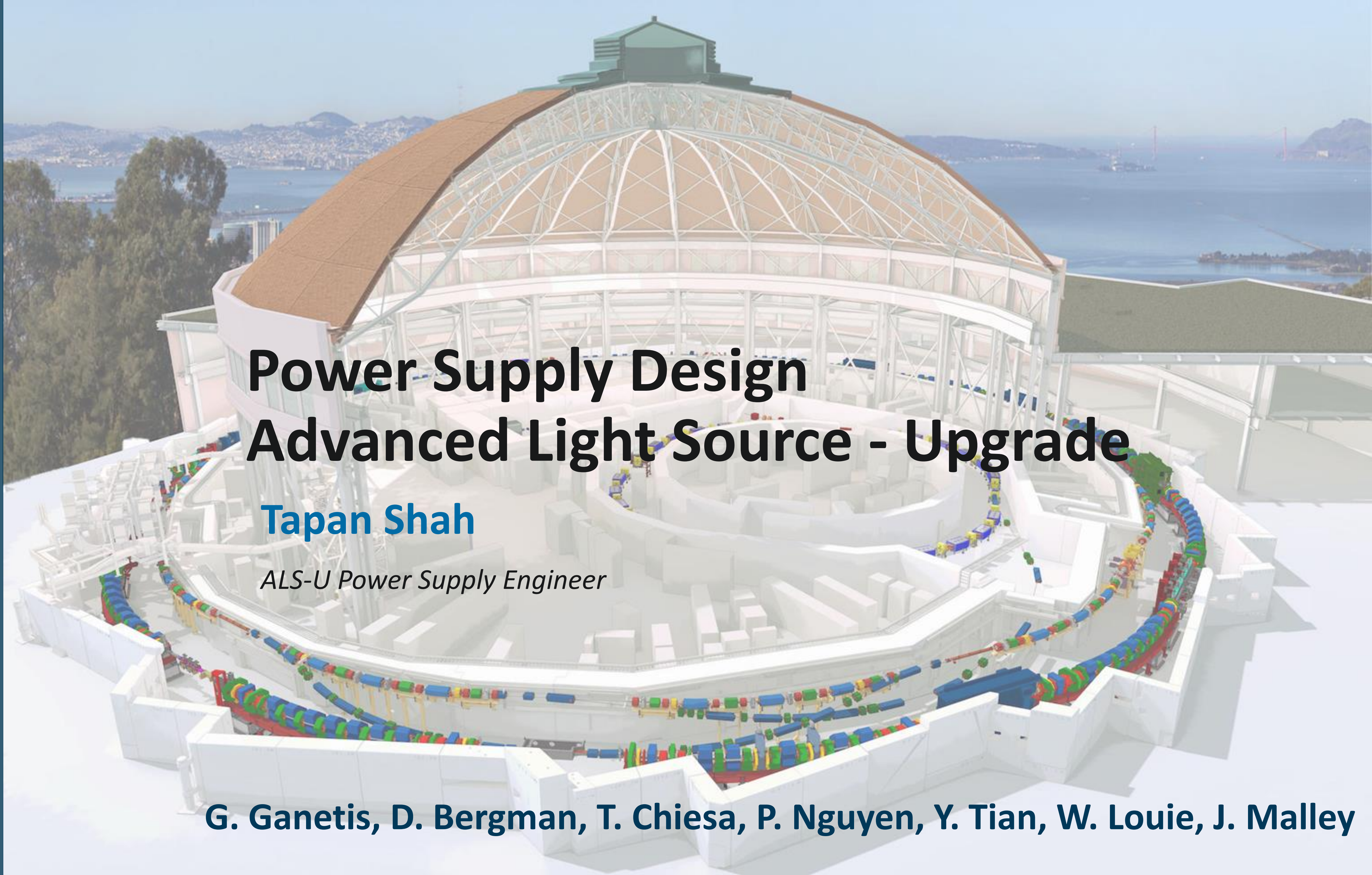

U.S. DEPARTMENT OF ENERGY
Office of Science

BERKELEY LAB

ALS-U
ADVANCED LIGHT SOURCE

Power Supply Design
Advanced Light Source - Upgrade

Tapan Shah

ALS-U Power Supply Engineer

ALS-U Project | 7th POCPA Workshop | June 01 2023

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Outline

- Advanced Light Source
- ALS-U Power Supply Scope
- PS Requirement and Challenges
- Power Supply Design
- Prototype Results
- Build to Print Design/New Development
- Booster Bend Power Supply
- Conclusion

Advanced light Source

Advanced Light Source

- The Advanced Light Source (ALS) is a third-generation synchrotron, a specialized particle accelerator that generates bright beams of x-rays for scientific research.
- The ALS has been a global leader in soft x-ray science for more than two decades.

Parameter	Value
Beam particle	electron
Beam energy	1.9 GeV
Circumference	196.8 m
Beam current	500 mA
Radio frequency	499.642 MHz (±6 kHz)

FACILITY FACTS

1993	~200	950	$65M	5000	40
Year operations began	Total ALS staff	Refereed publications per year	Average operating budget per year	Average number of operating hours per year	Number of beamlines

Advanced light Source - Upgrade

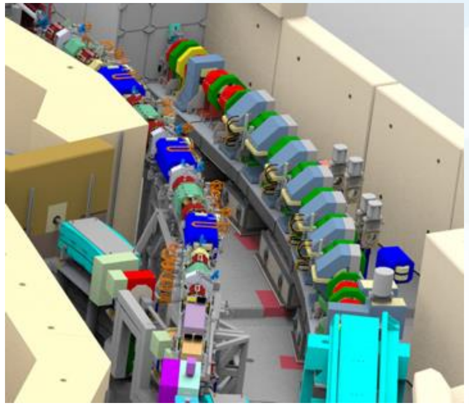
ALS-U Scope

ALS-U is an ongoing upgrade of the Advanced Light Source (ALS) at Berkeley Lab that will endow the ALS with revolutionary x-ray capabilities.

High-level Goals:

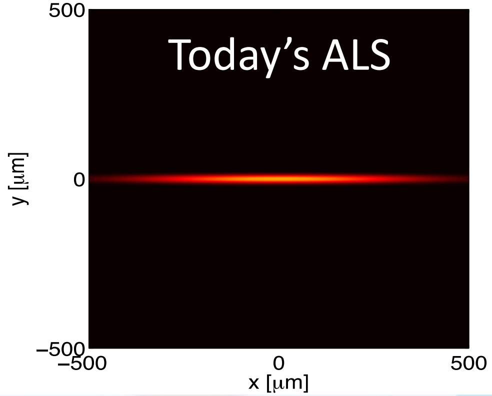
- Achieve an increase in brightness and coherent flux of soft x-rays (@1 keV) of at least 2 orders of magnitude beyond today's ALS capabilities
- Develop a set of experimental capabilities that will enable leadership in soft x-ray science
- Provide infrared and hard x-ray capabilities comparable to present-day ALS

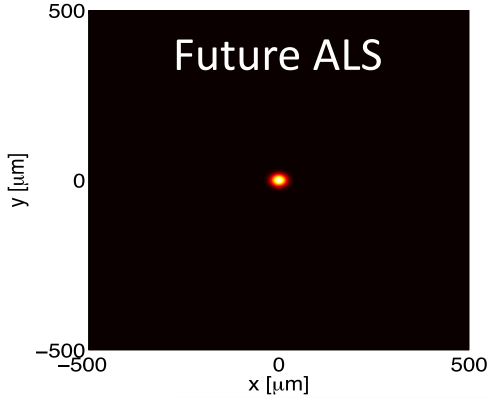
3BA



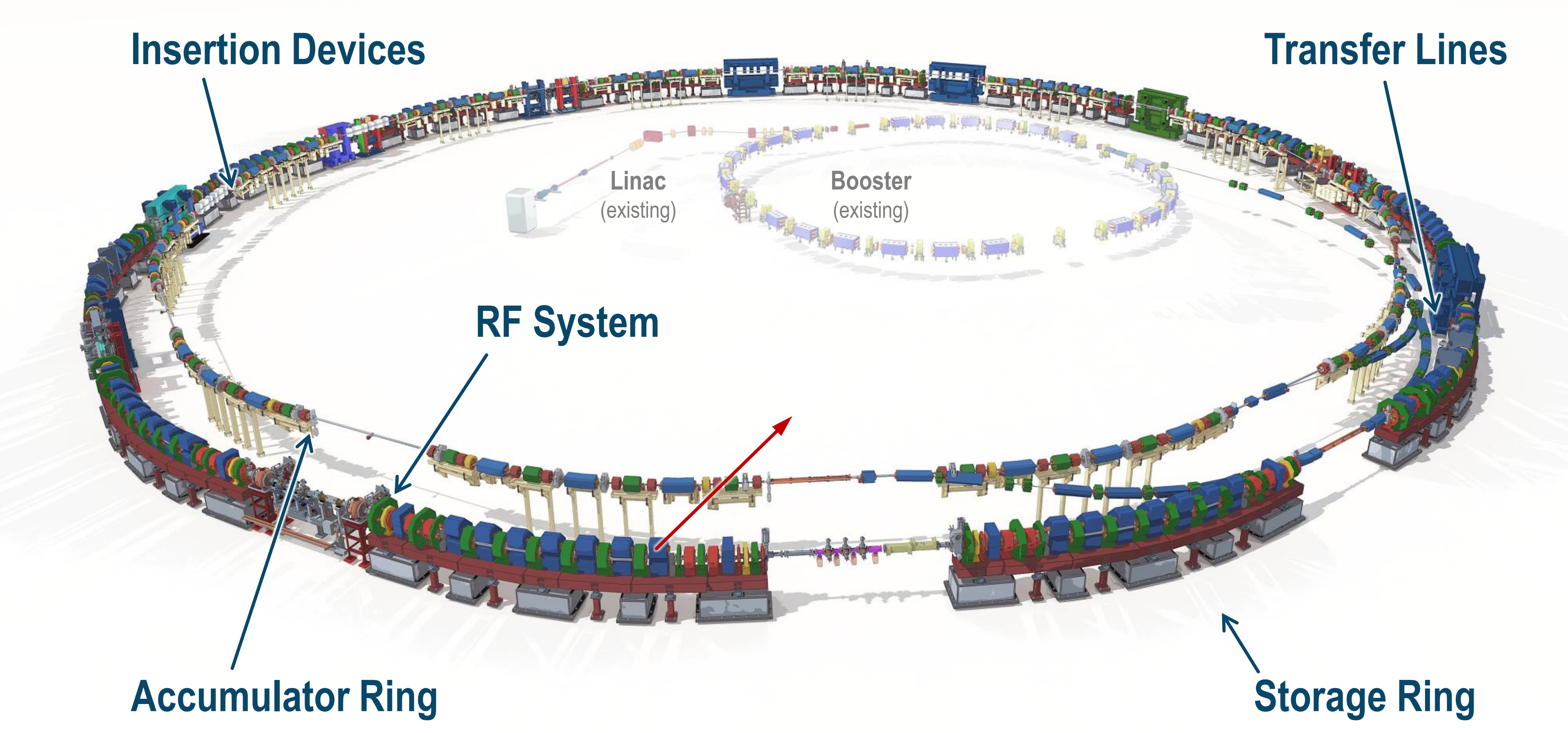
9BA

Electron Beam Profile





ALS-U Scope



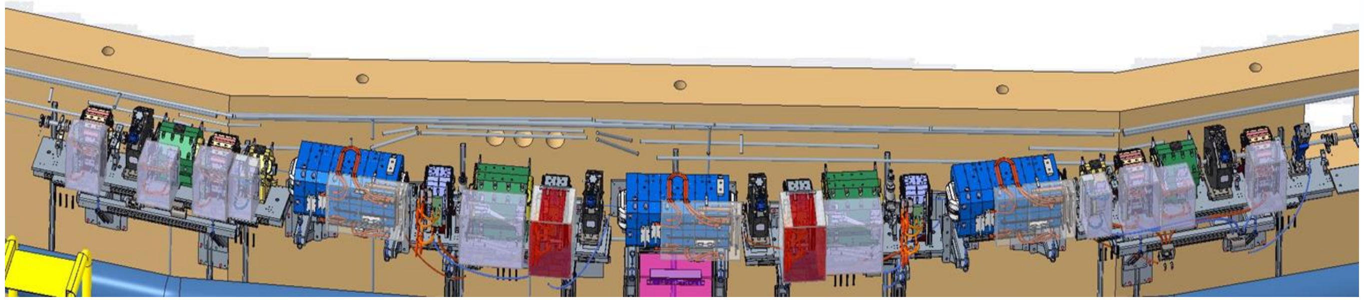
New 2.0 GeV Accumulator Ring for full energy swap-out injection and bunch train recovery

New 2.0 GeV 9BA storage ring in existing cave optimized for low emittance and high soft x-ray brightness and coherent flux

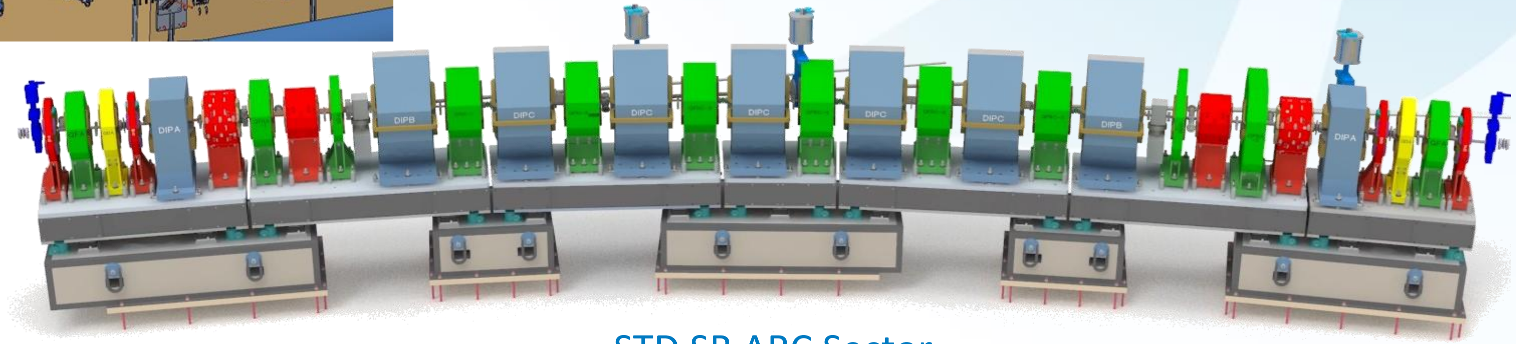
Scope of Power Supply Subsystem

- A total of 250 Power Supplies are required for the Accumulator Ring, 73 power supplies are required for the transfer lines, and 1128 power supplies are required for the storage ring.

- The power supply scope of ALS-U also encompasses the replacement of the existing ALS booster bend power supply with a new one, aiming to achieve a beam energy of 2.0 GeV for the ALS-U project.



AR Sector



STD SR ARC Sector

PS Requirements and Challenges

Requirements and Challenges

The upgraded ALS will occupy the same facility as the current ALS & use the existing ALS infrastructure. Space is the biggest Challenge. → Compact power supply Designs

The ALS-U power supply requirements vary based on output current of magnet, stability, circuit configuration, operating quadrant, resolution, and bandwidth. → Modular and Multi Channel Designs

More than two-thirds of the power supplies in the ALS-U are bipolar power supplies, and the current requirements range from 10 to 200 A along with FOFB requirement. → New Bipolar Power Supply Development

The power supply design should be compact and still serviceable, Cable entry and exit from the rack should be designed with the consideration of cable bend radius and equipment maintenance inside the rack. → Easy Assembly, Installation, and Serviceability incorporate into design

The power supply design should be such that it remains operational for the next 30 years with minimal maintenance.

BNL – LBNL Team for ALS-U Power Supply

- The ALS-U project established agreement with BNL in mid 2019 for ALS-U power supply design and procurements.
- The LBNL ALS-U and BNL NSLS-II teams are working together to deliver ALS-U Power Supply Scope as defined.
- The NSLS-II team has more that 10 years of experience of NSLS-II experience and the team successfully designed, procured, installed, and commissioned over $25M of scope for NSLS-II.
- The majority of design work is performed by the BNL team by leveraging of NSLS-II design whereas design involvement, procurement, assembly, testing, and final installation will be performed by the LBNL team with BNL team support.

Engineering Team and Key Expertise

George Ganetis – Team Lead

David Bergman –BPC & DCCT development and testing

Wing Louie –PSC digital hardware

Tapan Shah –Bipolar corrector & high current PS designs^

Yuke Tian –Programmer- FPGA & EPICS software integration.

Thomas Chiesa - FPGA firmware

Patrick Nguyen – Engineering Support

Note : ^ @ LBNL

Designer Team and Key Expertise

Jerry Malley – head of design group – manufacturer liaison/procurements

Scott Orban – Mechanical Design

Marc Pfeffer – Lead PCB Design

Steve Jarzabkowski – BNL, Electrical design

Lars Hugye - ALS-U Power supply Coordinator^

Billy Pham- ALS-U Power supply Coordinator^

Akira Comia- ALS-U Power supply Coordinator^

Technicians

Jason De Ponte - ALS-U Technicians Lead**^ + 3 Technician working for ALS-U Project**

Joe Gormley – Lead Tech – Surface mount specialist

Steve Devery – BNL, Assembly, testing

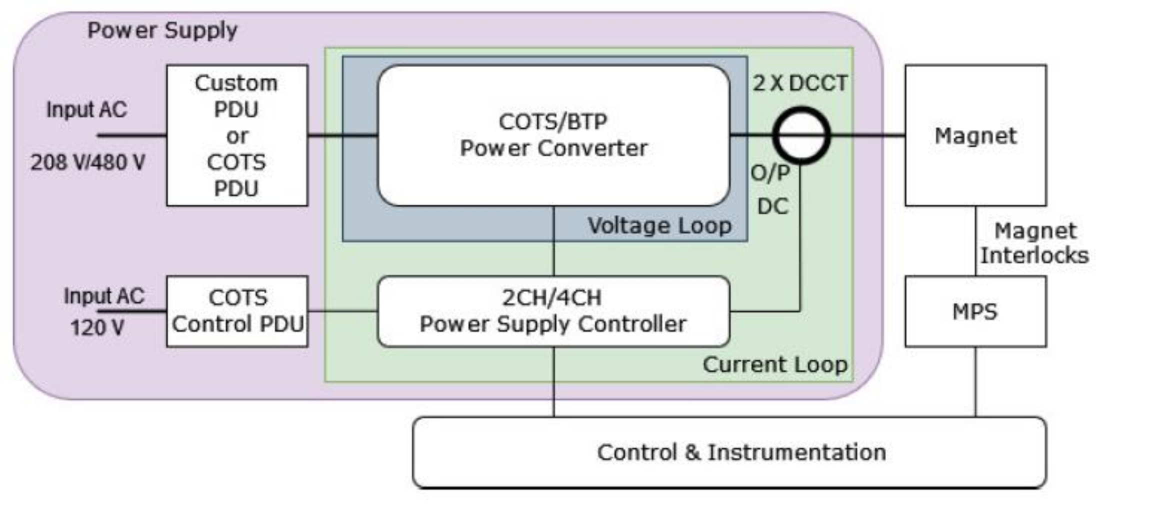
Richard Lyon – Assembly and Testing

Power Supply Design

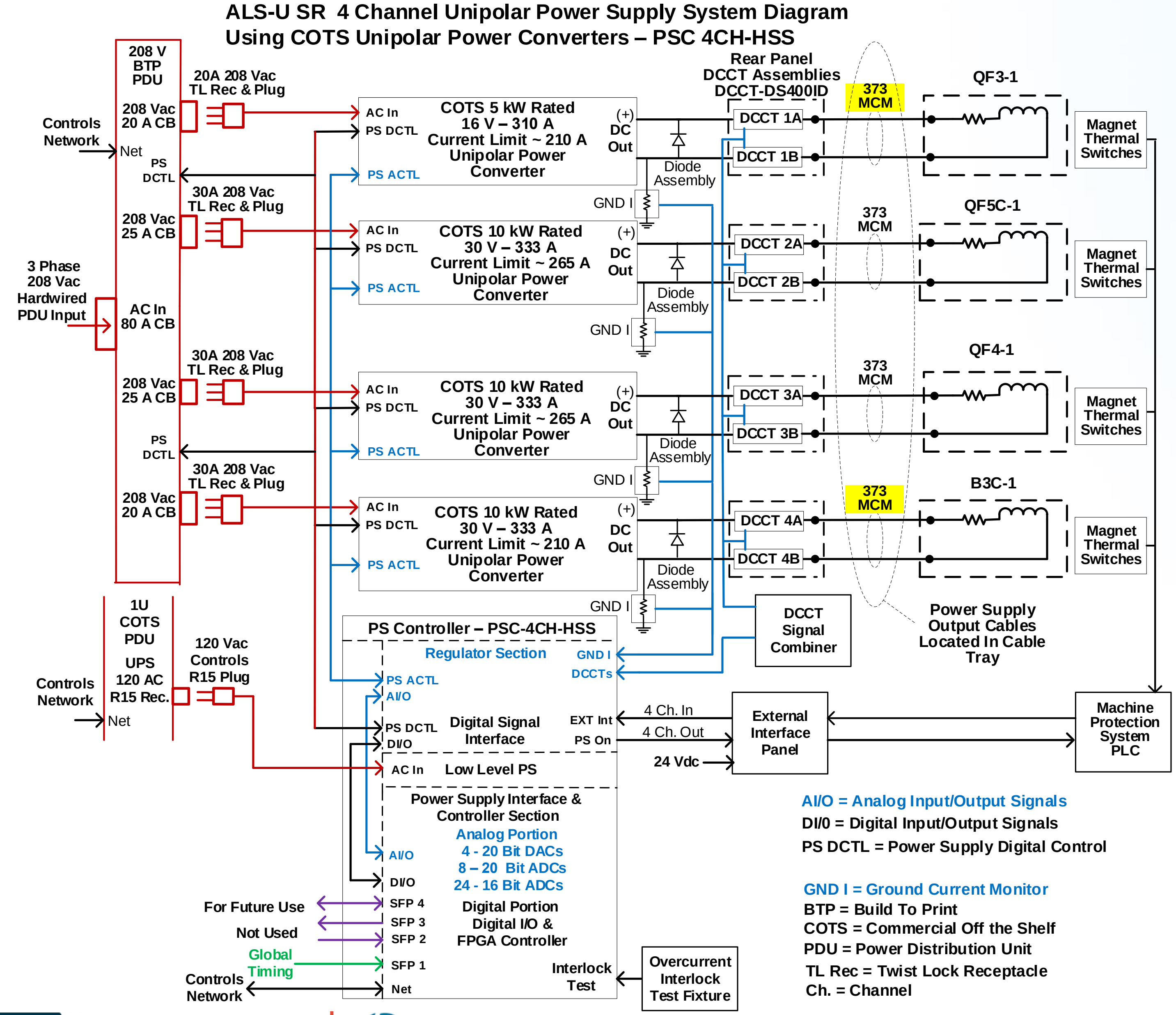
Power Supply Design to Overcome Design Challenges

- The commercial off-the-shelf (COTS) or custom build-to-print (BTP) power converter is typically switching at very high frequency to achieve high output bandwidth. The power converter will be operating in a voltage regulation mode, and external power-supply controllers (PSCs) and direct-current current transformers (DCCTs) will be doing the current regulation function for the overall power supply.

- The PSC provides the communication interfaces between the power supplies and the control and instrumentation network.
- The power converters are selected based on output current, stability, circuit configuration, operating quadrant, resolution, and bandwidth to meet magnet and physics requirements.
- The design is focused on the stability and reliability of power supplies.
- The design incorporates a large amount of monitoring instrumentation that is beneficial for the initial commissioning of power supplies as well as for the remote diagnostics during operations.

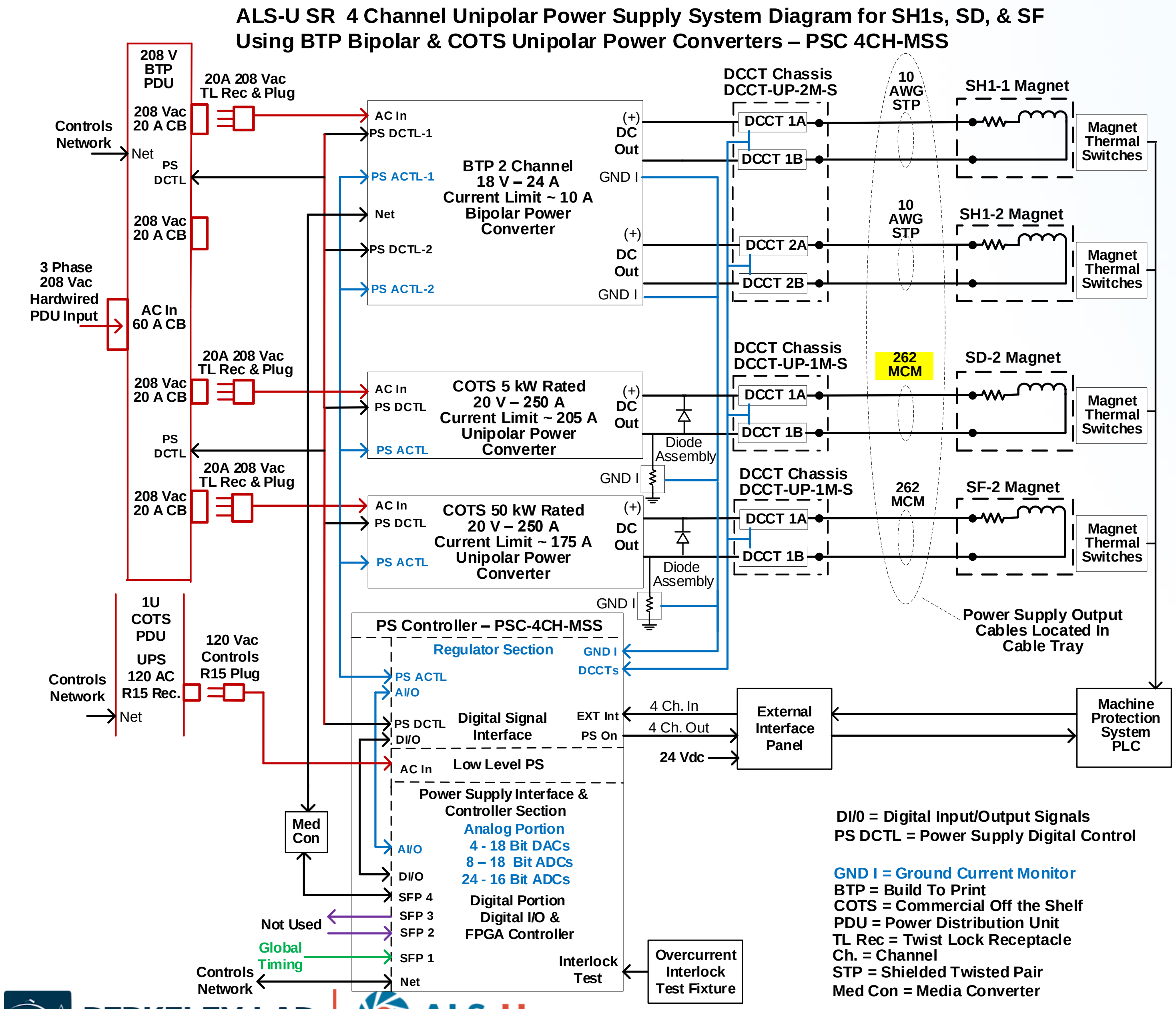


SR Dipole & Quad - Unipolar Power Supplies



- The systems uses Commercial Off The Shelf (COTS) programable power supplies, Build to Print (BTP) 4 channel PS Controllers, COTS DCCTs. , COTS and BTP PDUs
- This configuration will be used for high stability 10 ppm power supplies. (SR Dipole and Quad PS)
- The design is very efficient in the use of rack space.
- PS controller has built-in diagnostic functions. (PS I1, PS I2, PS V, GND I, Error, DAC, & Reg Out)
- Controls System Interface - Network & Global Timing
- MPS PLC Interface - External Interface – has MPS interlock & PS On status.

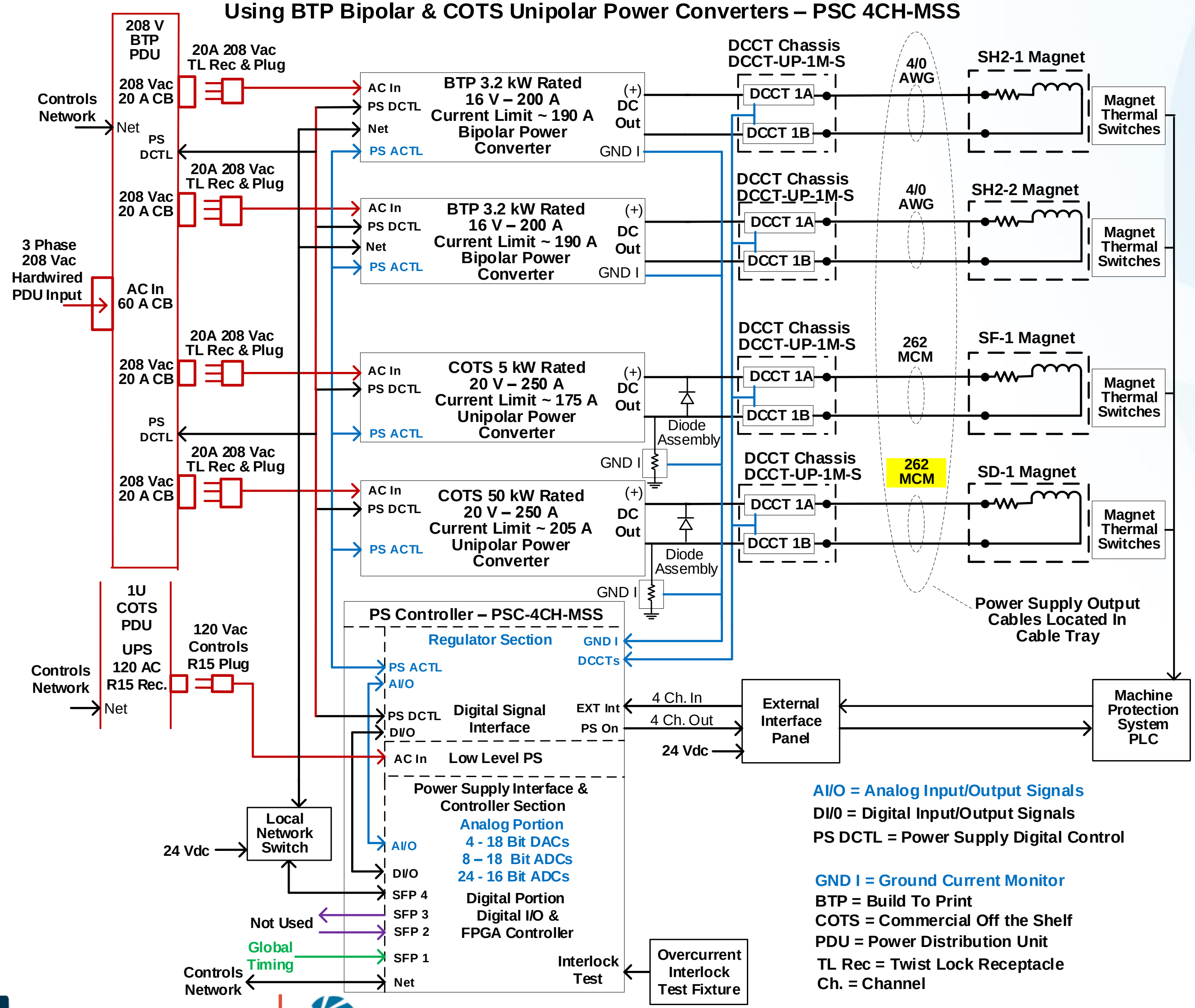
SR Sextupole –Bipolar and Unipolar Power Supplies



- The configuration uses COTS unipolar power converters and BTP 2 channel power converters, 4 channel PS Controllers COTS DCCTs in a DCCT Chassis, and a BTP PDU.
- This configuration will be used for medium stability 100 ppm power supplies. (SR Sextupoles)
- BTP power converters has provisions to communicate to the power supply controller through a media converter.

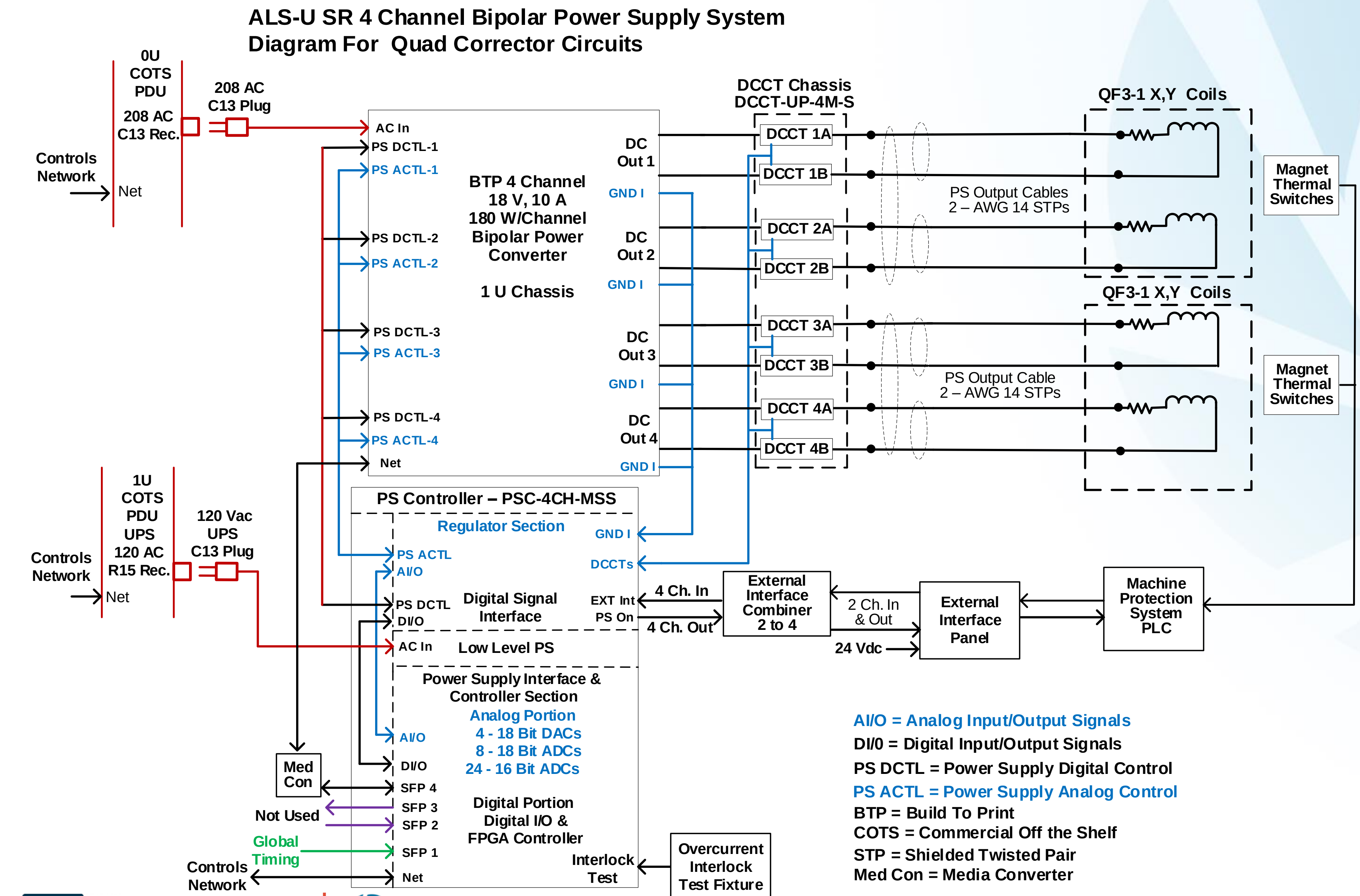
SR Sextupole –Bipolar and Unipolar Power Supplies

ALS-U SR 4 Channel Unipolar Power Supply System Diagram for SH2s, SD, & SF
Using BTP Bipolar & COTS Unipolar Power Converters – PSC 4CH-MSS



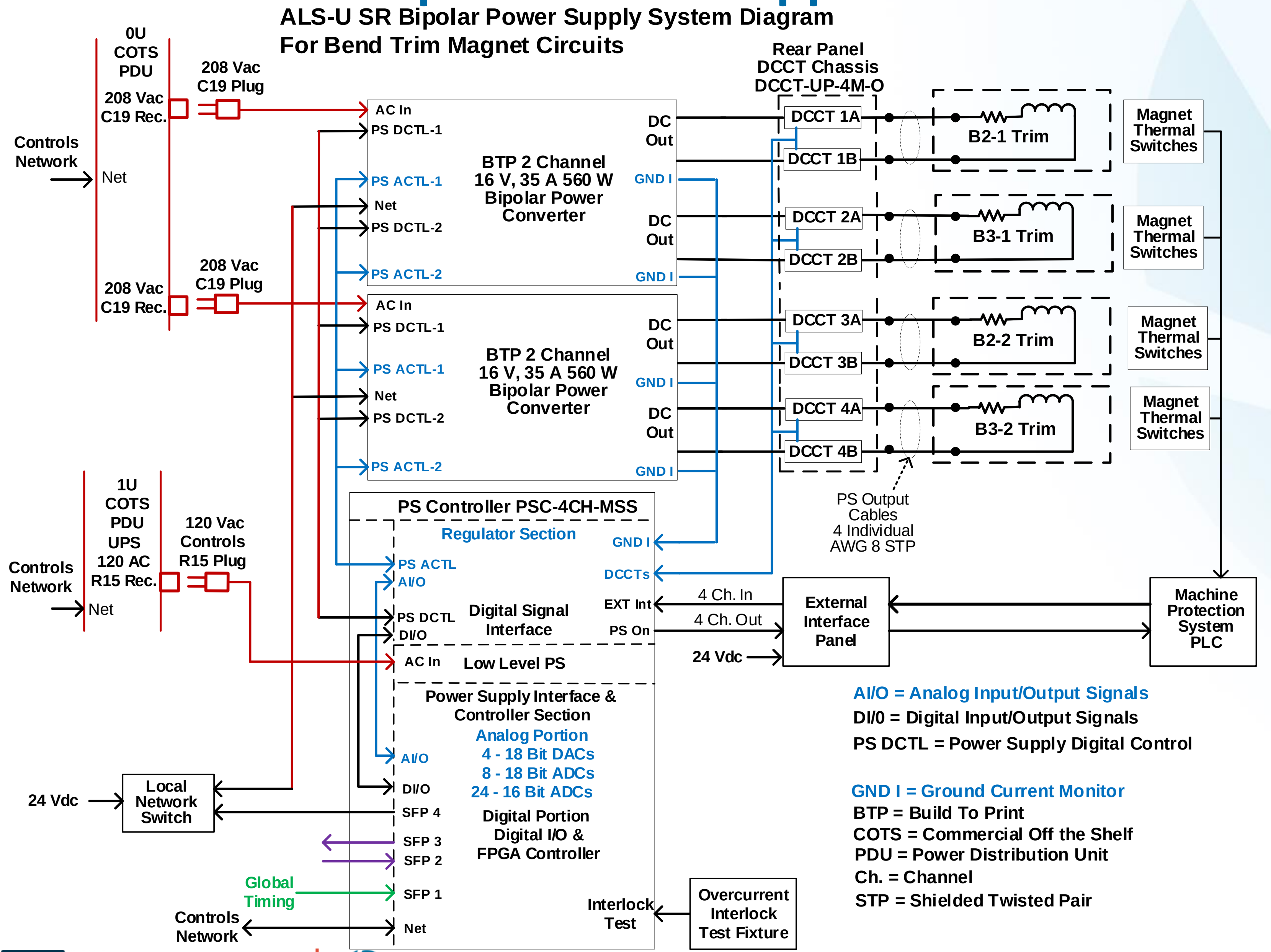
- The configuration uses COTS unipolar power converters and BTP 1 channel high power power converters, 4 channel PS Controllers COTS DCCTs in a DCCT Chassis, and a BTP PDU.
- This configuration will be used for medium stability 100 ppm power supplies. (SR Sextupoles)
- Local network switch is used when there are multiple bipolar power converters that will communicate to the power supply controller.

SR Corrector - Bipolar Power Supplies – 4 Channel Power Converter



- The systems uses BTP 4 channel bipolar power converters, 4 channel PS Controllers, and COTS DCCTs in a BTP Chassis.
- This configuration will be used for high and medium stability 10 to 100 ppm bipolar power supplies.
- The design is very efficient in the use of rack space. (2 U for 4 PS Channels)
- Controls System Interface - Network & Global Timing.
- MPS PLC - External Interface – uses a Combiner to limit the # of channels needed for the MPS system.

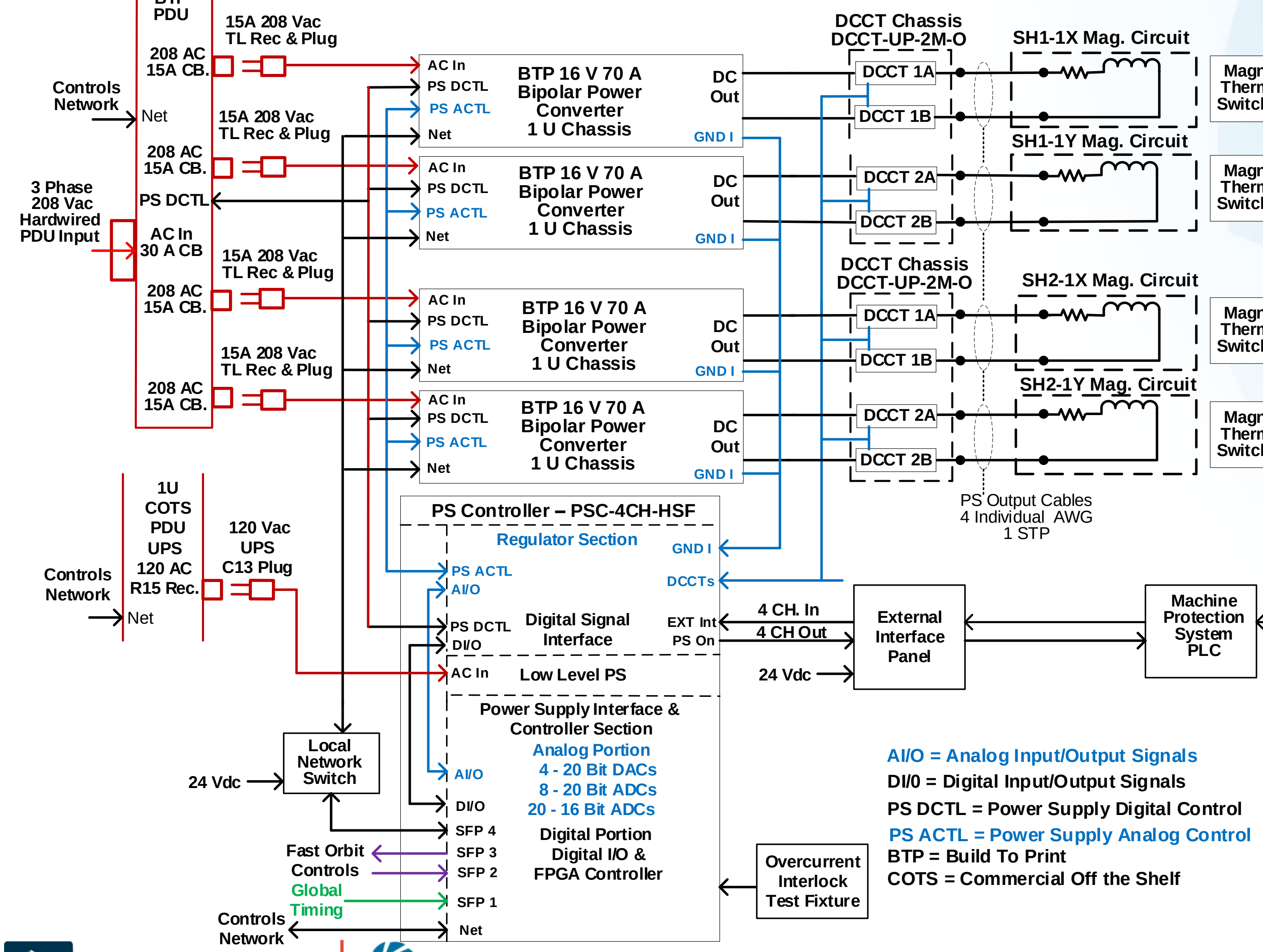
SR Corrector - Bipolar Power Supplies – 2 Channel Power Converters



- The systems uses BTP 2 channel bipolar power converters, 4 channel PS Controllers, and COTS DCCTs in BTP Chassis.
- This configuration will be used for medium stability 10 to 100 ppm bipolar power supplies.
- The design is very efficient in the use of rack space.
- PS controller has built-in diagnostic functions.
- Controls System Interface - Network & Global Timing.
- MPS PLC - External Interface needed for each PS channel.
- This PS will be used for the SR Dipole Trim Coils.

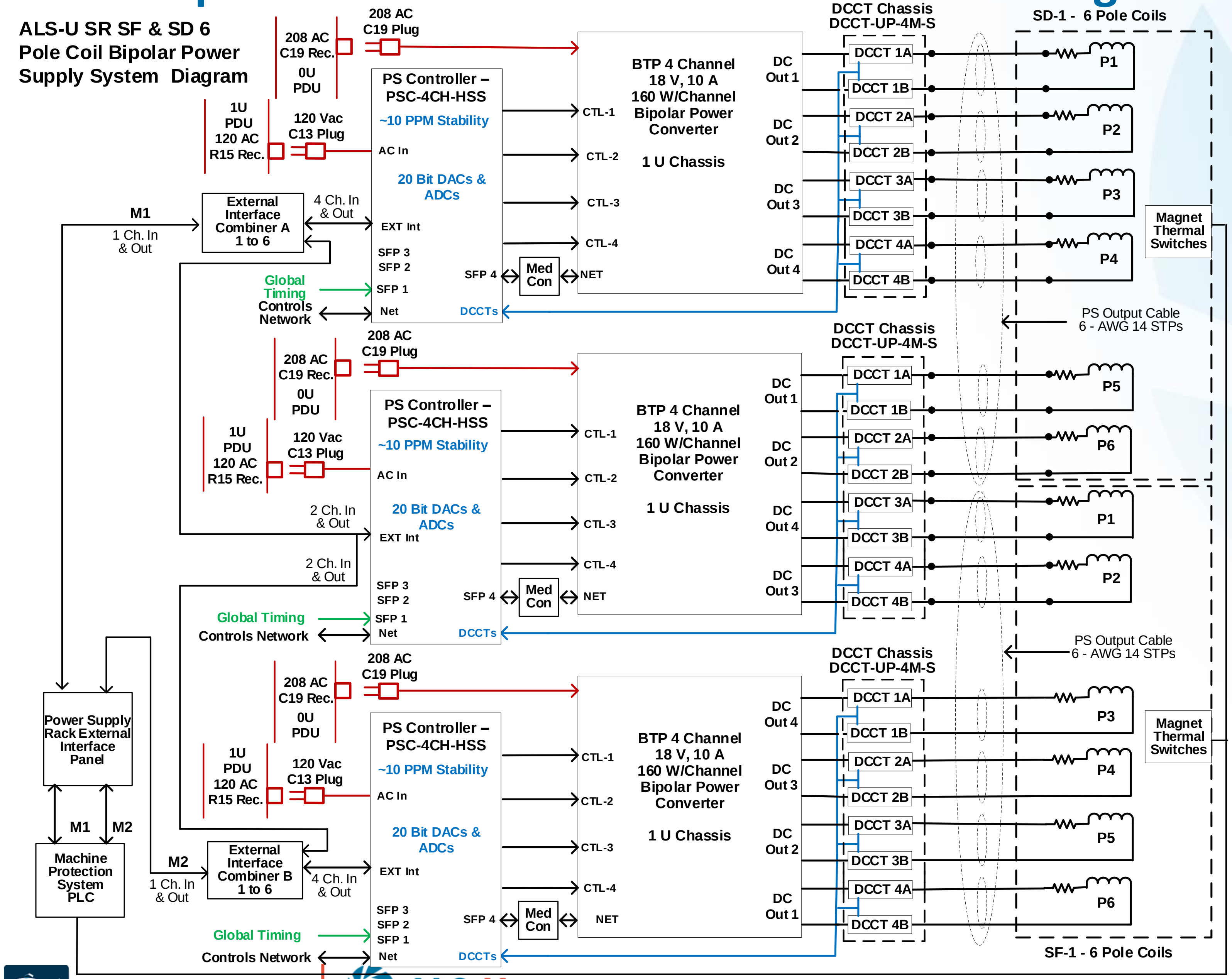
SR Corrector - Bipolar Power Supplies – 1 Channel Power Converters

ALS-U SR 4-Channel Bipolar Power Supply System Diagram for Fast Correctors
Using BTP 16V 70A Current Bipolar Power Converters



- The systems uses BTP 1 channel bipolar power converters, 4 channel PS Controllers, and COTS DCCTs in a BTP DCCT Chassis.
- This configuration will be used for High stability ppm bipolar power supplies.
- This configuration is used for fast corrector sextupole magnet coils .
- Controls System Interface - Network , Global Timing & FOFB system Cell Controller.
- MPS PLC - External Interface needed for each PS channel.

Sextupole Multi-Function Corrector SR PS Configurations



- The configuration uses three BTP bipolar power converters , three 4 channel PS Controllers COTS DCCTs in a DCCT Chassis, and COTS PDUs
- This configuration will be used for high stability 10 ppm power supplies for the 6 pole sextupole multi-function correctors.
- This systems will enable X, Y, Skew and Normal quad corrections. This was doe to minimize the corrector windings space on these sextupole windings.
- The IOC will perform the calculations for each independent channel.
- The use of the event ramp trigger and ramp function of the PSC can be used due simultaneous corrections with beam present.
- The MPS to External interface has only 1 channel per magnet, but it needs to be combined to 6 individual power supply channels. This is done with a 1 to 6 channel External Interface Combiner.

Summary– Accumulator Ring Power Supplies

Power Supply -Model	Qty	Max. Voltage PS	Max Current PS	Configuration	Stability	Operation
AR BEND gradient dipole (String)	1	475 V	400 A	Unipolar Switch-Mode , 2 Cha. PSC & - 2 DCCTs per ps. Custom Power Converter 480 Vac 3ph. Input – Direct Connection	10	DC 1 Quadrant
Quadrupoles - AR QFA (String) - AR QF (Solo) - AR QD (Solo)	 1 24 24	 200 V 12.5 V 12.5 V	 200 A 100 A 50 A	Unipolar Switch-Mode , 2 Cha. PSC & – 2 DCCTs per ps. COTS Power Converters 480 Vac 3 Ph. Input to 4 Cha BTP PDU	10	DC 1 Quadrant
Sextupoles - AR SF & SD (String) - AR SHF & SHD (String)	 2 2	 100 V 100 V	 125 A 60 A	Unipolar Switch-Mode , 4 Cha PSC & - 2 DCCTs per ps. COTS Power Converters 208 Vac 3 Ph Input to Two 2 Cha. BTP PDUs	100	DC 1 Quadrant
Correctors – Slow - AR SF & SD SKQ (Solo) - AR SF X & Y -(By & Bx) (Solo)	 12 48	 16 V	 24 A	Bipolar Switch-Mode , 4 Cha. PSC & - 2 DCCTs per ps. BTP 2 Cha Bipolar Power Converter -Slow 208 Vac 1 Ph. Input to 12 Cha COTS PDU	100	DC Hz to 100 Hz (Slow) 4 Quadrant
Correctors – Fast - AR SHD X & Y -(By & BX) (Solo) - AR SHF X & Y -(By & Bx) (Solo)	 48 48	 16 V	 24 A	Bipolar Switch-Mode , 4 Cha. PSC & - 2 DCCTs per ps. BTP 2 Cha Bipolar Power Converter -Fast 208 Vac 1 Ph. Input to 12 Cha COTS PDU	100	DC Hz to 2000 Hz (Fast) 4 Quadrant
Correctors – QFA Shunt Trim - AR- QFA- ST (Solo)	 4	 16 V	 10 A	Bipolar Switch-Mode , 4 Cha. PSC & - 2 DCCTs per ps. Isolated BTP 4 Cha Bipolar Power Converter –Slow Each PS Multiplexed to 6 QFA magnets 120 Vac 1 Ph Input to 8 Cha COTS PDU	100	DC Hz to 10 Hz (Slow) 4 Quadrant
Correctors – Dipole Trim -AR – T (Solo)	36	16 V	10 A	Bipolar Switch-Mode , 4 Cha. PSC & - 2 DCCTs per ps. BTP 4 Cha Bipolar Power Converter –Slow	100	DC Hz to 10 Hz (Slow) 4 Quadrant

- There are total 250 power supplies require for the Accumulator ring.
- There are 1 rack per sector for AR for Solo power supplies.
-

COTS = Commercial Off The Shelf
BTP = Build To Print
PSC = Power Supply Controller

Summary Table – SR Power Supply Models

Power Supply -Model	Qty	Max. Voltage	Max Current	Configuration	Stability / Resolution ppm of max I	Operation
Dipoles SR-Dipole-A SR- Dipole-B	 24 78	 25 V 25 V	185 A 210 A	Unipolar COTS Power Converter- PSC 4 Chan. HSS	10 1 (20 bit)	5 Hz Bandwidth 1 Quadrant
Quadrupoles SR-Quad-A SR-Quad-B SR-Quad-C SR-Quad-D	 48 48 72 12	 16 V 16 V 25 V 16 V	275 A 210 A 265 A 300 A	Unipolar COTS Power Converter- PSC 4 Chan. HSS “ “ “	10 1 (20 bit)	5 Hz Bandwidth 1 Quadrant
Sextupoles SR-Sext-A SR-Sext-B SR-Sext-C SR-Sext-D	 24 24 24 24	 16 V 16 V 20 V 20 V	10 A 190 A 200 A 210 A	Bipolar 4 Chan. BTP Power Converter – PSC 4 Chan. MSS Bipolar 1 Chan. BTP Power Converter – PSC 4 Chan. MSS Unipolar COTS Power Converter – PSC 4 Chan. MSS Unipolar COTS Power Converter – PSC 4 Chan. MMS	100 3.8 (18 Bit)	5 Hz Bandwidth 2 Quadrant 2 Quadrant 1 Quadrant 1 Quadrant
Correctors – Slow SR- Sext-Cor-SKQ SR- Quad-Cor-A (Bx&By) SR- Quad-Cor-B (Bx&By) SR -Dipole-Cor-A	 48 120 120 78	 16 V 16 V 16 V 14 V	 10 A 10 A 10 A 35 A	Bipolar 4 Chan. BTP Power Converter – PSC 4 Chan. MMS “ “ Bipolar 2 Chan. BTP Power Converter –PSC 4 Chan. MSS	100 3.8 (18 bit)	5 Hz Bandwidth 2 Quadrant
Correctors – Fast SR- Sext-FCor-A (By) SR- Sext-FCor-B (Bx&By)	 24 72	 16 V 16 V	 70 A 70 A	Bipolar 1 Chan. BTP Power Converter – PSC 4 Chan. HSF (Same Configuration different PID tune)	10 1 (20 bit)	3 kHz Bandwidth Limited 4 Quadrant
Corrector - Multi-Function SR-Sext-P	 288	 16 V	 10 A	Bipolar 4 Chan. BTP Power Converter – PSC 4 Chan. HSS	10 1 (20 bit)	5 Hz Bandwidth 2 Quadrant

Very large number of power supplies must fit in a limited number of racks. (6 per Sector)

The power supply designs must be very efficient in the space used and the heat dissipated in each rack.

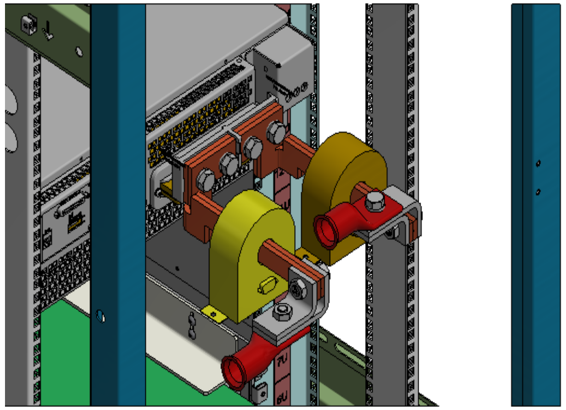
17 ps models cover all 1128 ps needed for the SR.

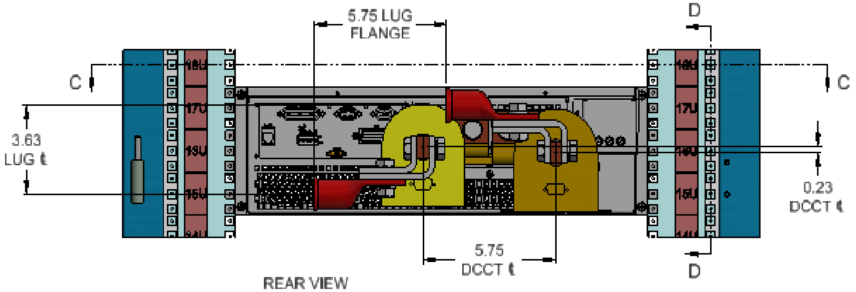
Total # SR Power Supply channels = 1128

COTS = Commercial Off The Shelf
BTP = Build To Print
PSC = Power Supply Controller

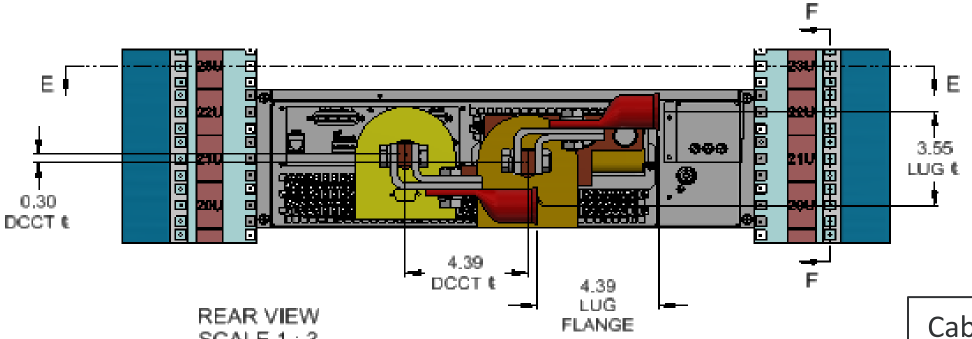
Prototype Results

Power Supply Rack Design





REAR VIEW
SCALE 1 : 3
LESS DCCT PANEL



REAR VIEW
SCALE 1 : 3
LESS DCCT PANEL

Cables exit the racks through ROXTEC seals

3 phase AC enters back of the ROCTEC seals

Hardwired Receptacles

1 U PDU for 120 Vac

4 U BTP PDU for 3 phase 208 Vac

Power Supply Position 1

Power Supply Position 2

Power Supply Position 3

Power Supply Position 4

2 PSC 4 Channels that control all 8 power supply positions

4 U BTP PDU for 3 phase 208 Vac

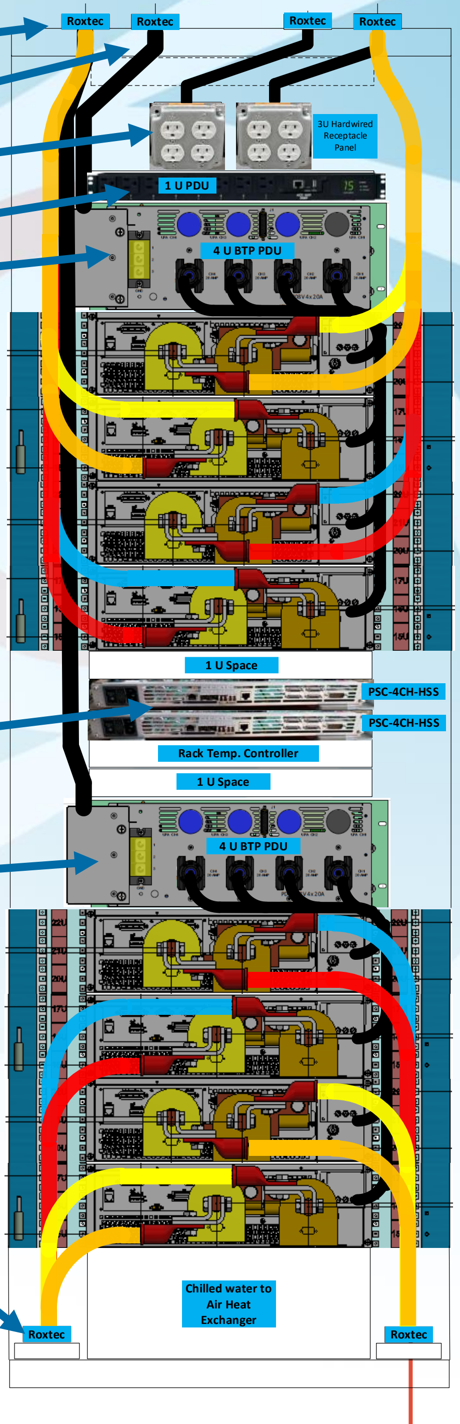
Power Supply Position 5

Power Supply Position 6

Power Supply Position 7

Power Supply Position 8

Cables exit the racks through ROXTEC seals

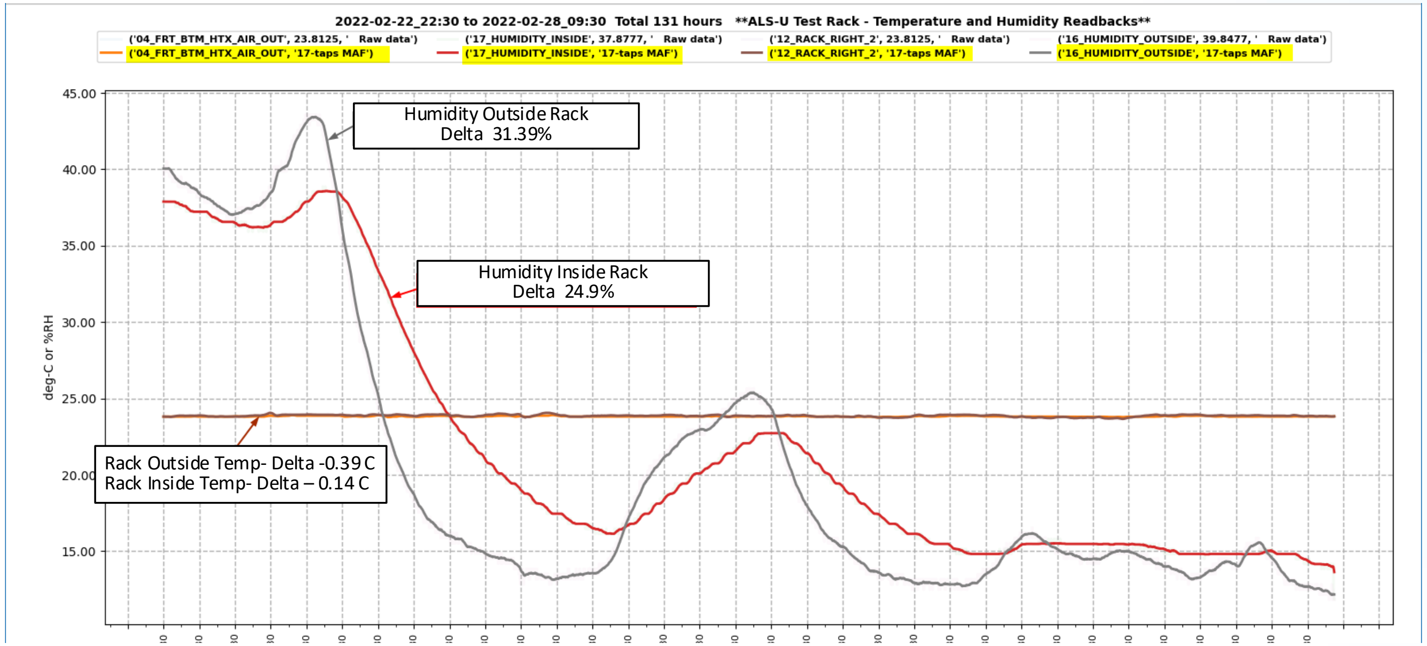


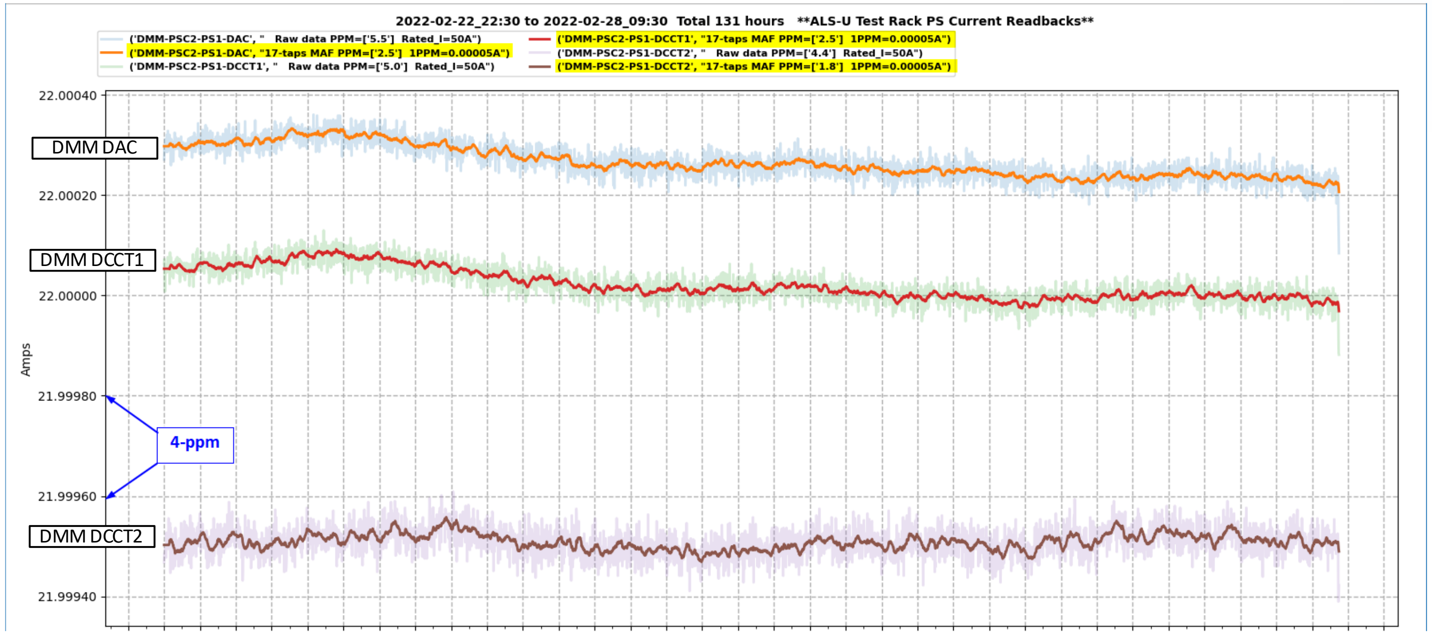
ALS-U PS Prototype Rack

Rack Front

- Test Rack is similar to an AR sector rack (the an old NSLS II Rack is used for testing)
- Rack Hardware and Cable Integration
- Power Supply Performance Testing – Stability and FOFB Plots
- 1-wire Temperature and humidity sensors are used to measure internal and external locations throughout the rack.
- EPICS was used to do most of the testing with CSS and Python.

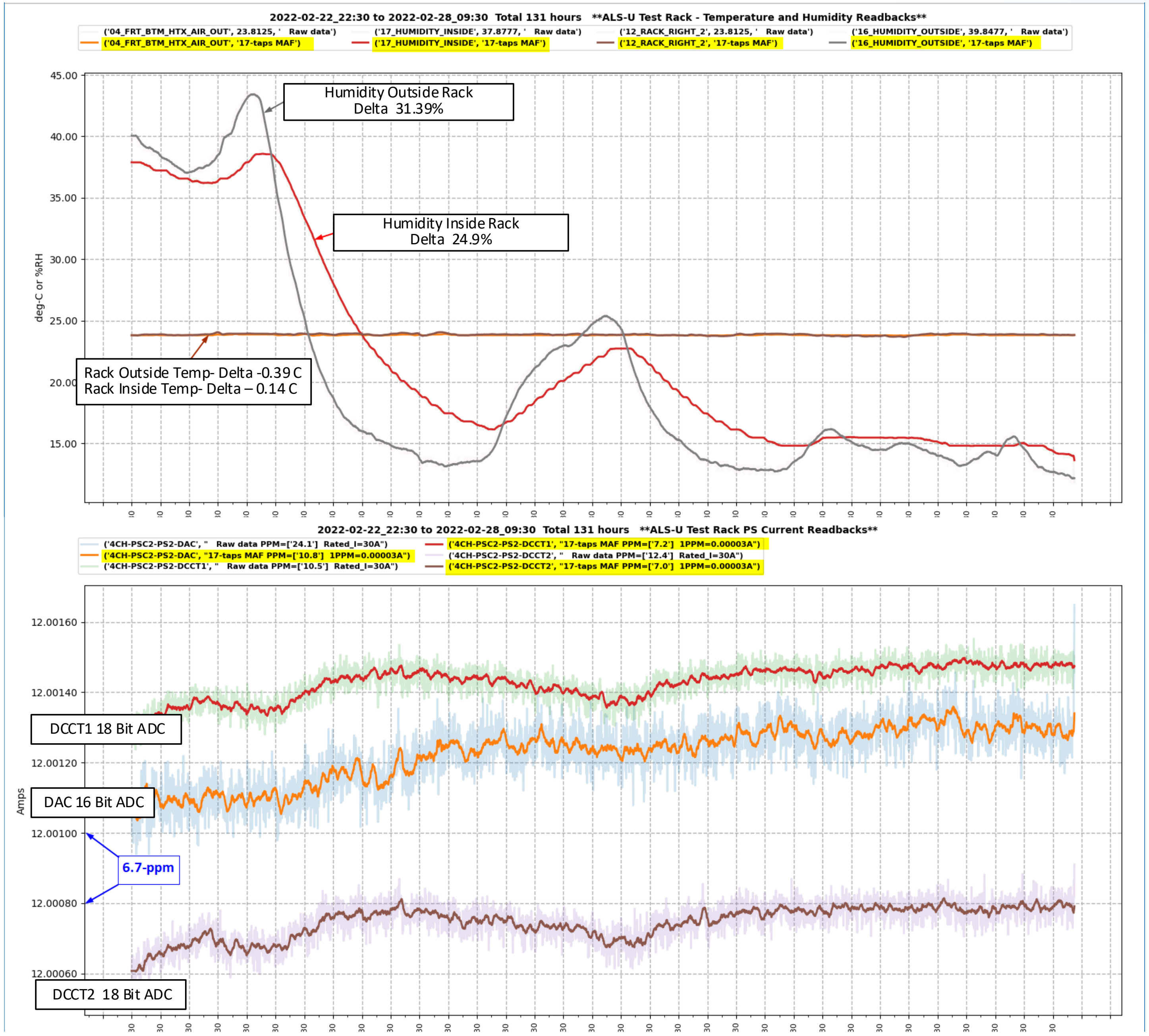
Rack Rear





Performance using Analog Current Loop Design on COTS Power Converters in the ALS-U Power Supply Test Rack

- The length of the testing was 5.4 Days
- The top plot shows the Humidity & Temperature inside and outside of the rack.
- The inside rack temp.is stable to ± 0.25 C .
- The inside humidity varies by ~ 25%
- We see that the humidity affect on the stability of the electronic has been reduce with the addition of ceramic case voltage references.
- This data shown is for the 2 Channel PSC which has a 10 ppm stability requirement.
- These measurements are taken with less then ideal conditions with modified circuit boards .

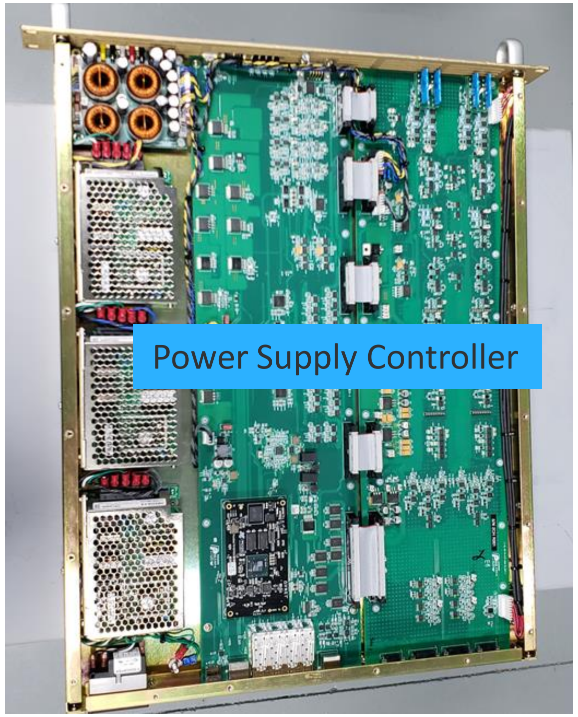


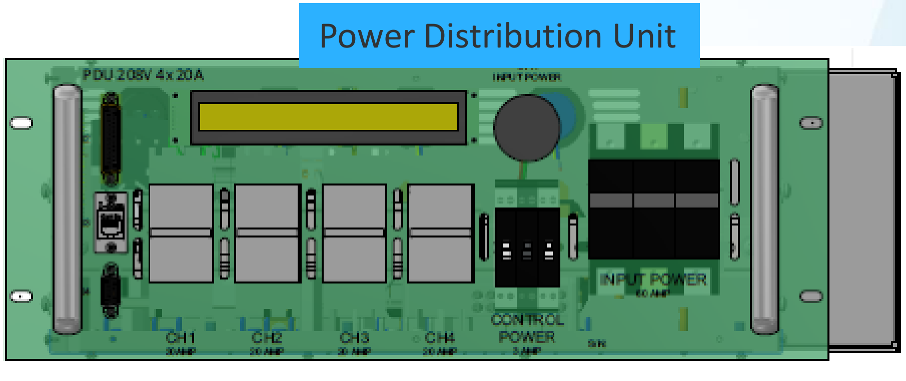
Performance using Analog Current Loop Design on BTP Bipolar Power Converters

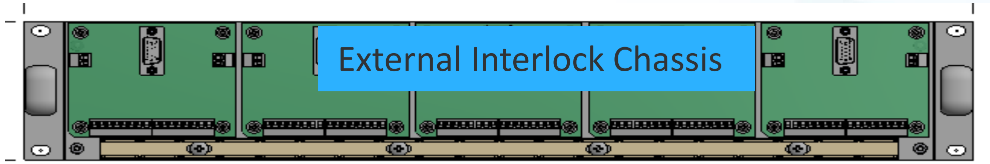
- The length of the testing was 5.3 Days
- The top plot shows the Humidity & Temperature inside and outside of the rack.
- The rack inside temp. is stable to ± 0.25 C .
- The rack inside humidity varies by ~ 25%
- These measurements were done on a 4 channel PSC which was configured for 100 ppm stability.
- This 4 Channel PSC has all plastic voltage reference chips.
- The cost difference between ceramic and plastic is ~ $5 a chip, so we will plan to use all ceramic chips for voltage references to minimize long term Humidity affects on stability.
- This will require a small PCB change on all the PSCs.
- With the ceramic reference voltage chips and the low noise DAC and ADC, the 4 channel PSC will meet the 10 ppm stability requirement.

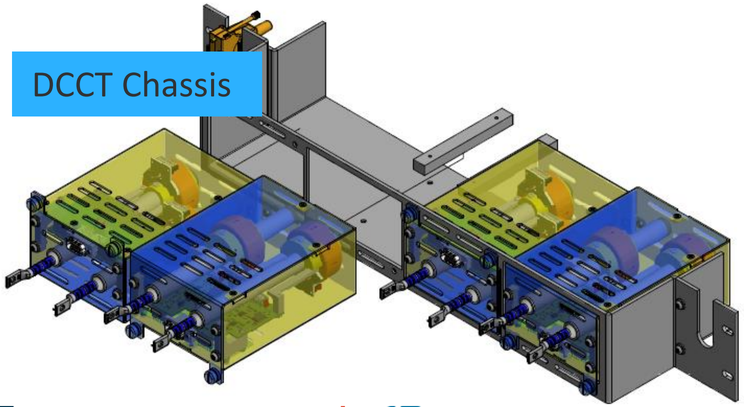
Build to Print Design/New Development

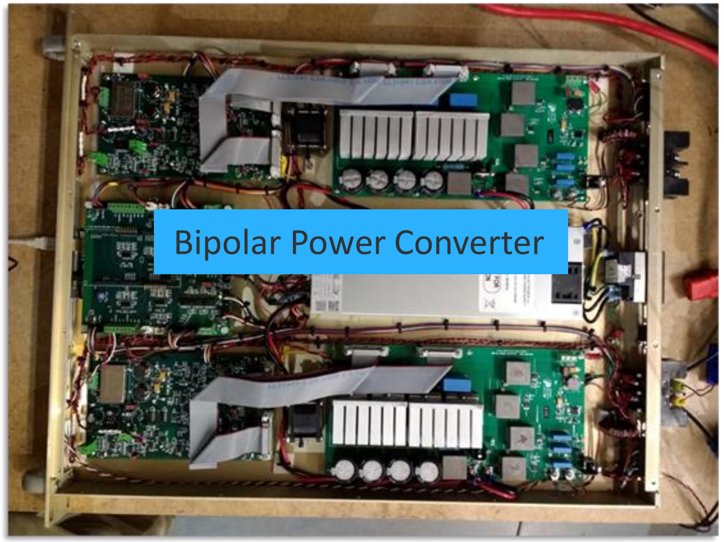
Build To Print Design











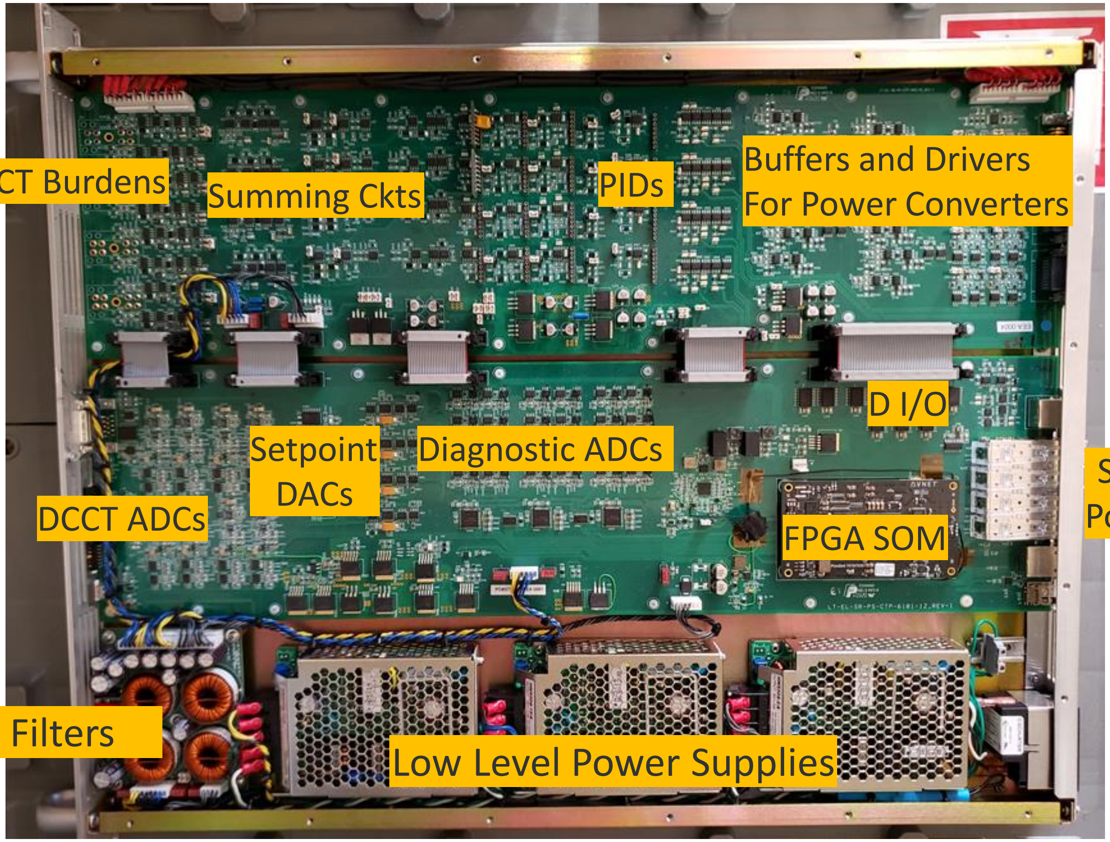
There are five main BTP chassis that will be used in the ALS-U power supply designs.

- Power Supply Controllers
- Power Distribution Units
- Bipolar Power Converters
- DCCT Chassis
- External Interlock Chassis

They were designed to meet many different requirements.

- Reduce rack space.
- Lower cost per PS channel.
- Not available in COTS devices
- Simplified integration to other systems.

4 Channel PS Controller



Front Panel

Rear Panel

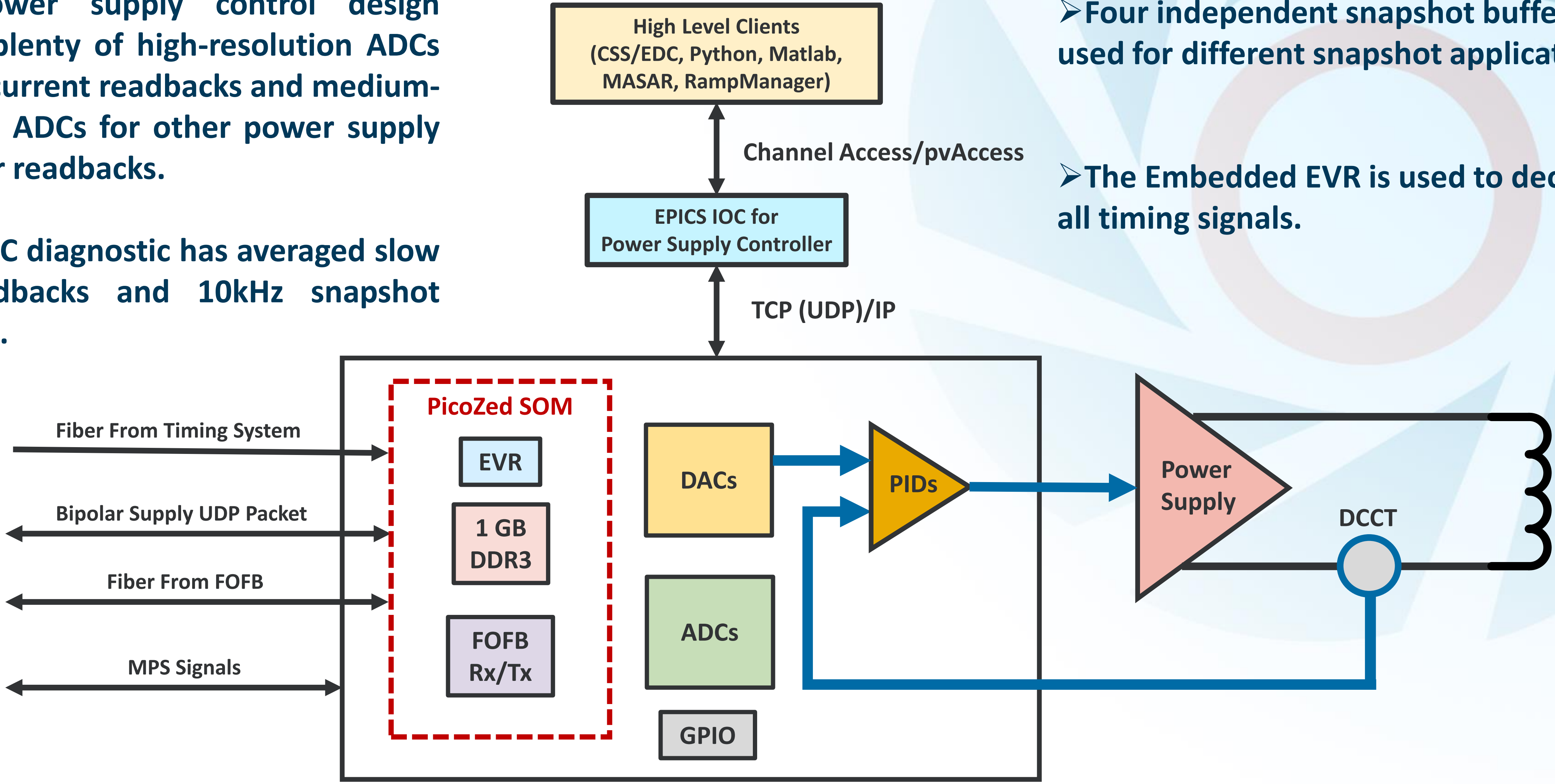
BTP PSC Models	Description
BTP PSC-2CH-HSS	PSC 2 Channel - High Stability -Slow
BTP PSC-4CH-MSS	PSC 4 Channel Medium Stability -Slow
BTP PSC-4CH-HSS	PSC 4 Channel High Stability for SD and SF magnets - Slow
BTP PSC-4CH-HSF	PSC 4 Channel High Stability for Fast Corrector magnets. Interface to FOFB

- High Stability version will use 20 Bit DACs, 20 Bit DCCT ADCs, better Burden resistors.
- Design has noise generators separated from sensitive analog circuits.
- Temperature sensitive components are at the front of the chassis to take advantage of the rack cooling .

Power Supply and Control Block Diagram

- The power supply control design provides plenty of high-resolution ADCs for DCCT current readbacks and medium-resolution ADCs for other power supply parameter readbacks.

- Each ADC diagnostic has averaged slow data readbacks and 10kHz snapshot readbacks.

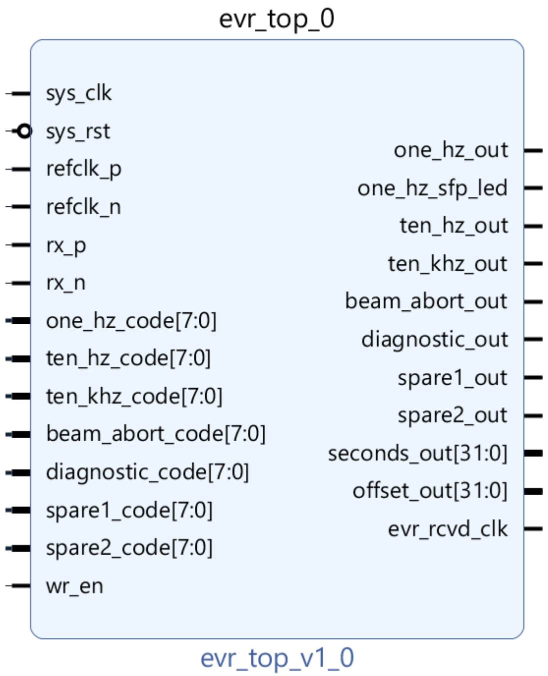


- Four independent snapshot buffers are used for different snapshot applications.

- The Embedded EVR is used to decode all timing signals.

Embedded Event Receiver

➢ **Embedded Event Receiver (EVR) module**



- **Si570 programmable crystal is functional in both the 2 and 4 Channel systems and is settable through EPICS**
- **Standard MRF Timestamp is acquired through the embedded EVR**
- **All timing signals are available and have been tested using a mock cell controller system and NSLS-II EVR link**
  - **10 Khz**
  - **10 Hz**
  - **Beam Abort Trigger**
  - **Beam Diagnostic Trigger**
  - **Spare Triggers**
- **All EVR Codes are settable through EPICS IOC**

Slow Diagnostic ADC Data

- Functions of Slow ADC Diagnostic Data
  - Live monitoring of powers supply system parameters for each channel:
    - Two High Precision DCCT current monitors: with average modes which can be used to measure the output current with high precision. At NSLS-II, this function is done by separate DMM units
    - DAC setpoint loopback: can be used to confirm the setpoint without turning on a power supply
    - Voltage Output Monitoring
    - Ground Current Monitoring
    - Regulator Voltage Monitoring
    - Error Voltage: to monitor power supply error as an indicator of the feedback loop performance
  - Slow ADC data can be used for power supply long term performance analysis and long term stability
  - With different average settings the slow ADC data has different low-pass filter settings
  - Each slow ADC has its own gain and offset for calibration
- Two channel PSC slow ADC data:

2-Chan. PSC ADC READBACK

DCCT 20-bit ADC READBACK

	Reg0	Reg1	Reg2	Reg3		
	0xF97A20D9	0xF97A0A5E	0xF4AC423E	0xF4ACAFEE		
	Chan1 DCCT1	Chan1 DCCT2	Chan2 DCCT1	Chan2 DCCT2		
Readback (A)	21.002148	21.006248	73.002916	73.001961		
SF (A/V)	-5.000	-5.000	-10.000	-10.000		
Gain	1.00707	1.00727	1.00763	1.00773	Ch1 DAC	CH2 DAC
Offset (A)	-0.019360	-0.020645	-0.045970	-0.043380		
DMM RB(A)	20.999828	21.005581	72.999275	72.975471	20.999624	72.997940

Ch1 Avg Mode	Ch2 Avg Mode
0x2	0x2

Mode=0: raw data
Mode=1: 167 averge
Mode=2: 500 average
Mode=3: 10 average

Monitor 16-bit ADC READBACK Chan 1

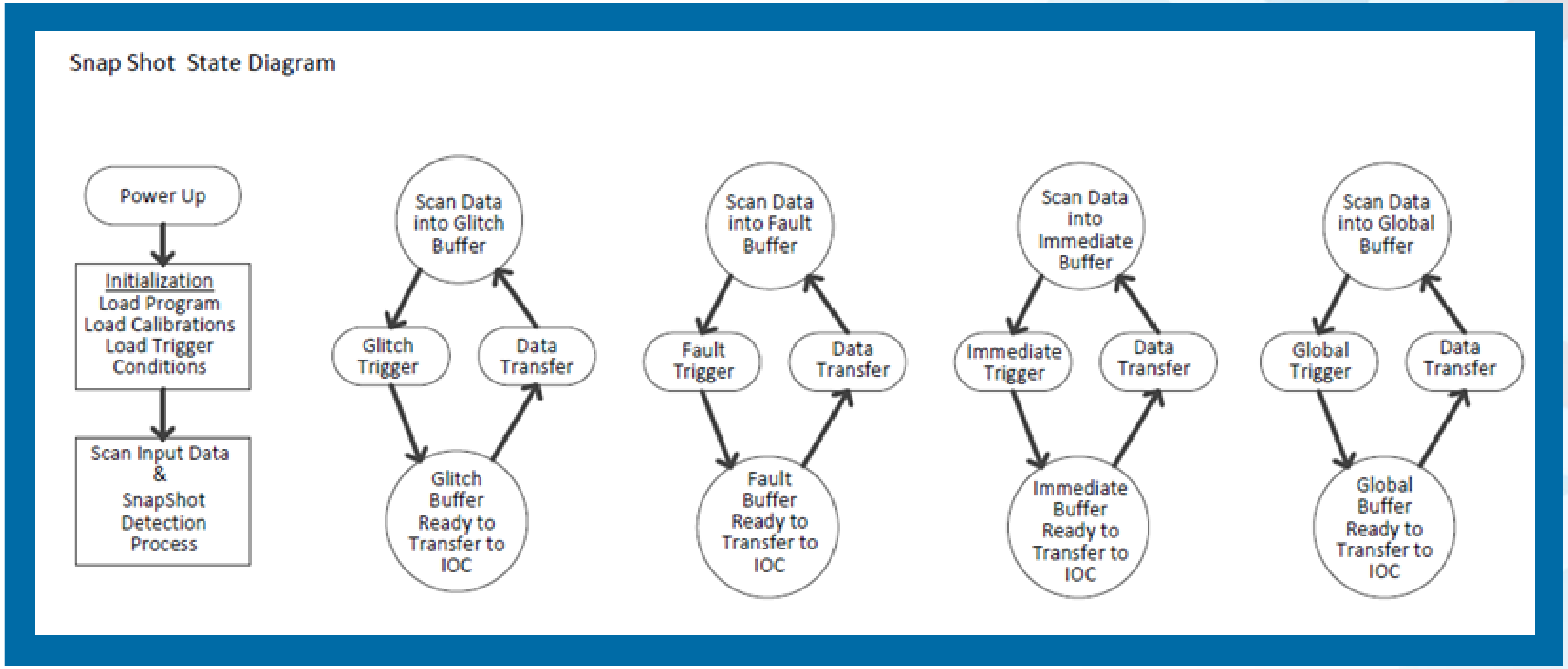
	Reg4	Reg5	Reg6	Reg7	Reg8	Reg9
	0x691D35	0xFFD6CA32	0x55	0xFFA8DD21	0x293373	0x691D35
Ch1	DAC-SP	VOLT-Mon	GND-Mon	Spare	PS-Reg-Out	PS-Err
Readback (A)	21.005884	2.060572	5.188147E-5	-3.485555	2.060112	0.005512
SF (A/V)	5.000	-1.250	1.000	1.000	1.250	1.000
Gain	0.99890	1.00000	1.00000	1.00000	1.00000	1.00000
Offset (A)	0.005550	0.000000	0.000000	0.000000	0.000000	0.000000

Monitor 16-bit ADC READBACK Chan 2

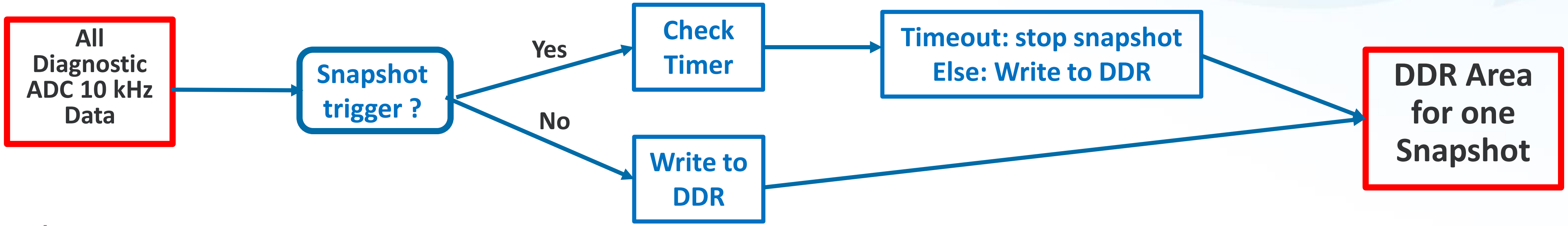
	Reg10	Reg11	Reg12	Reg13	Reg14	Reg15
	0xB6C476	0xFF5E287E	0xFFFFFBE9	0xFF68828B	0xA14AC9	0x47CD
	DAC-SP	VOLT-Mon	GND-Mon	Spare	PS-Reg-Out	PS-Err
	72.993378	8.092338	-0.000639	-6.059788	8.064853	0.011219
	10.000	-1.250	1.000	1.000	1.250	1.000
	0.99832	1.00000	1.00000	1.00000	1.00000	1.00000
	0.007000	0.000000	0.000000	0.000000	0.000000	0.000000

Snapshot ADC Data

- Snapshot occurs for different trigger conditions

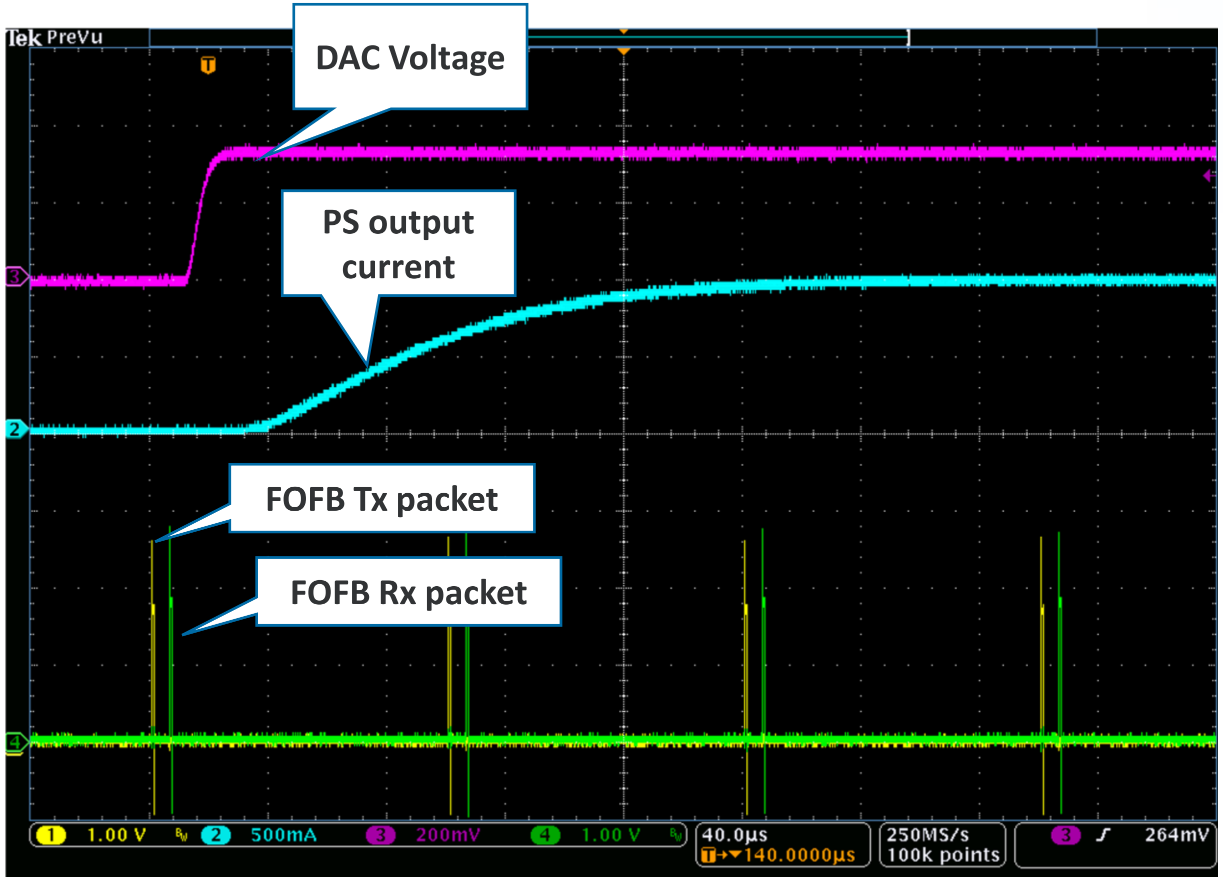


- The approach in the FPGA for the snapshot data taken at a 10kHz acquisition rate is as follows:



DAC Setpoint Mode: Fast Orbit Feedback

- FOFB Full System Response times

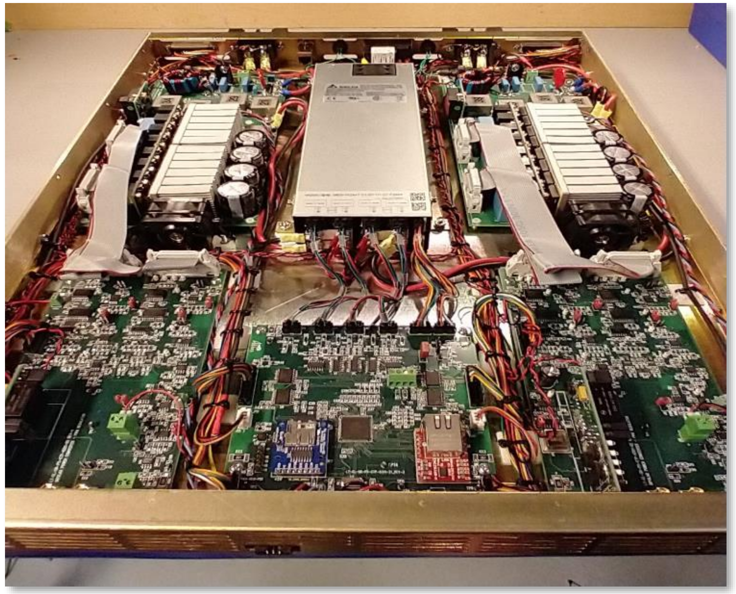


- Start of cell controller Tx to start of DAC step: ~12 us
- Time of DAC step: ~10 us
- End of DAC step to start of current response: ~10 us
- From start of current to commanded current: ~184 us
- From cell controller Tx to commanded current: ~216 us

Scope Legend:

- Pink: DAC Voltage
- Blue: Bipolar Supply Output Current
- Yellow: FOFB Tx packet from mock cell controller
- Green: FOFB Rx packet from PSC back to cell controller

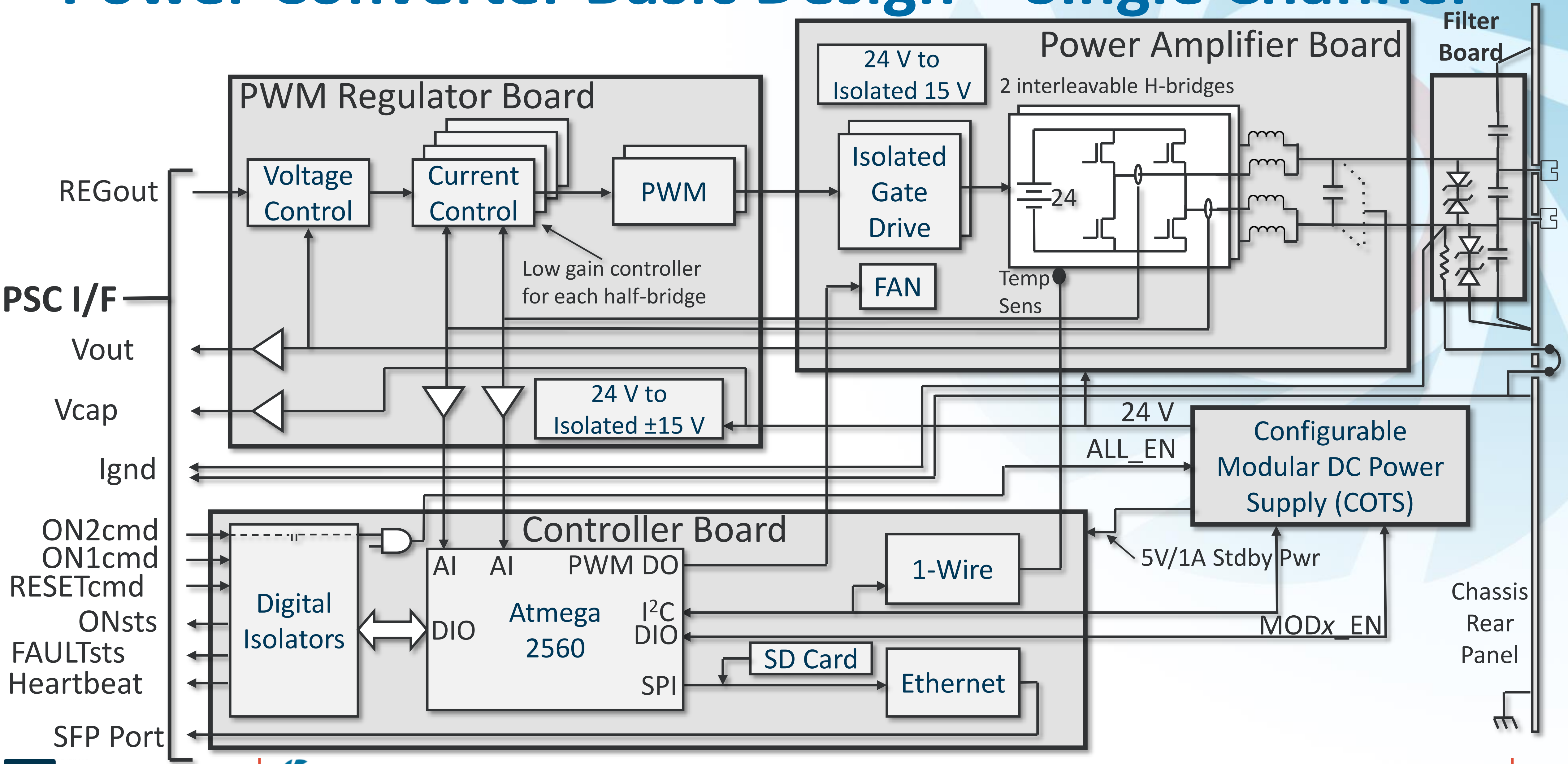
Bipolar Power Supply Design



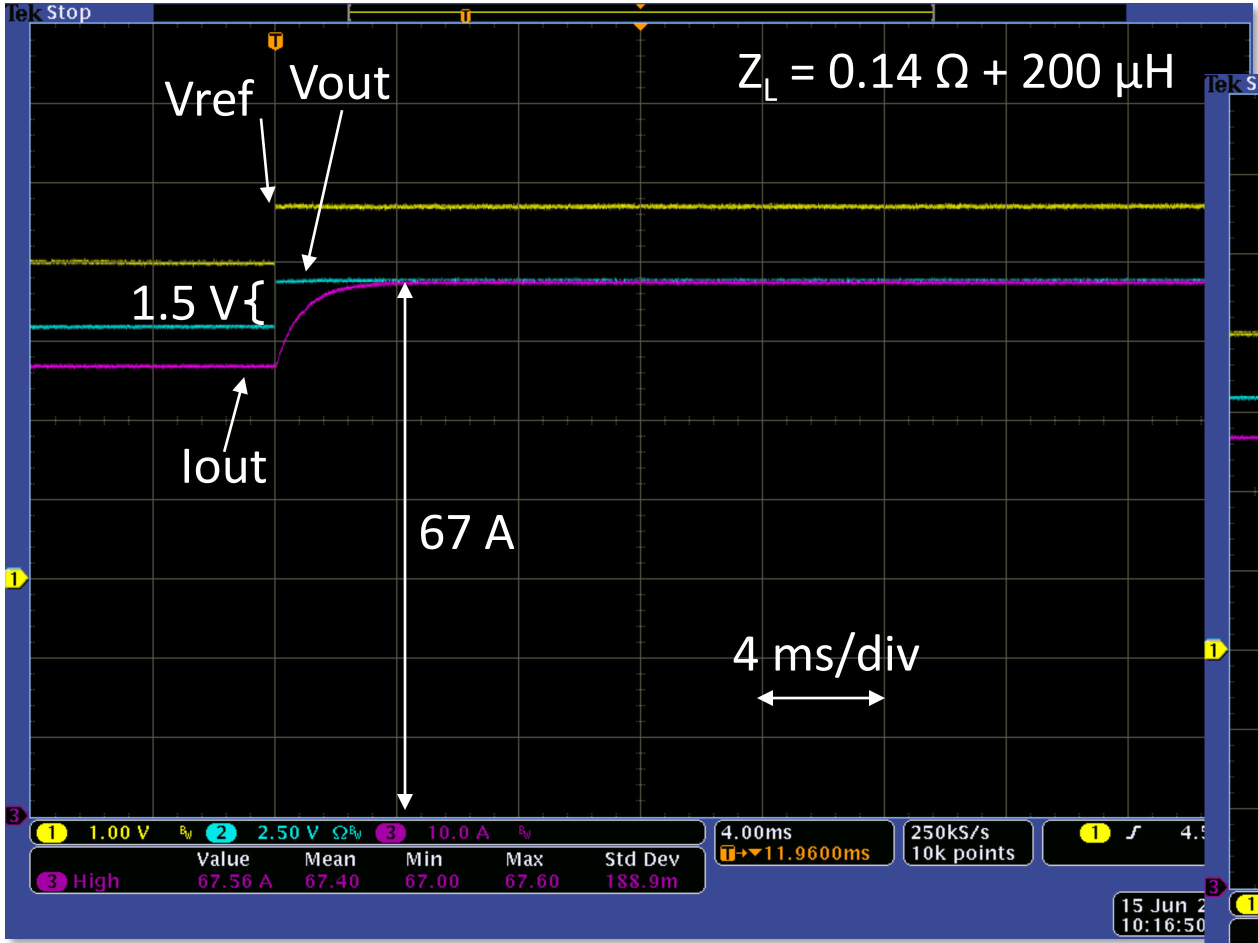
- Designed in-house and manufactured as build to print (BTP).
- Power converter is the power part of the overall BTP bipolar power supply. Power converters are voltage mode converters. PSC and DCCTs provide current regulation.
- Designed for the needs of ALS-U: packing density, remote diagnostic capability.
- Modular component designs to accommodate range of power supply types.

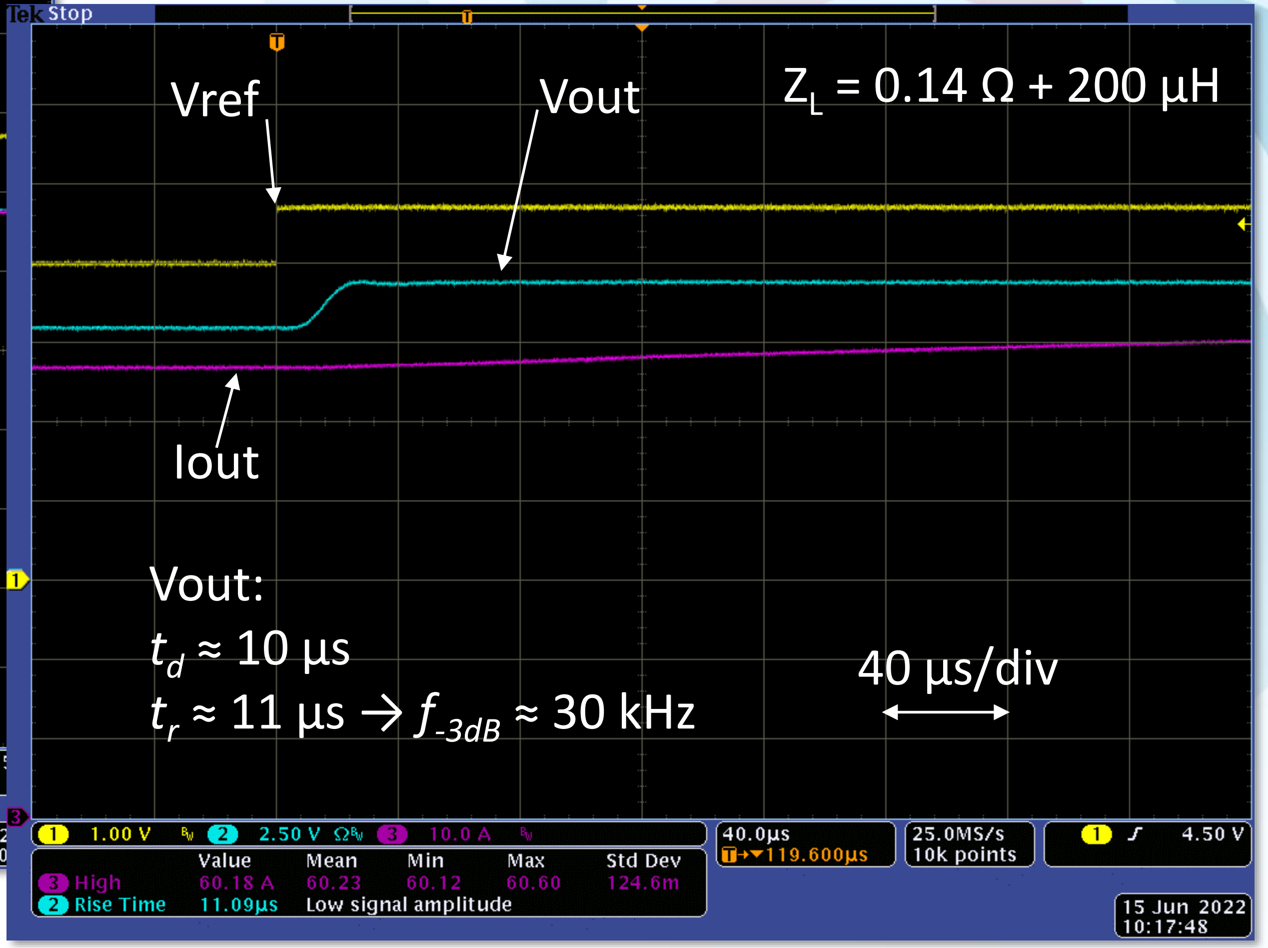
Type	V / I	Chassis Name	Power/Channel	Location	Chassis
2 Channel Fast	18V/24A	BPC-2CH-F-18V-24A	432 W	AR	1U
2 Channel Slow	18V/24A	BPC-2CH-S-18V-24A	432 W	AR	1U
4 Channel Slow	18V/10A	BPC-4CH-S-18V-10A	180 W	SR/AR	1U
2 Channel Slow	16V/35A	BPC-2CH-S-16V-35A	560 W	SR	1U
1 Channel Fast	16V/70A	BPC-1CH-F-16V-70A	1120 W	SR	1U
1 Channel Slow	18V/90A	BPC-1CH-S-18V-90A	1620 W	BTS	2U
1 Channel Slow	16V/200A	BPC-1CH-S-16V-200A	3200 W	SR	2U

Power Converter Basic Design – Single Channel



1 CH Fast BPC– 16V/70A Voltage Loop Step Response

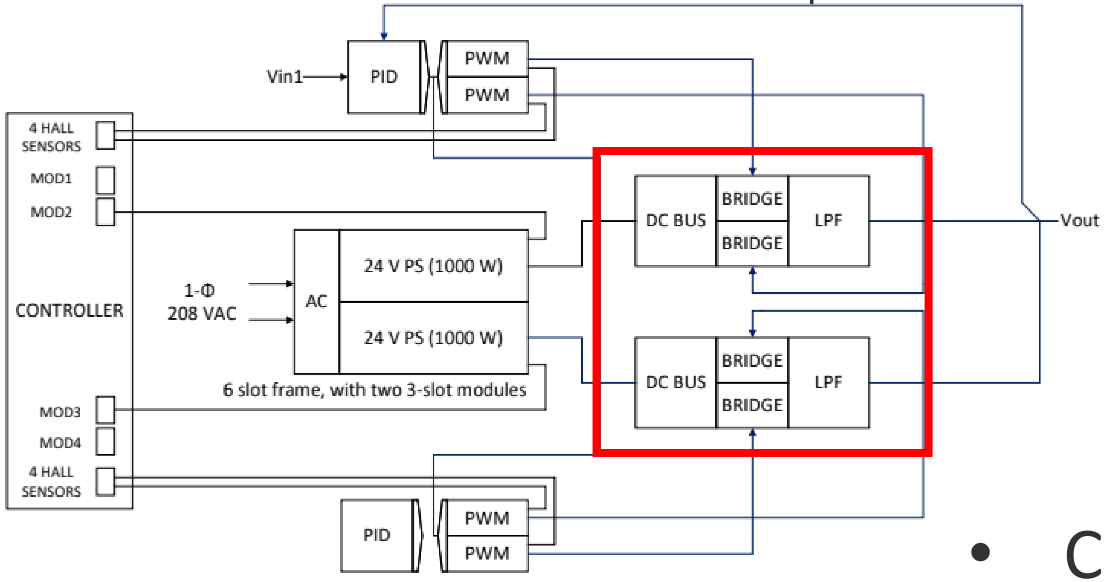




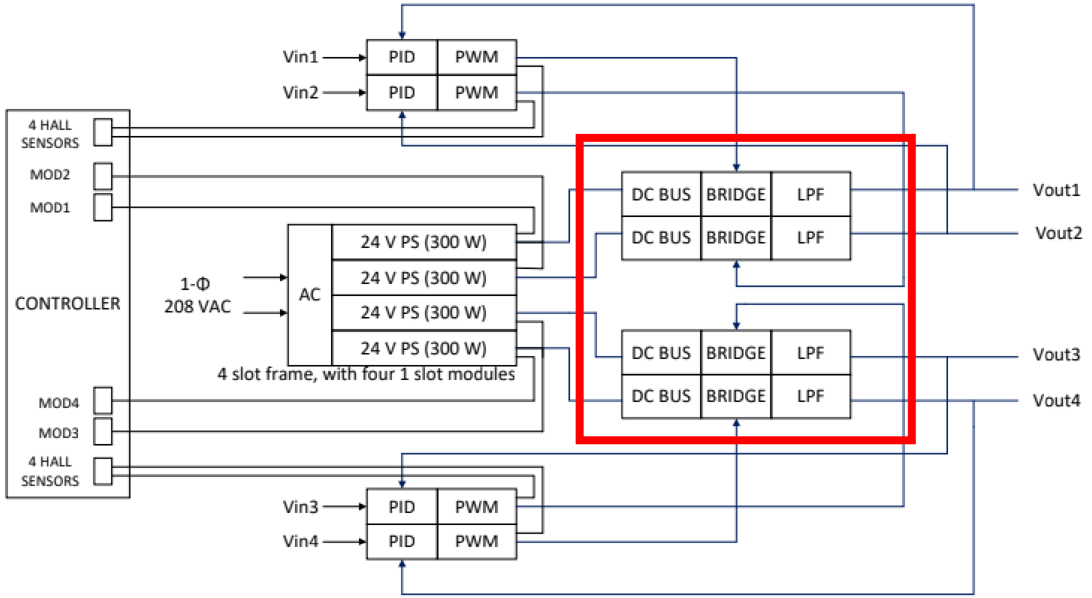
- Fast inner voltage loop for disturbance rejection.
- Outer current loop can achieve f_{-3dB} = 3 kHz.

Different PS Version with Single Power Amplifier board Design

Version 1: 1-Channel - 16V -70 Amp

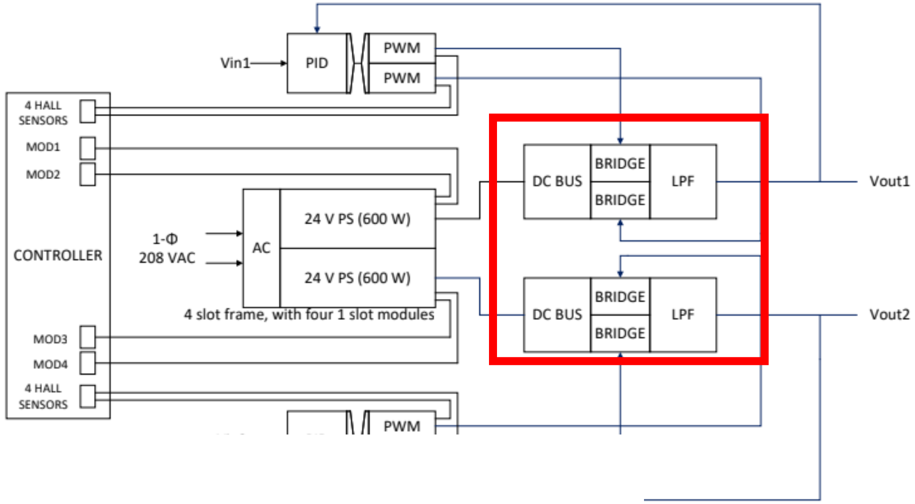


Version 2: 4-Channel 16V -10 Amp (Slow)

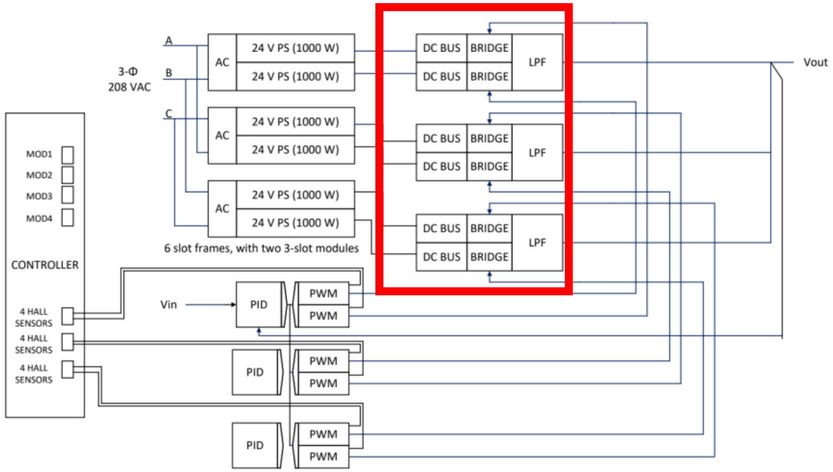


- Customized
- Optimized
- Flexible

Version 3: 2-Channel 18V -35 Amp

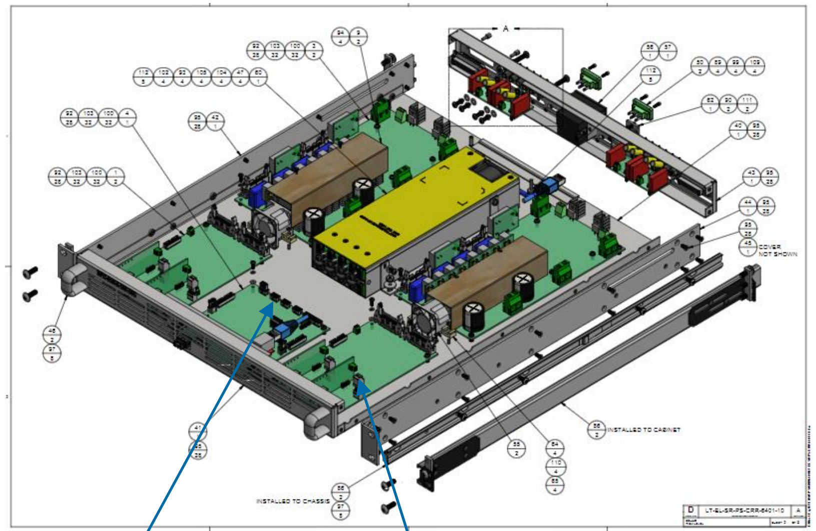


Version 4: 1-Channel 16V -200 Amp



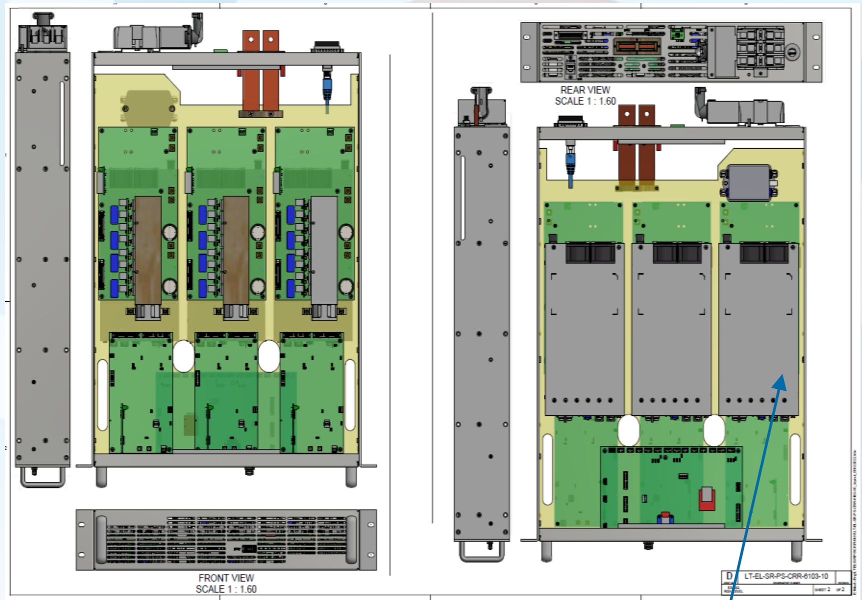
Different Model of the Bipolar Power Converters

BPC-2CH-18V-10A



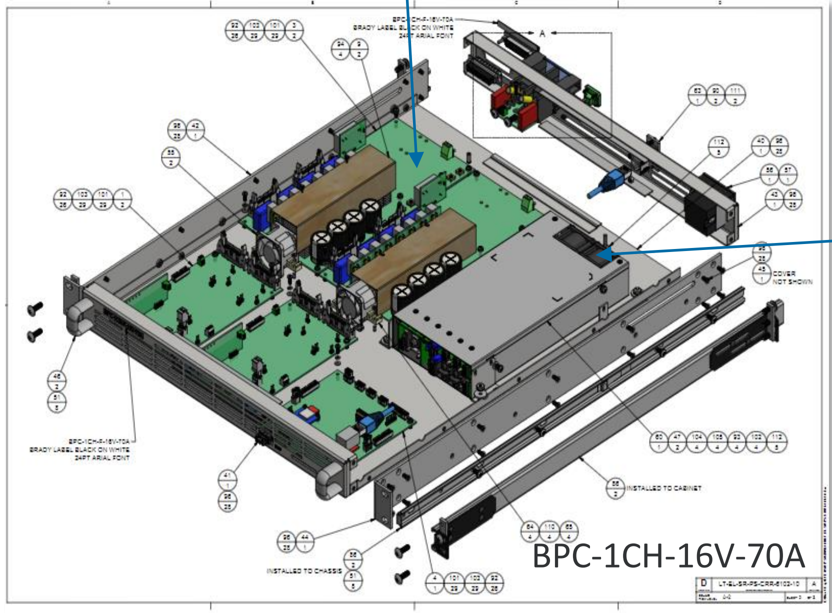
Power Amplifier Board

BPC-1CH-16V-200A



Controller Board

PWM Board



BPC-1CH-16V-70A

1.2 kW PS

2 kW PS

Booster Bend Power Supply

Existing Power Supply Specification

Existing Booster Bend Power supply is currently in operation at ALS.

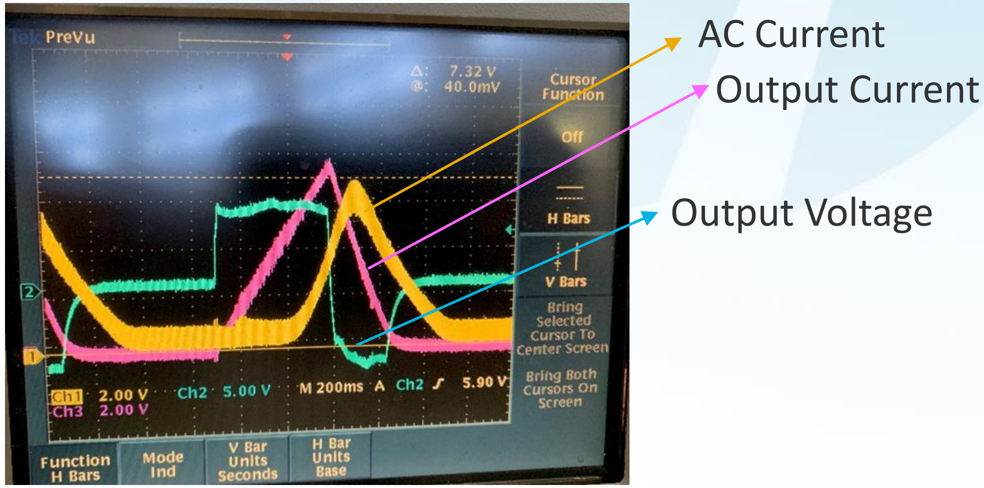
Following are specification :

- Input: 480 VAC, 3 Phase, 60 Hz, Power: 464 KVA
- Peak DC Voltage: 1800 V, DC Current: 400 A Continuous, Peak Current: 1050 Amp
- Load Current Tracking Error: 0.2% during Rise/fall, Slew rate: 1312 A/sec
- Output Voltage Ripple (Pk-Pk) : < 1 % (DC to 720 Hz)
- The current waveform is a single approximate triangle waveform with a 0.714 sec (1.4 Hz) period (Trise+Tfall) and the cycle time of waveform is 1.4 Sec (0.7 Hz) period (Trise + Tfall+ Zero Period).

Existing Booster Bend PS

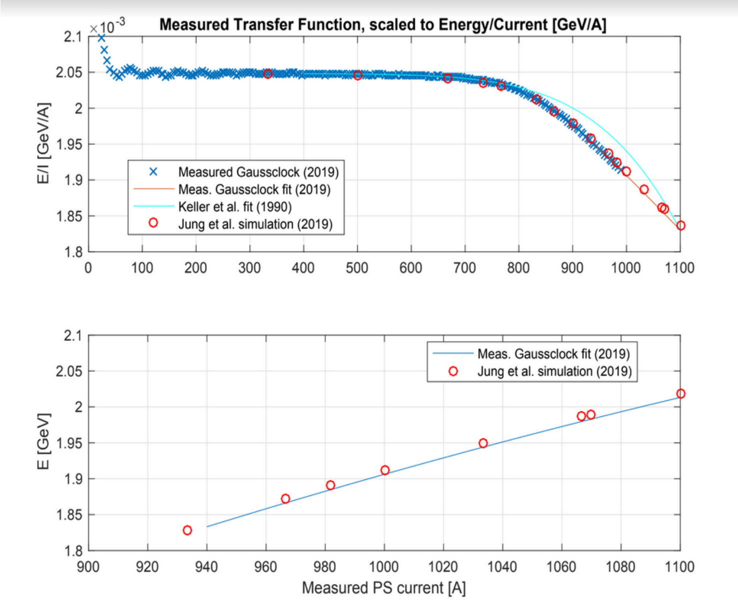
Booster Bend Dipole Magnet

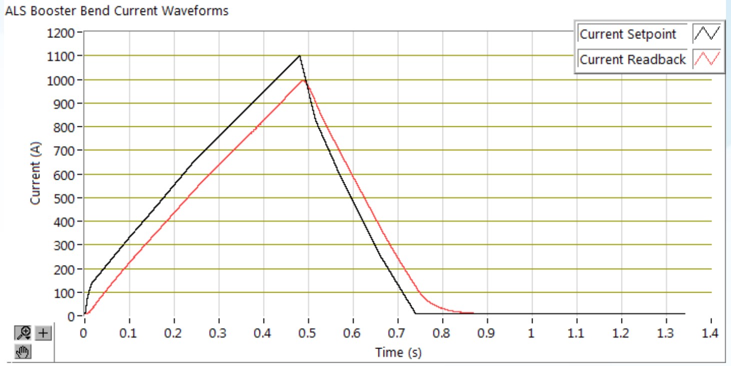
Waveform of Existing Booster Bend PS



Replacement of Existing Booster Bend Power Supply

- Necessity of Replacement
  - New Booster Bend Power Supply require to achieve 2.0 GeV for ALS-U
  - And Existing Booster Bend Power Supply current rating is not enough to achieve the 2.0 GeV Energy level.(Existing booster bend power supply maximum current rating is 1050 Amp and 1080 Amp is required for 2.0 GeV)
  - Some of the component of existing booster bend power supply will be end of life period at 2024.
  - Existing booster bend power supply is very difficult for operation and maintenance.

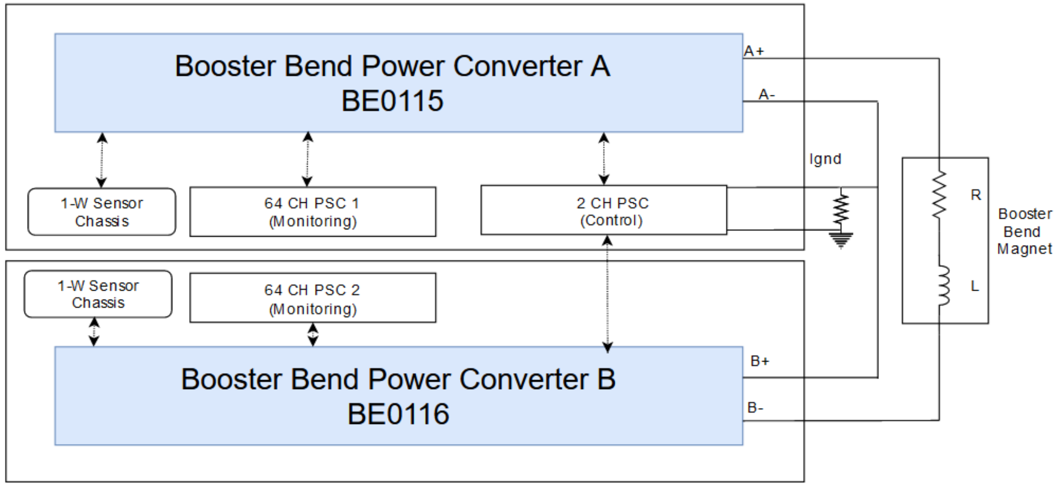


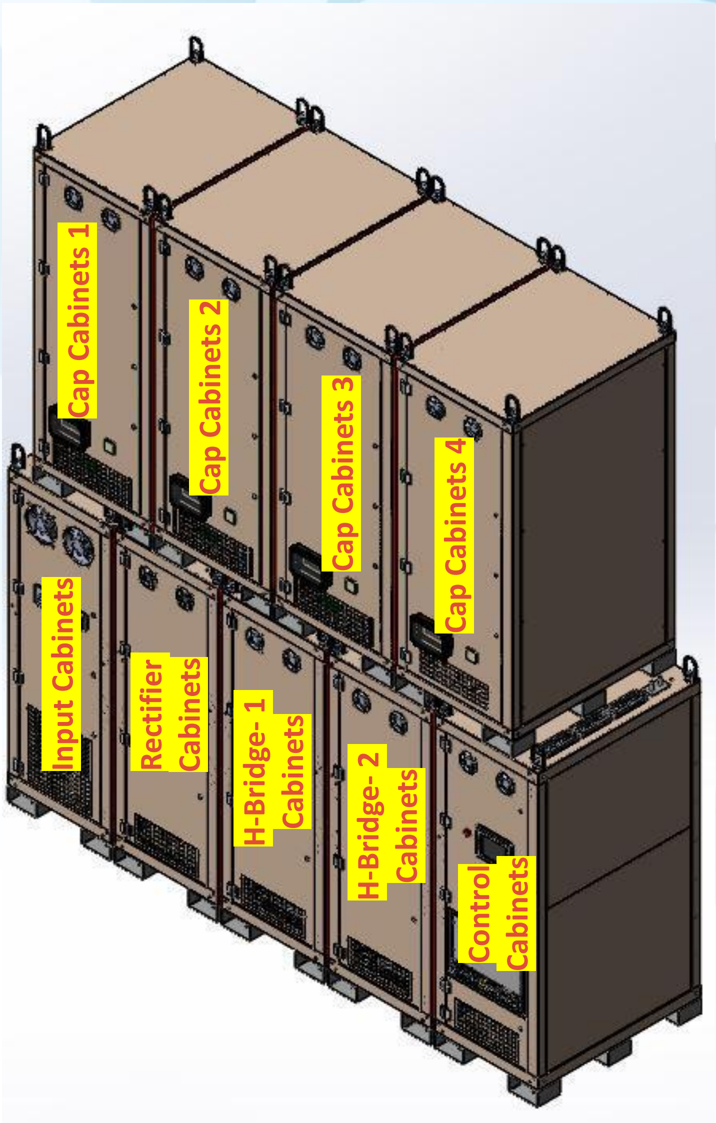


Booster Bend Power Supply Specification

Description	Value
Each PS Input Voltage Rated	3-Phase, 480V AC, 60 Hz, 3C+PE
Each PS Input Current rated	304 Amp AC @ 480 V
Each PS Output Voltage & Current	1100 Volt DC (Pulse) & 1200 Amp DC (pulse)
No of Power Supply in series	2
Total Output Voltage & Current of the system	2200 Volt, 1200 Amp
Pulse Duration for PS	1 Second
Total Capacitance per PS	1.4 F (Total 640 Capacitor per PS)

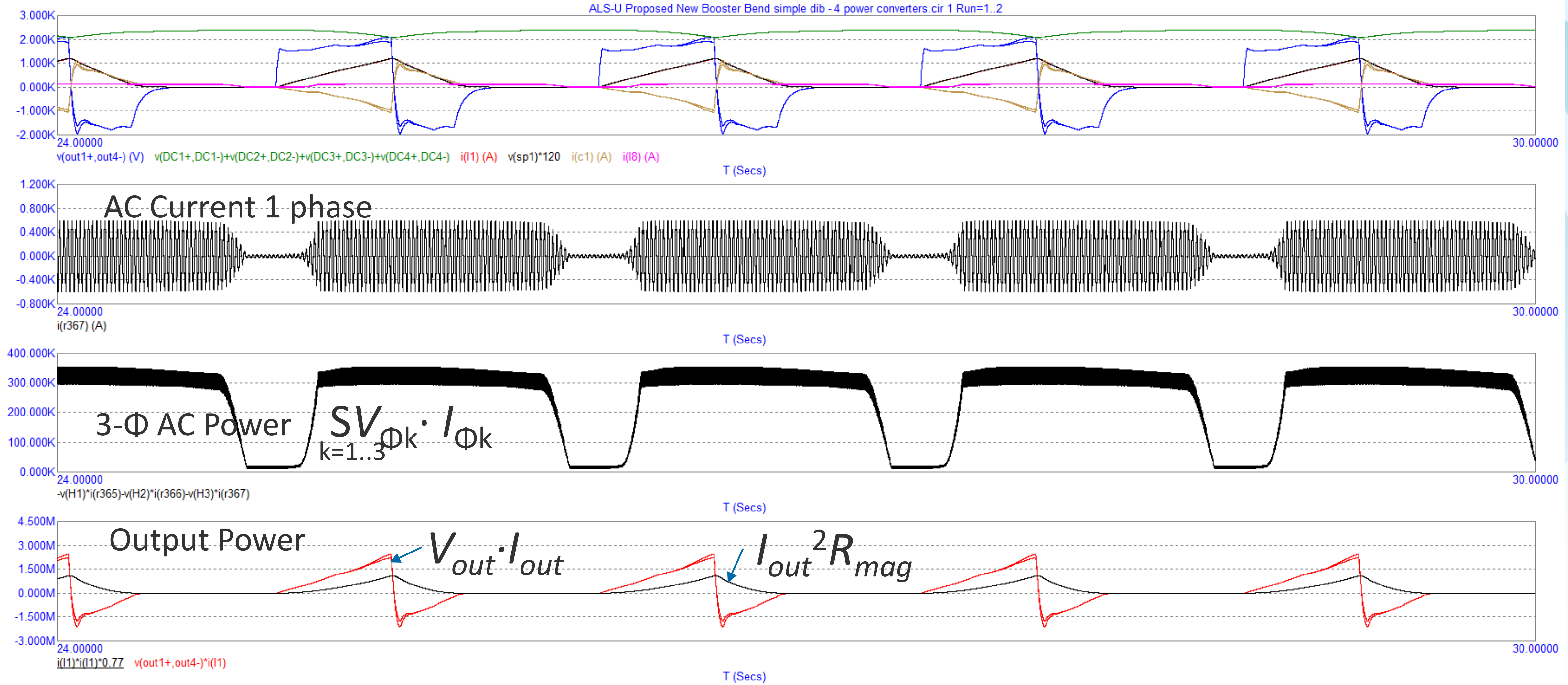
Booster Bend Power Supply Control Interface





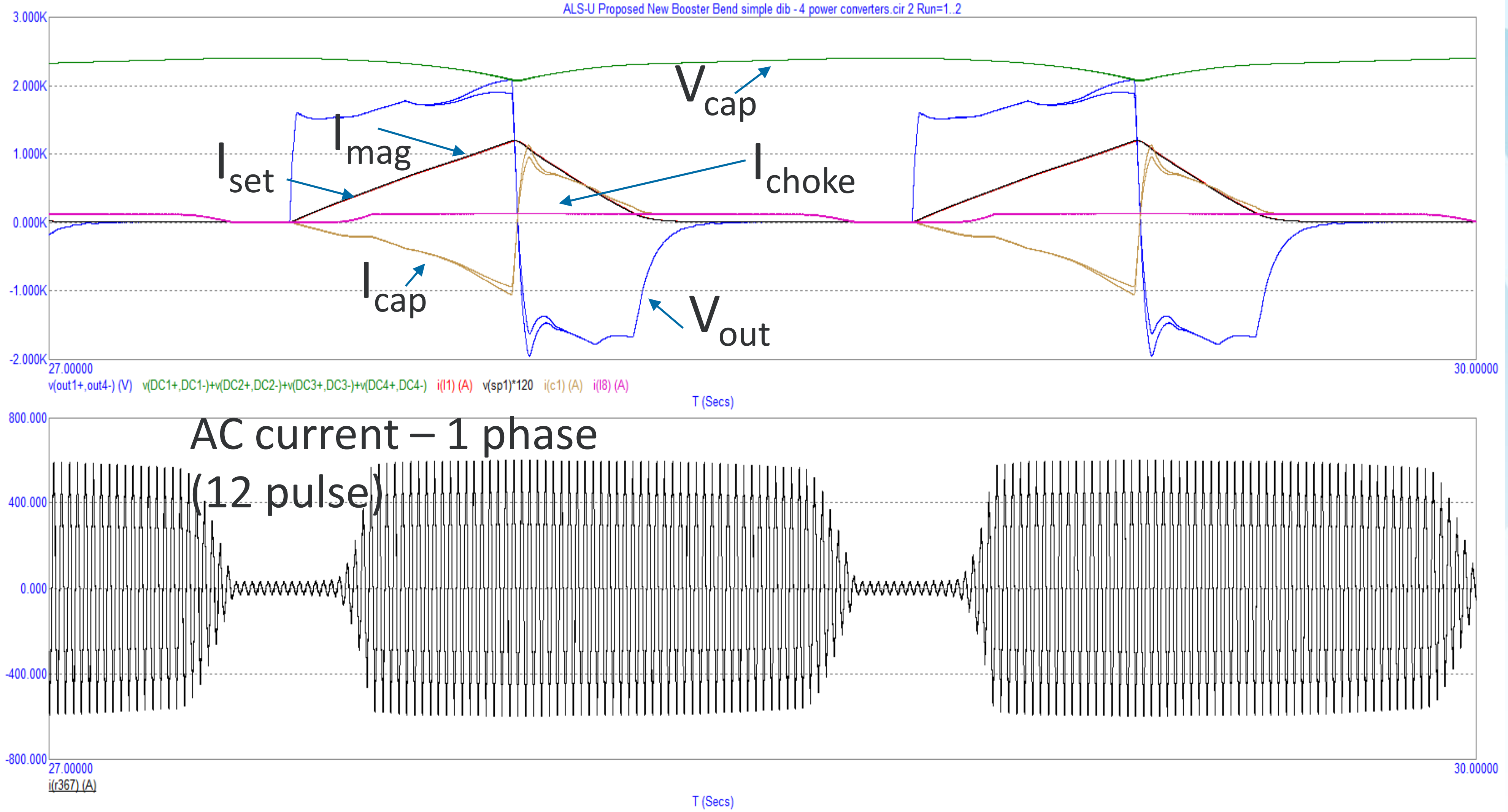
PS will be delivered next month

New Booster Bend PS – 125 A Limit on Capacitor Bank Charging Current



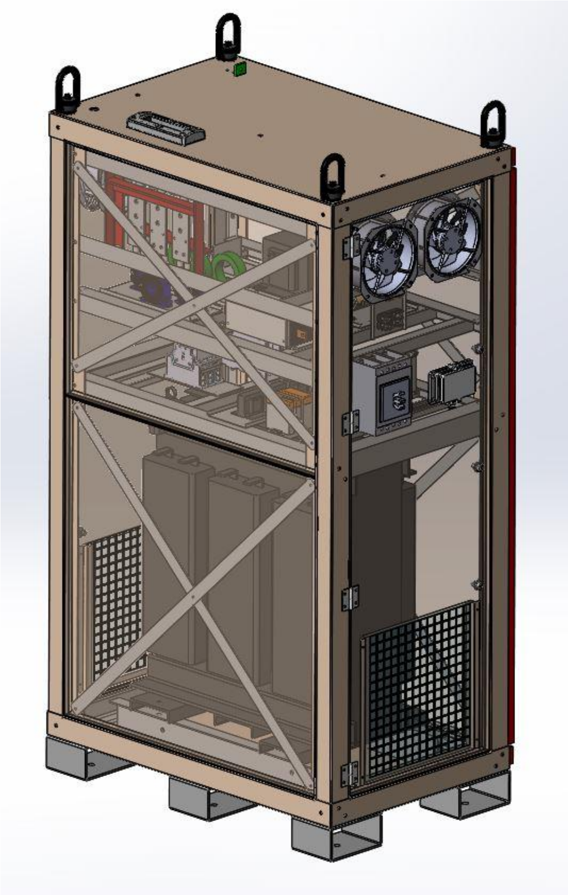
New Booster Bend PS – 125 A Limit on Capacitor Bank Charging Current – Expanded View

- Setpoint ramp is ALS ramp *readback* data scaled for 1200 A peak.
- Magnet current peak is 1200 A.
- L_{scr} = 1 mH.
- Effect of magnet nonlinearity evident in V_{out}.
- Cap bank dips lower with limited charging.

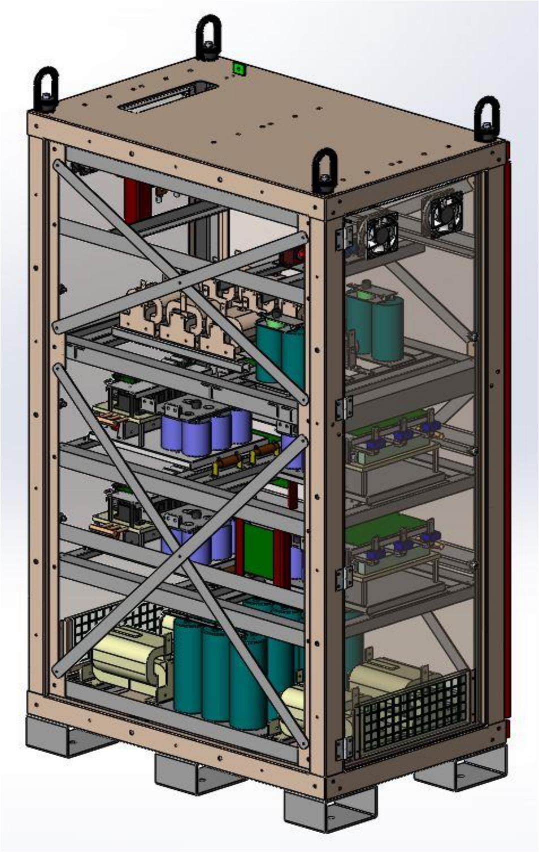


Booster Bend Power Supply

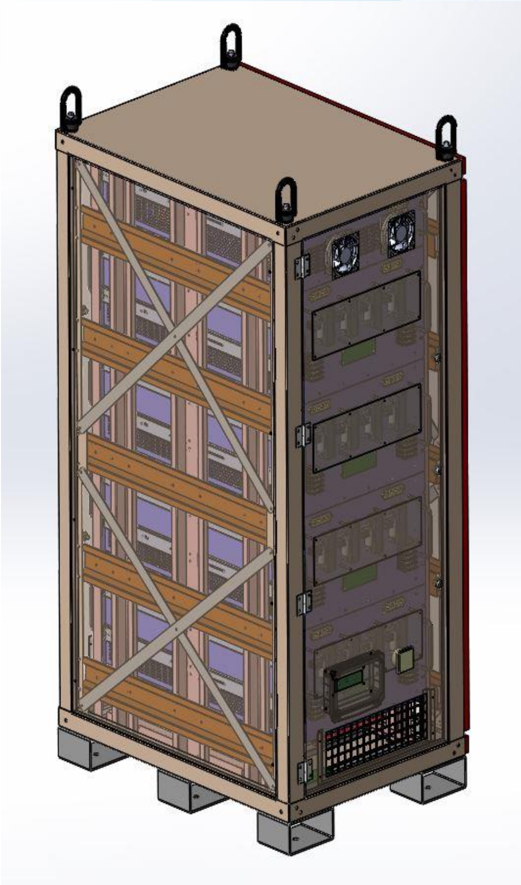
AC Input & Transformer Cabinet



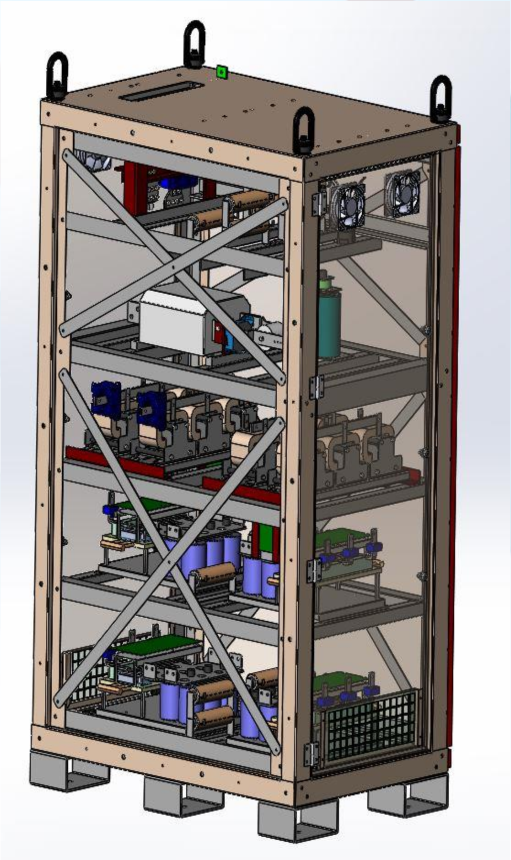
Rectifier Charger Cabinet



Capacitor Bank Cabinet



Switch-Mode Interleaved H Bridge



Booster Bend Power Supply

Conclusion

Conclusion

- A large number of power supplies means that reliability and availability are critical. Therefore, the ALS-U design incorporates numerous monitoring and diagnostic features.
- The upgraded ALS will occupy the same facility as the current ALS, utilizing the existing ALS infrastructure. Consequently, space presents a significant challenge, emphasizing the importance of modularity and compact design for the power supply components.
- The design takes into consideration factors such as easy assembly and installation. The team has successfully developed a highly compact design to accommodate the limited space available at ALS-U.
- Prototypes testing confirm the overall performance for the different power supply configurations. The stability requirements will be met with planed changes to the Power Supply Controller design.
- ALS-U Team completed final design milestone last year, Team is working on procurements, prototype rack testing, and production. The supply chain issue had a significant impact on sourcing electrical & electrical components for the ALS-U project.
- Overall, the ALS-U power supply subsystem has successfully overcome numerous challenges so far. The compact, modular design and monitoring and diagnostic features are the cornerstones of the ALS-U power supply design.