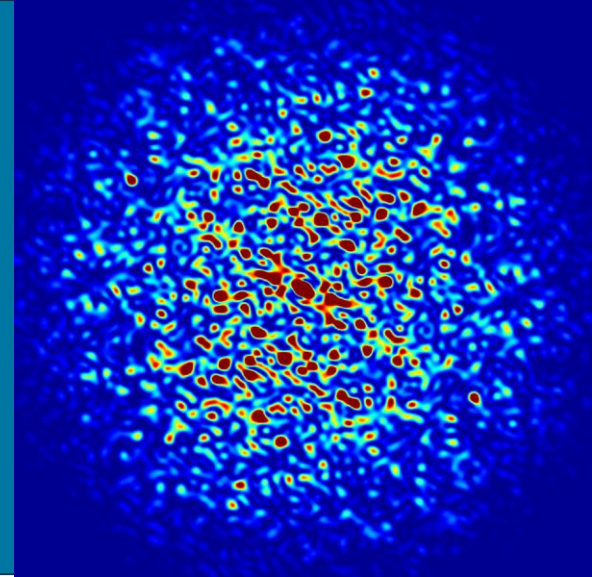


APS-U Magnet Power Supply Systems Status POCPA 2018 – Brazil



Fernando Rafael

APU Power Supplies CAM
Argonne National Laboratory

Advanced Photon Source Upgrade (APS-U) Project

September 24 - 26, 2018

Outline

- APU – APS Upgrade Project
- Scope of this system and requirements
- External interfaces and integration
- Systems design maturity (status)
- Cost and schedule
- ES&H
- Summary

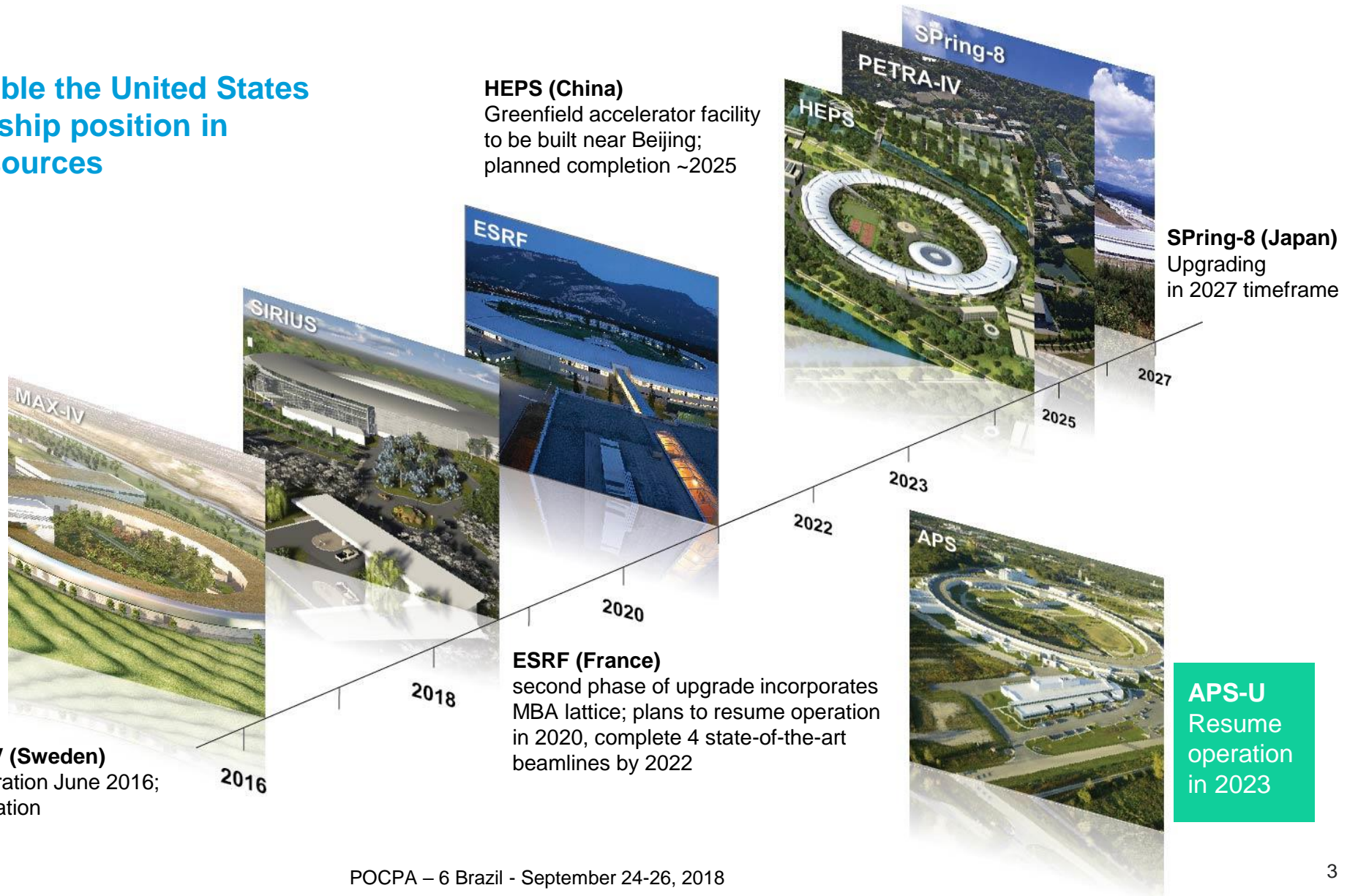
Why, What and How.

International High Energy DLSR Development

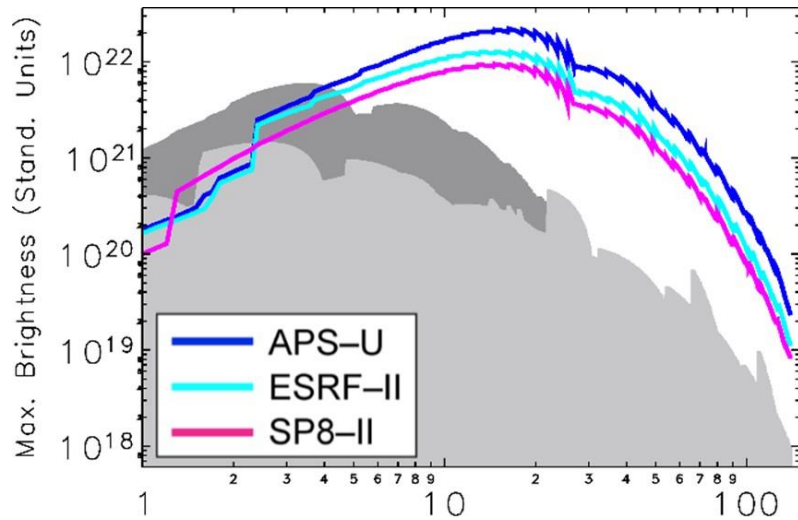
APS Upgrade plans to enable the United States to maintain a world leadership position in storage ring-based x-ray sources

$$\frac{\lambda}{4\pi}$$

$$\lambda = 1\text{\AA} \Rightarrow \epsilon_{\text{diff}} = 8 \text{ pm-rad}$$



APS-U Parameters

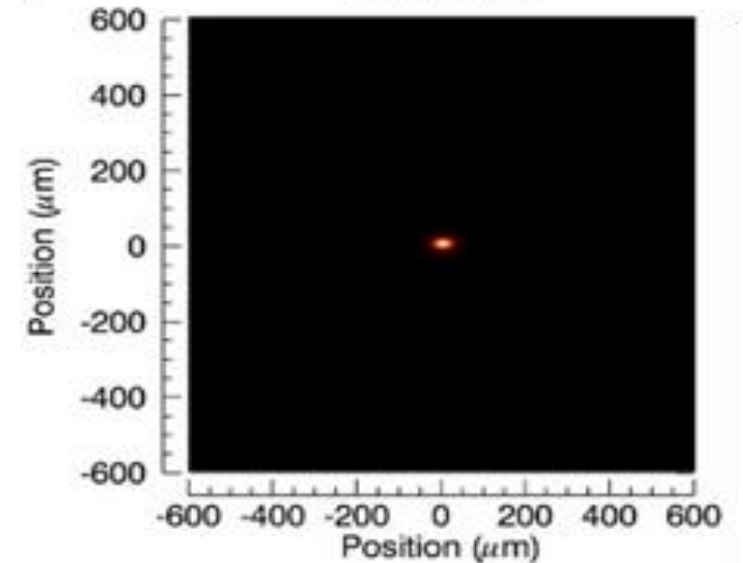
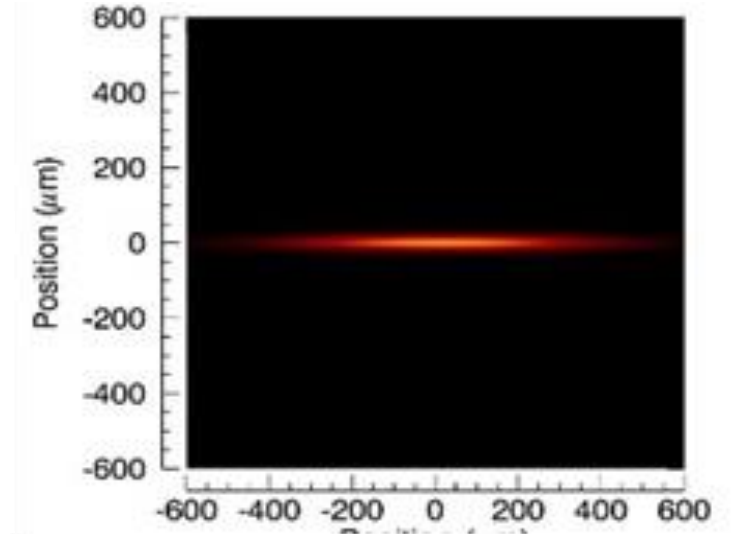


Curves for APS, ESRF, and SP8 upgrades based on present designs, assuming identical undulators

HEPS/Beijing may exceed APS-U brightness by a small amount due to larger circumference (1.3 km vs 1.1 km), as could SP8-II (1.44 km)

PETRA-IV could exceed APS-U brightness by a larger amount due to even bigger circumference

Quantity	APS Now	APS MBA Timing Mode	APS MBA Brightness Mode	Units
Beam Energy	7	6	6	GeV
Beam Current	100	200	200	mA
Number of Bunches	24	48	324	
Bunch Duration (rms)	34	104	88	ps
Energy Spread (rms)	0.095	0.156	0.130	%
Bunch Spacing	153	77	11	ns
Emittance Ratio	0.013	1	0.1	
Horizontal Emittance	3100	31.9	42.2	pm-rad
Horizontal Beam Size (rms)	275	12.6	14.5	μm
Horizontal Divergence (rms)	11	2.5	2.9	μrad
Vertical Emittance	40	31.7	4.2	pm-rad
Vertical Beam Size (rms)	10	7.7	2.8	μm
Vertical Divergence (rms)	3.5	4.1	1.5	μrad



APS-U Preliminary Design Report, September 2017

Magnet Power Supplies Scope of the Work

Magnet Power Supply Systems

L-Bend Dipole Magnet Power Supply System

Unipolar Power Supply System

DC Trim Bipolar Power Supply System

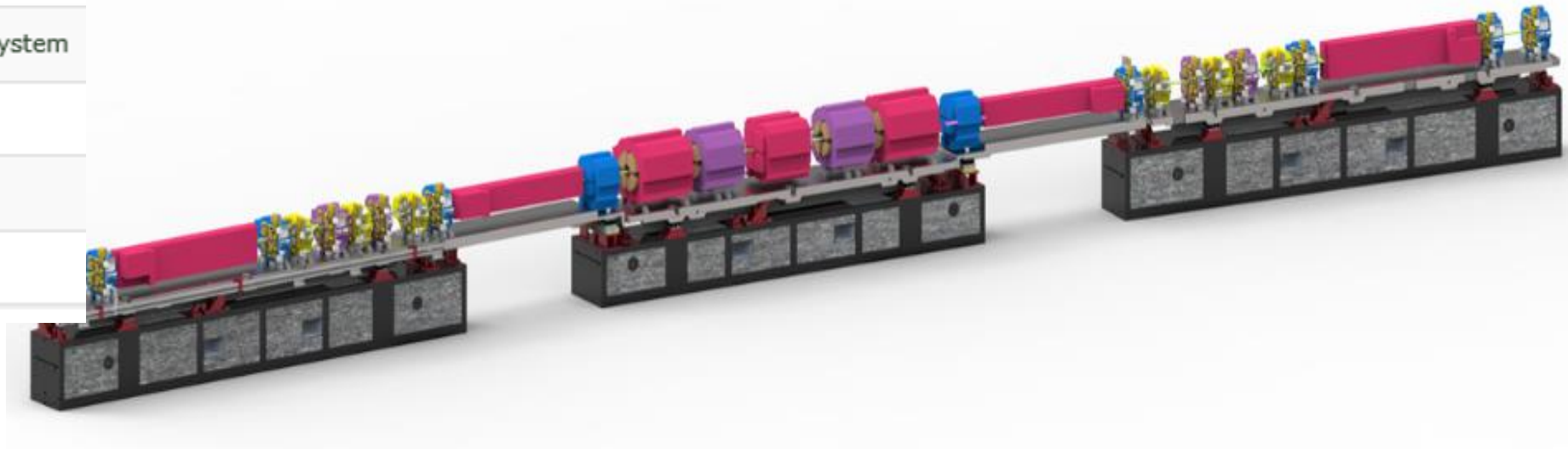
Fast Corrector Bipolar Power Supply System

Power Supply Controllers

Magnet TC Monitoring System

Power Supply Pre-Installation Testing

- SR consists of 40 Sectors. Each with 33 arc magnets; 27.6 meters / sector
- Each sector is hybrid 7BA¹ (with longitudinal bends and reverse bends²)



¹ Raimondi et al., ESRF

² Streun et al., PSI

Total cost for Magnet Power Supply Systems is ~ **\$30 MI**

Magnet Power Supplies Specification

Parameters*	Q1-8	Q-Bend	L-Bend	Sextupoles	Bi-Trim	Bi-Fast	Unit
Current (range)	135 - 250	230 - 254	245 - 441	62 - 88	+/-15	+/-15	A
Initial Accuracy	100	100	100	100	100	100	ppm
Repeatability	100	100	100	100	100	100	ppm
Settablility (ENOB)	18	18	18	18	16	16	bits
Reproducibility	10	10	10	10	100	100	ppm
Current Stability	10	10	10	10	100	100	ppm
Quantity	640	120	2	240	921	322	2245

- From FReD (Function Requirements Documents)
- Covered by the Engineering Specification Document - ESD

**Total
Power Supplies**



Magnet Power Supply Systems Interfaces - ICD

- **Magnet Interfaces**
 - Power cables
 - Thermal switches and thermocouples
- **Utility Interfaces**
 - 480VAC and 120VAC – existing
 - Cooling water system – existing
 - Building temperature stability – 1°C stability
- **Controls Interface**
 - EPICS interface for general control and monitoring
 - Synchronized sampling and data read back
 - Time-stamped bulk data read back for power supply waveform capture
 - Fast Orbit Feedback (FOFB) System Interface for bipolar PS
- **Safety and Machine Protection Interfaces**
 - Beam energy interlocks
 - Tunnel access interlocks
 - Power supply cooling water interlocks
 - Power supply emergency turn-off
- **Interface with Removal and Installation**
 - Power supply test area
 - Power supply removal and installation

Magnet Power Supply System Value Engineering/Alternatives

- Re-using the existing infrastructure

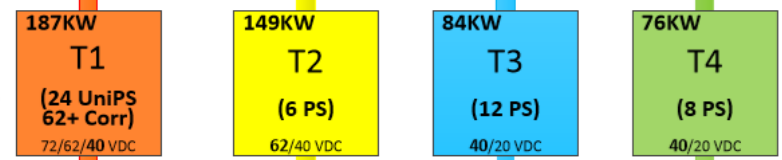
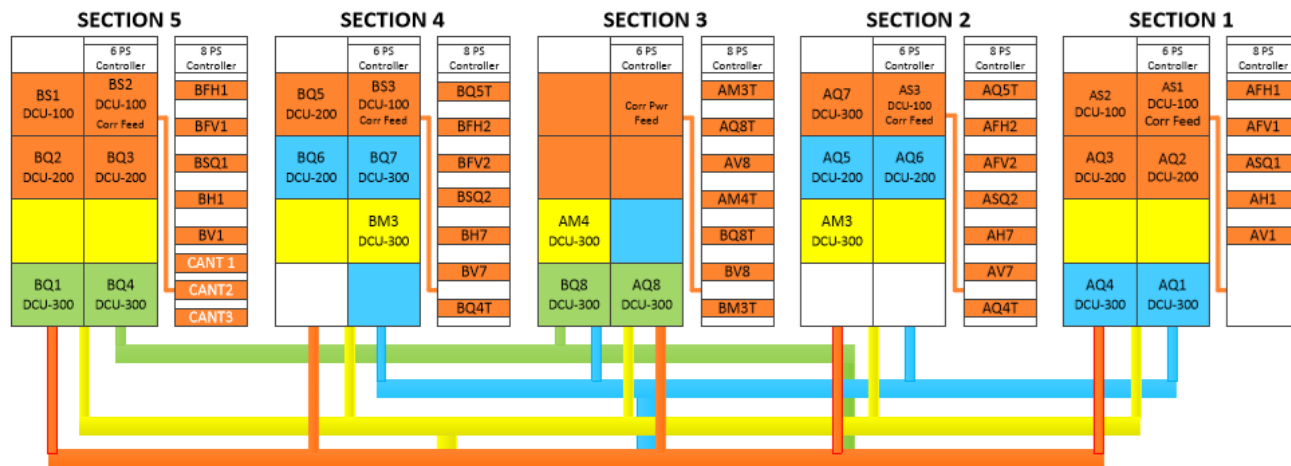
- Raw Power Supplies – Total of 80
- Converter Cabinets – Total of 200
- Cooling – LCW
- AC Distribution (M1 – M2)
- Stripline Bus (M1)

- Common Components/Design

- M1 and M2 – Same model
- Three (3) families of Unipolar Power Supplies – One design just different ratings
- Bipolar Trim and Fast correctors power supplies – One design with different frequency responses

T1	40	V
Config: 72/62/40	2600	A
T2	62	V
Config: 62/40	1200	A
T3	40	V
Config: 40/20	2100	A
T4	40	V
Config: 40/20	1900	A

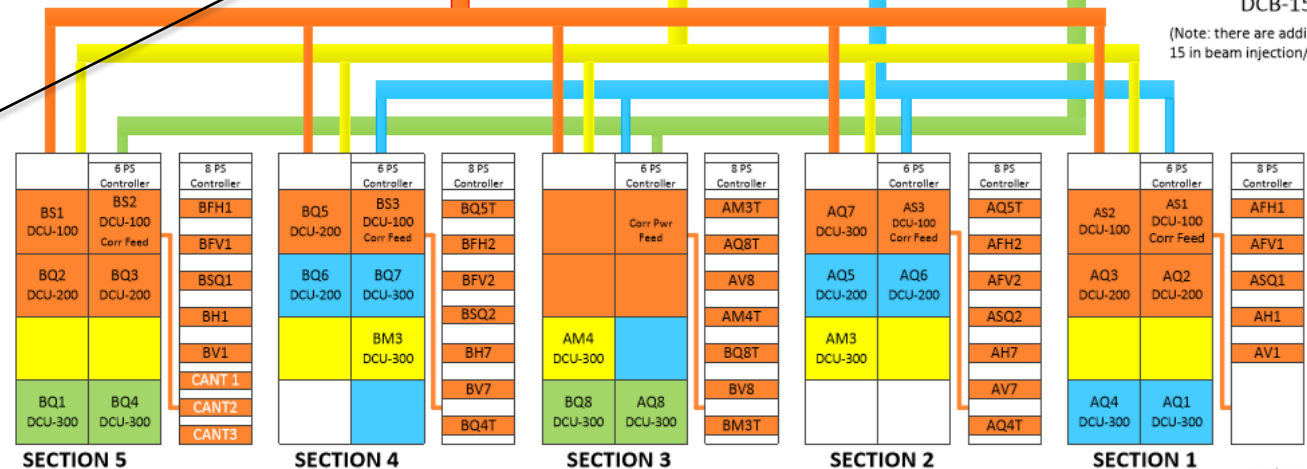
Unipolar, Bipolar and Controllers Power Supplies System Overview



DC/DC Converter Dbl Sector Quantity

DCU-100:	12
DCU-200:	16
DCU-300:	22
FCB-15:	16
DCB-15:	46

(Note: there are additional two FCB-15 and one DCB-15 in beam injection/extraction section)

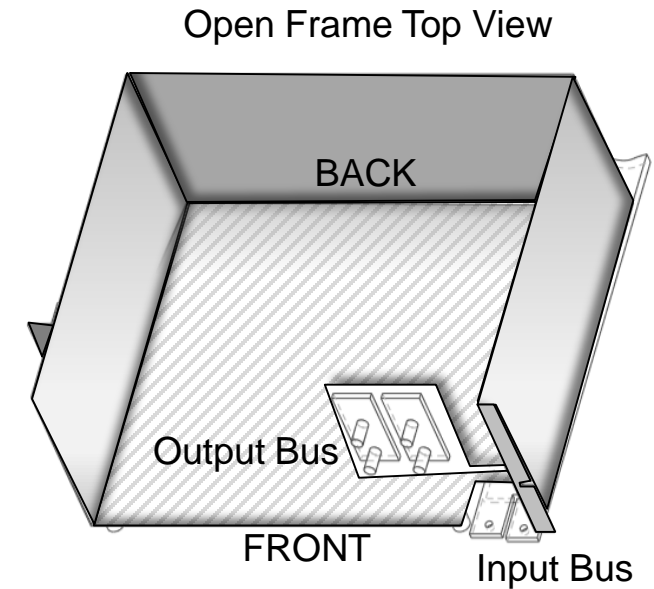
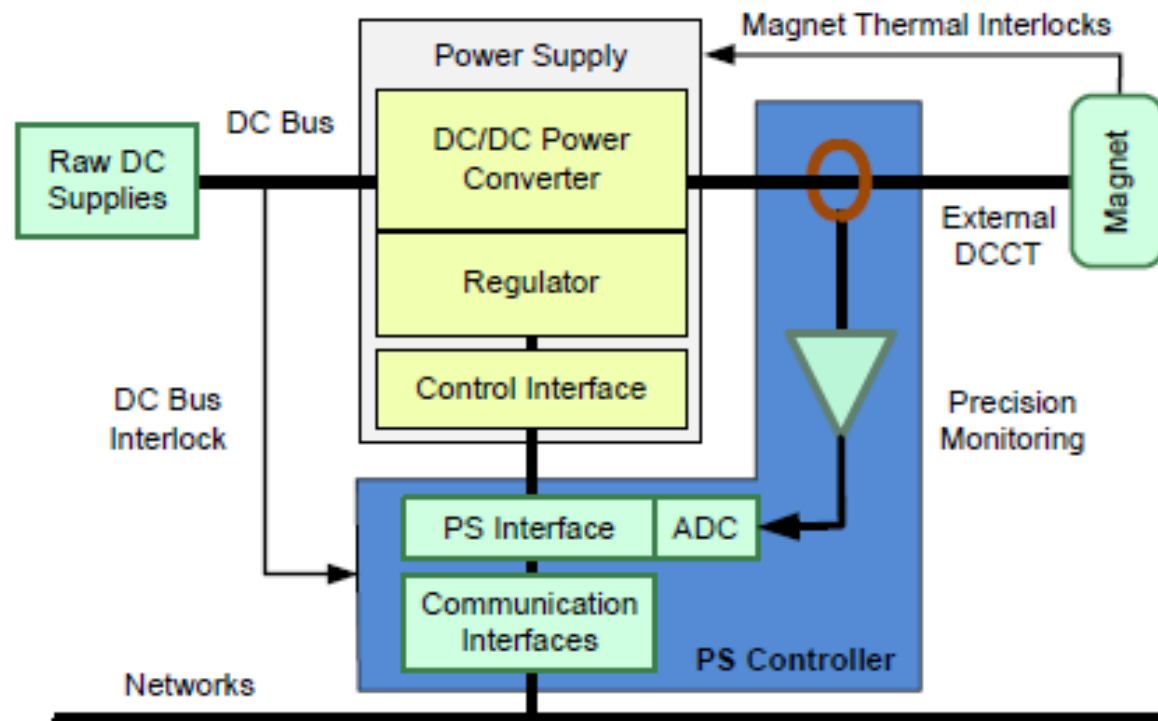


GMM
7/18/2018
GMM5\APS-U\ConvCab & PS Rack Layout July18
Based on 41pm lattice Ver 5

Unipolar Power Supply System

■ Unipolar Power Supply System – LLP

- RFQ sent on 06/20/2018
- Received 6 bids
- Phase I – Prototyping vendors awarded on 09/11/2018



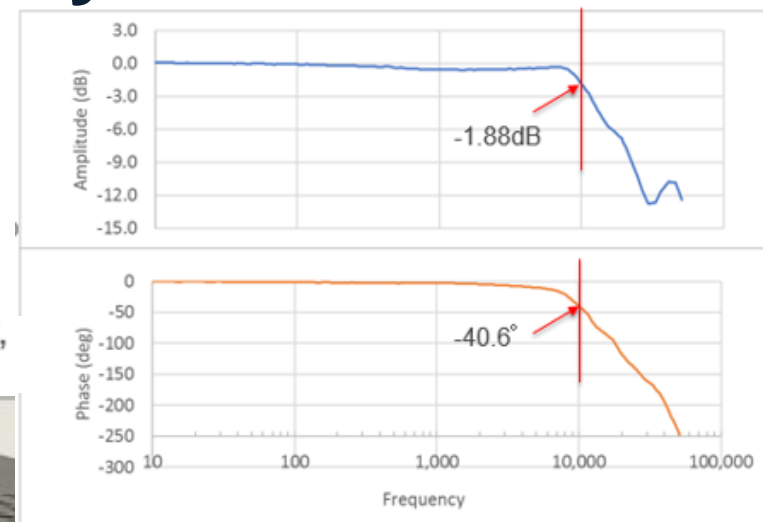
1,000 - Units

- 240 – DCU 100 – 15 Vdc – 100 A
- 320 – DCU 200 – 15 Vdc – 200 A
- 440 – DCU 300 – 45 Vdc – 300 A

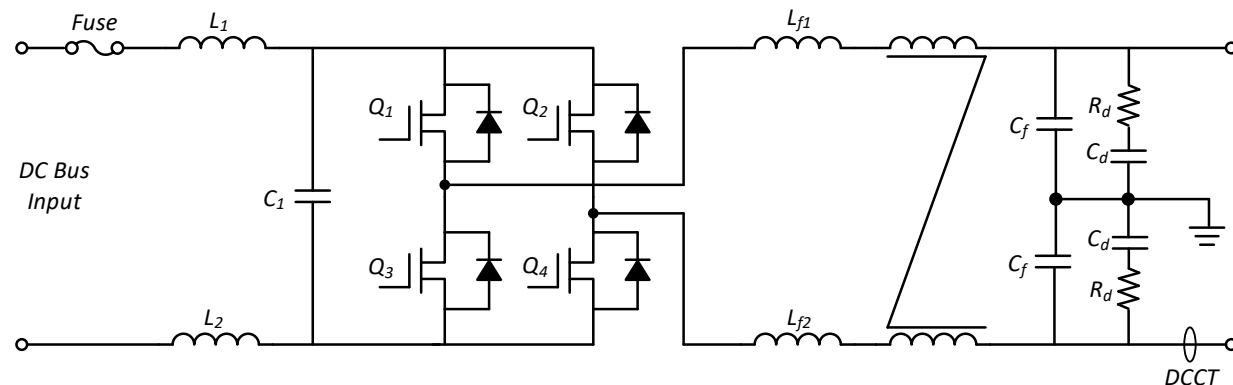
Trim/Fast Bipolar Power Supply System Design

- Trim/**F**ast Bipolar Power Supply System
 - Final Design – Nearly complete

Frequency response with 8-pole magnet, small signal (1%) with 7.5A DC bias



- 40VDC input
- $\pm 15A$ output
- **10 kHz*** bandwidth for up to 1% signal
- Differential analog reference input
- DCCT for current sensing
- 250 kHz PWM with interleaving



* Fast Corrector

L-Bend Dipole Power Supply System Design & Design Maturity

■ L-Bend Dipole Power Supply System

– Power Supplies

- 500 A, 584 kW
- Commercial solution (ex: Danfysik 8500 series)
- Same model for both M1 and M2 magnets

– Stripline Bus

- M1 Existing – Documentation traced
- M2 (new)

– AC power Distribution

Danfysik System 8500, 10 ppm stability

DC Output ratings

Power range	: 80-1,500 kW
Standard current range	: 300-2,000 A
Optional current voltage	: 300-10,000 A
Voltage range	: 0-2,000 V



Power Supply Controllers System Overview

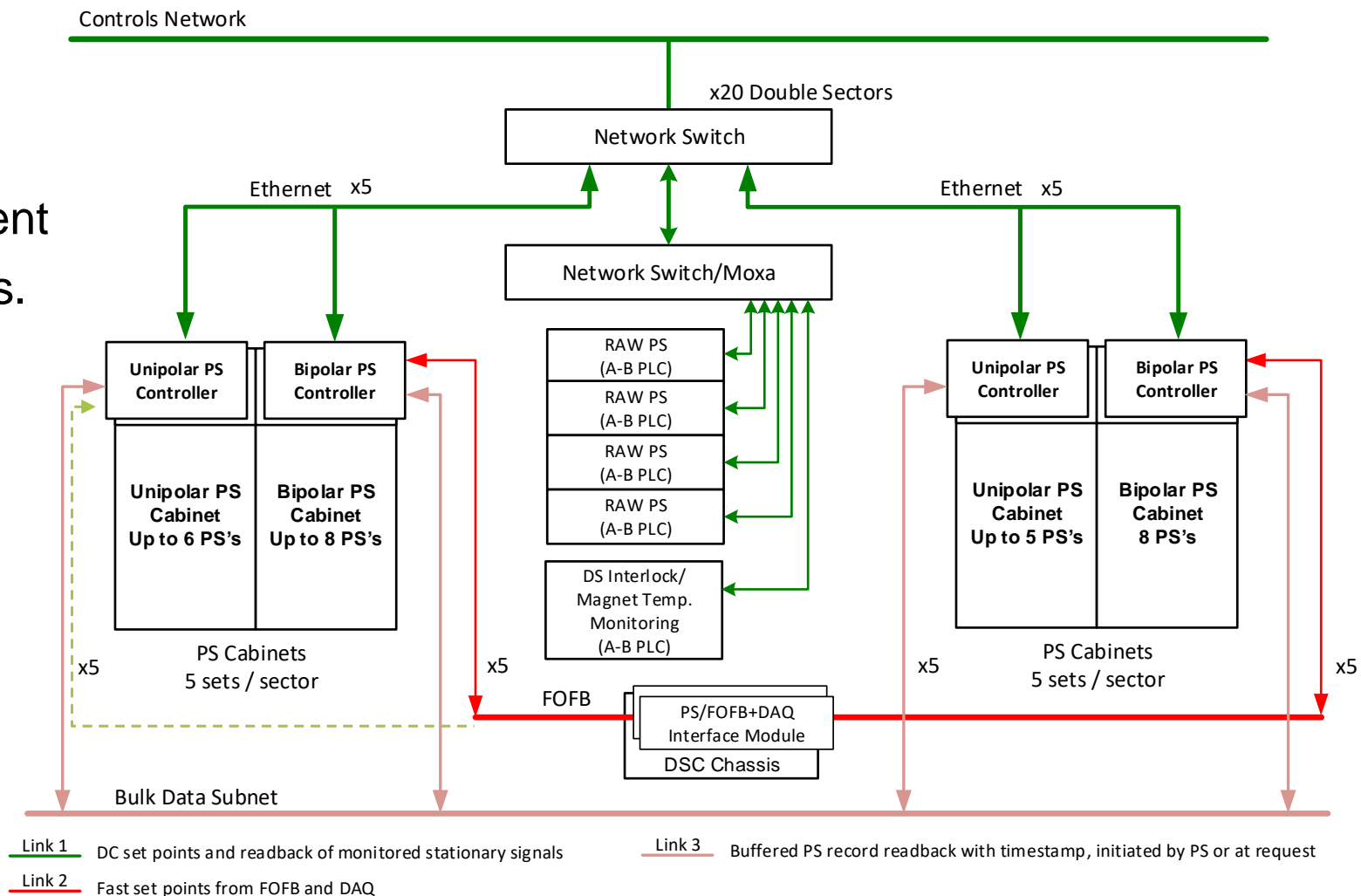
Power Supplies Controllers

Communication Architecture

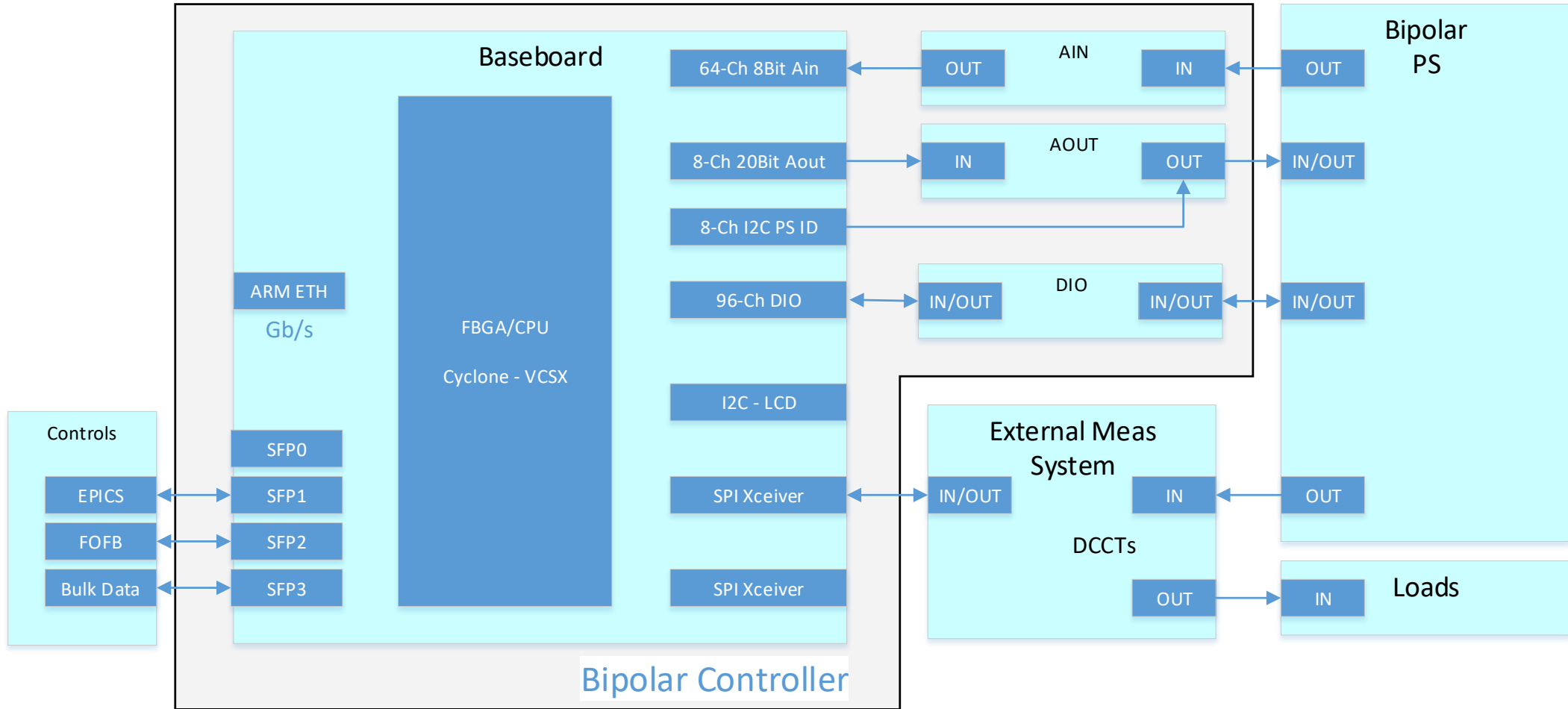
Three links to accommodate different PS control/monitoring requirements.

- Giga Bit Ethernet – EPICS
- SFP – 1 Gb/s – FOFB
- SFP – 1 Gb/s – Raw Data
- External Digital interface
 - SPI – 18 bit ADC @ 22.6 kHz BW
 - Bipolar PS – Analog
 - Unipolar – Ethernet/UDP

* External Monitoring link not shown



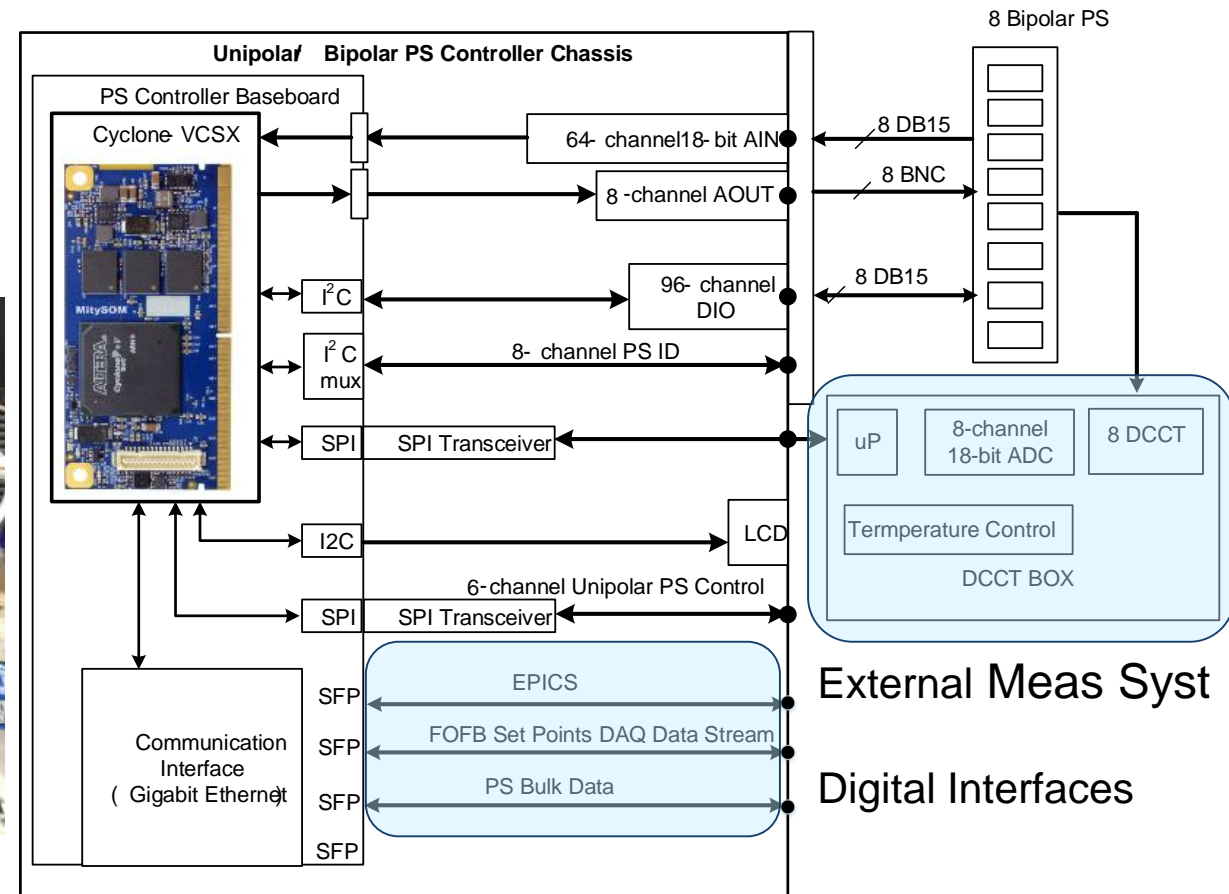
Power Supply Controllers System Bipolar



Bipolar Power Supply Controller System Design

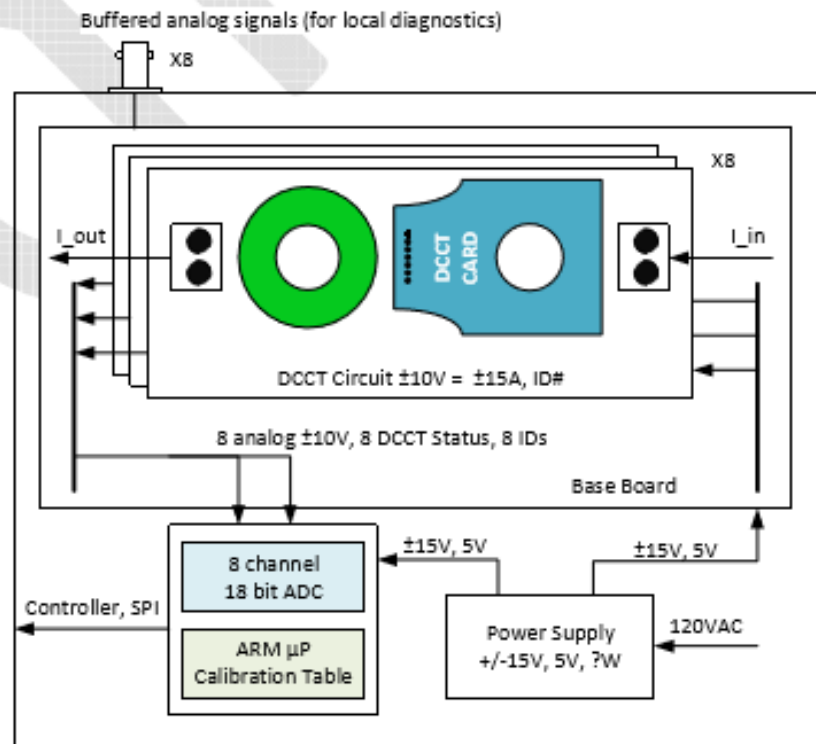
■ Bipolar Power Supply System

- 200 Bipolar power supply controllers
- 22.6 kHz Sample Rate



Bipolar Power External Current Monitoring System Design

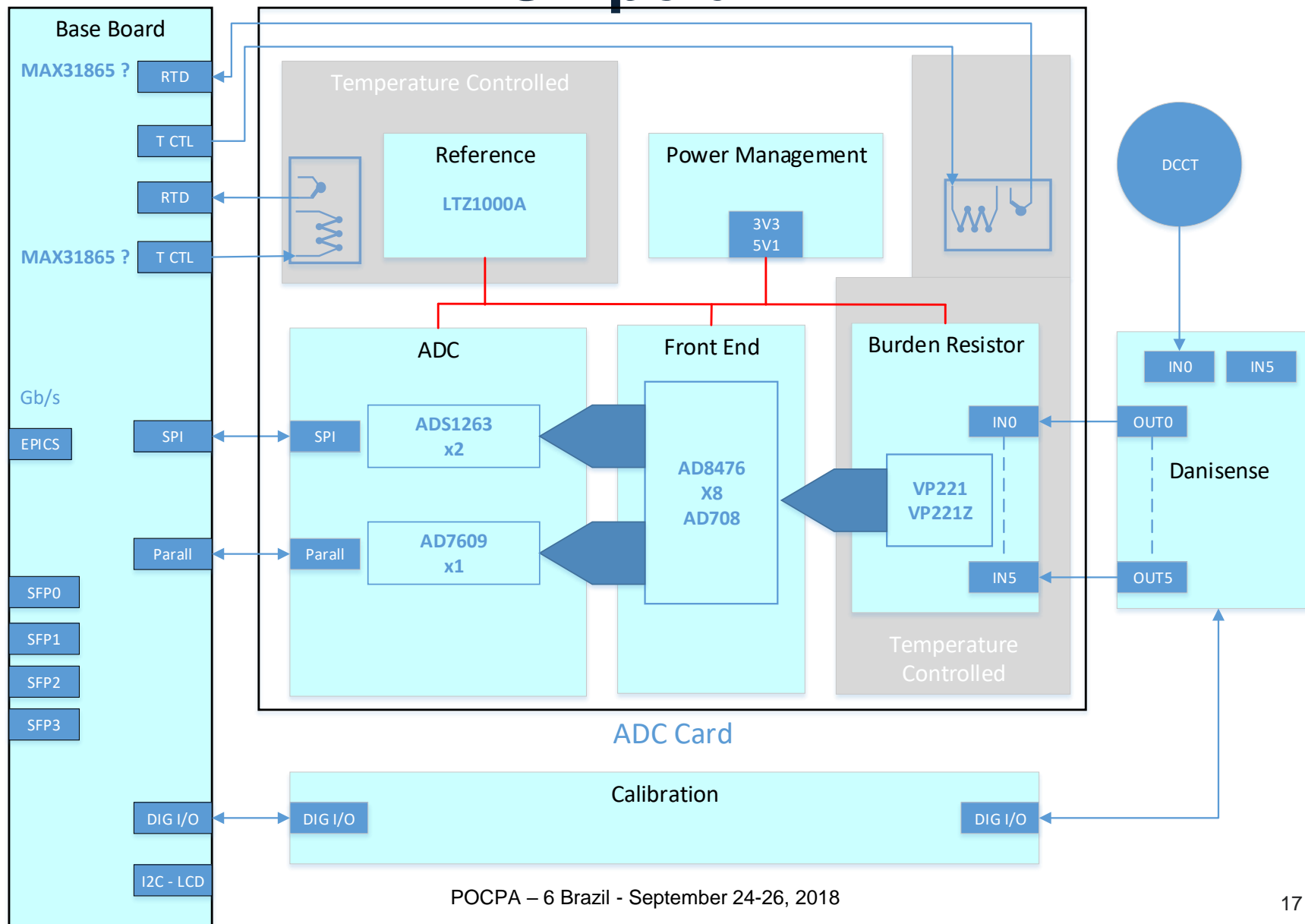
- Bipolar Power External Current Monitoring System
 - 200 units – 1600 channels
 - Preliminary Design - Completed



Digital Link to Controller Tested @ 40 kHz
8 Channels

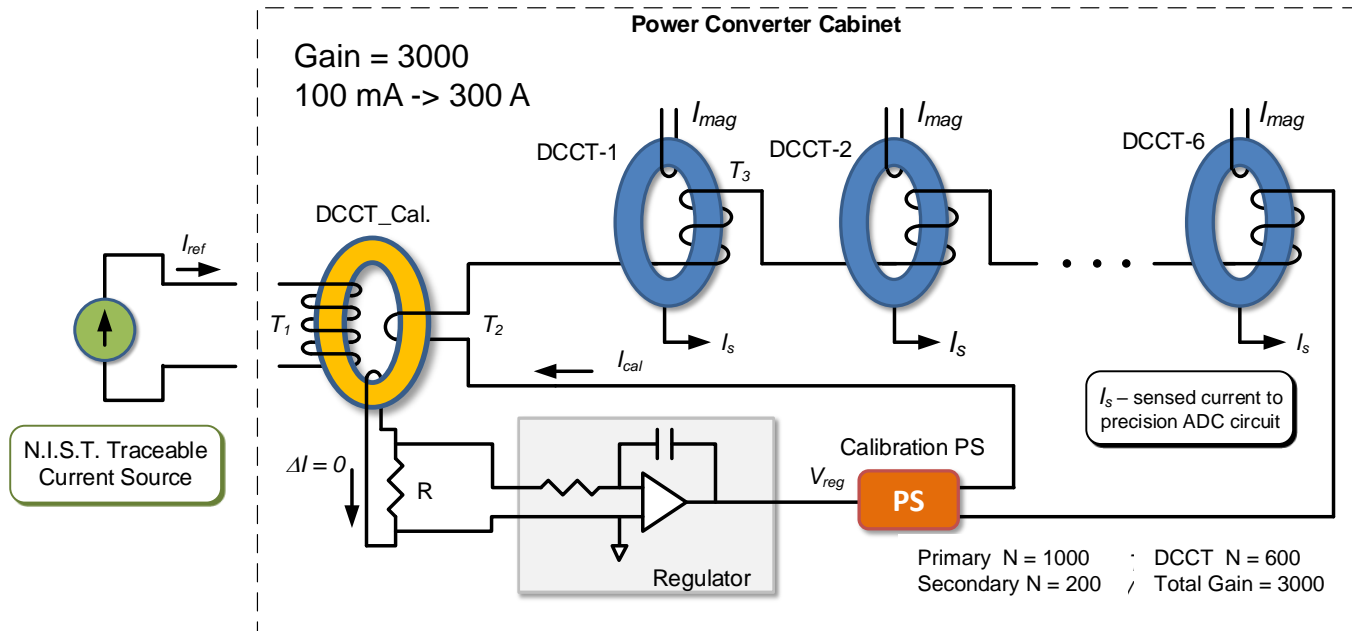
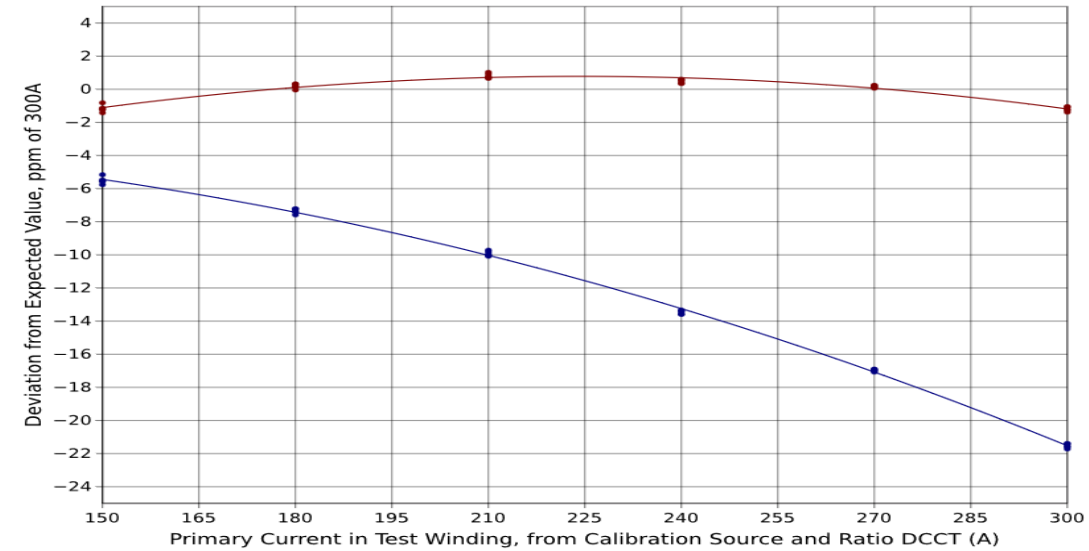


Power Supply Controllers System Unipolar



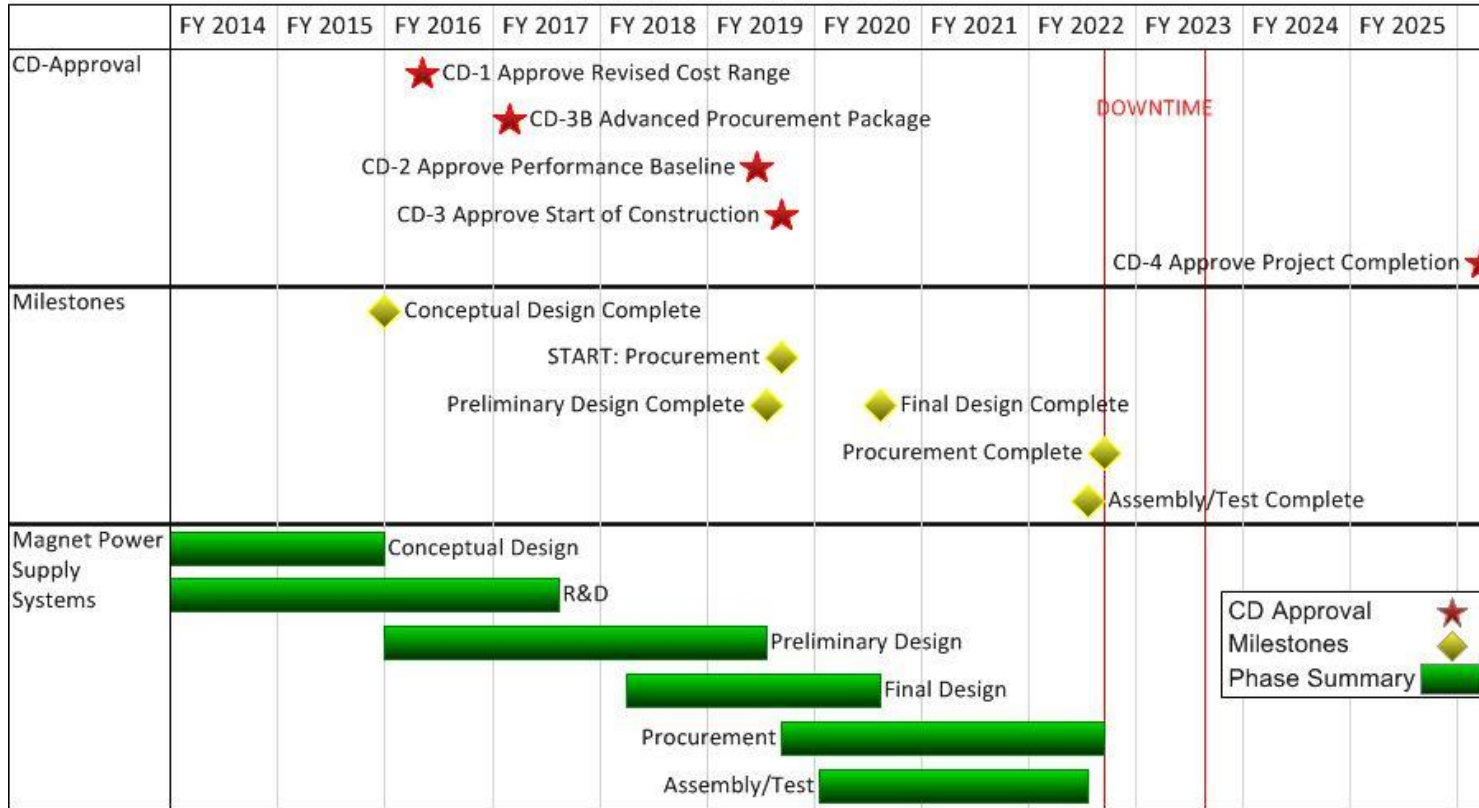
Unipolar Power Supply Controller System Design

- **Unipolar Power Supply Controller System**
 - 200 Unipolar power supply controllers
 - Preliminary Design
- **Unipolar PS External Current Monitoring System**
 - Preliminary Design

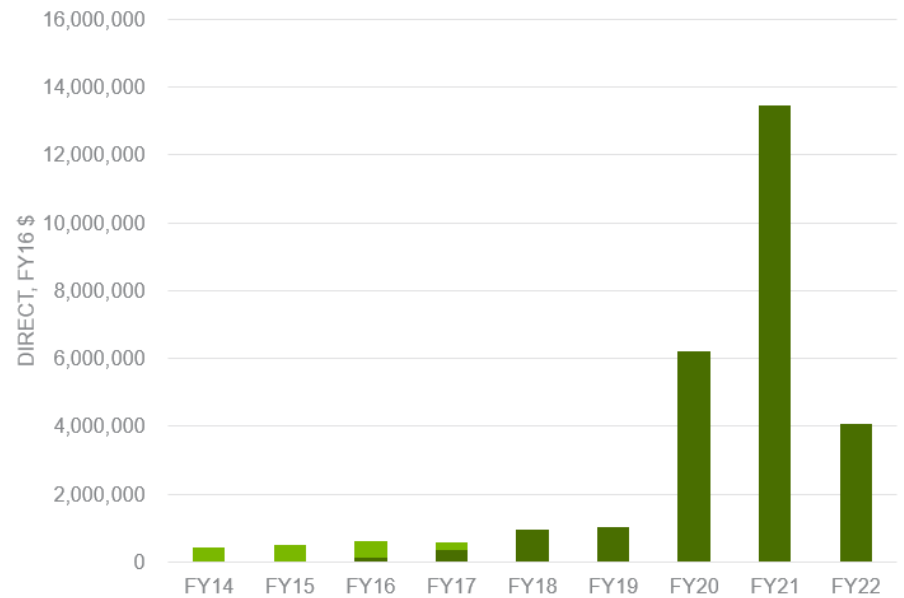


High-level Schedule

Magnet Power Supply Systems



Stripline bus installation supplies



Magnet Power Supply System ES&H

- All electrical equipment comply with Argonne “Electrical Safety Manual”
 - Part I: Electrical Hazards
 - Part II: Electrical Safe Work Practices
 - Appendix D: References for QEW Skill of the Worker Work
- All electrical equipment either NRTL or DEEI.
 - Field Evaluation & Approval Of Unlisted Electrical Equipment
- All electrical worker QEW-II trained

Summary

- **The Magnet Power Supply System has a large number of components:**
 - Two large AC/DC power supplies for L-bend (M1/M2) dipole magnet strings
 - 1000 unipolar 10-ppm stability-class commercial DC/DC power supplies - LLP
 - 921 slow +/-15A bipolar power supplies
 - 322 fast +/-15A bipolar power supplies
 - 200 unipolar power supply controllers – Design ongoing
 - 200 bipolar power supply controllers – Preliminary Design Complete
 - Magnet TC Monitoring System – Design ongoing
- **CD-2 – October 10 -12, 2018 (Performance Baseline)**
- **CD-3 – Spring 2019 (Construction Begins)**

Backup Slides

Magnet Power Supply Systems Total Cost Summary

WBS	WBS Description	FY16\$ Direct	Escalation	Overhead	Total
U2.02.01.02.06	Power Supply R&D	1,666,847	5,481	180,455	2,063,724
U2.03.03.03	Magnet Power Supply Systems	26,226,523	3,455,375	1,254,970	31,421,544
Grand Total		27,893,370	3,460,857	1,435,425	33,485,268

M1 and M2 AC Distribution Design & Design Maturity

02.03.03.03.01 – L-Bend Dipole Power Supply System



480V SWGR
SG-R2

SPARE
CB – R26

M2
CB – R26

SR Dipole PS
CB – R27

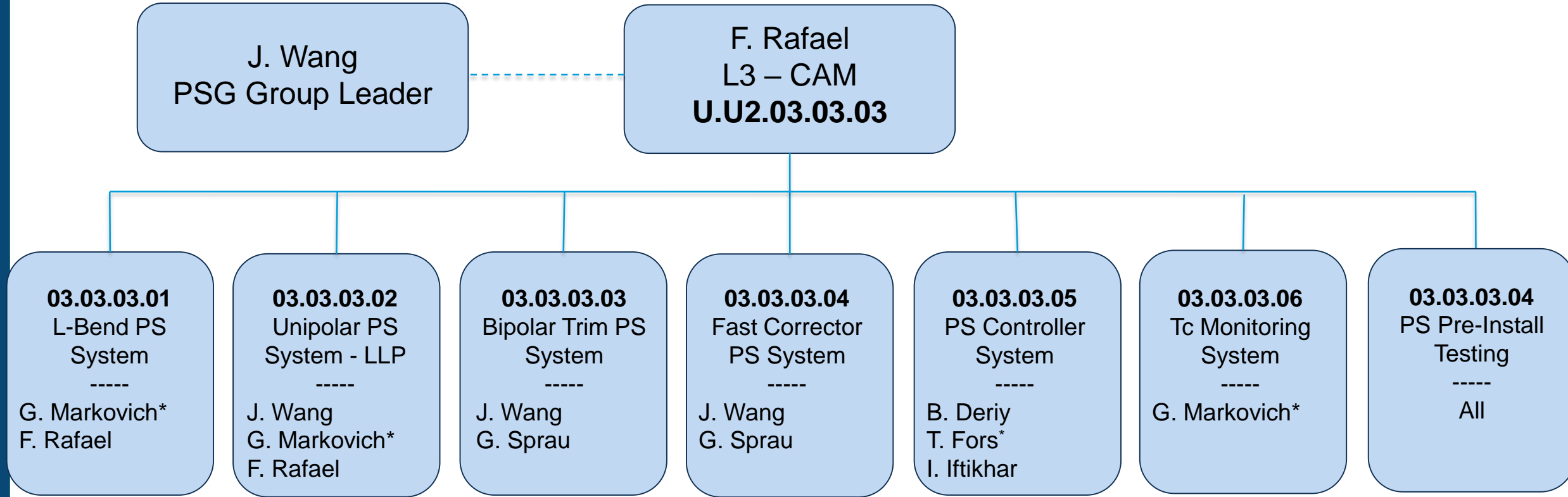
M1
CB – R27

Bipolar Power External Current Monitoring System Design & Design Maturity

- 02.03.03.03.05 – Power Controllers

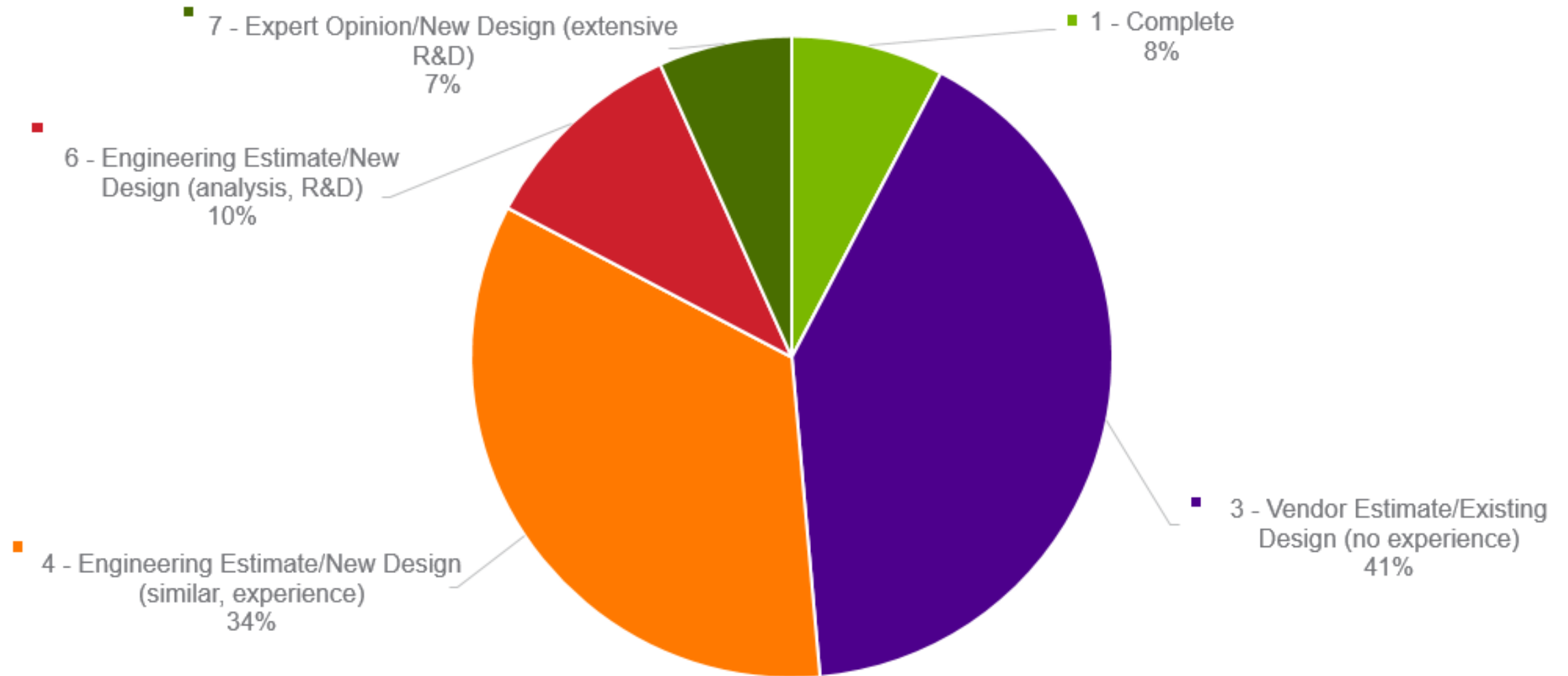


03.03.03 - Magnet Power Supplies Organization



* Not from PSG

Basis of Estimate Category Summary



BOE % based on direct, FY16\$