Overview of the Dream Chaser® Electrical Power System

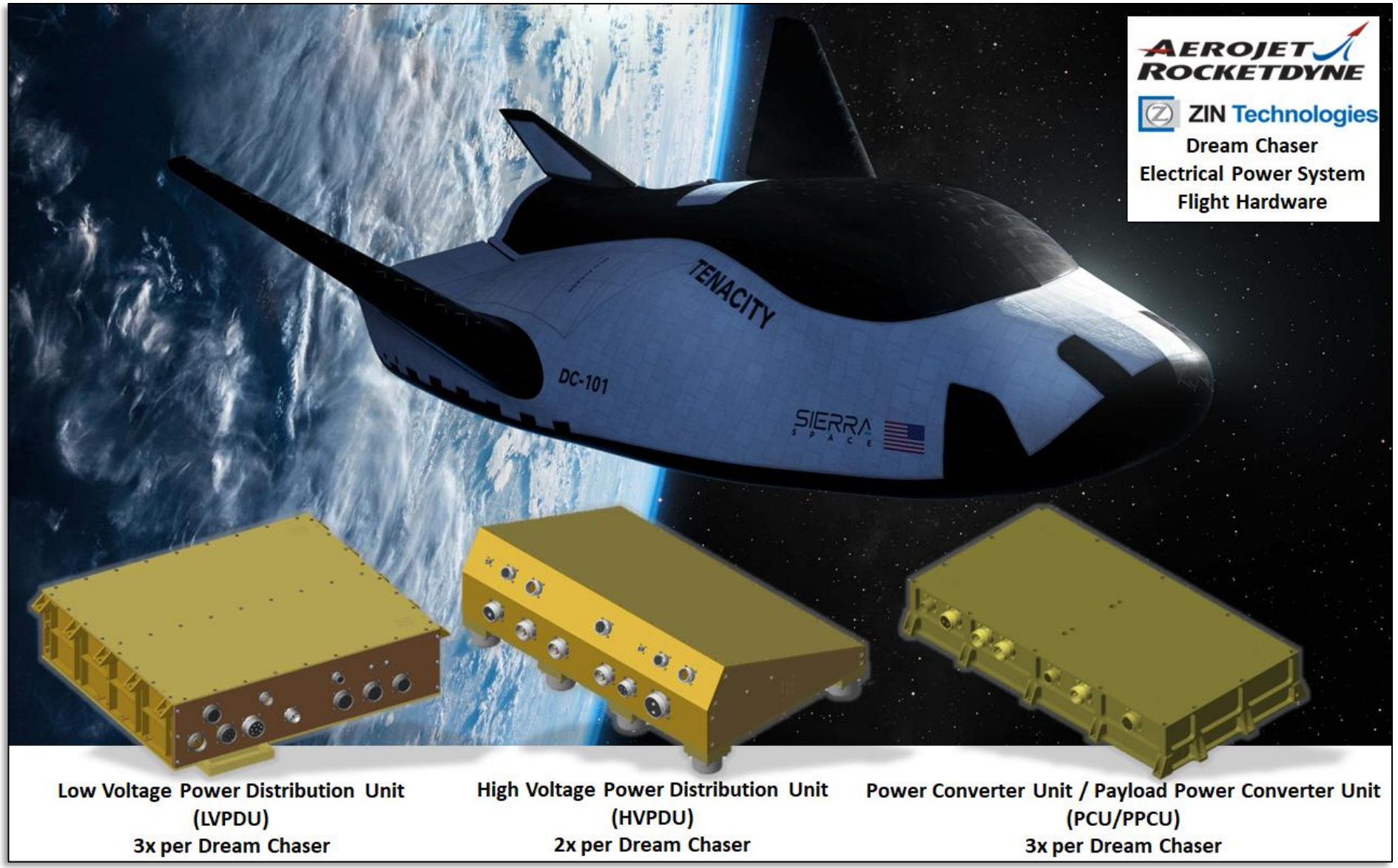
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Introduction

- **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

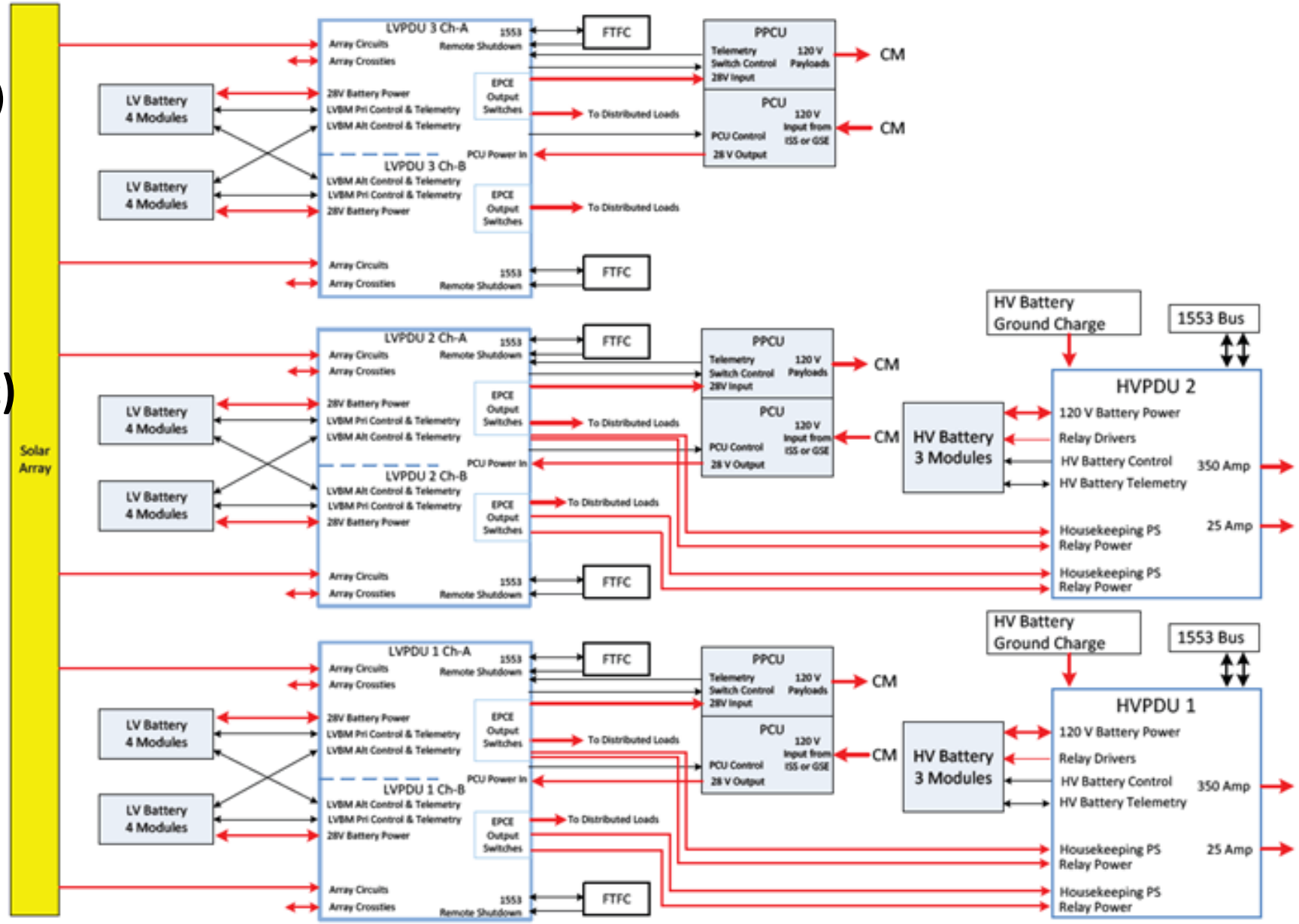


Introduction

- **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.**

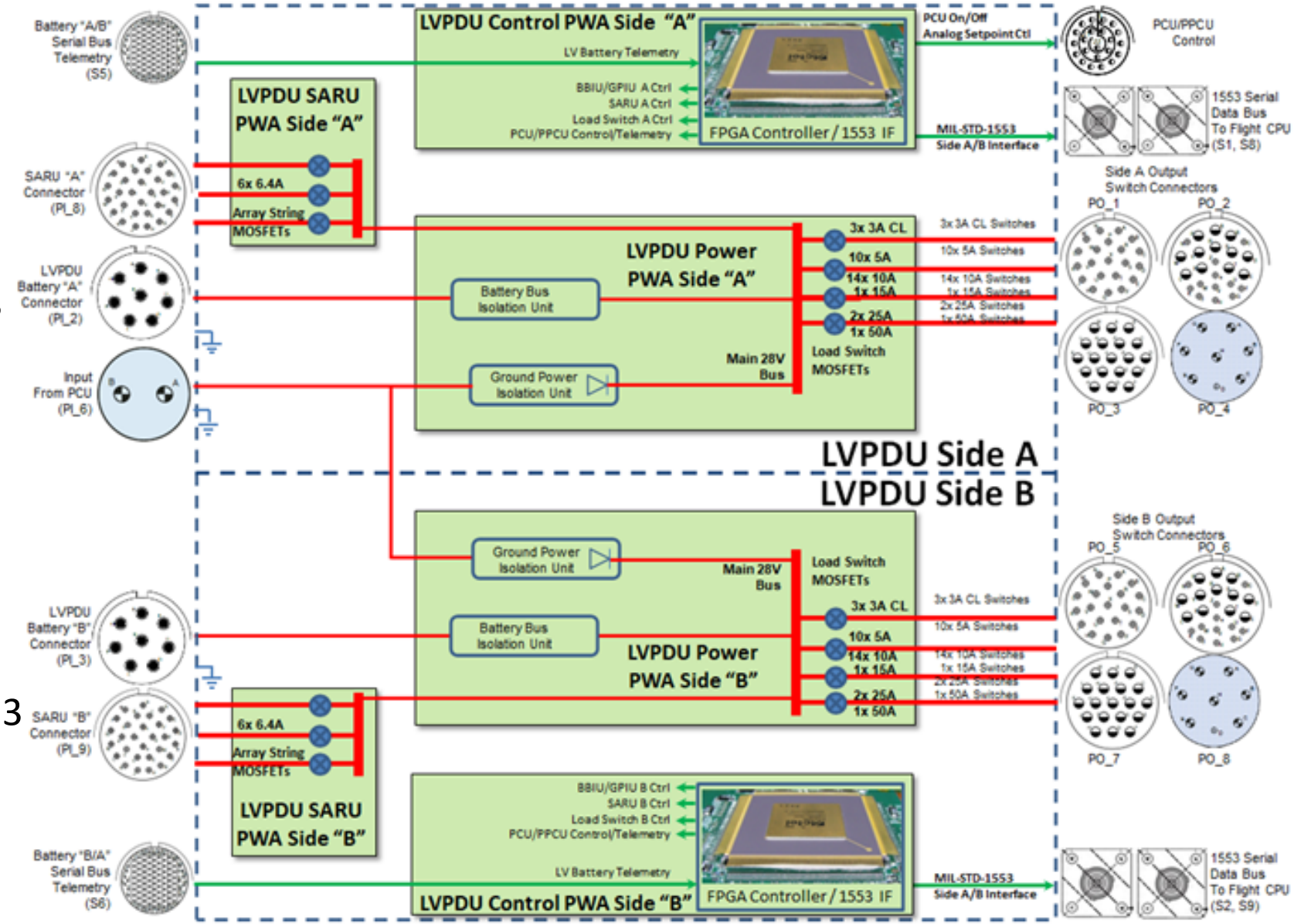
Dream Chaser EPS Block Diagram

- **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



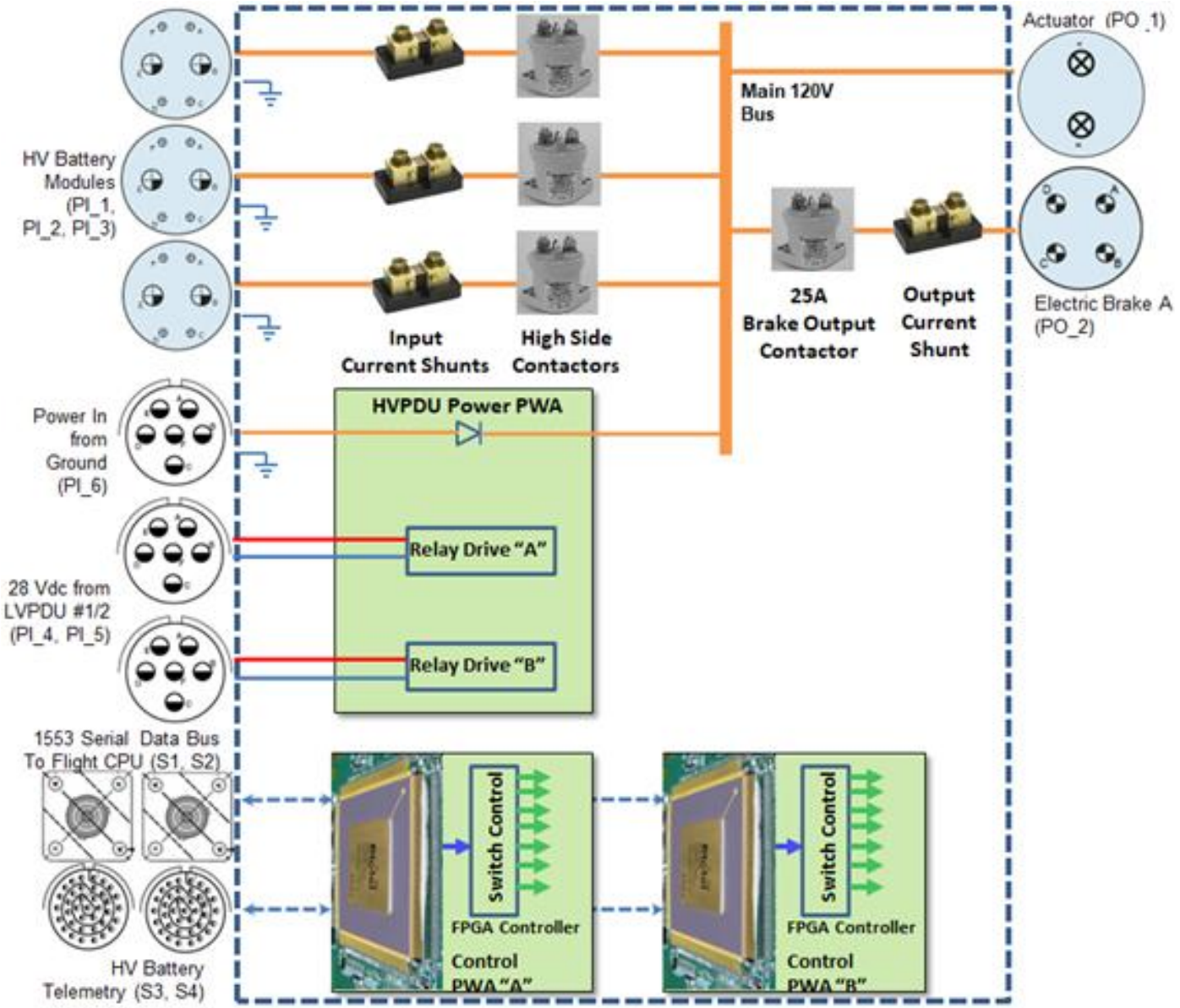
LVPDU Block Diagram

- **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

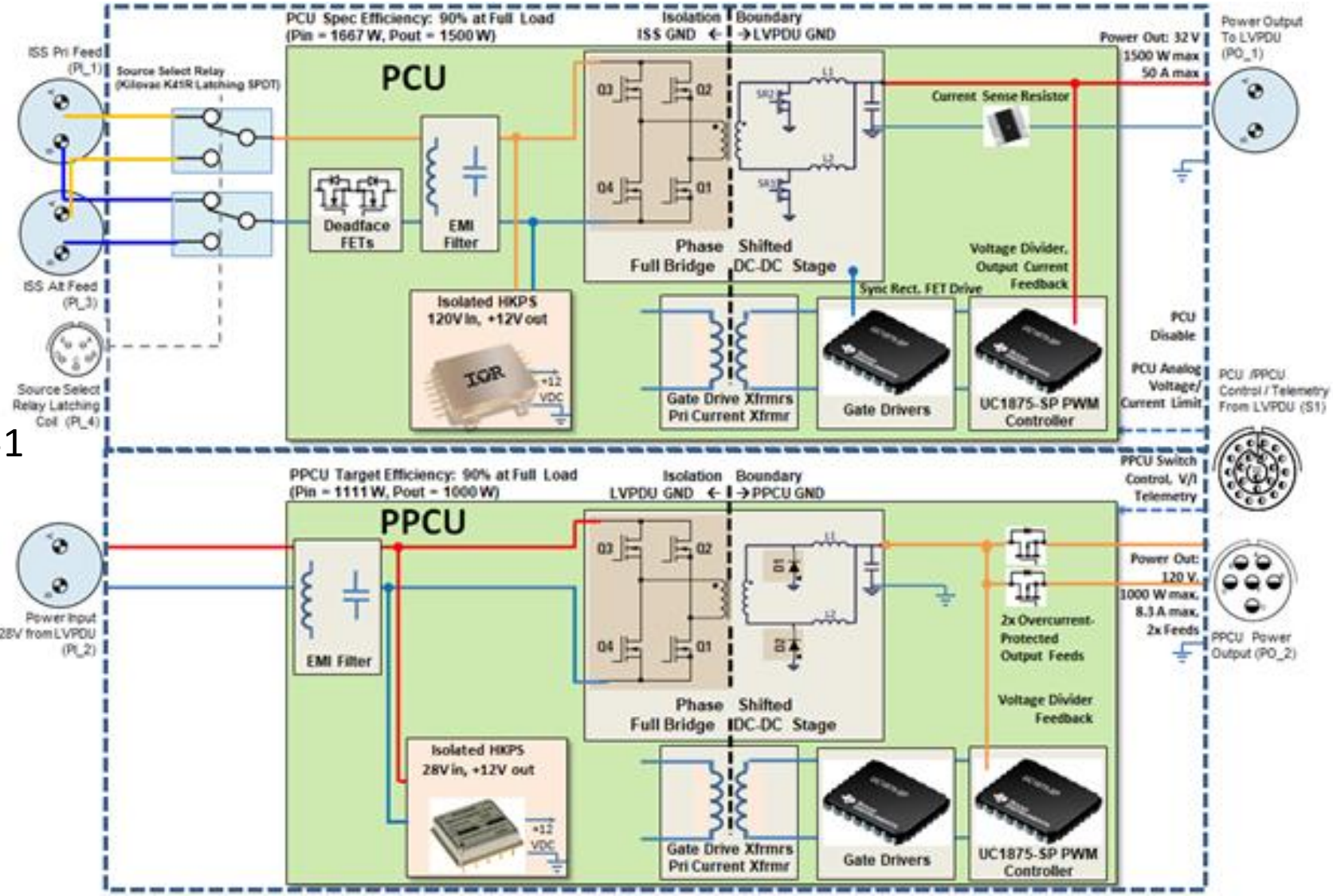
- **DCEPS high voltage system is characterized by high current, transient loads during reentry**
  - AR and ZIN considered solid-state vs. electromechanical contactor power switches.
  - HVPDU power switch on-state must carry transient load currents up to 350A.
  - HVPDU power switch off-state must bidirectionally 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.

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.

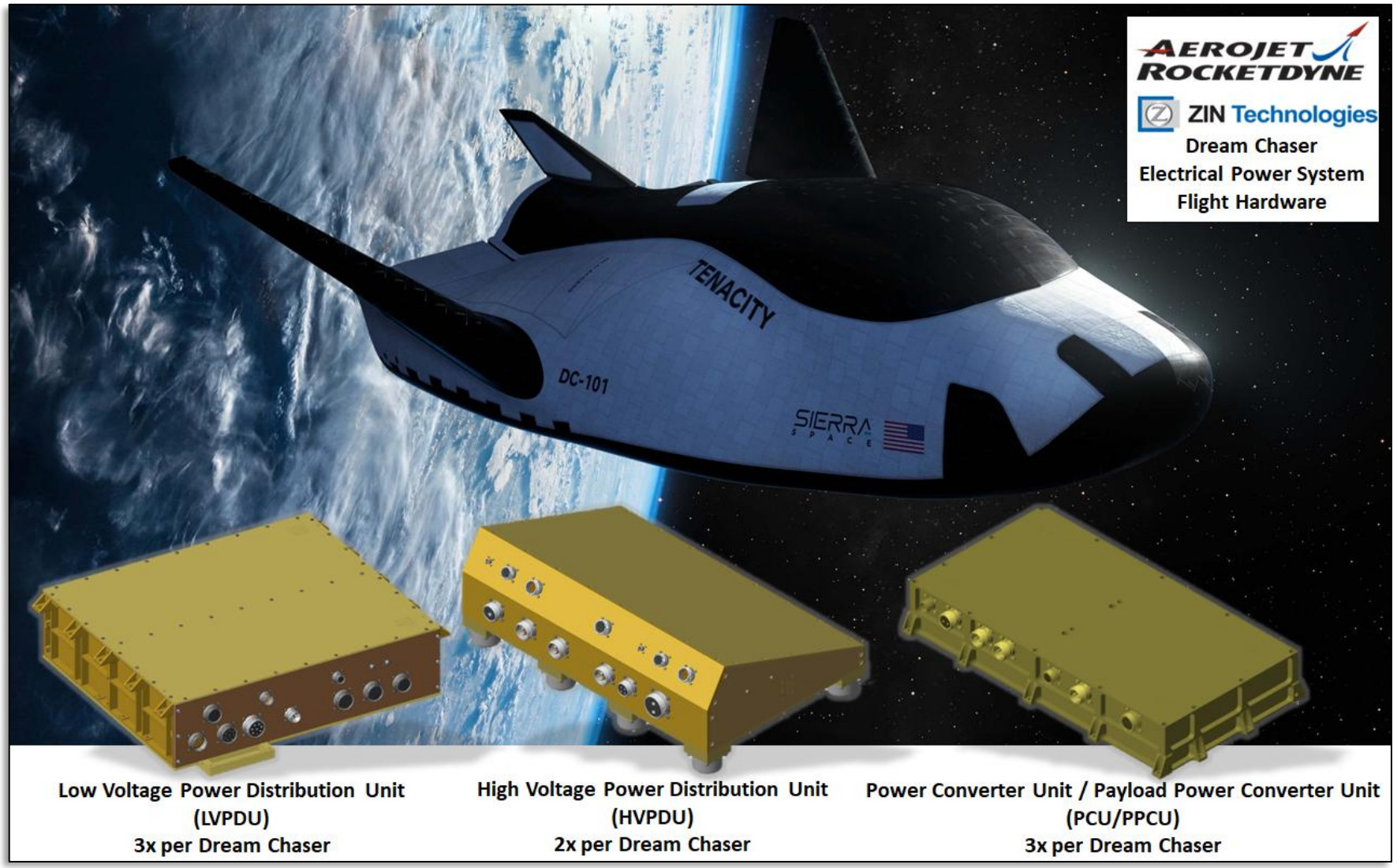
- **PPCU EMI testing per MIL-STD-461F requirements**
  - These requirements drove the design of the PPCU front end filtering.
  - The PPCU has low input impedance (low input voltage, high input current), the output impedance of the EMI filter must be very low to meet the Middlebrook criterion.
  - This 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?


AEROJET ROCKETDYNE
ZIN Technologies
Dream Chaser
Electrical Power System
Flight Hardware
TENACITY
DC-101
SIERRA SPACE
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