Jefferson Lab

Thomas Jefferson National Accelerator Facility is managed by Jefferson Science Associates, LLC, for the U.S. Department of Energy's Office of Science

Accelerator operations and reliability Jefferson Lab magnet power supplies

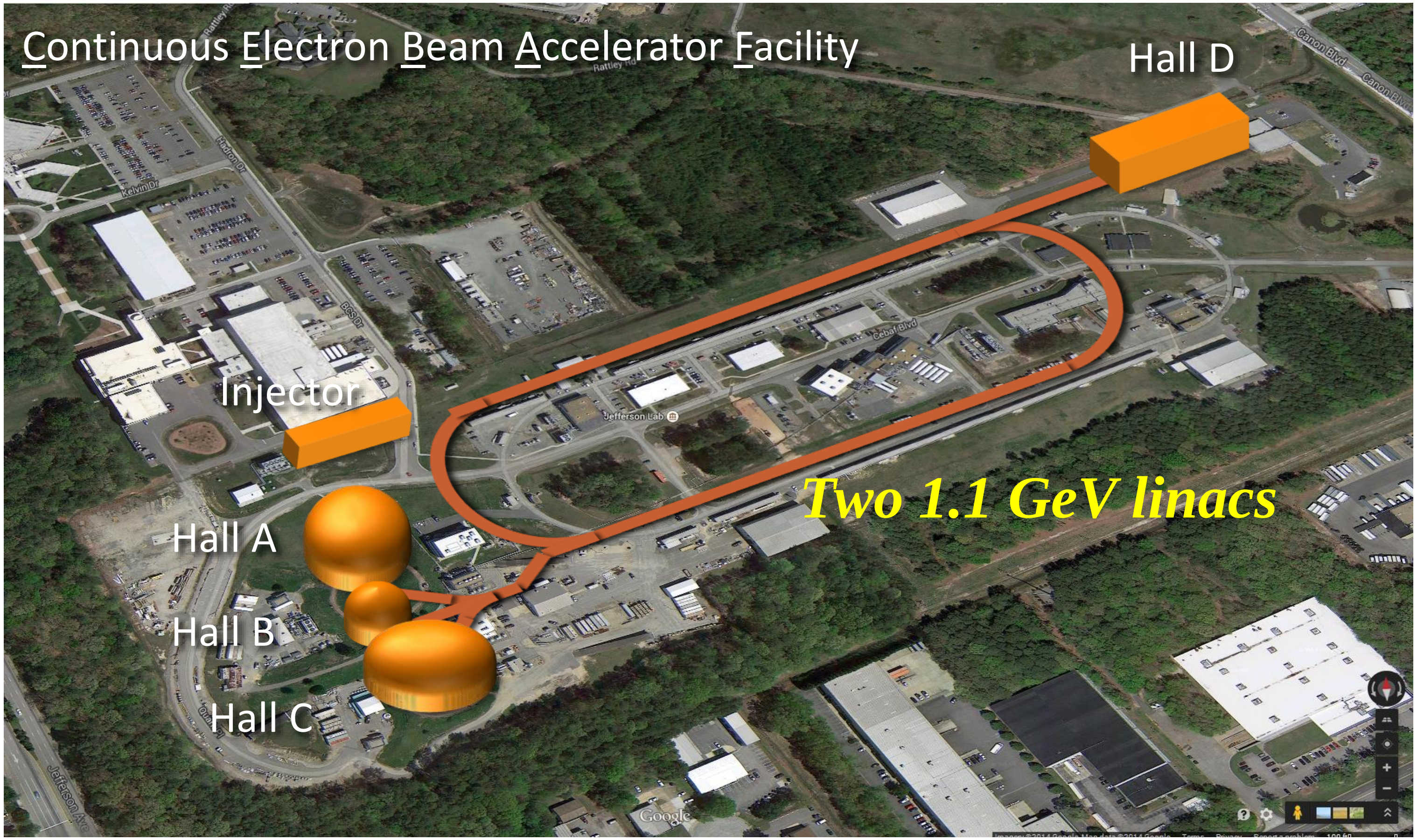
Sarin Philip
Electrical Engineering Services
DC Power Group Leader

EES DC

Thomas Jefferson National Accelerator, “Jefferson Lab, or JLab”

- Linear accelerator, 4 Halls with detectors for experiments
- Electron beam
- Operating since 1995 -- initially at 4GeV, then 6GeV
- Variable energy upto 12GeV at HallD, upto 11.5 GeV at Halls A,B,C
- Superconducting RF cavities
- Two Linacs - 1.1 GeV each at fully operational gradient
- 12GeV capabilities were commissioned in 2013
- The main machine is also known as “CEBAF”
- Smaller accelerators for testing and new applications

CEBAF Layout



Arcs connecting the linacs - ~600 meters each

Magnet Systems from original machine

10 AMP TRIM

2,300 Cards

200 Bulk supplies

SCR-TRANSISTOR BANK

Phase controlled rectifier

SHUNT SYSTEM

Electrically floating current source/sink

YA SYSTEM

Low voltage FET module and bulk power

OPS + Maintenance

Repairs and support

SPECIAL SYSTEMS

Fast Feedback

Raster, field measurement

EESDC

Present magnet systems

300W TRIM
2000 Cards
200 Bulk supplies

1.5kW AMP TRIMS
300 units AC to DC

SCR-TRANSISTOR BANK
Legacy units

SWITCH MODE SUPPLY
100kW to 1.2 MW
Upto 2kV
Upto 900 A

SHUNT SYSTEM
Electrically floating source/sink – 120 units

DOGLEGS
Jlab developed
40kW units (12)

YA SYSTEM
Low voltage FET module and bulk power

OPS + Maintenance
Repairs and support

COMMUNICATIONS
RS-485, Ethernet, PC104

SPECIAL SYSTEMS
Fast Feedback
Support for SC magnets, magnetic field measurement

EESDC

Applications

Trims

- Mostly small angle correctors
- Quadrupole magnets for focusing
- Solenoids for adjustment of electron beam properties
- Can be used for low frequency application depending on load properties (DC to 1kHz)

SCR, SMPS, Doglegs

- Large Dipole magnets in ARCS
- Transport beam to Halls
- Path-length adjustment for RF

Shunts, YA's

- Series pass regulators built using FETS
- Fine control of magnetic field in ARCs

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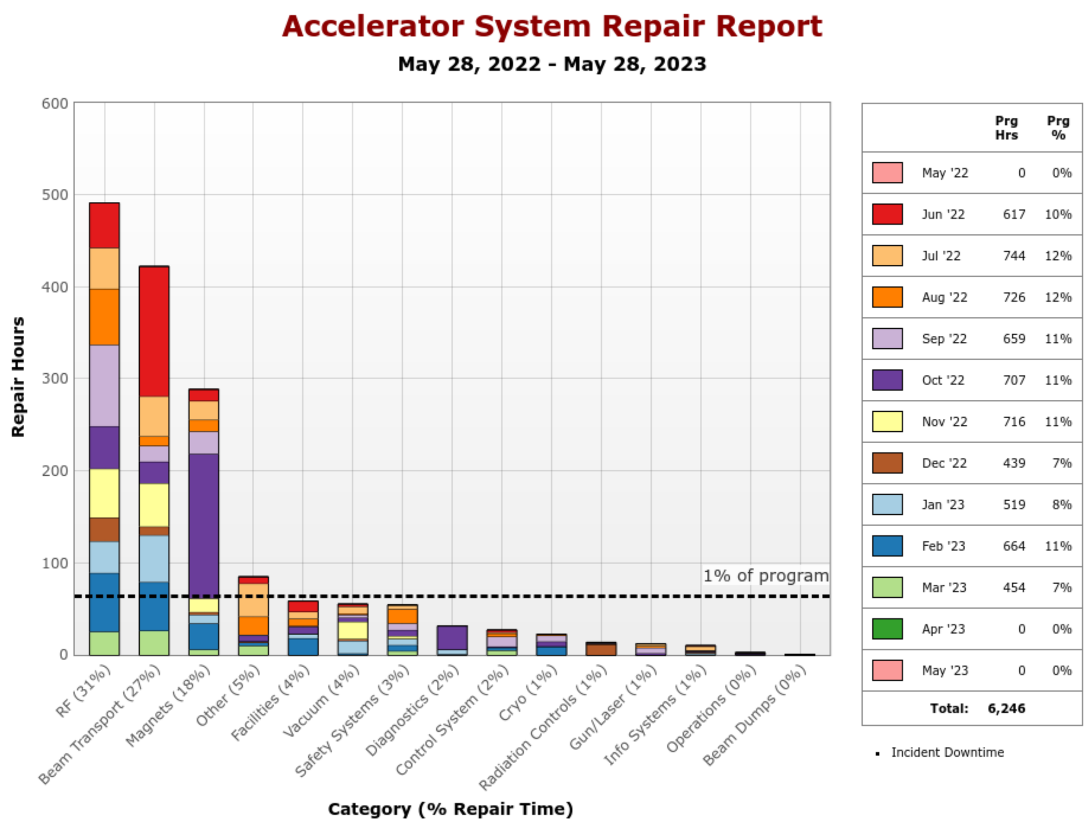
Reliability data

Analysis – Data used to plan projects

- Data from operations and self tracking of repairs
- 2014 to 2020 data showed increasing failures for particular systems
  - Power Sequencer for 300W trim system obsolete and causing downtime (approximately 1 failure every 3 weeks)
  - “Bulk” power supplies failing after 30+ years in service (approximately 2 failures every month)
  - Communications failures for many systems with aging micro-controller 20+ yrs, (100’s of soft failures daily, one or two hard failures per week)
  - Need for higher field in dogleg magnets. Operations unable to send stable beam
  - Pressure variations in cooling water (LCW) systems affecting large power converter performance (few instances per year)
  - Quality of LCW and related magnet issues (few occurrences a year)
  - Occasional site AC power quality issues (hard failure average of once every 16 weeks)
  - Temperature related failures while operating in summer if Air conditioning fails

Operations reliability data



Self-tracking database for reliability

All Access Objec...

Search...

Tables

- Fall Run 2017
- Fall Run 2018
- Spring Run 2015
- Spring Run 2016
- Spring Run 2017
- Summer Run 2019
- Winter Run 2015
- Winter Run 2016
- Winter-Spring Run 2018
- Winter-Spring Run 2019

Summer Run 2019 | Winter Run 2015 | Winter-Spring Run 2018 | **Winter-Spring Run 2019**

ID	Day	Hours Spent	Type	System Name	Subs
1	2/6/2019	0.167	Trims	W501B12	
2	2/7/2019	0.183	Shunts	MXV4R04	
3	2/7/2019	1.3	Box PS	ARC4	
4	2/7/2019	0.6	Shunts	MBC8A24V	
5	2/7/2019	1.3	Trims	W501B12	
6	2/7/2019	0.8	Shunts	MXV4R04	
7	2/7/2019	0.42	Trims	W501B12	
8	2/7/2019	0.267	Trims	MBC8A24V	
9	2/7/2019	1.03	Trims	W501B12	
10	2/10/2019	3	Trims	W501B13	
11	2/10/2019	0.283	Trims (20A)	MQN8E03	
12	2/13/2019	1.93	Trims	E501B12	
13	2/13/2019	0.216	Trims	BS04B13	M
14	2/14/2019	0.283	Trims	SA01B07	
15	2/14/2019	0.483	Trims	W501B12	M
16	2/14/2019	2.2	Trims	E301B11	
17	2/14/2019	0.233	Trims	W501B12	M
18	2/15/2019	0.37	Trims	SV01B25	
19	2/16/2019	0.25	Trims	MBC1H01V	
20	[illegible]	[illegible]	[illegible]	[illegible]	
Total		**40.6134**			

Record: 1 of 53 | No Filter | Search

Datasheet View | Num Lock

Analysis – New failure modes, no previous data

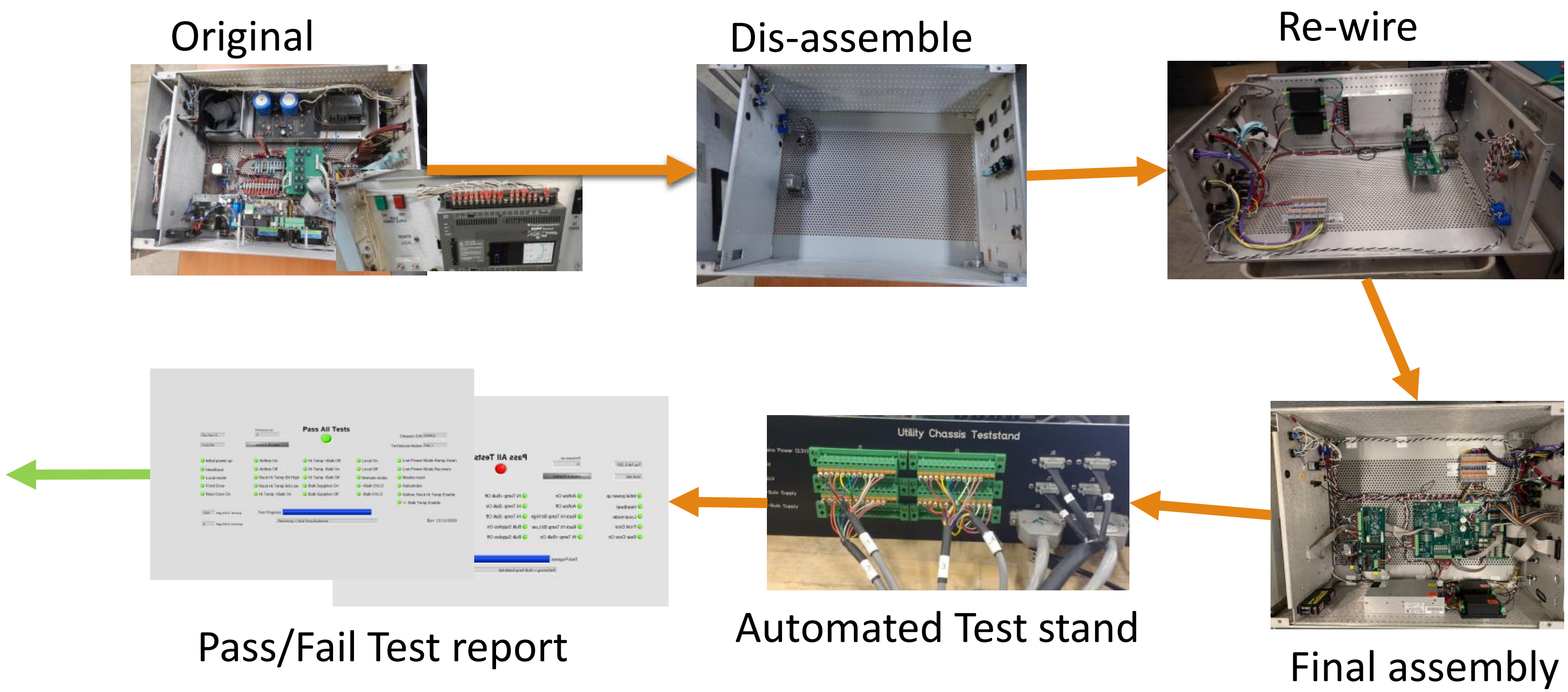
- Failures in magnetics
  - Sensitive to temperature
  - Material properties different than expected by designer
- IGBT problems
  - Encapsulation leaks
  - in cooling water systems affecting large power converter performance

System improvements based on reliability data

Improvements based on analysis

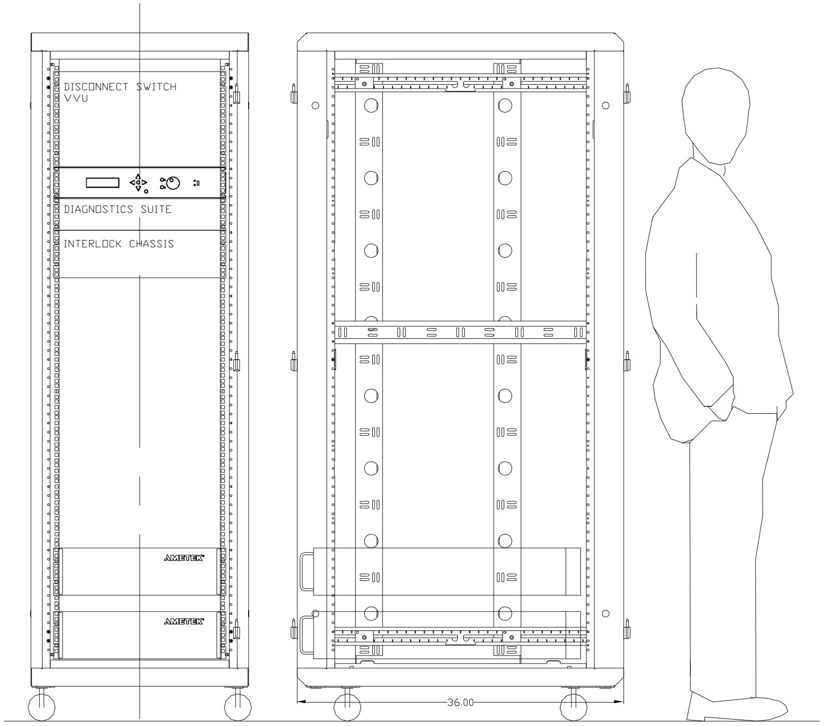
- Power Sequencer for 300W trim system obsolete and causing downtime
  - Replaced PLC based controller to in-house designed FPGA based control
  - Assembly line re-build of ~80 units 2019 to 2021
- "Bulk" power supplies failing after 30+ years in service
  - Multi-year plan to replace with newer units
  - Higher efficiency & reliable modern off the shelf units
- Communications failures for many systems with aging micro-controller (20+ yrs)
  - Replace with in-house designed solution
- Need for higher field in dogleg magnets
  - Designed in-house system around a custom "off-the-shelf" power module
  - Designed and built eleven 40kW units in ~12 months
- Pressure variations in cooling water systems affecting large power converter performance
  - Designed a better internal water distribution system
  - Approved by original equipment manufacturer

Example Project to replace PLC



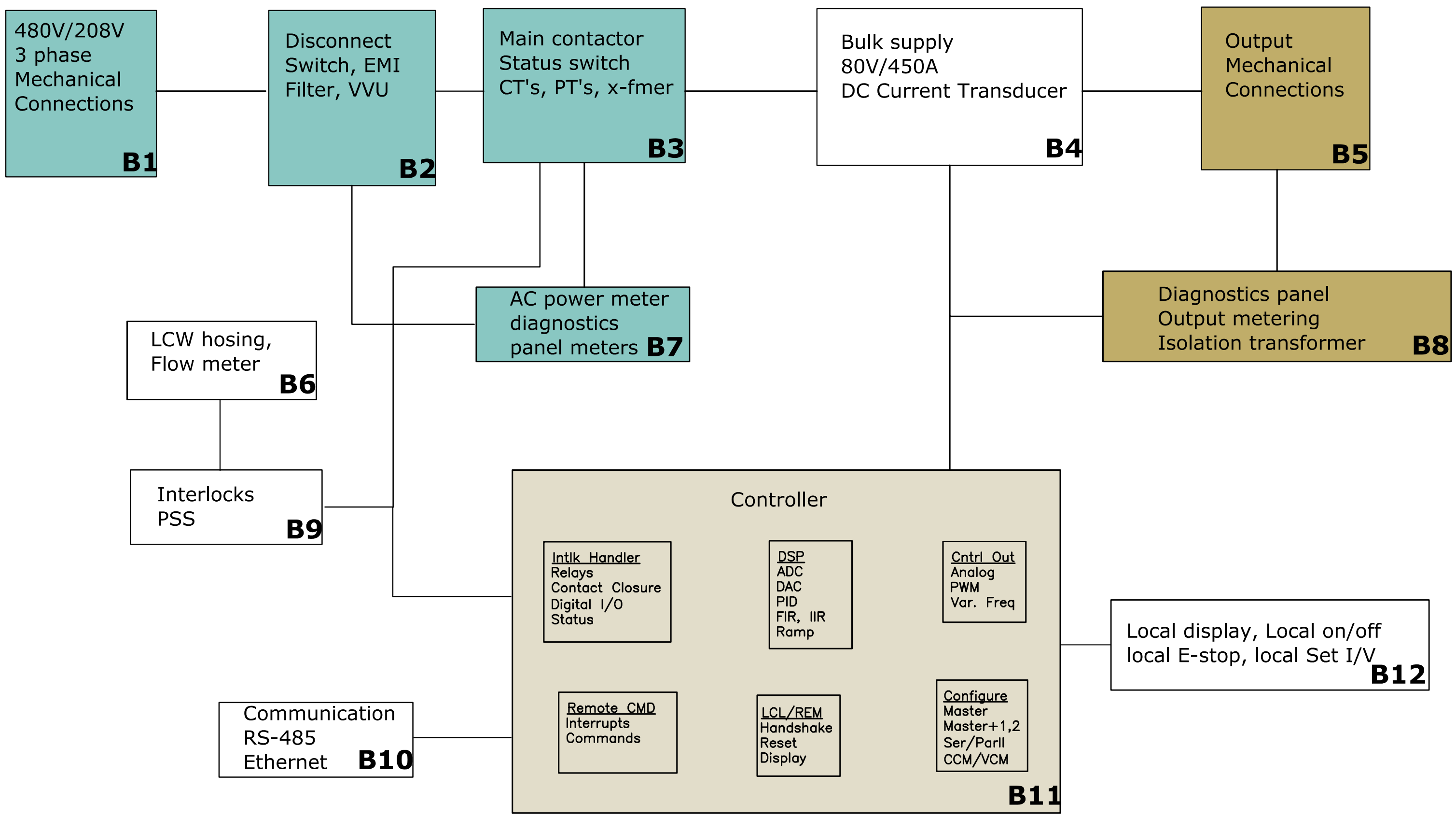
Example: Power supply for Dogleg magnets

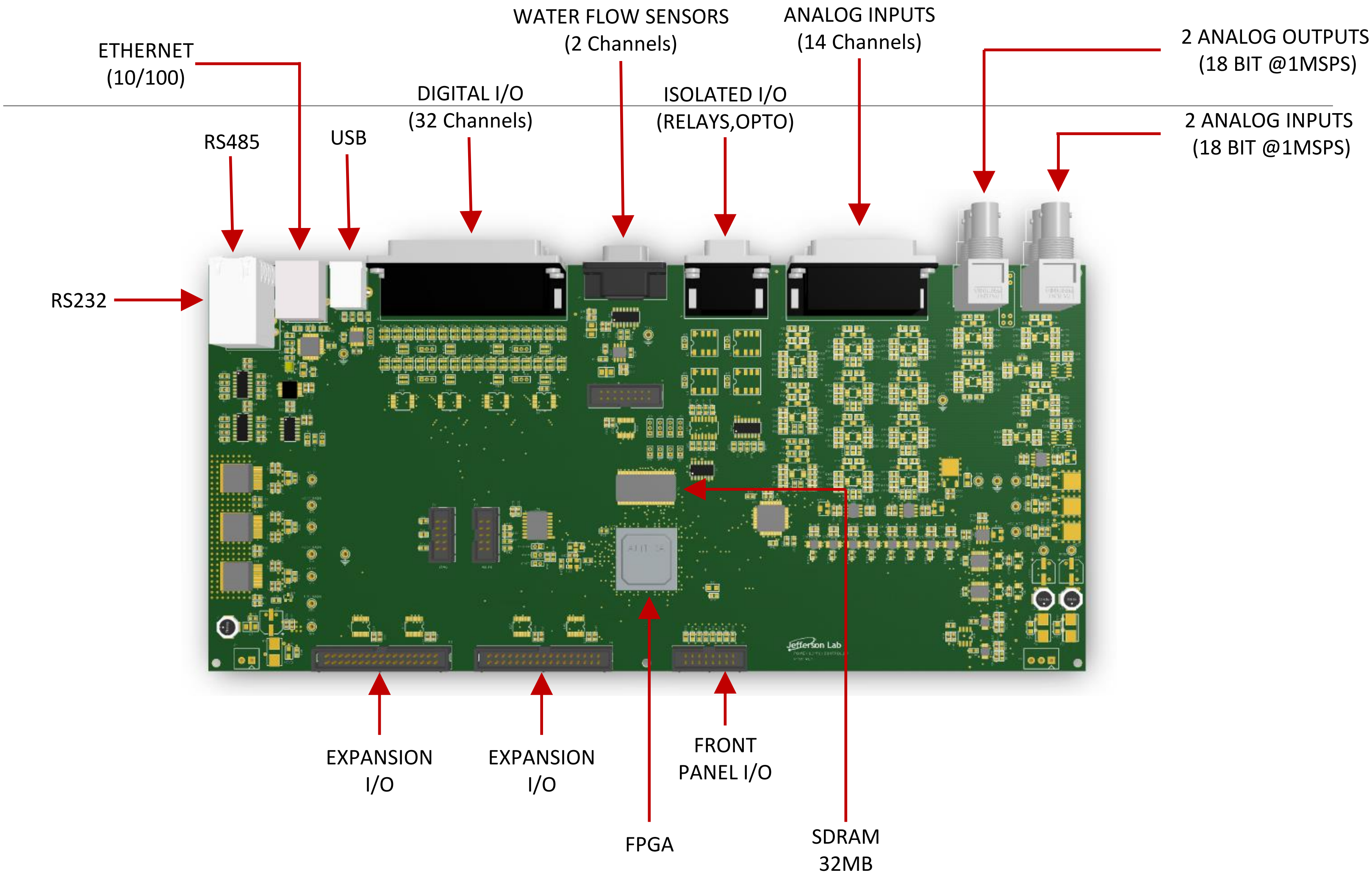
- Modular design
- Use existing designs where appropriate
- Use existing components where appropriate (minimize spares)
- Keep it simple
- Improve on the designs of vendors
- Design so that it can be used for future projects
- Use UL approved products where possible
- Use best engineering practice (national codes, IEC standards)



Early concept of general layout

Example: Power supply for Dogleg magnets

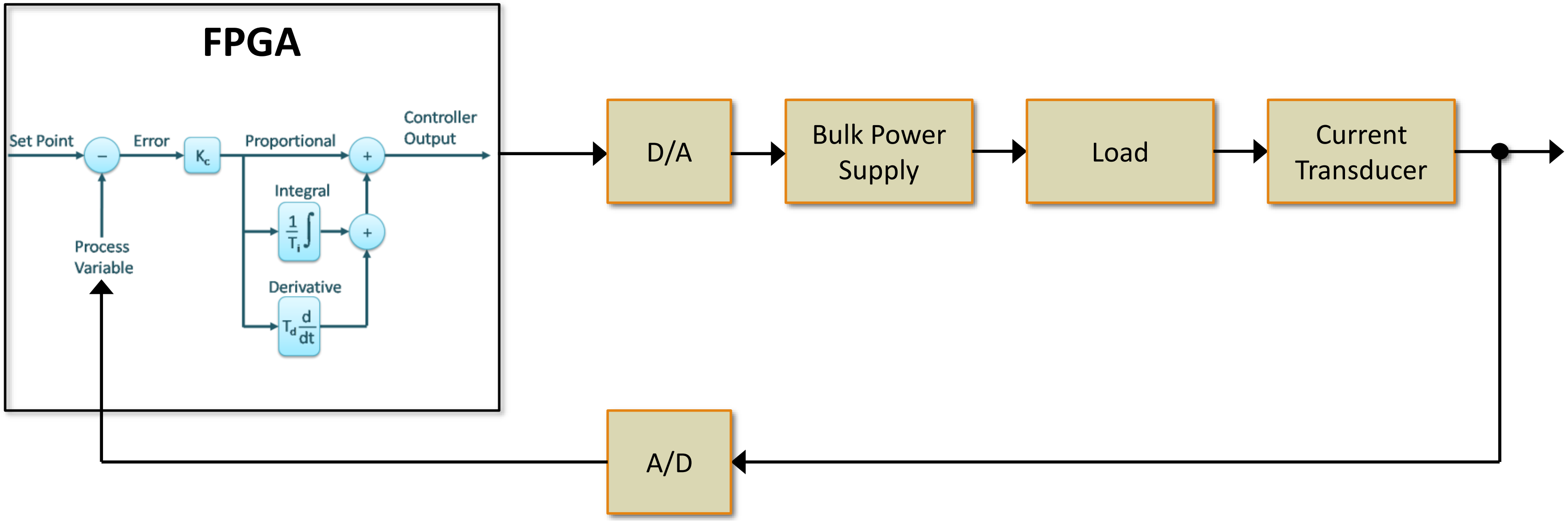



ETHERNET
(10/100)
WATER FLOW SENSORS
(2 Channels)
ANALOG INPUTS
(14 Channels)
2 ANALOG OUTPUTS
(18 BIT @1MSPS)
DIGITAL I/O
(32 Channels)
ISOLATED I/O
(RELAYS,OPTO)
2 ANALOG INPUTS
(18 BIT @1MSPS)
RS485
USB
RS232
EXPANSION
I/O
EXPANSION
I/O
FRONT
PANEL I/O
FPGA
SDRAM
32MB

Controller and top level design

<u>Why Digital ?</u>

- Flexibility
- Easily reconfigured for different systems
- Adaptive (temperature compensation, etc…)
- Ability to implement modern control methods (State Space, etc…)



Design versus actual installation

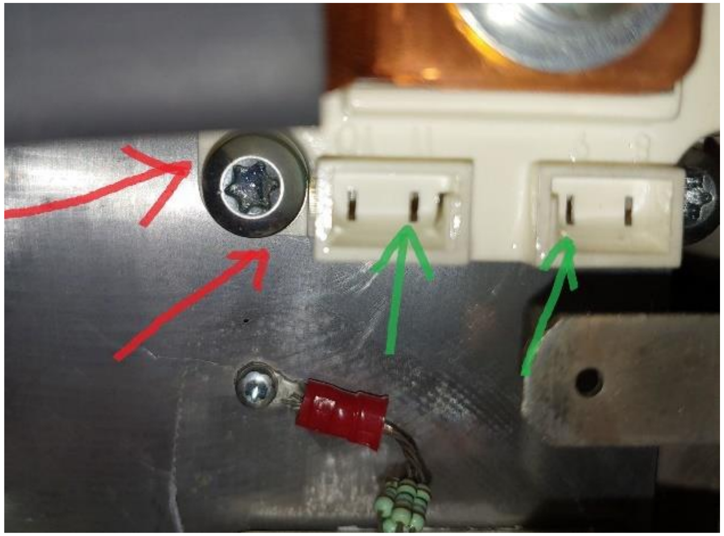
Reliability of components

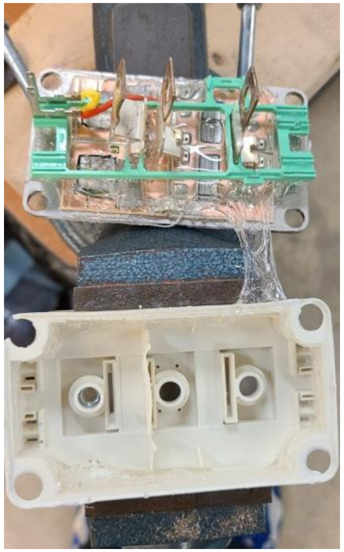
Analysis – New failure modes

- Failures in magnetics
  - Improved cooling within high power compartments
  - Added temperature monitoring and shutdown systems in service building
  - Working with facilities to improve cooling and thermal stability
  - Working with vendor to design new lower loss inductors for the same switching frequency
- IGBT problems
  - Manufacturer unable to provide failure analysis
  - Replaced ~200 IGBT's in all power converters to prevent failure
- Parts shortages
  - IC's and embedded controls chips in short supply
  - Long lead times for many power components and semiconductors
  - Discontinuation of equivalent parts from alternate manufacturers

Analysis – New failure modes

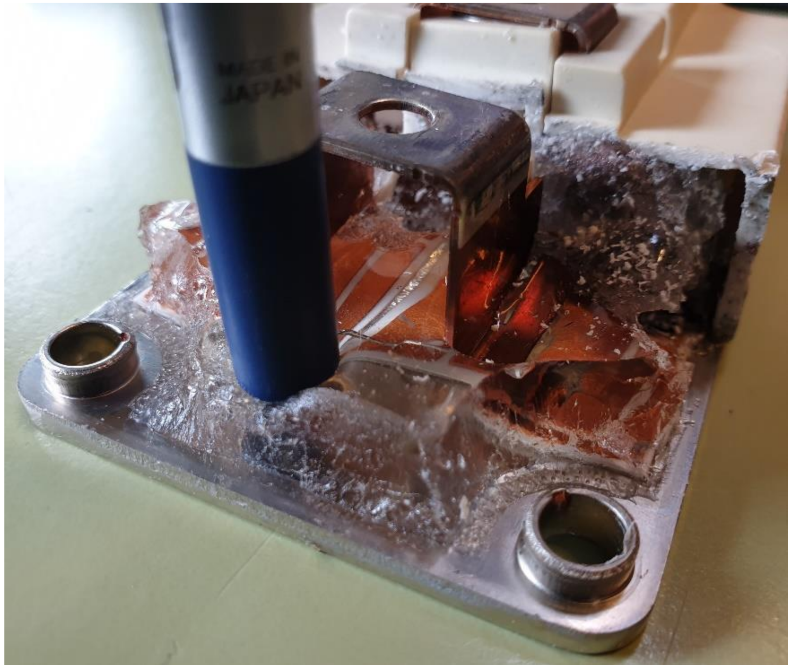
- IGBT problems
  - IGBT Manufacturer unable to provide failure analysis
  - Replaced IGBT's in all power converters to prevent failure





Analysis – New failure modes

- IGBT problems
  - Not overheating
  - Chemical analysis conducted, does not appear to be due to environment



Results for comparison

- 2014 to 2020 data showed increasing failures for particular systems
  - Power Sequencer for 300W trim system obsolete and causing downtime (approximately 1 failure every 3 weeks)
    - ✓ 1 failure in 12 months of operation so far
  - "Bulk" power supplies failing after 30+ years in service (approximately 2 failures every month)
    - ✓ 1 New unit failed because of a fan seizing up. All other new units have been operational without any failures
  - Communications failures for many systems with aging micro-controller 20+ yrs, (100's of soft failures daily, one or two hard failures per week)
    - ✓ Replaced all micro-controllers for shunt system. Zero communications failures since new design has been installed
  - Dogleg power supplies.
    - ✓ 1 Failure of a voltage imbalance sensor since 2015. No other failures to note

Continuing improvement

- Quality of LCW and related magnet issues (few occurrences a year)
- Occasional site AC power quality issues (hard failure average of once every 16 weeks)
- Temperature related failures while operating in summer if Air conditioning fails
- Some projects on hold due to unavailability of parts since pandemic, especially FPGA's and microcontrollers.

- Future projects: SiC diodes for rectifiers and FETS for regulators

Summary

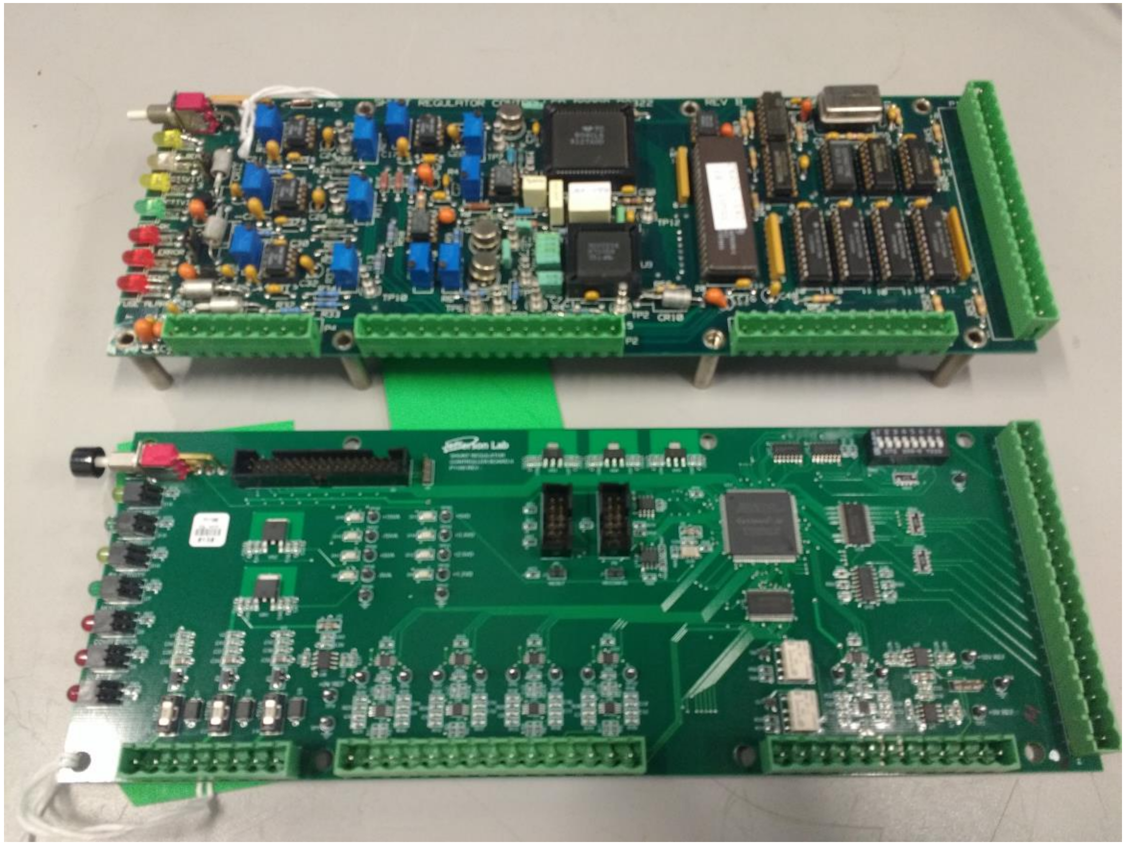
- Reliability analysis and methods discussed
- Improvements to systems discussed

- Welcome comments and suggestions for improvements

Questions?

Supplemental

Embedded boards to reduce communications related failures



Example dipole magnet string