Abstract

Two key Pegasus systems have been recently upgraded: the Ohmic-transformer IGCT bridge control system, and the plasma-gun injector power system. The Ohmic control system contains two new microprocessor controlled components to provide an interface between the PWM controller and the IGCT bridges. An interface board conditions the command signals from the PWM controller. A splitter/combiner board routes the conditioned PWM commands to an array of IGCT bridges and interprets IGCT bridge status. This system allows for any PWM controller to safely control IGCT bridges. Future developments will include a transition to a polyphasic bridge control. This will allow for 3 to 4 times the present pulse length and provide a much higher switching frequency. The plasma gun injector system now includes active current feedback control on gun bias current via PWM buck type power supplies. Near term goals include a doubling or tripling of the applied bias voltage. Future arc bias system power supplies may include a simpler boost type system which will allow access to even higher voltages using existing low voltage energy storage systems.

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Mission Statement for the PEGASUS Toroidal Experiment

- The PEGASUS Toroidal Experiment is a university based plasma magnetic confinement experiment designed to study high-pressure plasmas in a low aspect ratio axisymetric toroidal geometry.



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Overview of PEGASUS and Facility

- **Upgrade Motivation**
  - Access to flexible Vloop Control
  - Enhanced EMI noise immunity to improve operations at high voltages
  - Provide current control for point-source helicity injectors

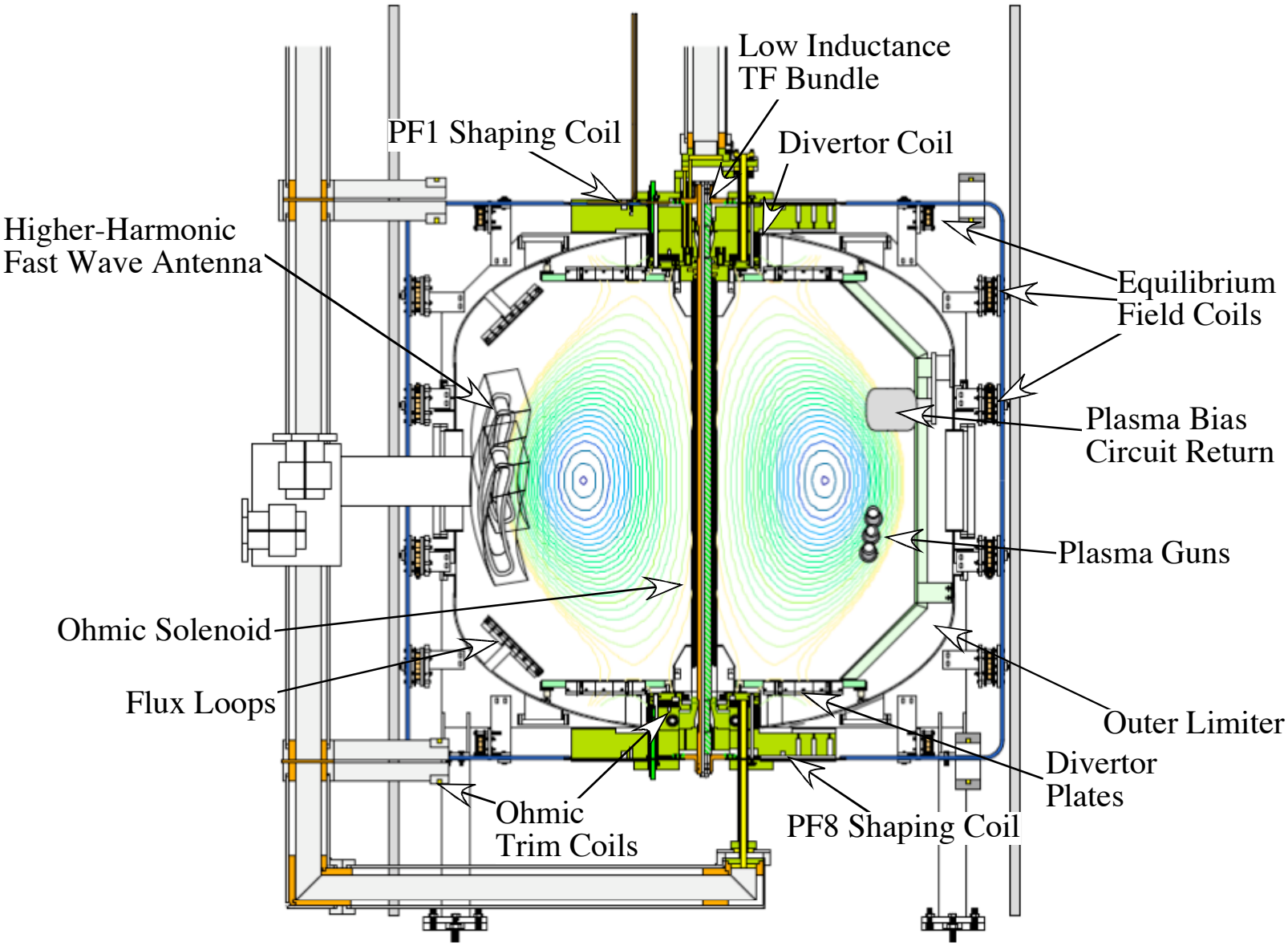
- **Microprocessor Control**
  - Interface between PWM controllers and IGCT Bridges
  - Conditions control signals sent to the IGCT devices
  - Monitors data from IGCT devices
  - Allows for remote monitoring and control

- **Plasma-Gun Injector Power System**
  - Pulse Width Modulated (PWM) Control
  - High Power IGCT Based H-Bridges
  - 2 Bridge system, 7kA @2400V/500kJ
  - Ballast resistor stabilized

- **Status**
  -IGCT Based 2-Quadrant, 2 Bridge system operational
  -IGCT 8 Bridge Ohmic Heating System to be installed

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PEGASUS Toroidal Experiment



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IGCT Bridge Control System

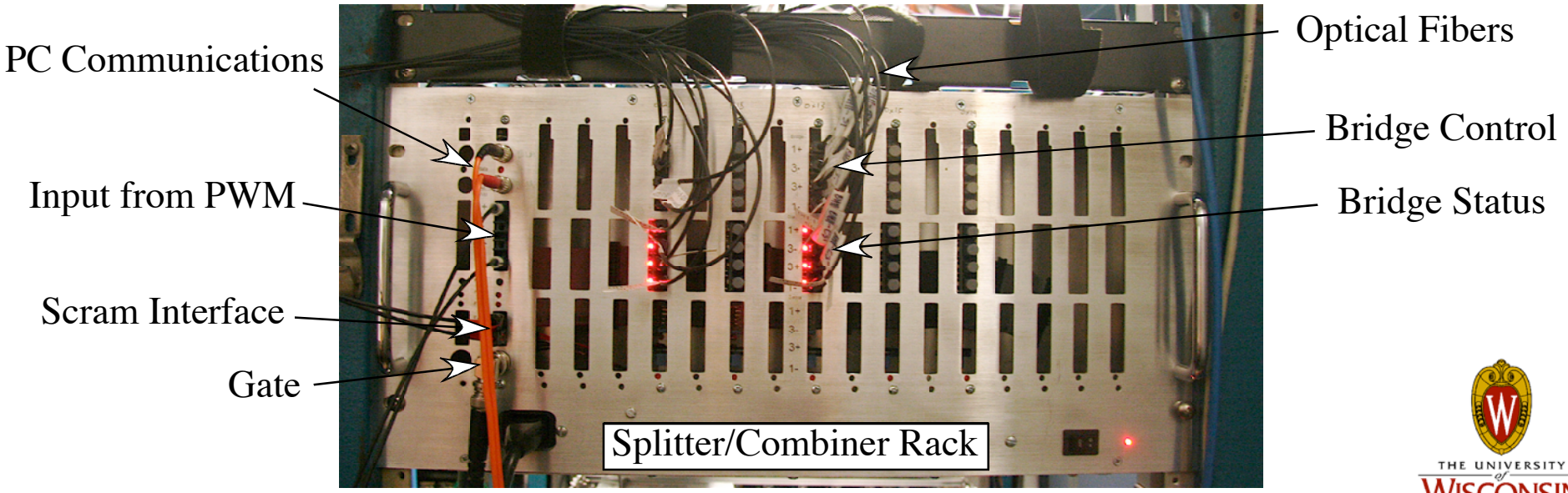
• Bridge Control System Motivation

- IGCT based bridge systems require more sophisticated controls

- Ensures stated limits of IGCT devices and bridges are not exceeded
  - 10μsec minimum ON/OFF for IGCT Devices
  - Ensure safe shutdown in the event of a IGCT device or system fault

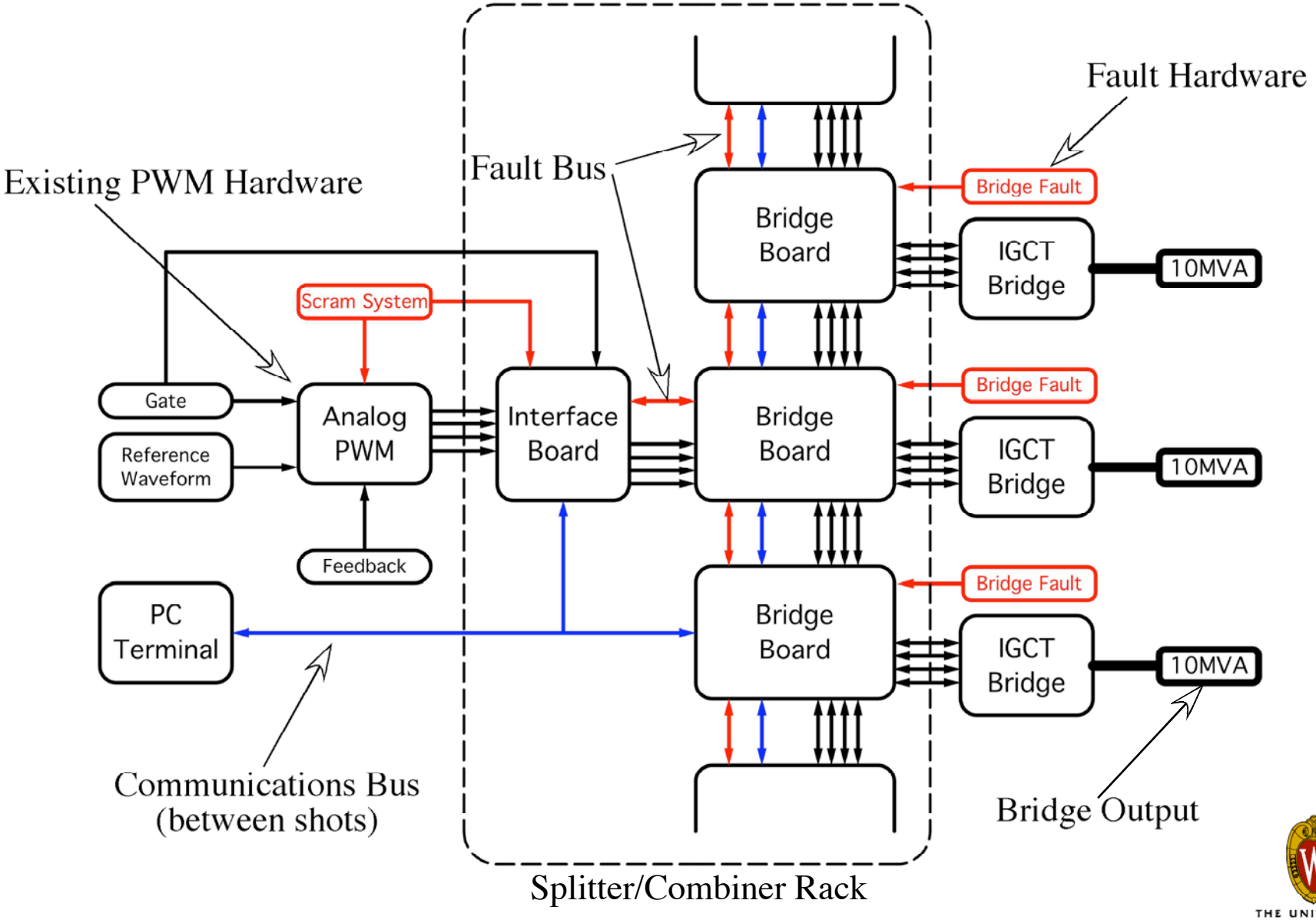
- Allows for remote monitoring of IGCT Bridge status

- Allows existing PWM hardware to safely control IGCT bridges



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IGCT Bridge Control System



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IGCT Bridge Control System - Requirements

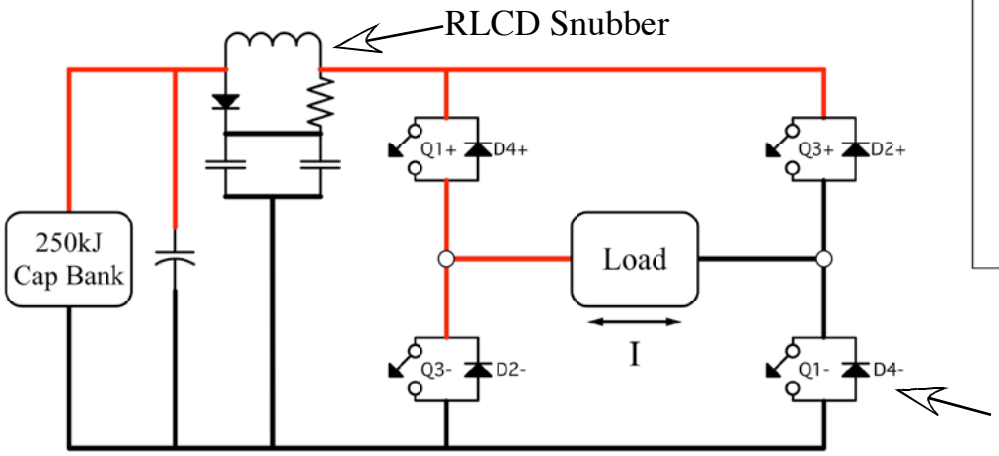
- **Interface Board**

  - Condition commands from PWM hardware to meet the specific operating requirements of an IGCT based H-Bridge

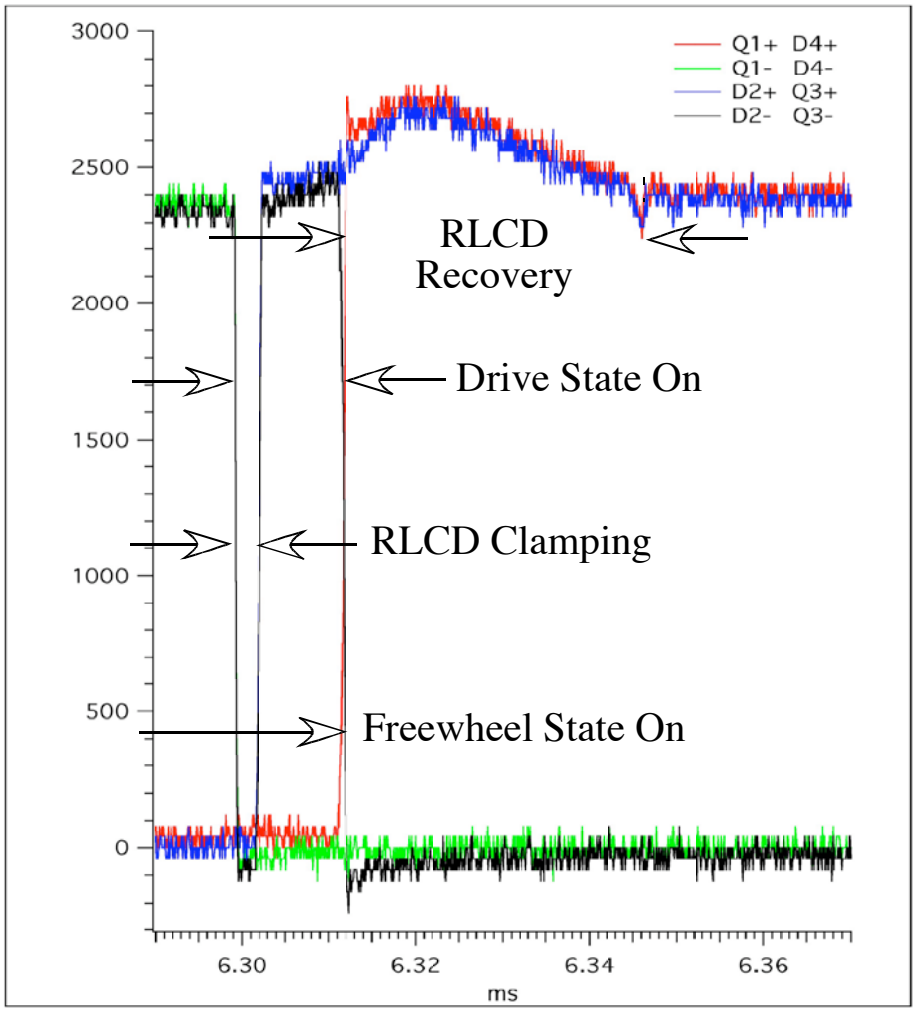
  - RLCD is a bridge snubber that forces voltage across the bridge diodes to zero to allow for safe diode turnoff.

  - RLCD Clamping ~ 3 to 10μsec
    - Ensures the safe turn-off of bridge diodes
    - 10μsec min ON/OFF time enforced

  - RLCD Recovery ~ 25 to 30μsec
    - Time needed to reset RLCD
    - Overvoltage condition could occur if bridge shutdown occurs during recovery period



Bridge switch device voltages
for a 12μsec drive event



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IGCT Bridge Control System - Bridge Board

- **Bridge Board**

  - Relays commands from Interface Board to the IGCT bridge

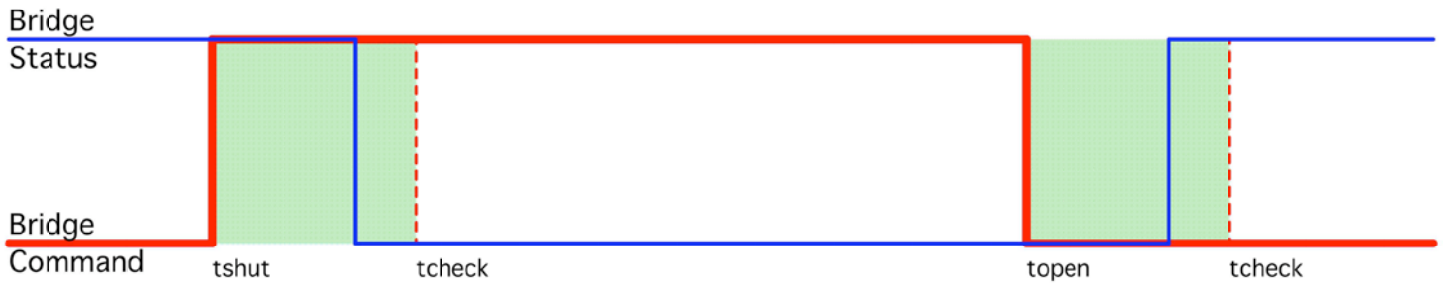
  - Monitors status from IGCT bridge and relays a fault back to the Interface Board
    -t_{check} at 15 μsec to ensure IGCT device health

- **IGCT Status**

  - Status (blue) mirrors Command (red)

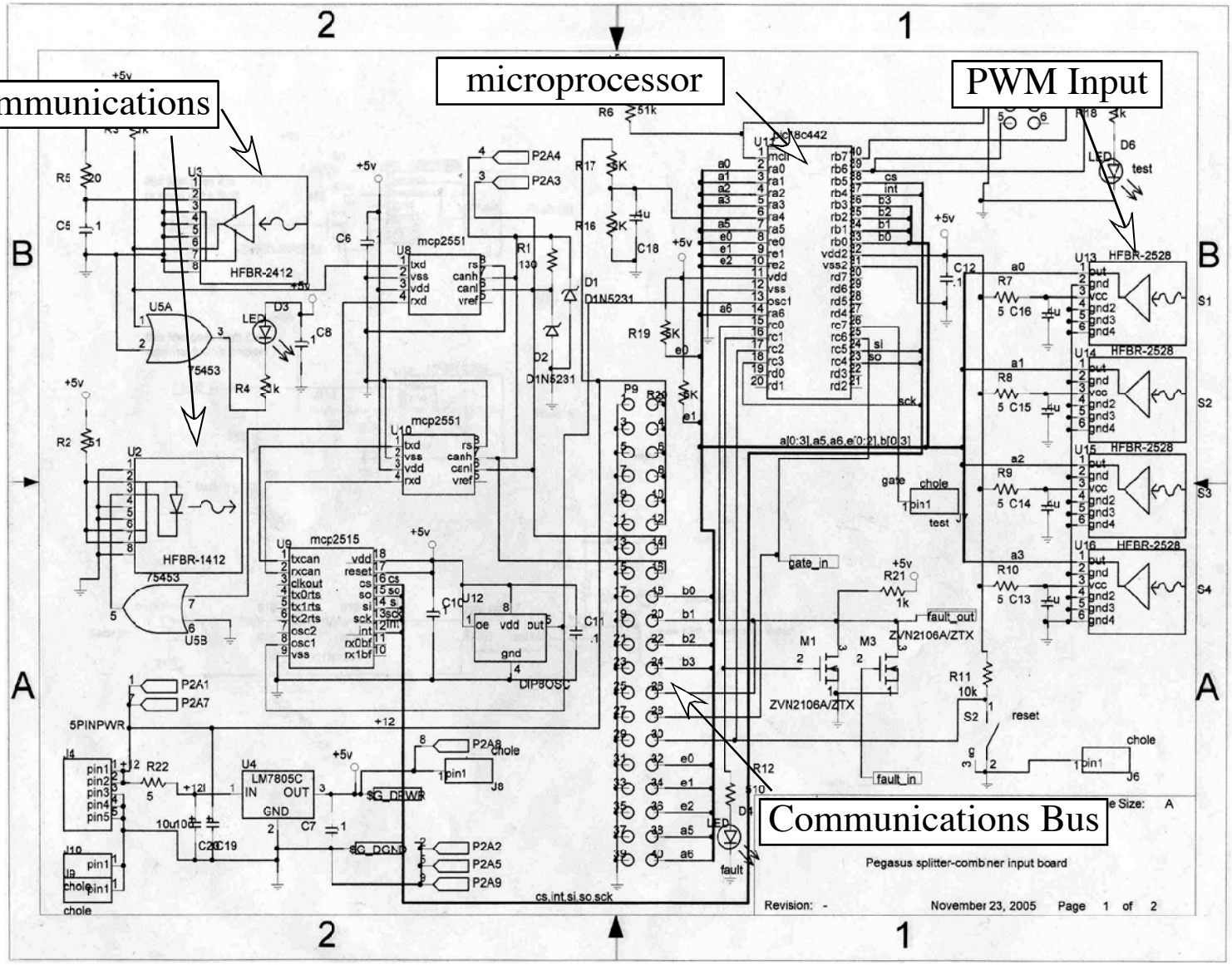
  - Status follows Command if in a fault condition

  - Delay of 3.5 μsec is nominal (7 μsec max) based on IGCT load conditions



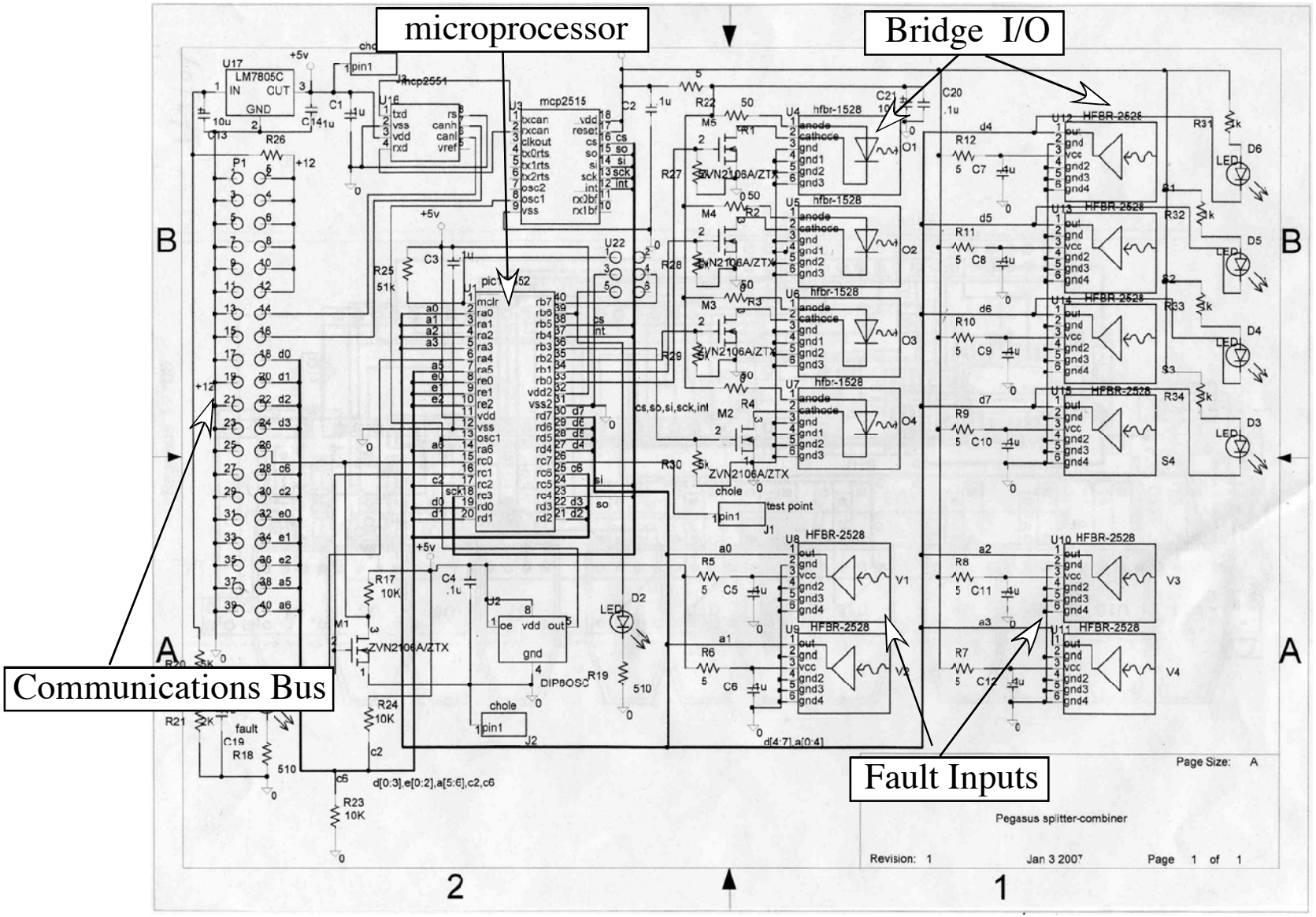
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IGCT Bridge Control System - Interface Board



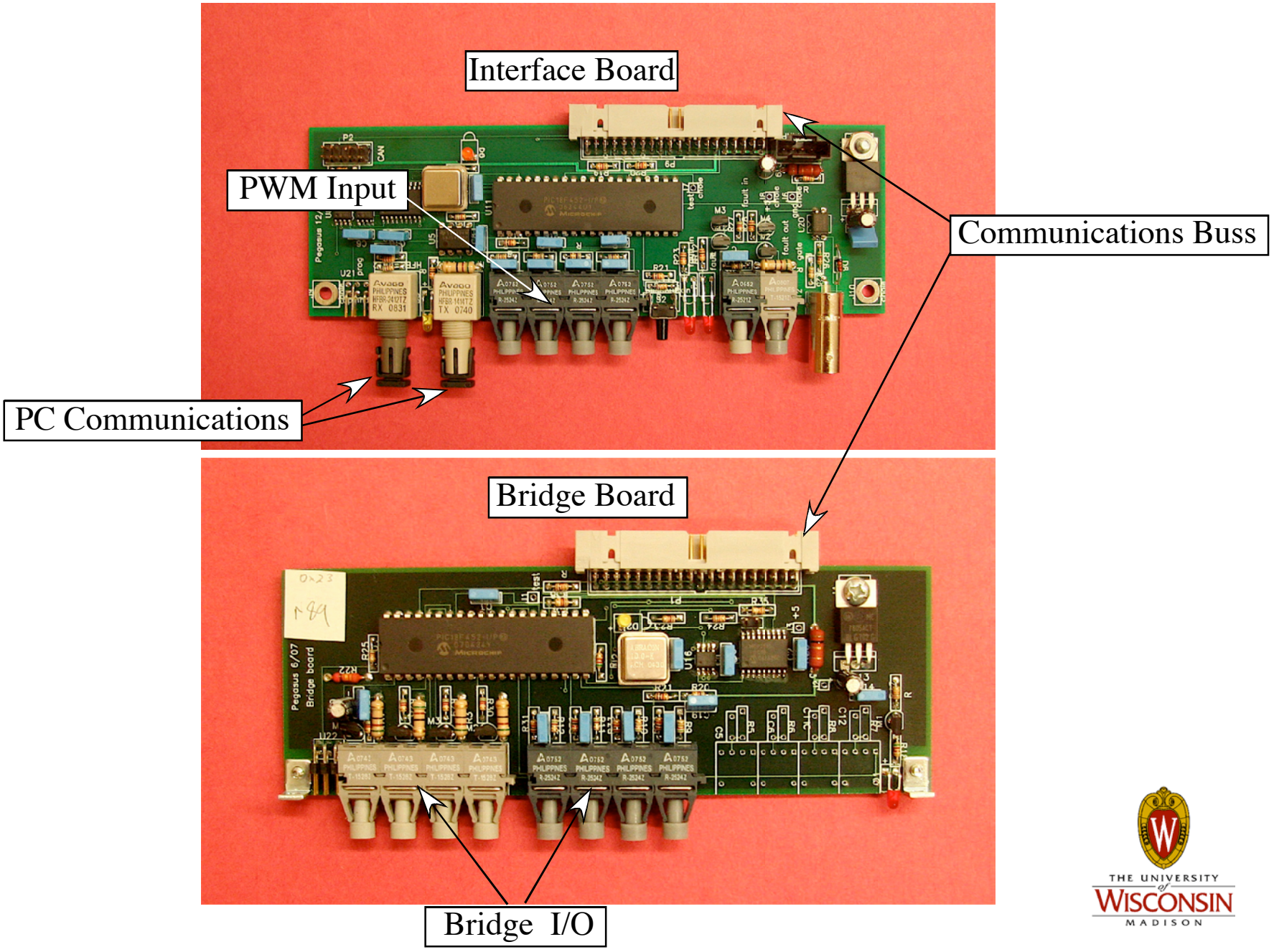
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IGCT Bridge Control System - Bridge Board



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IGCT Bridge Control System - Circuit Board

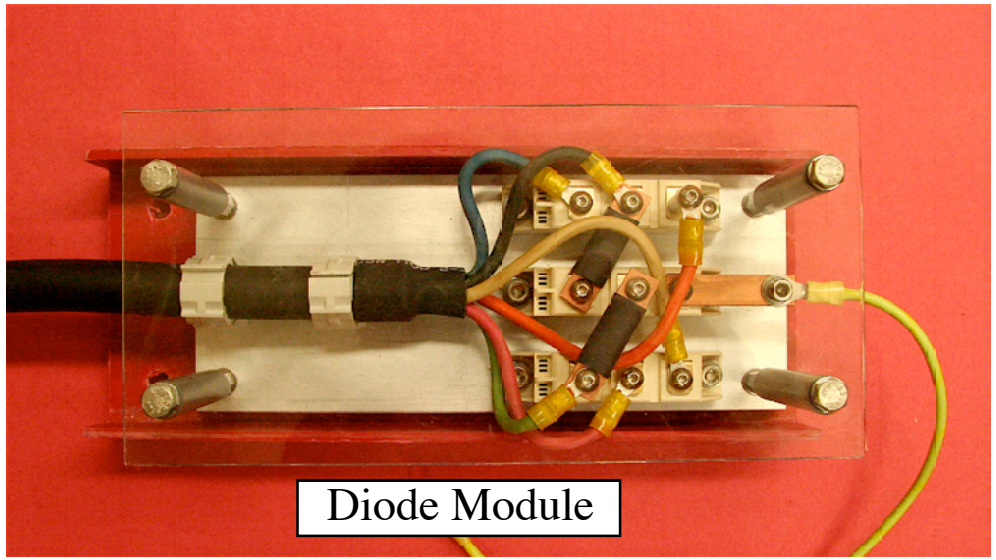


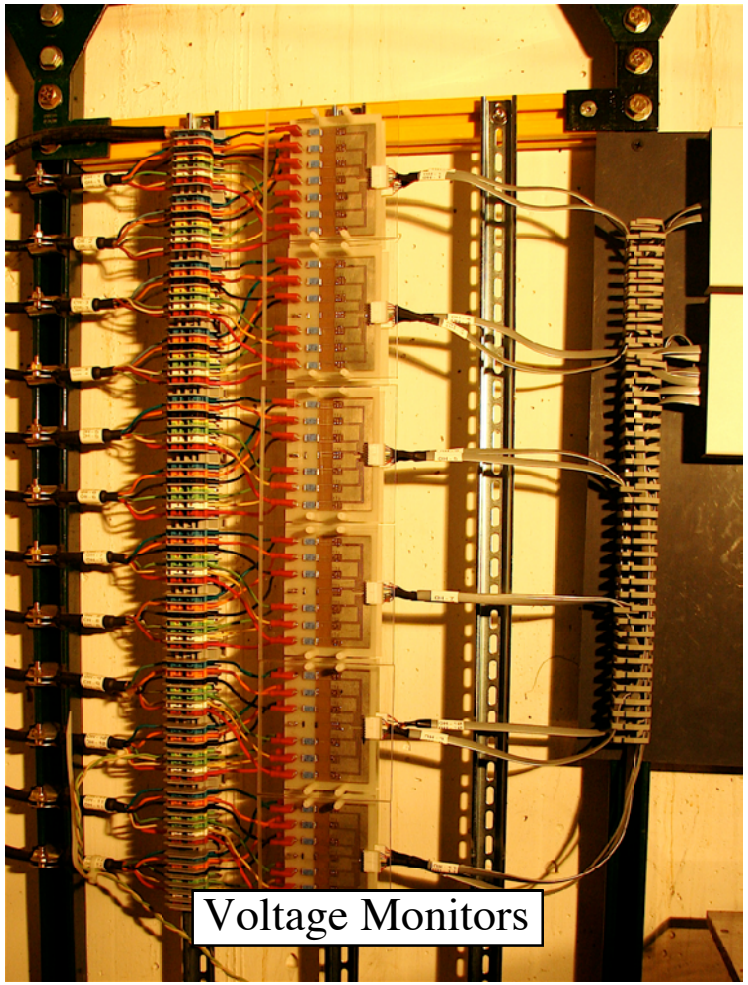
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Ohmic Energy Storage System Monitoring

- **Monitors individual capacitor module voltages**
  - Real time LabView interface
  - Monitors all panel voltages
  - Provides alerts for abnormal conditions

- **Reverse Bias Capacitor Module Protection Diodes**
  - Prevents capacitor modules from being reversed biased


Diode Module


Voltage Monitors

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IGCT Based Gun Bias System

- **Present single IGCT high power system to drive plasma gun array**

- Allows access to applied voltages up to 2100V

- Single High Voltage Bias for multiple guns

- Simple ballast resistor stabilization

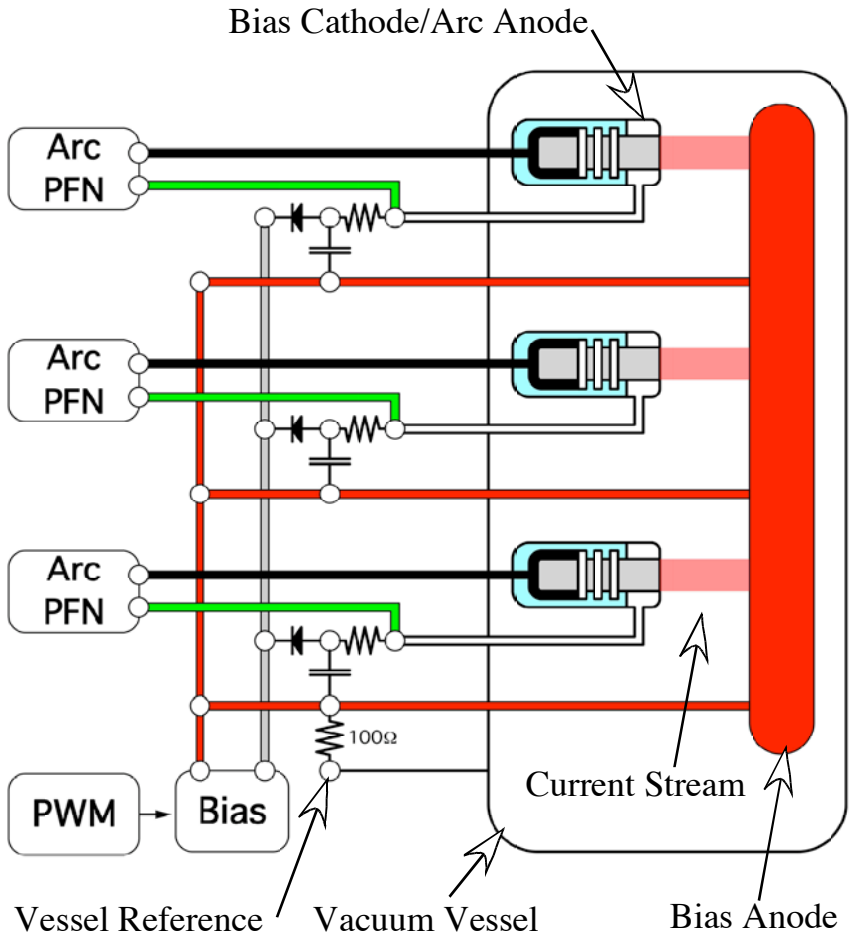
- Modest LC Filtering

- Fault detection and interruption capability

- Arc PFN Power Supply for each gun system
  - Δt = 8ms, I = 2kA, V = 1.4kV

- Single Bias IGCT Power Supply
  - Δt = 8ms+, I = 7kA, V = 2.1kV

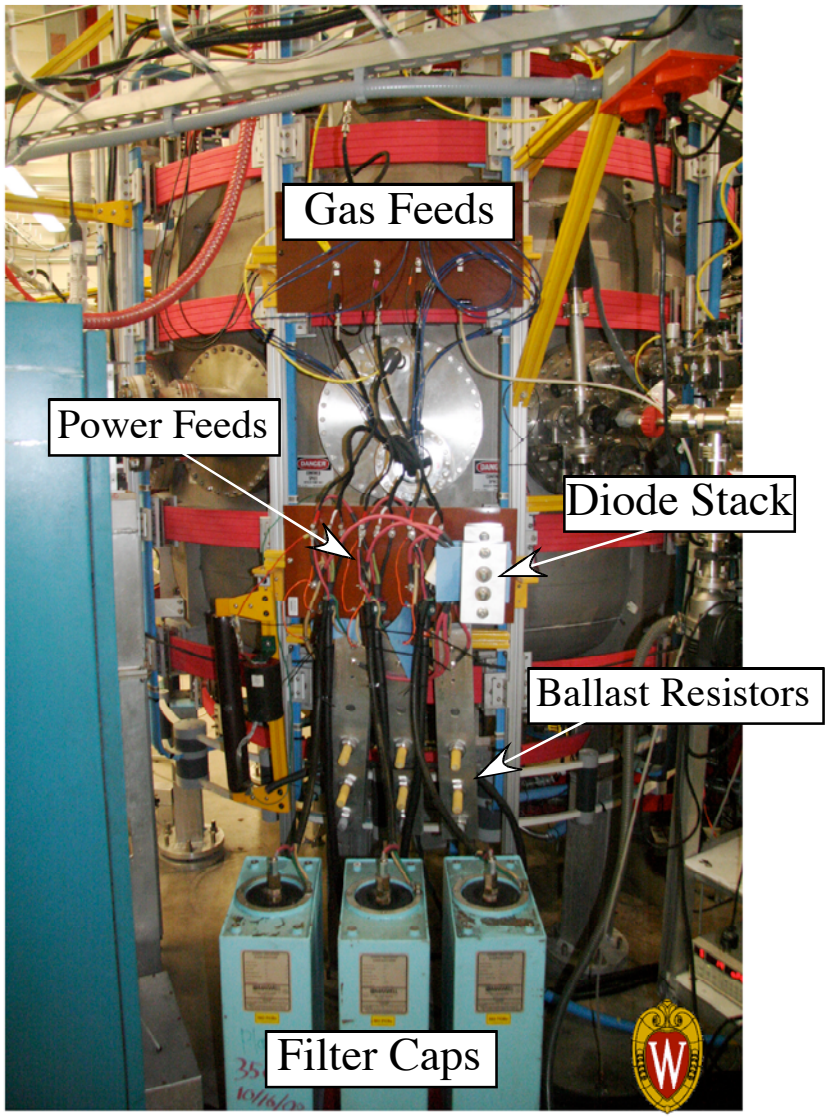
Bias and Arc circuit



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High Voltage Gun Bias Supply

- **Need high V and I for plasma gun sources**
  - Increased helicity injection => higher drive Ip
- **Present Buck supply limited to $V_{capbank}$**
  - Only single quadrant needed for system
  - System more suspectable to voltage droop
- **Buck/Boost supply to allow $V_{applied} > V_{capbank}$**
  - Allows use of existing 3MJ - 2700V capacitor banks
  - Use single power supply for multiple gun sources
  - Allows access to 2 - 3x $V_{capbank}$
  - Only one active semiconductor per switch assembly
  - Arc PFN Power Supply for each gun system
  - Δt = 8ms, I = 2kA, V = 1.4kV
  - Bias IGCT Power Supply - for all gun systems
  - Δt = 8ms, I ~ 7kA, V ~ 4 - 6kV

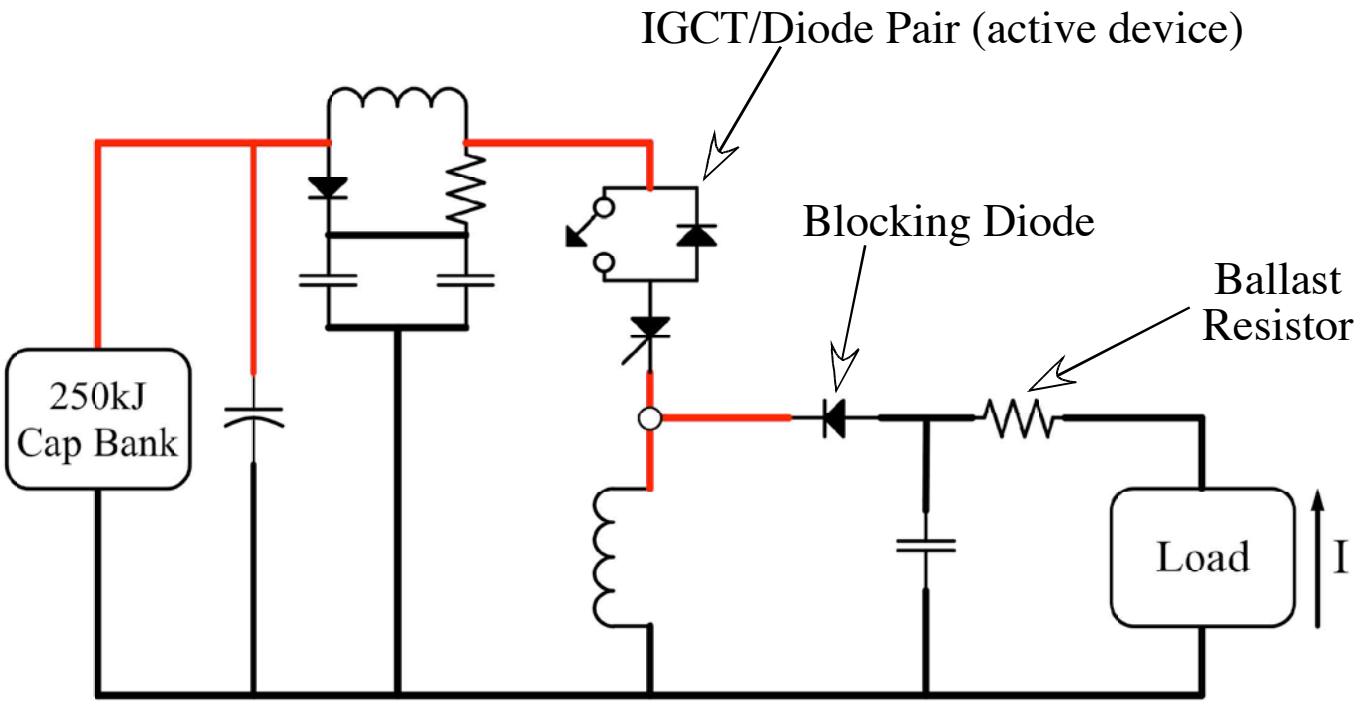


Buck/Boost Power Supply

- **Motivation**
  - Access to higher voltages to expand operating space

- **Buck/Boost supply to allow $V_{applied} > V_{capbank}$**

  - Allows use of existing 3MJ - 2700V capacitor banks
  - Allows access to 2 - 3x Vcapbank
  - Only one active semiconductor per switch assembly
  - SCR added to access higher voltage rating than single IGCT device



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H-Bridge Semiconductor Transient Limits

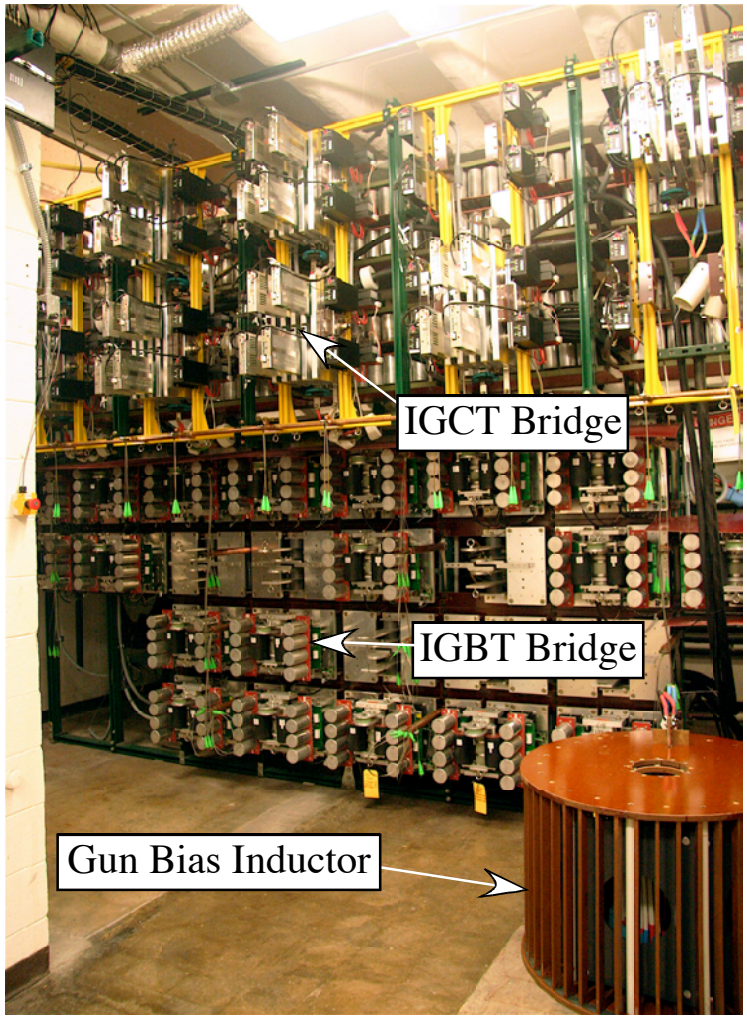
- **ABB 5SHY35L4511 IGCT**
  - Steady State Rating 2.8kV, 3.8kA at 300Hz
  - Switching Frequency
    - Dependent on current/voltage switched as well as device integrated controller
    - Can switch at 300Hz steady state
    - Can switch beyond 300Hz for a finite number of pulses (~100s)
  - Switched Voltage
    - Heating is minimized with reduced voltage operation
  - Switched Current
    - Cannot control (turn off) more current than device rating (3.8kA)
    - Heating is minimized with reduced current
  - Primary heating derived from switching losses

- **Eupec FZ2400R17KE3 IGBT**
  - Steady State Rating 900V, 2.4kA at 1kHz
  - Switching Frequency
    - Only dependant on controller (up to 5kHz)
  - Switched Voltage
    - Heating is minimized with reduced voltage operation
  - Switched Current
    - Repeated operation at 2x switch rating (4.8kA)
    - Single fault current interrupt at 9.6kA
  - Primary heating derived from conduction losses

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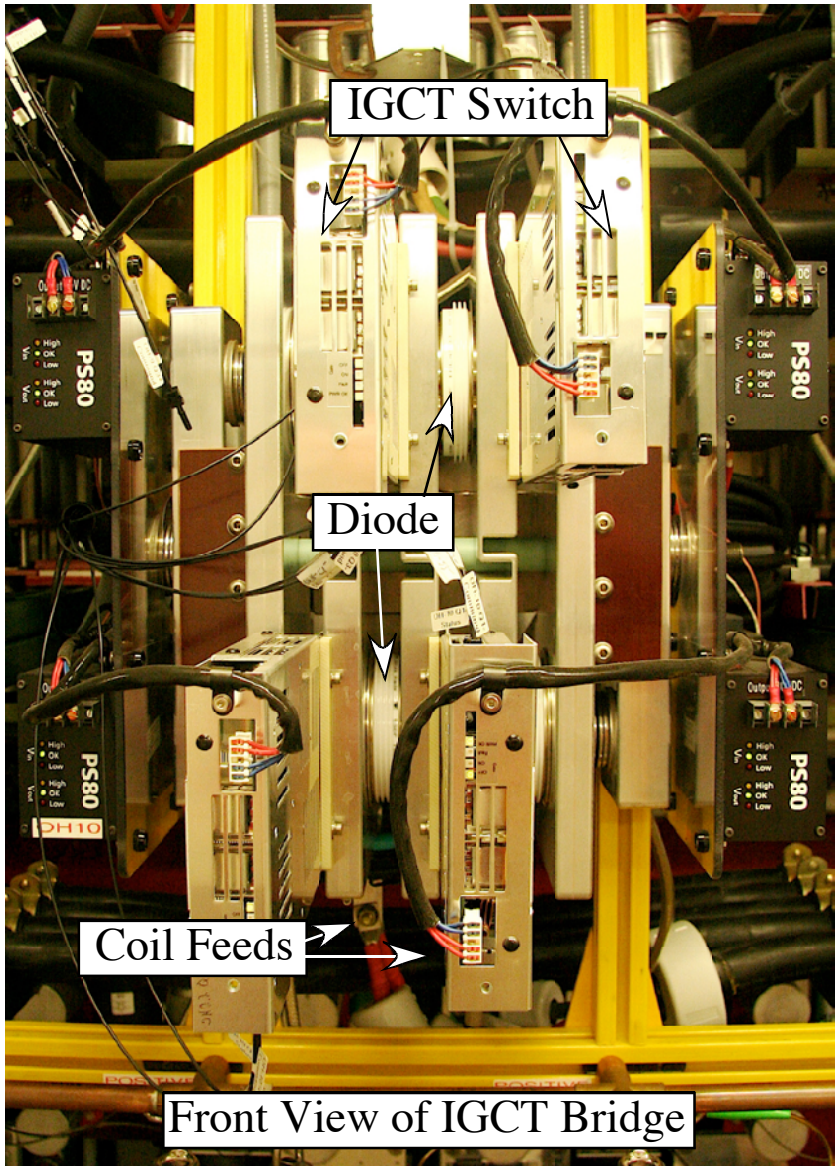
Details of PEGASUS Power Supplies

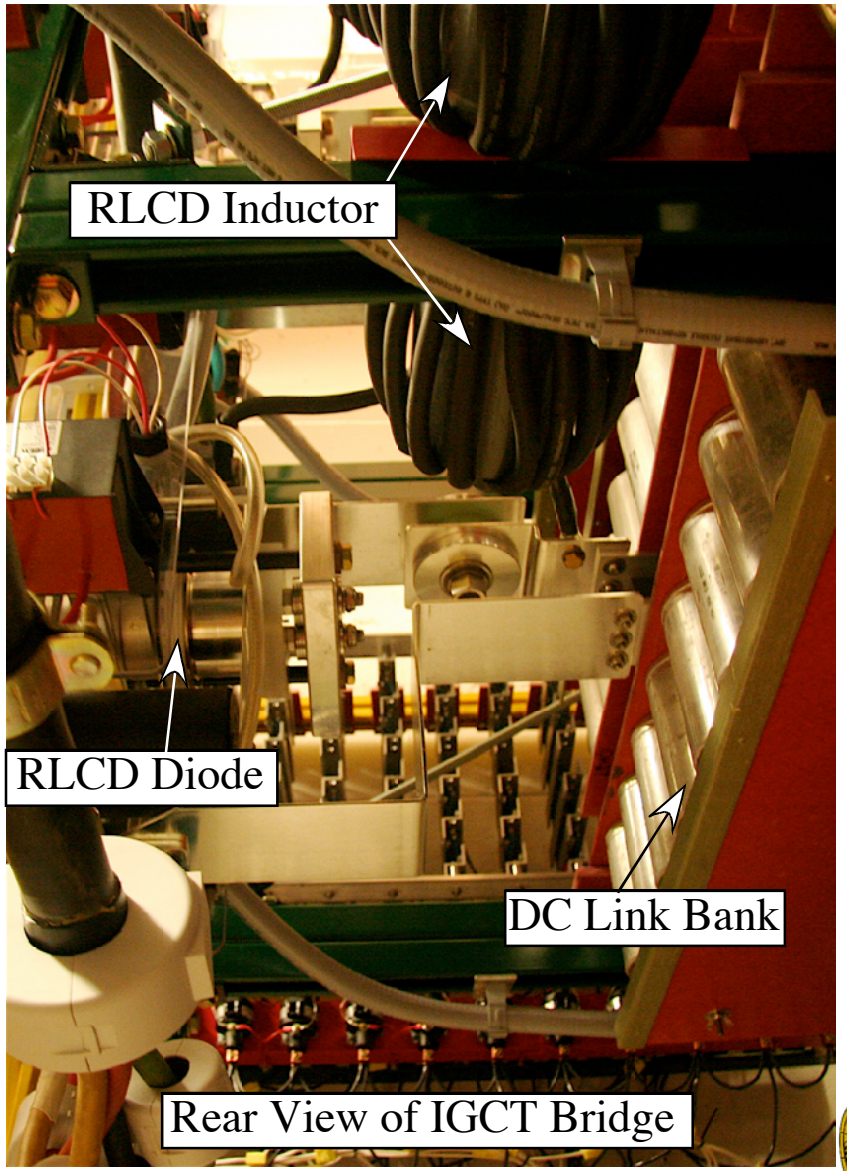
- **Ohmic Heating (OH) [85MVA]**
  - 8 systems provide ±36kA @ 2400V/2021kJ
  - Four Quadrant Control
  - Efficient utilization of up to 60mV/sec Ohmic Flux
  - Minimize heating of OH Solenoid by utilizing regeneration mode
- **HV Gun Bias System (OH) [1.5MVA]**
  - 2 systems provide +7kA @ 2400V/500kJ
  - Single Quadrant Control
- **Toroidal Field (TF) [35MVA]**
  - 8 systems provide 0 to +38kA @ 900V/673kJ
  - Two Quadrant Control
  - Allows for rapid current ramping
  - Maximum of 450kA rod current
- **Equilibrium Field (EF) [85MVA]**
  - 8 - 900V/42kJ and 12 - 900V/84kJ - 0 to ±4.0kA @ 900V
  - Two and Four Quadrant Control
  - Up to 8 independent coil sets
  - Provides positioning and shaping fields with active feedback



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IGCT Four-Quadrant H-Bridge





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Future Directions

- **Commission IGCT Bridge Control System**
  - Allow more reliable operations at high voltage operations
  - Increase available stored energy by 30%
- **Development of higher voltage power systems for gun operations**
  - Exploration of helicity voltage limits
  - Improvements to stabilization of bias arc (larger ballast resistors)
  - Access to more stored energy (adding more capacitor banks)
- **Active Feedback Control**
  - Vloop/Ip for plasma evolution and sustainment
  - Radial Position Control
  - Plasma Elongation
- **Reallocate IGCT system for proposed non-solenoidal plasma operations**
  - ~1/2 to high power helicity injection array
  - ~1/2 to fast response vertical field system

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Reprints

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PEGASUS Power System Facility Upgrades

Abstract	Bridge Control System	Bridge Control Block	IGCT Gun Bias	HV IGCT Bias
Pegasus Mission	Interface Board Overview	Bridge Board Overview	Buck Boost	IGCT Bridge
Overview	Interface Board Schematic	Bridge Board Schematic	Transient Limits	Future
Pegasus Toroidal	S/C Boards	Energy Storage Monitor	Pwr Sys Details	Reprints

