Overview of the Dream Chaser® Electrical Power System

James Bontempo, ZIN Technologies
Alyssa Brigeman, ZIN Technologies,
Thomas Tolan, Sierra Space Corporation
Conner Glatt, Sierra Space Corporation
Kenneth Whalen, Aerojet Rocketdyne
Eric Edwards, Aerojet Rocketdyne

Space Power Workshop
April 25-27, 2023

Introduction

- **Dream Chaser® EPS Hardware Items:**
- **LVPDU**:
  - Low Voltage Power Distribution Unit
- **HVPDU:**
  - High Voltage Power Distribution Unit
- **PCU/PPCU:**
  - Power Converter Unit/Payload Power Converter Unit

Low Voltage Power Distribution Unit (LVPDU) 3x per Dream Chaser

High Voltage Power Distribution Unit (HVPDU) 2x per Dream Chaser

Power Converter Unit / Payload Power Converter Unit (PCU/PPCU) 3x per Dream Chaser

Introduction

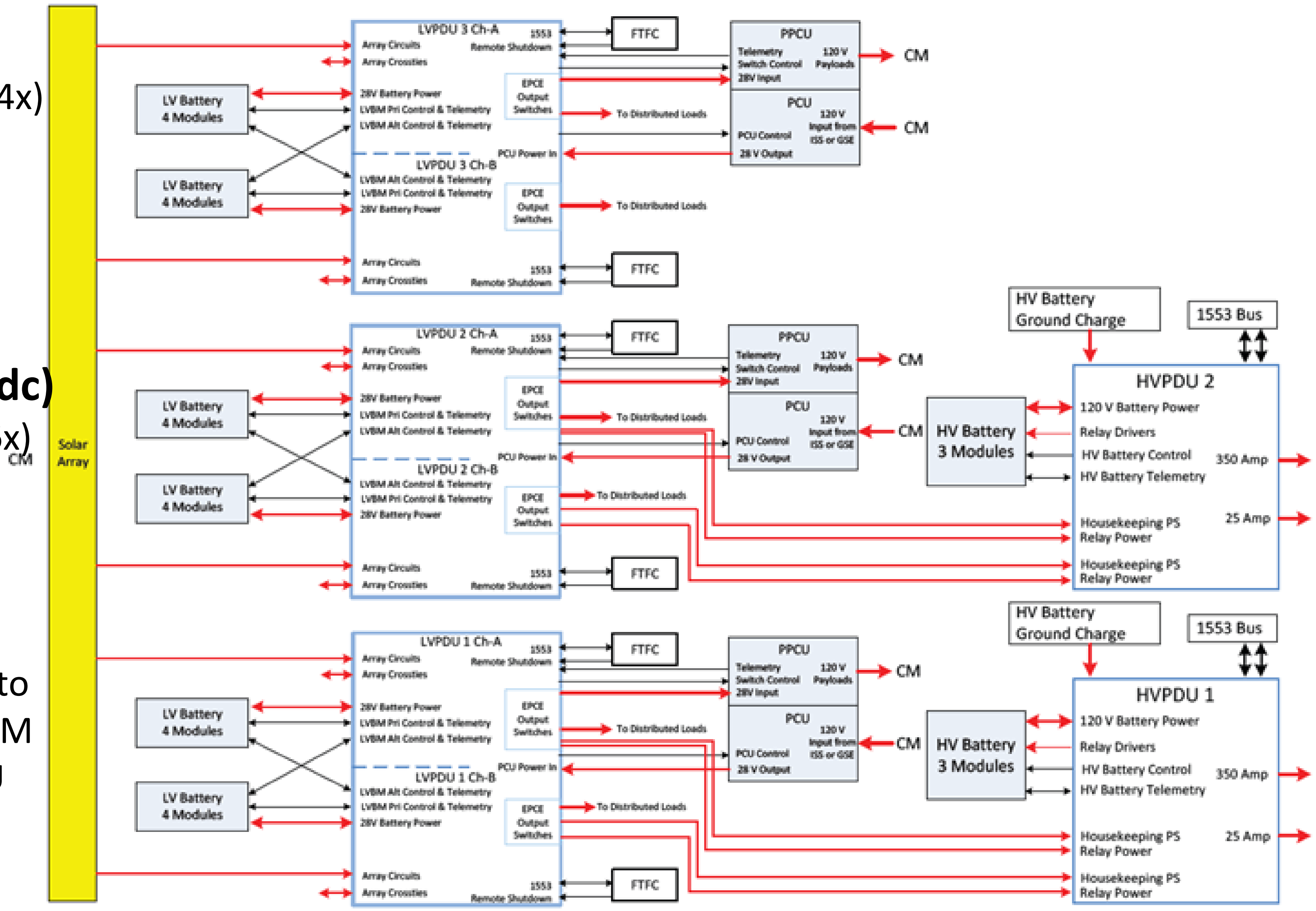
- **Sierra Space's Dream Chaser is a reusable lifting body spacecraft.**
- **Designed to transport cargo to and from low-Earth orbit (LEO) destinations.**
- **ZIN Technologies (ZIN) and Aerojet Rocketdyne (AR) have been subcontractors to Sierra Space for the Dream Chaser's Electrical Power System (EPS) since 2012.**
- **Since 2016, the Dream Chaser program produced its first spacecraft, *Tenacity*™, for NASA's Commercial Resupply Services (CRS-2) contract to supply ISS cargo.**
- **From 2016 to 2022, ZIN designed, built, and tested (acceptance and qualification) 14x Flight hardware assemblies for *Tenacity's* Flight units, Flight spares, and qualification units.**

SIERRA SPACE

Dream Chaser EPS Block Diagram

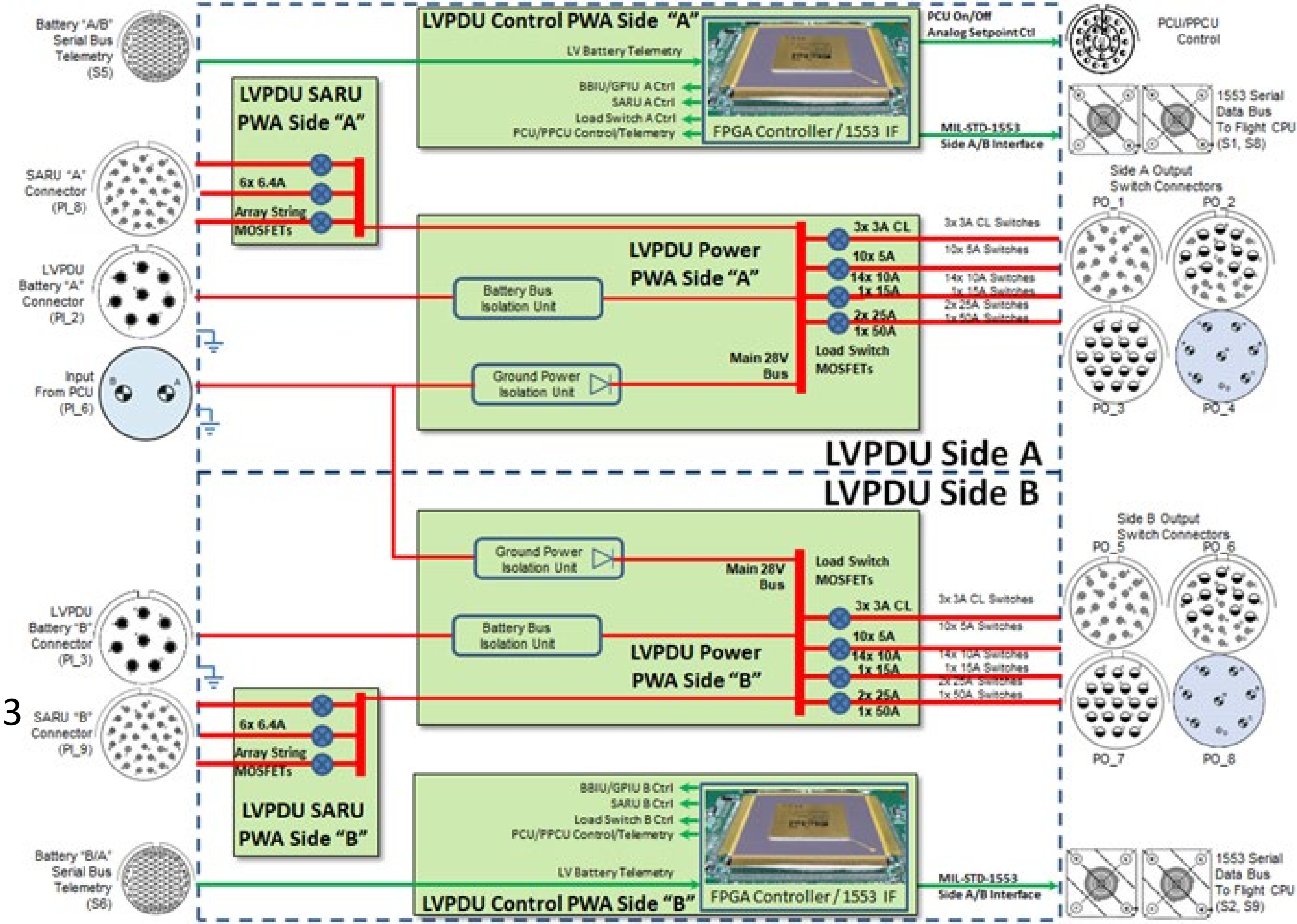
AEROJET ROCKETDYNE
ZIN Technologies

- **Low Voltage (24 to 32 Vdc)**
  - Low Volt Battery Modules (24x)
  - 3x LVPDU Units w/ Side A, B
  - 4x LVBM per LVPDU Side
  - Solar Array Strings (36x)
  - 6x Strings per LVPDU Side
- **High Voltage (108 to 140 Vdc)**
  - High Volt Battery Modules (6x)
  - 2x HVPDU Units
  - 3x HVBM per HVPDU
- **Power Converter Unit**
  - PCU converts 120V from ISS to power LVPDU, recharges LVBM
  - 3x PCU Units, one per LVPDU
  - 1.5 kW (30V, 50A) per PCU



LVPDU Block Diagram

- **LVPDU Power Inputs**
  - LV Battery Modules (4x per side)
  - Solar Array Strings (6x per side)
  - PCU/Ground Power Input
- **LVPDU Power Output Switches**
  - 32x Output Switches per Side
  - 4x 3A Current Limiting Switches
  - Time Delay Switches: 10x 5A, 14x 10A, 1x 15A, 2x 25A, 1x50A
- **LVPDU Features**
  - Channelized Side A, Side B
  - FPGA Controllers w/ MIL-STD-1553
  - Battery on the Bus architecture
  - Telemetry interface to LVBMs
  - Space-grade, rad hard parts per EEE-INST-002 Level 2



LVPDU Block Diagram

- **LVPDU “battery on the bus” impact on output switch design.**
  - LVBM modules are a low impedance power source.
  - Short circuits on the output switches can cause unacceptably high fault currents, even if the overcurrent protection circuits turn the MOSFETs off within microseconds.
  - The LVPDU output switch design solved this issue by using a current limit circuit on each MOSFET.
  - AR and ZIN performed extensive analysis to estimate max fault current, MOSFET SOA.
  - The LVPDU uses P-channel MOSFETs due to simple gate drive circuits.
  - P-Channel MOSFETs have higher SOA due to the larger die size versus N-channel devices with similar Rds_on.
  - P-Channel MOSFETs require multiple parallel devices for higher current switches (15A, 25A, 50A).

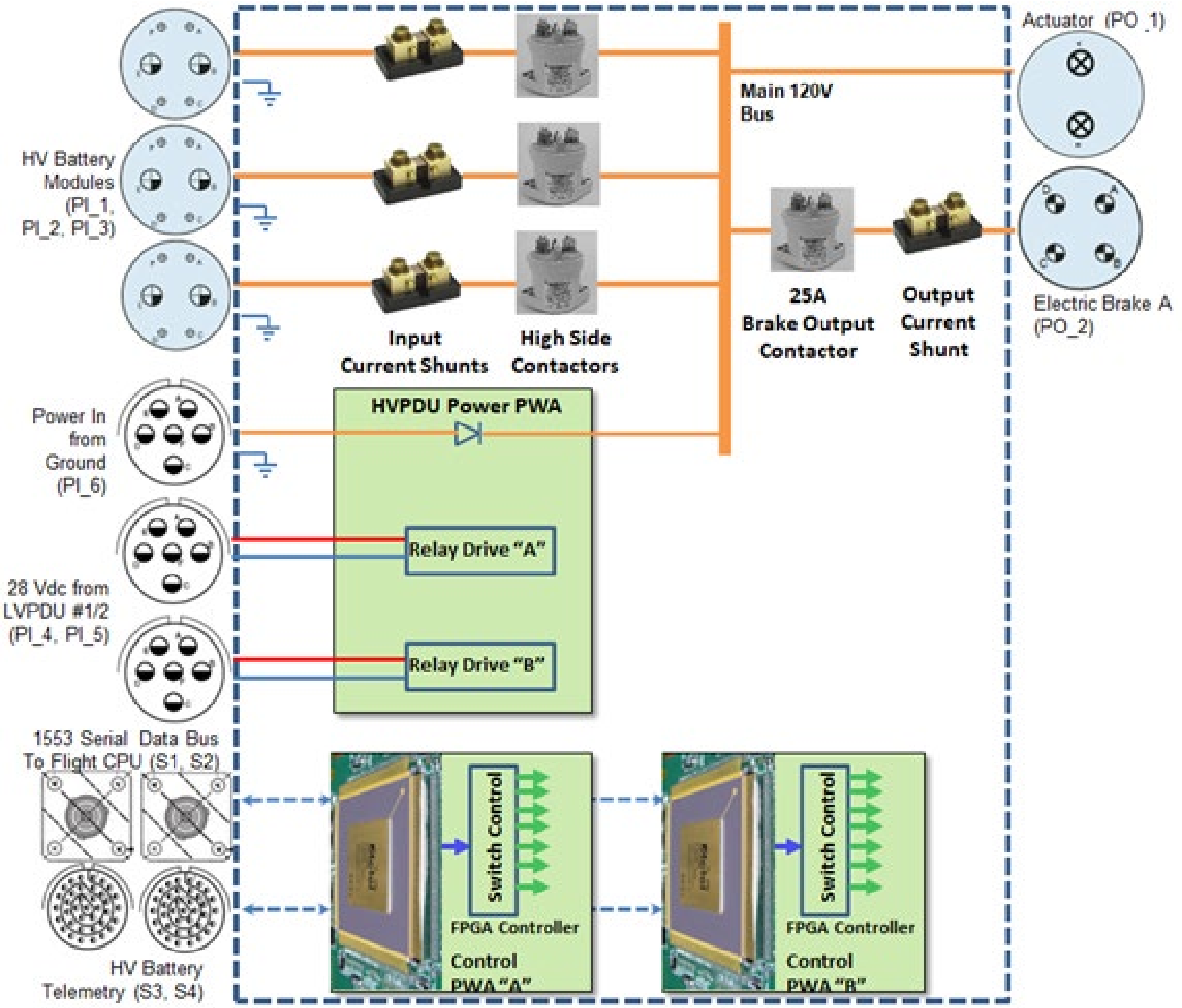
- **LVPDU receives commands/sends telemetry to/from Flight computer using MIL-STD-1553.**
  - Implemented using a rad-hard Microchip RTAX antifuse FPGA with Microchip’s Core1553 protocol IP core.
  - The FPGA implements a simple state machine for each controlled switch.
  - The FPGA collects all voltage, current, and temperature telemetry for the Flight computer.
  - The LVPDU uses a specialized digital interface to collect telemetry from the LVBM units.
  - Makes LVBM telemetry available to the MIL-STD-1553 bus without requiring costly electronics on the LVBM.

HVPDU Block Diagram

- **HVPDU Power Inputs**
  - HV Battery Modules (3x per HVPDU)
  - Current Shunt/High Side Contactor per HVBM
  - Ground Power Input (10A)

- **HVPDU Power Outputs**
  - Unswitched 350A output to ACU
  - Switched, Overcurrent Protected 25A to BCU

- **HVPDU Features**
  - Redundant Side A, Side B Control Electronics
  - FPGA Controllers w/ MIL-STD-1553
  - Battery on the Bus architecture
  - Telemetry interface to HVBMs
  - Space-grade, rad hard parts per EEE-INST-002 Level 2



HVPDU Block Diagram

- **DCEPS high voltage system is characterized by high current, transient loads during reentry**
  - AR and ZIN considered solid-state vs. electromechanical contactor power switches.
  - HVPDU power switch on-state must carry transient load currents up to 350A.
  - HVPDU power switch off-state must bidirectionally isolate the ACU and BCU loads from HVBM units.
  - These requirements drove the HVPDU to use electromechanical contactors, which are implemented using a Kilovac MAP200 base part custom screened and qualified to EEE-INST-002 Level 2 requirements.

- **HVPDU receives commands/sends telemetry to/from Flight computer using MIL-STD-1553**
  - Implemented using a rad-hard Microchip RTAX antifuse FPGA with Microchip’s Core1553 protocol IP core.
  - The FPGA implements a simple state machine for each controlled switch.
  - The FPGA collects all voltage, current, and temperature telemetry for the Flight computer.
  - The HVPDU uses a specialized digital interface to collect telemetry from the HVBM units.
  - Makes HVBM telemetry available to the MIL-STD-1553 bus without requiring costly electronics on the HVBM.

SIERRA SPACE

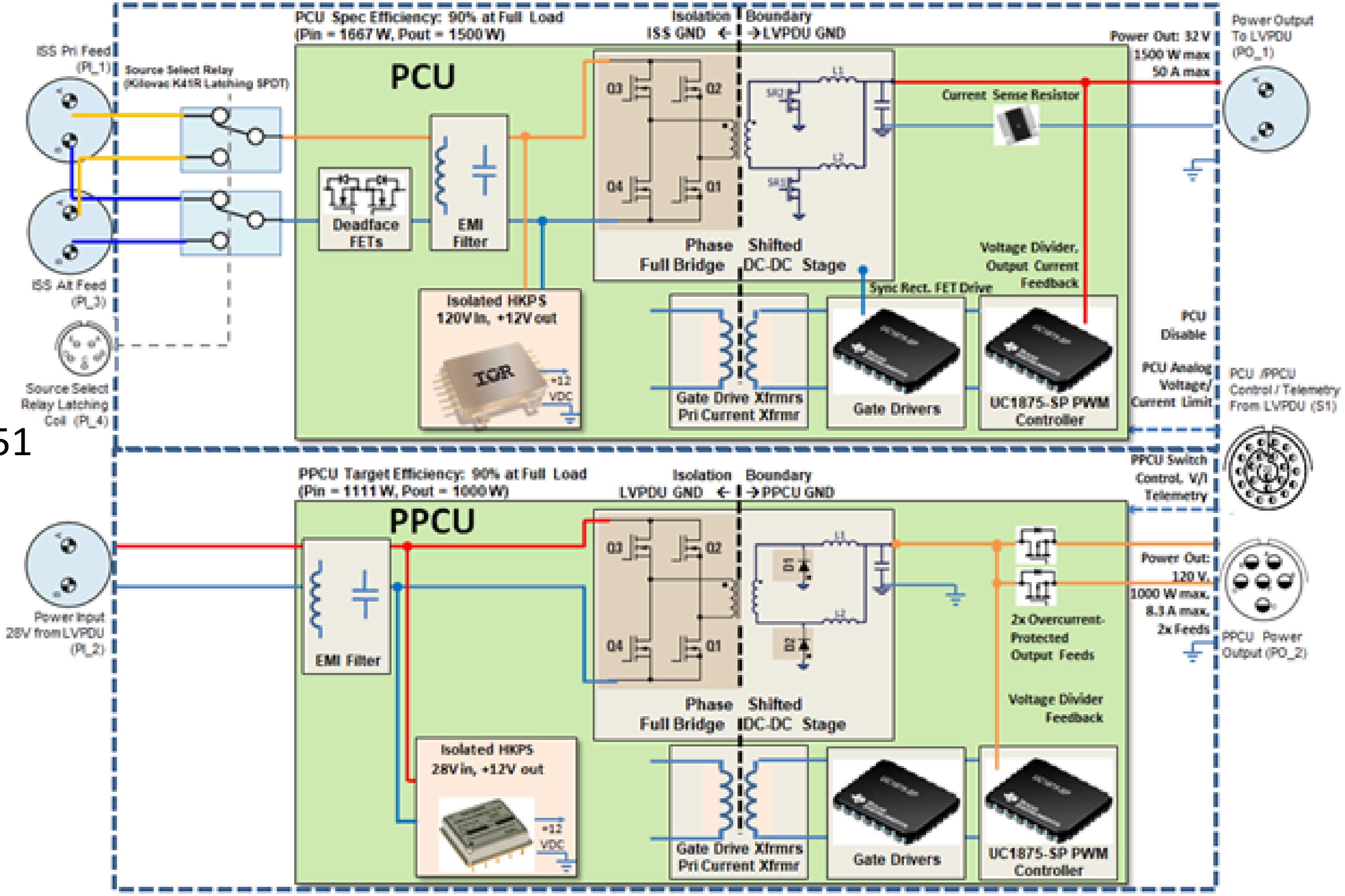
AEROJET ROCKETDYNE

ZIN Technologies

PCU/PPCU Block Diagram

- **PCU Features**
  - 120V from ISS Primary/Alternate
  - Phase Shifted Full Bridge DC-DC
  - Current Doubler, Sync Rectifier
  - >90% efficiency
  - Outputs 30V, 50A max
  - LVPDU programs PCU output voltage/current setpoints
  - Meets ISS Load reqs per SSP 52051

- **PPCU Features**
  - 28V from LVPDU 50A Switch
  - Phase Shifted Full Bridge DC-DC
  - Current Doubler, Diode Rectifier
  - >90% efficiency
  - Outputs 120V, 8.33A max
  - Telemetry interface to LVPDU
  - Meets ISS Source req's per SSP 30482



PCU/PPCU Block Diagram

- **PPCU input power sourced from the LVPDU Side A 50A output switch**
  - The PPCU emulates the ISS “Interface B” 120 Vdc feed to a payload per SSP 30482.
  - SSP 30482 controls the PPCU output impedance magnitude/phase, stability, and transient response.
  - SSP 30482 requirements were very challenging to meet, as they reflect the large, complex ISS power system.
  - Challenging for the PPCU to meet these requirements. Required iterations to control loop, output impedance.

- **PPCU EMI testing per MIL-STD-461F requirements**
  - These requirements drove the design of the PPCU front end filtering.
  - The PPCU has low input impedance (low input voltage, high input current), the output impedance of the EMI filter must be very low to meet the Middlebrook criterion.
  - This resulted in small series inductors and large parallel capacitors in the EMI filter.
  - The small input inductors did not sufficiently filter common mode currents, and therefore the PPCU required a separate common mode filter element.

Conclusions

- **The ZIN / Aerojet Rocketdyne team designed, built, tested, and delivered:**
  - 5x LVPDU, 4x HVPDU, and 5x PCU/PPCU flight power electronics assemblies for Dream Chaser *Tenacity*
  - Flight units were designed and built at ZIN Technologies from 2020 to 2021.
  - Environmental tests (shock, vibe, EMI, TVAC, burn-in) at test labs across the United States from 2021 to 2022.
  - DCEPS hardware passed all acceptance/qualification testing and achieved Technology Readiness Level (TRL) 8.
  - Flight hardware delivered to Sierra Space in early 2022.
  - Hardware integrated onto Dream Chaser *Tenacity* for spacecraft level testing in 2023.

- **This paper provided an overview of the Dream Chaser Electrical Power System**
  - The design drivers of the Dream Chaser EPS were identified, and design approaches were discussed.
  - ZIN and AR developed the Dream Chaser EPS over ten years, as the project evolved from crewed to cargo.
  - This required an agile design team to operate under challenging schedule/cost pressures.

Questions?

Low Voltage Power Distribution Unit (LVPDU) 3x per Dream Chaser

High Voltage Power Distribution Unit (HVPDU) 2x per Dream Chaser

Power Converter Unit / Payload Power Converter Unit (PCU/PPCU) 3x per Dream Chaser