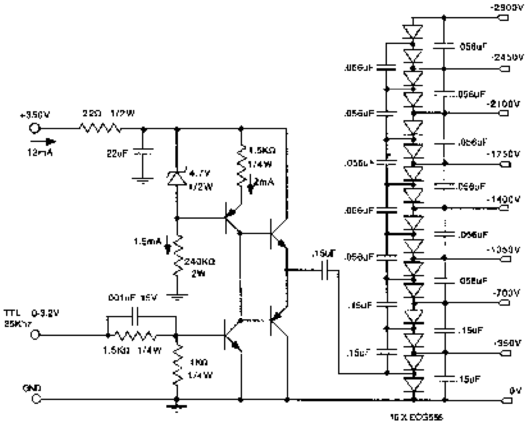

Figure 1. Charge Pump mounted on photo-multiplier base.

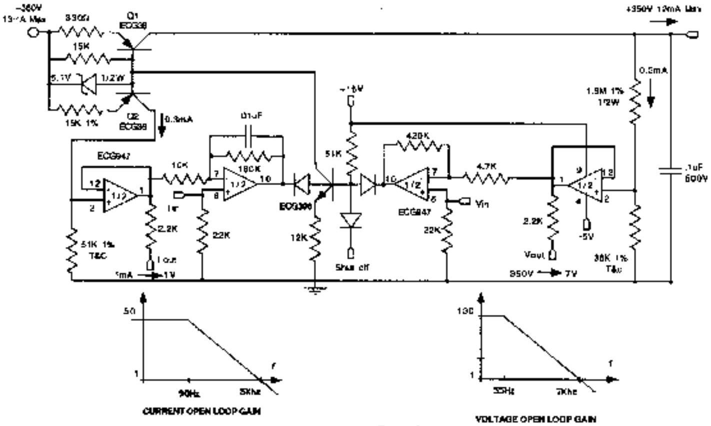

Figure 2. Voltage Regulator.

4 Data Acquisition System

For each of the 5000 - 10000 PMT's we must remotely control voltage (and optionally current limit), and remotely read voltage and current (and optionally high voltage). Below we describe several options. The off the-shelf solutions (options 1 and 2) are discarded due to the large number of racks they occupy and the corresponding high cost. The optimum solution may be option 3.

Option 1: VME interface boards RTI-600 and RTI-602.

For remote sensing use Analog Devices RTI-600 VME interface boards with 32 single ended analog inputs, from 0 to +10V, with 12 bit resolution. For remote control use Analog Devices RTI-602 VME interface boards with 4 analog outputs, from 0 to +10V, 12 bit resolution. These boards plug into VME P1 connectors. For the minimum option we control one voltage, and measure one voltage and one current per PMT supply. In one 19" crate we can plug in 2 RTI-600 and 8 RTI-602 to control 32 PMT supplies. Assuming 10 crates per rack, and 5000 PMT's, we would require 5000/(32*10) = 16 racks of electronics for the Data Acquisition Circuits (DAC) alone. The same number of racks is obtained with other data buses as well.

Option 2: RS-232 interface using μMAC-5000 and μMAC-4000.

We consider using Analog Devices μMAC-5000 and μMAC-4000 series modules. These modules interface to RS-232. The network can have up to 16 clusters. Each cluster has one μMAC-5000 and up to 6 μMAC-4000 series expansion modules. The resolution is 12 bits. We consider the following cluster configuration: 1 μMAC 5000 with 12 analog inputs, 3 μMAC-4015 with 12 analog inputs each, and 3 μMAC-4030 with 8 analog output channels each. Then one cluster controls 24 PMT supplies (control of one voltage, and remote sensing of one voltage and one current per PMT). Since the network can have up to 16 clusters we can control up to 16*24=384 PMT supplies with a single RS-232 communication port. One cluster occupies a 19" crate, 15.75" high. Assuming 5 crates per rack, and 5000 PMT's, we would require 5000/(5*24) = 42 racks of electronics for the DAC alone. At 19Kbaud we could read out the current and voltage of the 384 PMT supplies per RS-232 communication port in about (384*2 channels)*(2 words/channel)*(11.5 bits / word)*(1.5 overhead factor) /19Kbaud = 1.4 seconds.

Option 3: Custom design with Ethernet interface.

The off-the-shelf options 1 and 2 fill too many racks of electronics. We therefore consider the following custom design. Each 19" crate, 10.5" high, contains 15 "Regulator Boards" with 8 PMT regulators each, and one "Control Board". Thus 15*8 = 120 PMT regulators and the Data Acquisition Circuits (DAC) and Ethernet IEEE 802.3 interface fit in one crate. Assuming 9 crates per rack and 6960 PMT's we would need 6960/(9*120) = 6.5 racks for the DAC and the regulators. Each rack contains in addition three regulated power supplies: +360V, 15A; +15V, 20A; and -5V, 20A for the 9*120 = 1080 PMT regulators of that rack, see Figure 5.

Regulator Board

This board contains 8 PMT regulators shown in Figure 2, and the Data Acquisition Circuits (DAC) shown in Figure 3. The DAC sets the voltage, and reads the voltage and current of each of the 8 regulators. The DAC has two MAXIM MAX-180 each with 8 A/D channels with 12 bit resolution, and two MAXIM MAX-527 each with 4 D/A channels with 12 bit resolution. A 4-bit dip switch defines the address of the Regulator Board.

Control Board

The board shown in Figure 4 controls the 120 PMT regulators of that crate. It has one DALLAS SEMICONDUCTOR DS-5000 micro controller with the following characteristics: 8 bit CPU, 32 input/outputs, 8K of NVRAM for program or data, and full duplex serial port. The set of instructions is compatible with the INTEL MCS-51 micro controllers. It can process Boolean, has 5 interrupts, and 2 16-bit timer/counters. The NVRAM permits the programming of the chip without removing it from the board, an important system consideration. The A/D and D/A channels are treated as locations of the memory. Two MAXIM MAX-180 provide a total of 16 A/D channels for monitoring voltages and currents common to the 120 regulators. The Control Board includes an Ethernet GVC Pocket Adapter to permit the connection to the local area Ethernet network in a bus configuration.

The DAC for all the PMT's is controlled by one personal computer with one Ethernet network card and one RS-232 serial port. A thin coax (RG58) connects the PC and all Control Boards and is terminated with 50 ohm on both ends (see Figure 5). The computer is connected to the local network of the control room.

The computer has direct control over each individual channel. No crate controlled block readouts need be implemented since the entire readout of the 6960 PMT voltages and currents can be realized in less than 1 second. Software to be developed will ramp, set and trip power supplies (in groups or individually), monitor and record the system voltages and currents, exhibit alarms, and present the voltages at a glance with a color coded display.

Software

The software was developed using the ASSEMBLER language of the micro controller DS 500. It includes two modules: management of A/D and D/A converters; and management of communications. In addition we developed high level software in

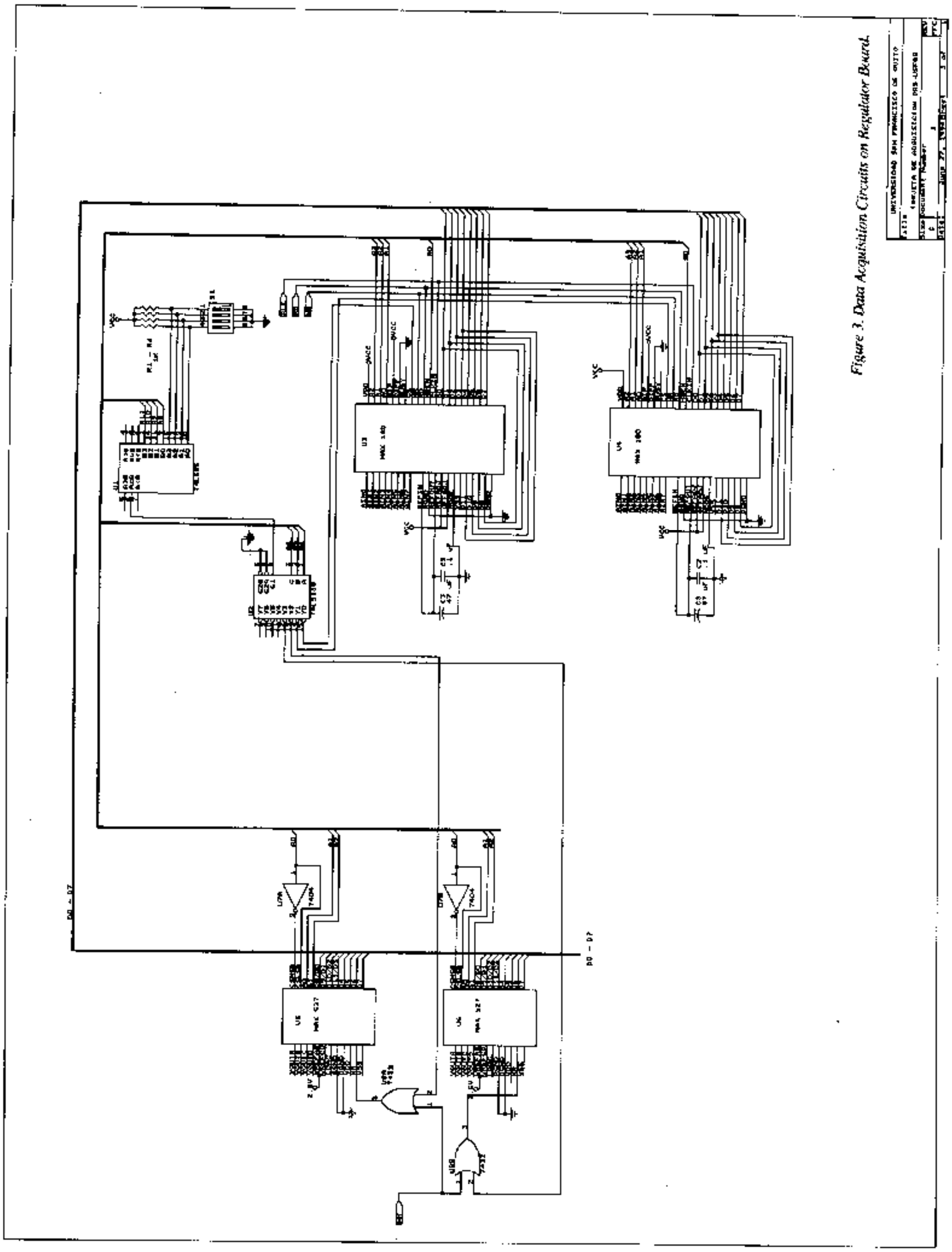

Figure 3. Data Acquisition Circuits on Regulator Board.

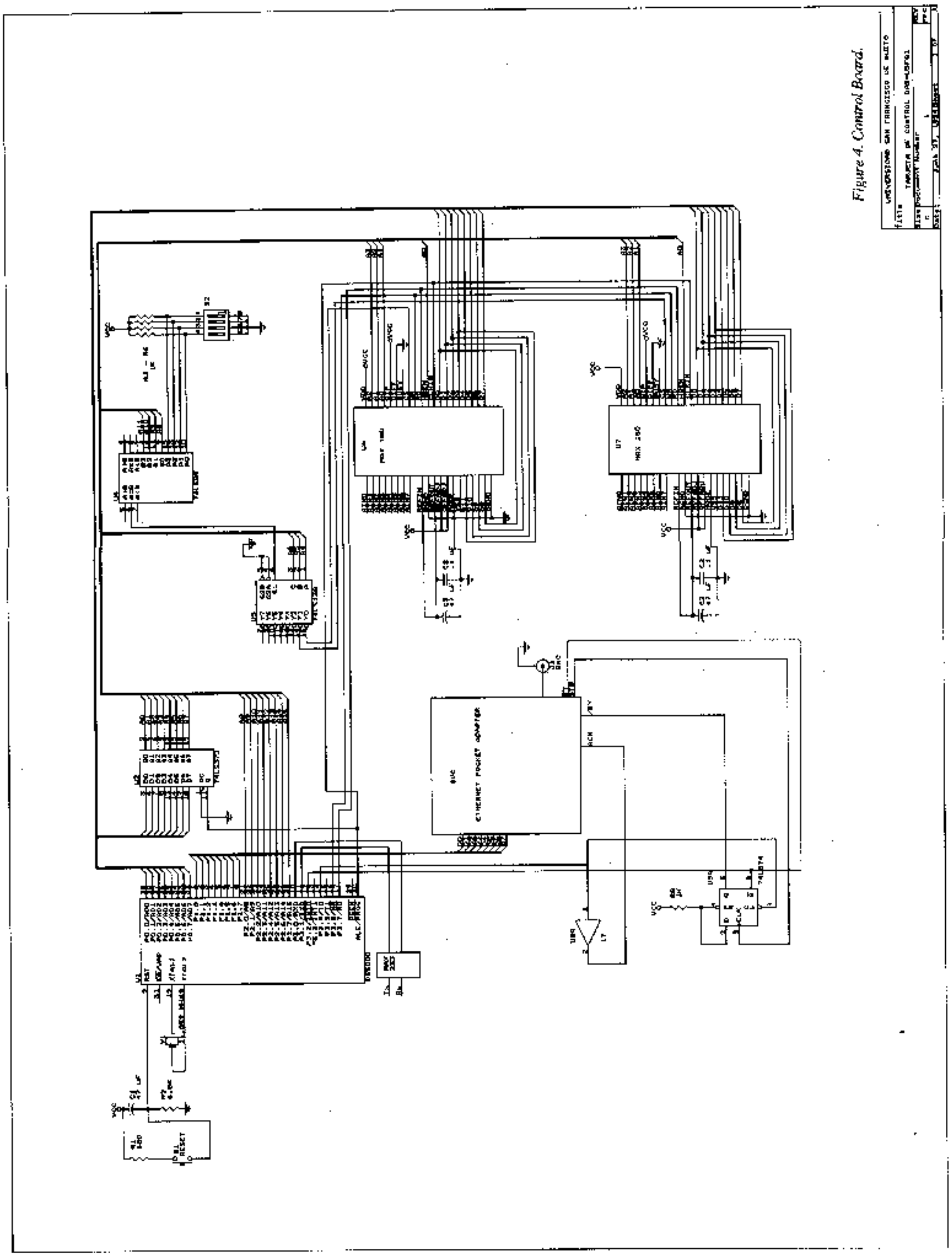

Figure 4. Control Board.

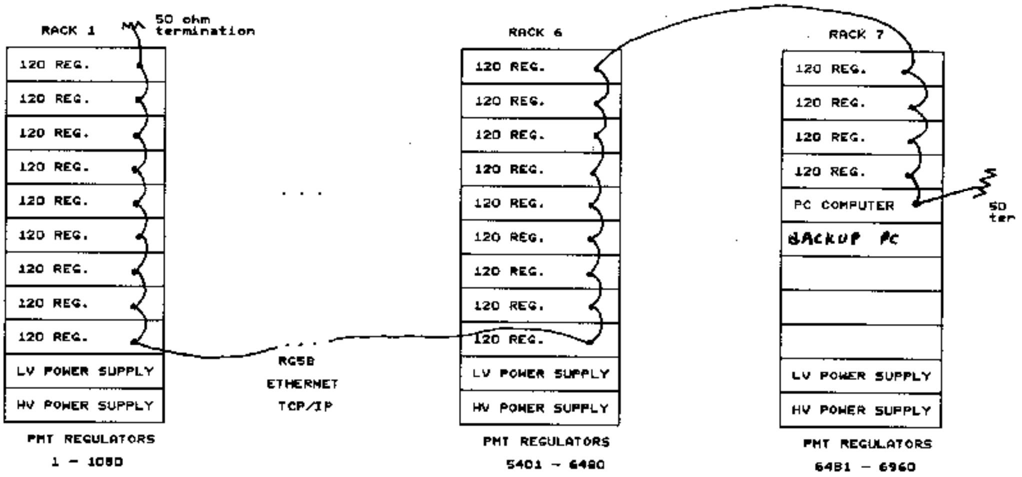

Figure 5. Rack layout.

C language for the system control from any Personal Computer connected to the network.

5 System tests and conclusions

One Charge Pump, one Regulator Board (implemented with one regulator), and one Control Board were built and tested. The control board was connected to a personal computer using a thin-wire ETHERNET coax and the TCP/IP protocol. The entire system performed reliably as designed, and is cost effective compared to off-the-shelf equipment.

The Data Acquisition System developed in this research project can find applications in the laboratory, industry, power generation, and where ever digital or analog remote control and sensing is required. The software can be modified to meet individual needs.

Acknowledgment

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