# SLAC NEXT-GENERATION HIGH AVAILABILITY POWER SUPPLY*

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## *Abstract*

SLAC recently commissioned forty high availability (HA) magnet power supplies for Japan's ATF2 project[1]. SLAC is now developing a next-generation N+1 modular power supply with even better availability and versatility. The goal is to have unipolar and bipolar output capability. It has novel topology and components to achieve very low output voltage to drive superconducting magnets. A redundant, embedded, digital controller in each module provides increased bandwidth for use in beam-based alignment, and orbit correction systems. The controllers have independent inputs for connection to two external control nodes. Under fault conditions, they sense failures and isolate the modules. Power supply speed mitigates the effects of fault transients and obviates subsequent magnet standardization. Hot swap capability promises higher availability and other exciting benefits for future , more complex, accelerators, and eventually the International Linear Collider project.


## POWER SYSTEM OVERVIEW

The high availability power system consists of the components depicted in Figure 1. It consists of bulk voltage sources, power supplies, controllers, current regulators, programmable logic controllers (PLC) and other devices needed for equipment protection and current regulation. All components are redundant. This paper focuses on the development of the power supplies, the constituents of which are power modules and imbedded controllers. Coverage and description of the power system regulators and other illustrated components will occur later.

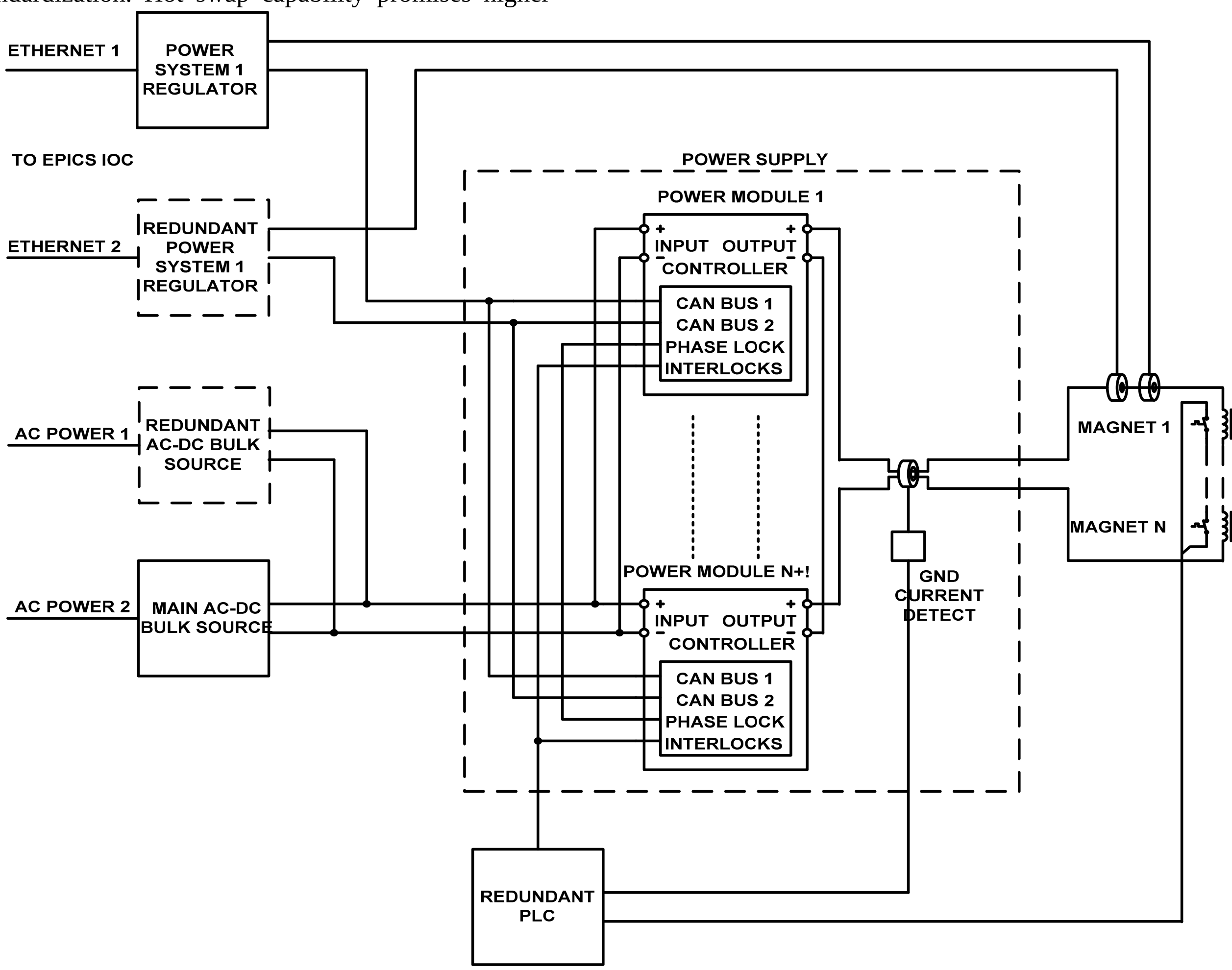


Figure 1 Power System Block Diagram – Redundant Bipolar Operation is Illustrated

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## POWER SUPPLY

The power supply is modular, consisting of power modules and controllers. It is capable of unipolar or bipolar operation. Figure 1 depicts bipolar operation, but only a minor reconnection of the output leads configures the modules for higher current unipolar operation. Unipolar and bipolar operation is possible from a single, AC-DC, unipolar, two-wire output bulk source. Redundant bulk sources yield availability enhancement. A ground current detector alerts for the event of leakage current that bypasses the magnet.

The power supply topology allows for scaling from watts to hundreds of kilowatts. Its 1 kHz bandwidth makes the power supply attractive for beam-based alignment, and orbit correction systems. It is important to note that both unipolar and bipolar power supplies can operate from a common, two-wire bulk voltage source.

## POWER MODULES

Figure 2 depicts a 1.3 kW, dc-dc two-quadrant power module. The model shown requires 48 V, 30A DC input for 0 to 40 V, 0 to ±33 A output. It is possible to parallel as many as eight modules. The buck regulator topology provides low output current ripple and scaling of output power to tens of kilowatts. Developments to date are for paralleled 1.3 kW modules to power a 5.2 kW unipolar magnet and power a 2.6 kW bipolar magnet when paralleled. The architecture lends itself to higher output power scalability.

The input and output FETs permit module hot swap and fault isolation. Individual, autonomous, modules can fail without a regulation loss. Paralleling the FETs to lower the conduction losses is easy, since they exhibit a positive temperature coefficient of resistance.

The modules also feature four FETs as the main switching elements instead of the usual one or two. Not only are they switches in the traditional sense, but in this low-loss design they replace conventional free wheeling diodes and allow bipolar operation. Figures 3 and 4 show the modules configured for redundant unipolar and bipolar operation, respectively. The FETs also enable use of two small saturable ferrite chokes to reduce FET switching losses and obviate snubber circuits. In particular, the use of the FET input switch, in conjunction with the ADCs in the embedded controller allow the capability of monitoring the health of the input filter capacitors, historically prime failure components.

Over-rated modules and components operate at lower temperatures and contribute high availability.

## EMBEDDED CONTROLLERS

Figure 3 illustrates the embedded controller[2]. The controllers are Microchip dSPIC60F12A digital signal processor (DSP) based to provide autonomous operation, intelligent start-up and shutdown, output voltage regulation, current sharing, fault sensing and general diagnostics. The controllers synchronize the switching frequency and phase of the modules for low output ripple. Embedding the controllers with local intelligence removes this burden from the network and achieves the very fast power supply response. A dual CAN bus interface provides redundant control of each power module.

The controller operates power modules with a wide range of outputs. Pulse width modulation circuits in the DSP drive the FET switches at 20 to 100 kHz. The DSP and some ancillary circuitry ensure current sharing, synchronized switching and soft-start for hot-swap.

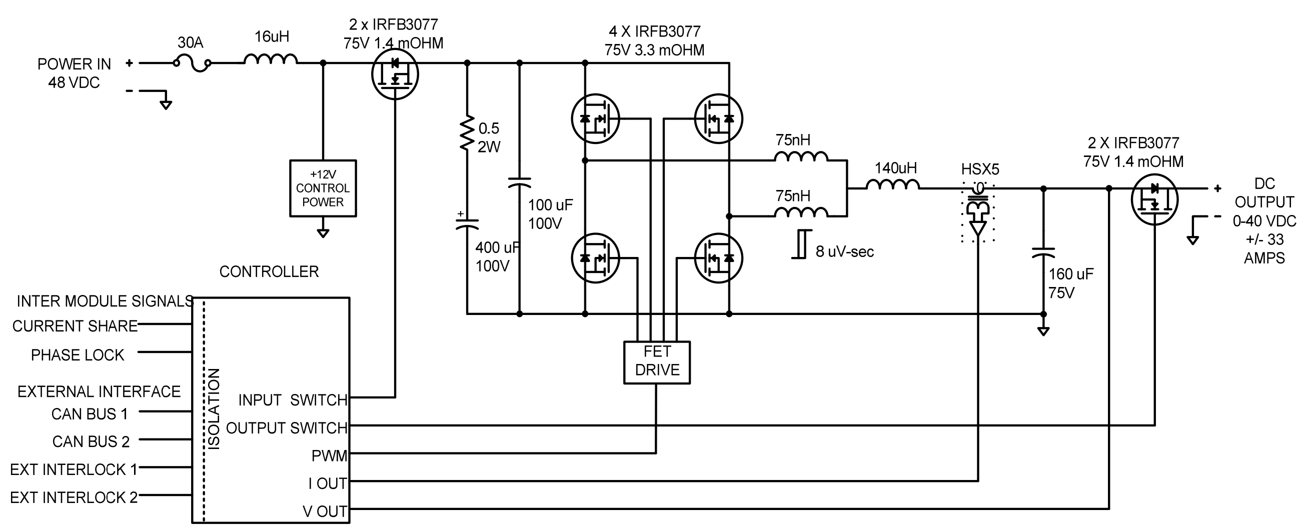


Figure 2 Power Module Schematic Diagram

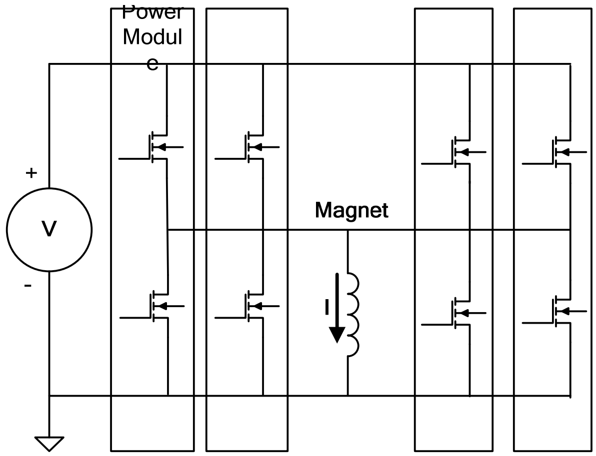


Figure 3 Power Modules Arranged for Unipolar Output

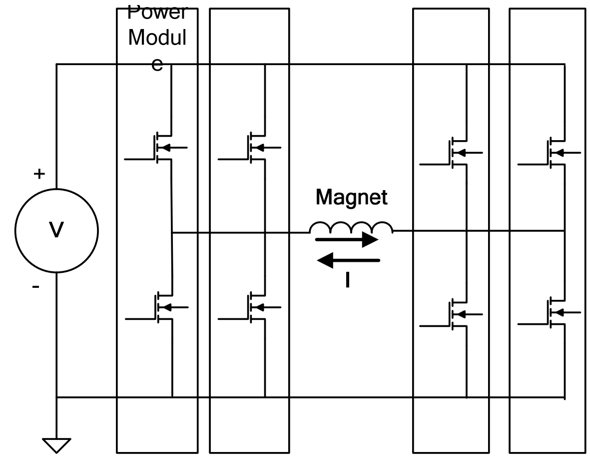


Figure 4 Power Modules Arranged for Bipolar Output

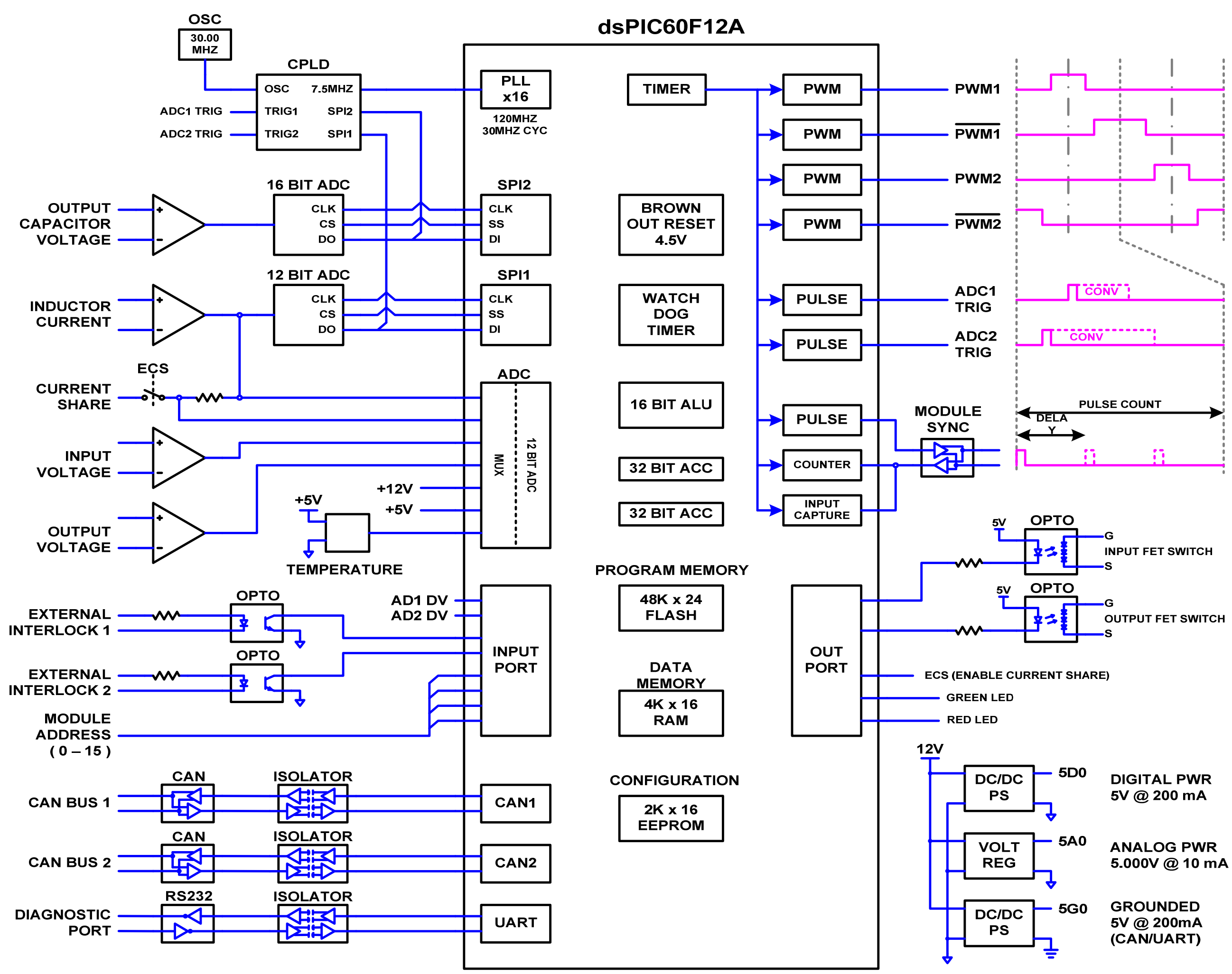


Figure 5 Controller Block Diagram

## HOT SWAP CAPABILITY

When combined with redundancy, the single most effective way to maximize availability is to replace components without shutting the system down or causing disruptions in system operation. Advance power and ground pins and other mechanical means are the traditional methods to hot swap components. These suffer from the disadvantage of requiring custom components. The embedded controller in each power module eliminates these disadvantages. This control allows module replacement (hot swap) while the power supply is operating. The controller turns off the input and output FETs to allow failed modules to be isolated from the power source and load. It controls the soft-start, and the turn on of the input FET to eliminate current surges and safe charge of the input filter capacitors.

## STATUS

SLAC built five power module prototypes with embedded controllers. Testing to date shows that each module exhibits full load efficiency better than 97%. The controllers are undergoing extensive evaluation, but are performing well. In early 2009, SLAC's goal is to demonstrate a 40V, 100A, 4kW unipolar system. The system will support reconfiguration to a 40V, 33A, 1320W bipolar system. The demonstration will include hot swap capability.

Additional work to define the other power system components, not covered in this paper, is ongoing. The object is to provide a complete magnet power system for ATF 2 upgrades, the ILC, or other future accelerators. SLAC will issue periodic reports as work progresses.

## REFERENCES


[1] B. Lam, P Bellomo, A de Lira, D MacNair, "ILC-ATF2 DC Magnet Power Supplies" 22nd PAC, Albuquerque, New Mexico, USA June 2007.

[2] D. MacNair, "Digitally Controlled High Availability Power Supply" XXIV Linear Accelerator Conference, Victoria, British Columbia, Canada Sep-Oct 2008