



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







- 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



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LVPDU 3 Ch-A Low Voltage (24 to 32 Vdc) 1553 FTFC PPCU Array Circuits Remote Shutdown Telemetry 120 V CM Array Crossilies Switch Control Pavloa 28V Input EPCE Low Volt Battery Modules (24x) 28V Battery Powe Output LV Battery PCU LVBM Pri Control & Telemetry Switches To Distributed Loads 120 V 4 Modules VBM Alt Control & Telemetry input from CM 3x LVPDU Units w/ Side A, B PCU Control ISS or GSE 28 V Output PCU Power 8 LVPDU 3 Ch-B VBM Alt Control & Telemetry 4x LVBM per LVPDU Side LV Battery LVBM Pri Control & Telemetry EPCE 4 Modules To Distributed Loads Output NV Battery Proces Switches Solar Array Strings (36x) Array Circuits FTFC 5553 6x Strings per LVPDU Side Array Crossilier Remote Shutdown **HV Battery** 1553 Bus Ground Charge LVPDU 2 Ch-A FTFC 1553 PPCU Remote Shutdown Array Circuits 120 V Telemetry CM Array Crossilies Switch Control Payloads High Voltage (108 to 140 Vdc) HVPDU 2 28V input EPCE 28V Battery Power Output LV Battery PCU 120 V Battery Power VBM Pri Control & Telemetry Switches To Distributed Load 130 V 4 Modules High Volt Battery Modules (6x) input from HV Battery VBM Alt Control & Telemetry CM Relay Drivers PCU Control Solar ISS or GSE 3 Modules HV Battery Control PCU Power Ir 28 V Output 350 Amp Array LVPDU 2 Ch-B – 2x HVPDU Units HV Battery Telemetry LVBM Alt Control & Telemetry LV Battery To Distributed Loads EPCE LVBM Pri Control & Telemetry 4 Modules Output 28V Battery Powe 25 Amp 3x HVBM per HVPDU Switches fousekeeping PS **Relay Power** Housekeeping PS Array Circuits FTFC 1553 Relay Power Array Crossities Remote Shutdown **HV Battery** Power Converter Unit 1553 Bus Ground Charge LVPDU 1 Ch-A 1553 FTFC PPCU Array Circuits Remote Shutdow **Telemetry** 120 V CM PCU converts 120V from ISS to **Array Crossities** Switch Control Payloads 28V input HVPDU 1 EPCE 8V Battery Powe LV Battery Output PCU 120 V Battery Power LVBM Pri Control & Telemetry power LVPDU, recharges LVBM 4 Modules To Distributed Loads 120 V Switcher LVBM Alt Control & Telemetry input from CM HV Battery Relay Drivers PCU Control ISS or GSE 3x PCU Units, one per LVPDU 3 Modules PCU Power Is 28 V Output HV Battery Control 350 Amp LVPDU 1 Ch-B HV Battery Telemetry LVBM Alt Control & Telemetry LV Battery LVBM Pri Control & Telemetry EPCE To Distributed Loads 4 Modules - 1.5 kW (30V, 50A) per PCU 28V Battery Powe Output Switches Housekeeping PS 25 Amp Relay Power Array Circuits Housekeeping PS FTFC 1553 Array Crossilies Relay Power Remote Shutdown Page 4

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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



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• 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.

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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



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• 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



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Isolation Boundary **PCU** Features PCU Spec Efficiency: 90% at Full Load Power Output ISS GND ← → LVPDU GND (Pin = 1667 W, Pout = 1500 W) Power Out: 32 V To LVPDU ISS Pri Feed 1500 W max (PO_1) (PL1) Source Select Relay PCU 50 A max 120V from ISS Primary/Alternate Kilovac K41R Latching SPOT 03 = Ea Current Sense Resisto Phase Shifted Full Bridge DC-DC **Current Doubler, Sync Rectifier** ΰŵ 04 3 0 >90% efficiency Deadface EMI FETS Filter Phase Voltage Divider DC-DC Stage Full Bridge **Output Current** Outputs 30V, 50A max Feedback ISS At Feed Sync Rect. FET Drive Isolated HKPS 120V In, +12V out PCU LVPDU programs PCU output Disable PCU Analog voltage/current setpoints +12 Voltage/ Control / Telemetry Source Select Gate Drive Xfrmrs UC1875-SP PWM Current Limit Relay Latching From LVPDU (S1 Gate Drivers **Pri Current Xfrmr** Controller Coll (PL4) Meets ISS Load reqs per SSP 52051 PPCU Target Efficiency: 90% at Full Load Isolation Boundary Control, V/I (Pin = 1111 W, Pout = 1000 W) LVPDU GND ← I → PPCU GND Telemetry PPCU **PPCU** Features ٥, 83 Power Out: 00 120 V ۲ 1000 W max 28V from LVPDU 50A Switch 8.3 A max Power Input 2x Overcurrent 2x Feeds 28V from LVPDU Protected PPCU Power 04 E Phase Shifted Full Bridge DC-DC (PL2) Output (PO 2) **Output Feeds EMI Filter** Current Doubler, Diode Rectifier Voltage Divider Phase Shifted Full Bridge IDC-DC Stage Feedback Isolated HKPS >90% efficiency 28V in, +12V out Outputs 120V, 8.33A max Gate Drive Xfrmrs Telemetry interface to LVPDU UC1875-SP PV Gate Driver Pri Current Xfrmr Controll Meets ISS Source req's per SSP 30482

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• 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.

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- 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?



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Page 12