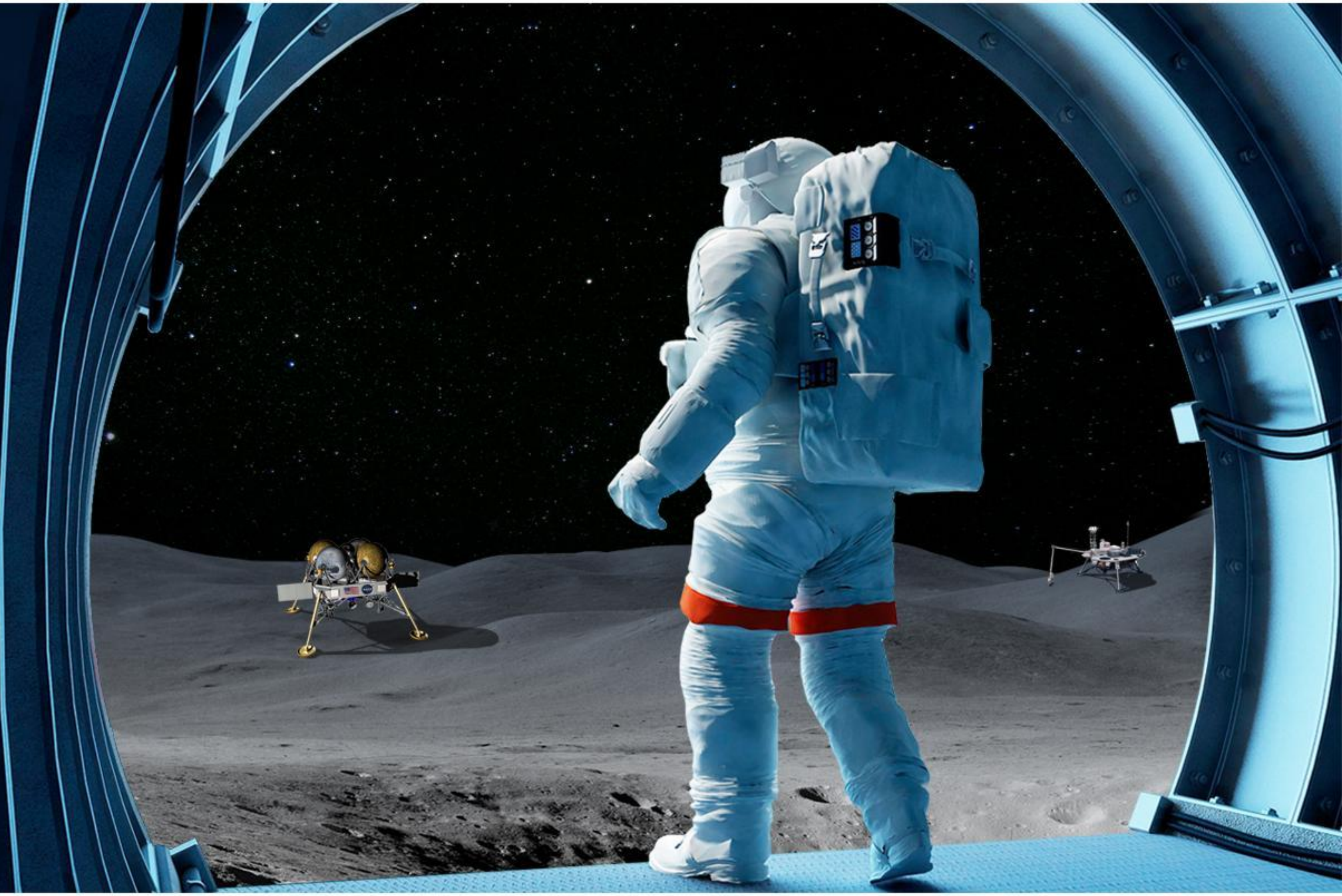
Modular Standards for Space Power Systems

National Aeronautics and Space Administration



International Aerospace Congress 2019

Washington, D.C., October 21 – 25

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NASA Glenn Research Center
Cleveland, Ohio

October 2019

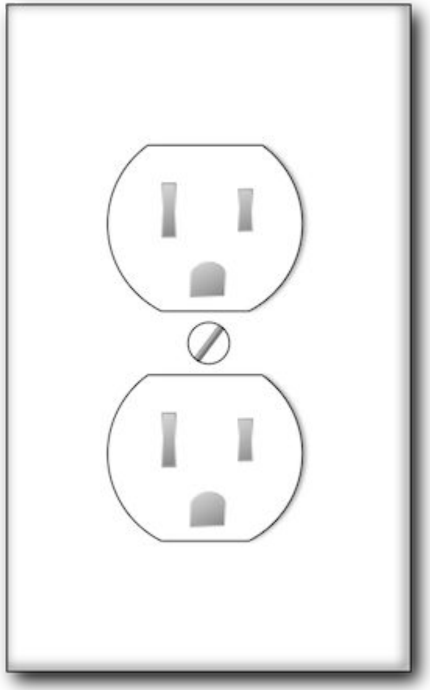
Outline

- Standardization
  - Interfaces
  - Modularization
- AMPS Project
- Modular Electronics Standard for Space Power Systems (MESSPS)
  - Definitions
  - Module “Trading Cards”
  - Examples
- Future Work & Conclusions

Edison Screw (E26)

1880+

Hubbell Socket (NEMA 1-15)



1912+

USB

1996+

Standardization of interfaces:

- Focuses innovation on function/performance of device
- Increases competition by allowing easier injection into market
- Allows for multiple supply chain options
- Improves efficiency (fewer adapters, etc.)
- Reduces cost to consumer

Modularization is an extension of standardization, adding functional requirements to a standardized interface. However, the effects are mixed:

Pros:

- **Commonality/Reusability**
  - Interchangeable between systems
  - Allows scavenging from unused systems
  - Reduces sparing needs
- **Flexibility**
  - Meant for scalable systems
  - Unrestricted system architecture/topology
- **Reliability/Maintainability**
  - Reduced capability over complete loss of use
  - Removable replacements minimize downtime

Cons:

- **Unoptimized Design**
  - Higher mass/volume due to packaging and/or incremental nature
  - Greater complexity due to more interconnects
- **System Verification**
  - Integration of multiple vendor products
  - Replacing modules invalidates system testing
- **Limited Extensibility**
  - More difficult to ensure backwards compatibility (“future-proof”)

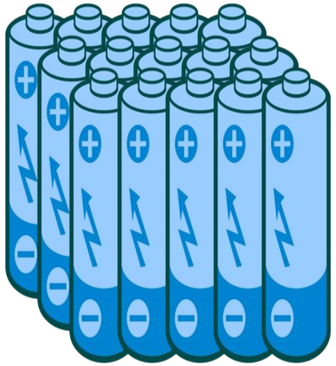
As systems become larger and/or more complex, modularity can prove to be more economical.

Example: Battery design

For the same energy storage capacity, a modular design is more complex and has a higher mass, but offers less tangible benefits:

- Component reuse in dissimilar systems
- Lower-mass replaceables
- Fault tolerance (at reduced capacity)

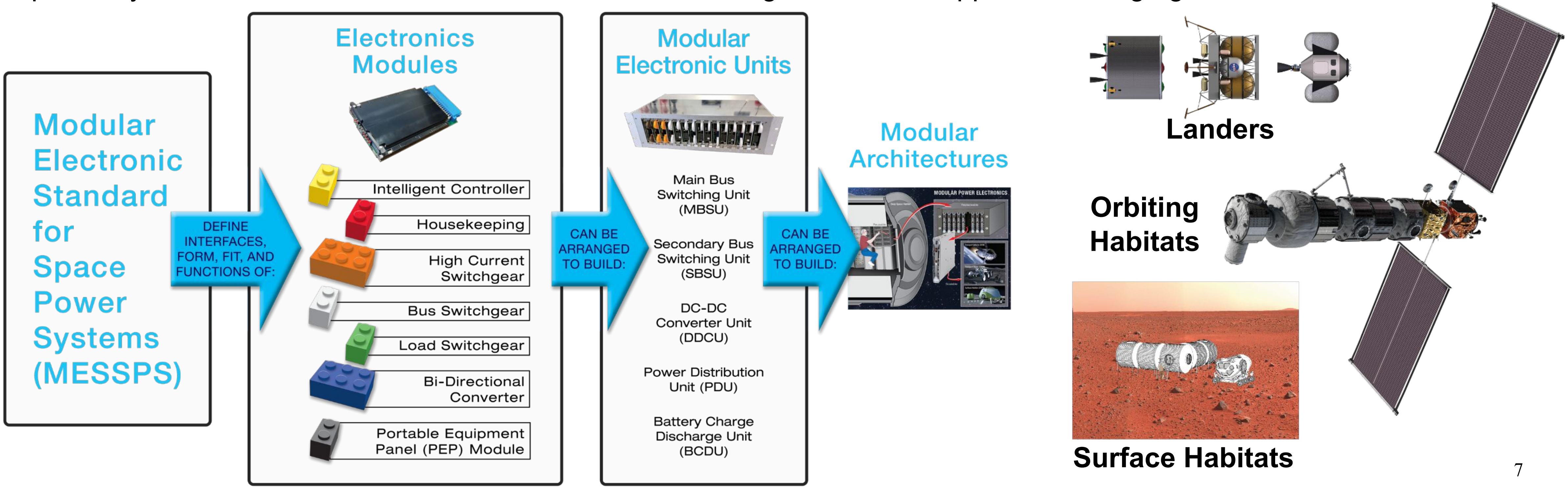
Modularization can seem unappealing unless all factors are taken into account. This makes "selling" modularity a challenge.



Solution	Modular	Optimized
Components	15 "AAA"	1 "D"
Mass	172.5 g	139 g
Volume	57 cm^3	56 cm^3

Advanced Modular Power Systems (AMPS) – Overview

- **<u>Why is this project important?</u>**
  - Modular power systems provide opportunities to minimize maintenance operations, improve power system availability, and reduce the number of unique spare parts, thus enabling sustainable future human exploration missions and systems
  - This project matures modular power system technologies, inclusive of a modular power standard, modular power electronics, autonomous power controls, and a modular power testbed in support of NASA's cis-lunar Gateway
- **<u>Objectives:</u>**
  - The AMPS project seeks to ***transform future space power system architectures*** with a modular approach, standardizing the power system at the electronics module level, and validating the modular approach through ground-based demonstrations



Advanced Modular Power Systems (AMPS) - History

1995 - Modular electric space power system proposed by Button & Baez (NASA GRC)

… NASA focuses on Shuttle, ISS, & Constellation Program (no modular concepts) …

2012 - NASA's Advanced Exploration Systems (AES) program begins **AMPS** project

… Early prototypes of modular concepts developed, interfaces formalized, 4 module types defined …

2016 - First draft of modular electronics standard generated

… Prototype designs refined, 3 module types added, system-level testing …

2019 - Modular Electronics Standard for Space Power Systems (MESSPS) generated

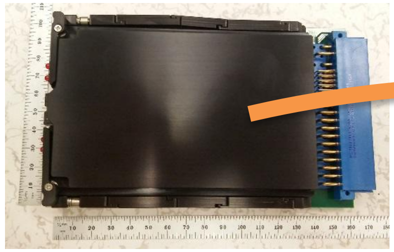
… Being considered for lunar missions and beyond …

Advanced Modular Power Systems (AMPS) - Scope

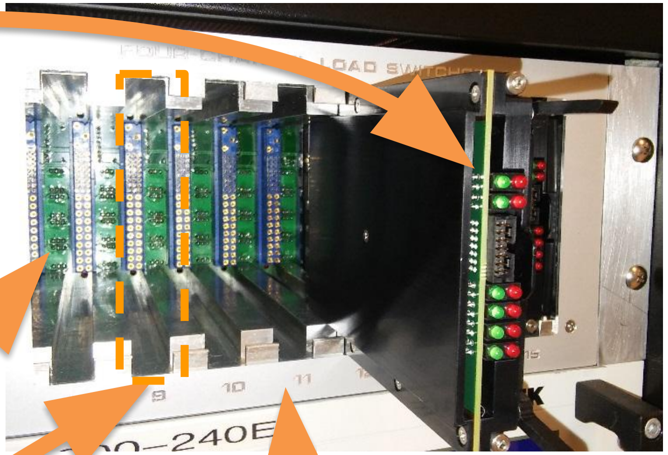
AMPS targets:

- Larger, multi-kilowatt, multi-vehicle/element manned missions
- Power distribution & conversion, not generation or storage (yet)
- 120VDC primary distribution bus (SAE AS5698/ISPSIS compatible)
- In-space replacement of modules (cold/warm swap, blind mate)
- Standardizing module functions & interfaces, not designs

Modular Electronics Standard for Space Power Systems (MESSPS) - Definitions



Module

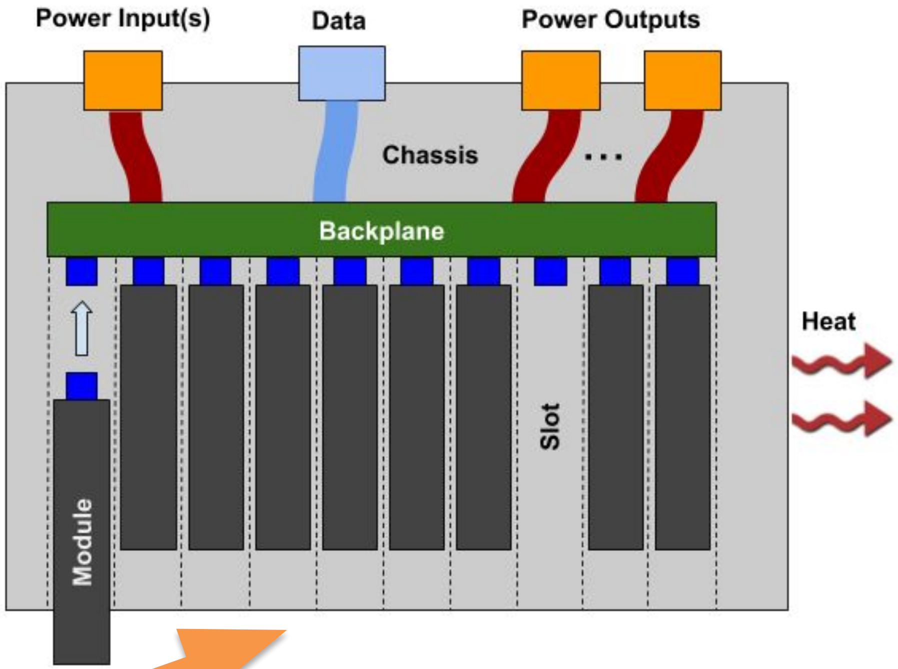


Backplane

Slot

Chassis

Assemblies

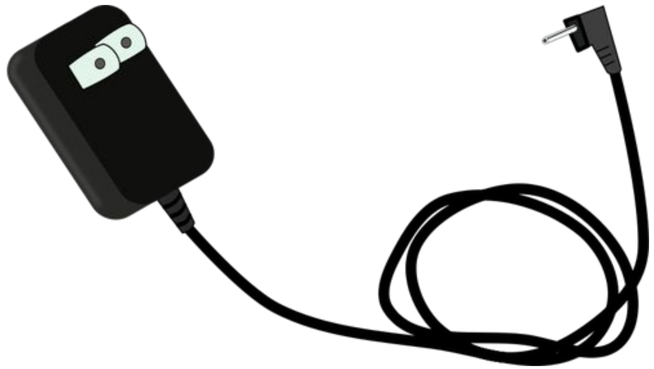


Electronics **modules** can be arranged into **chassis** to form **assemblies**.
Backplanes have unique **slot** arrangements and connections for each application.

Modular Electronics Standard for Space Power Systems (MESSPS) - Modules

The MESSPS currently defines 7 modules:

- **Utility modules**: supporting functions
    - Controller Module (CTLM)
    - Housekeeping Power Module (HKPM)
- **Switchgear modules**: remote control & fault protection
    - Load Switchgear Module (LSGM)
    - Bus Switchgear Module (BSGM)
    - High Current Switchgear Module (HCSM)
- **Converter modules:** voltage conversion & regulation
    - Portable Equipment Power Module (PEPM)
    - Bidirectional Converter Module (BDCM)



No specific backplanes are defined (yet), but there are requirements for implementing any backplane.

Controller Module (CTLM)

Functions:

- Spacecraft-to-internal network adapter
- Validates chassis configuration
- Monitors module status
- Translates commands & telemetry

SCCN: Spacecraft Communications Network

Inputs/Outputs:

- Spacecraft communication network (Ethernet)
- Internal data bus (dual CAN)

Size: 3U x 1 Slot

TRL: 4

Status: 4th gen. prototype demonstrated in chassis

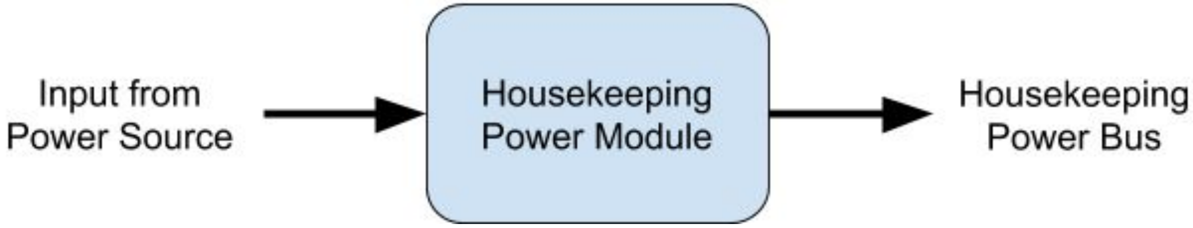
Prototype Design / Major Components:

- Raspberry Pi Compute Module running Raspbian operating system
- Ethernet & CAN controllers

Housekeeping Power Module (HKPM)

Functions:

- Generates Housekeeping Power Bus (5VDC) from 120VDC source



Inputs: 120VDC
Outputs: 5VDC @ 30A (150W)

Size: 3U x 1 Slot
TRL: 4
Status:

- 3nd gen. prototype demonstrated in chassis

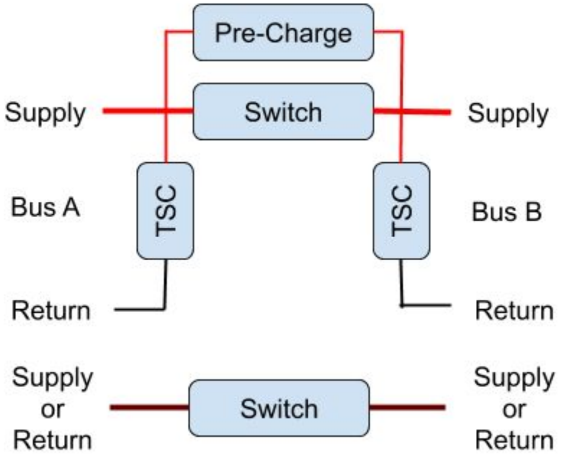
Prototype Design / Major Components:

- Digilent Cmod A7 FPGA module
- 150W Vicor "Micro" DC/DC converter

Bus Switchgear Module (BSGM)

Functions:

- Bidirectional bus switch (supply & return, or supply only with lower on-state resistance)
- Bidirectional pre-charge circuit
- Configurable, resettable trip
- Transient suppression



TSC: Transient Suppression Circuit

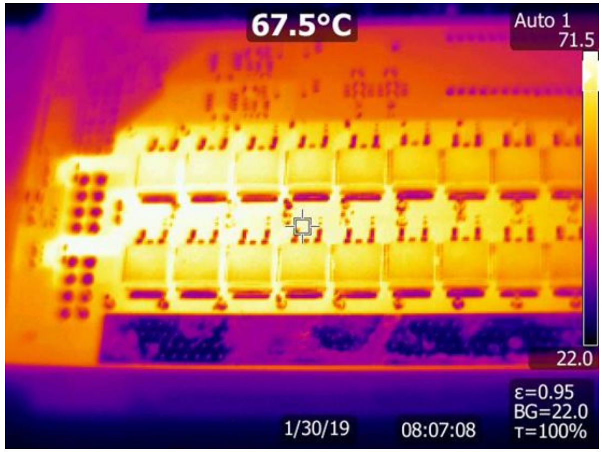
Inputs/Outputs: 2 ports @ 120VDC, 40A

Size: 3U x 1 Slot

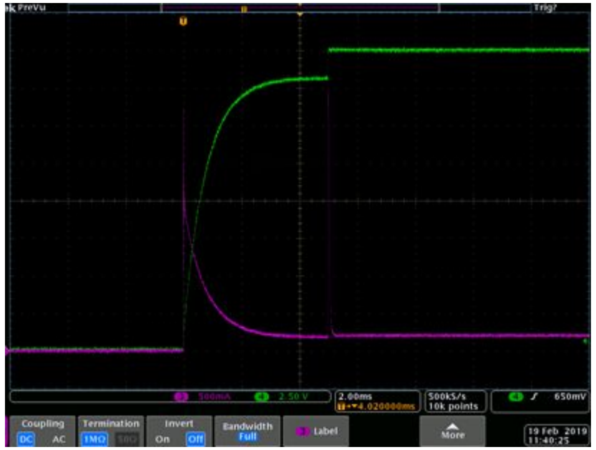
TRL: 4

Status:

- 5th gen. prototypes demonstrated in chassis



Thermal Test

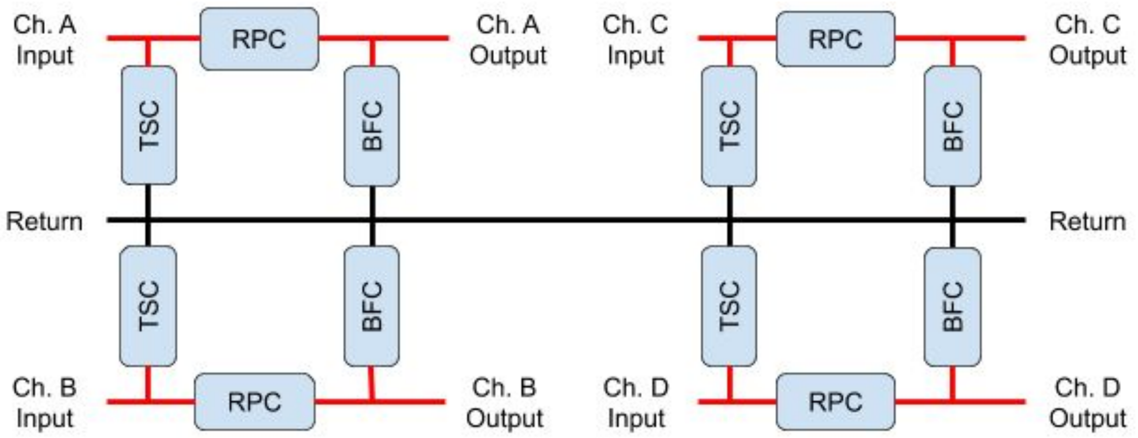


Pre-Charge/Make Test

Load Switchgear Module (LSGM)

Functions:

- 4-channel unidirectional switch
- Current-limiting with configurable levels
- Resettable trip
- Parallelable channels can form “virtual power channels” (VPCs)
- Inductive load protection, safe discharge



RPC: Remote Power Controller TSC: Transient Suppression Ckt. BFC: Bleeder-Flyback Ckt.

Inputs: 4 @ 120VDC, 4A

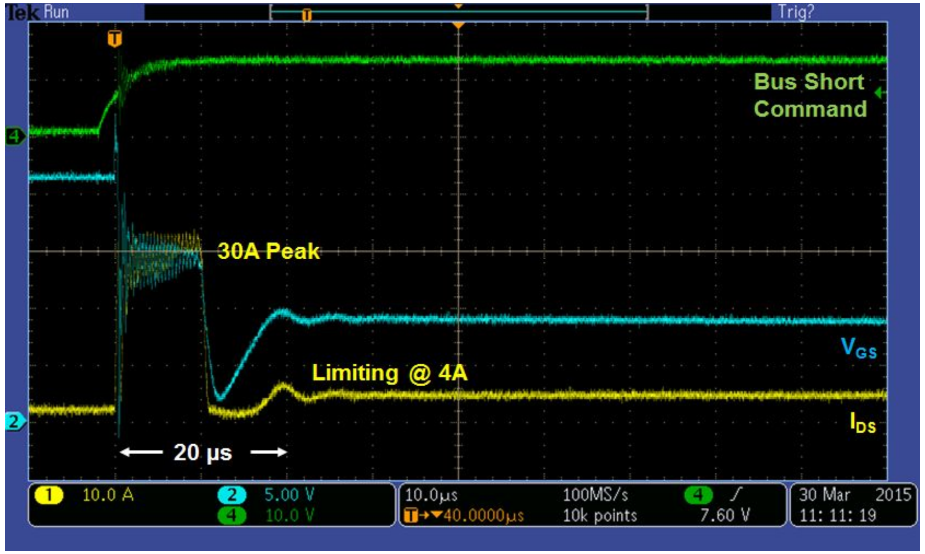
Outputs: 4 @ 120VDC, 4A

Size: 3U x 1 Slot

TRL: 4

Status:

- 6th gen. prototypes demonstrated in chassis, paralleled 8 channels across 2 modules



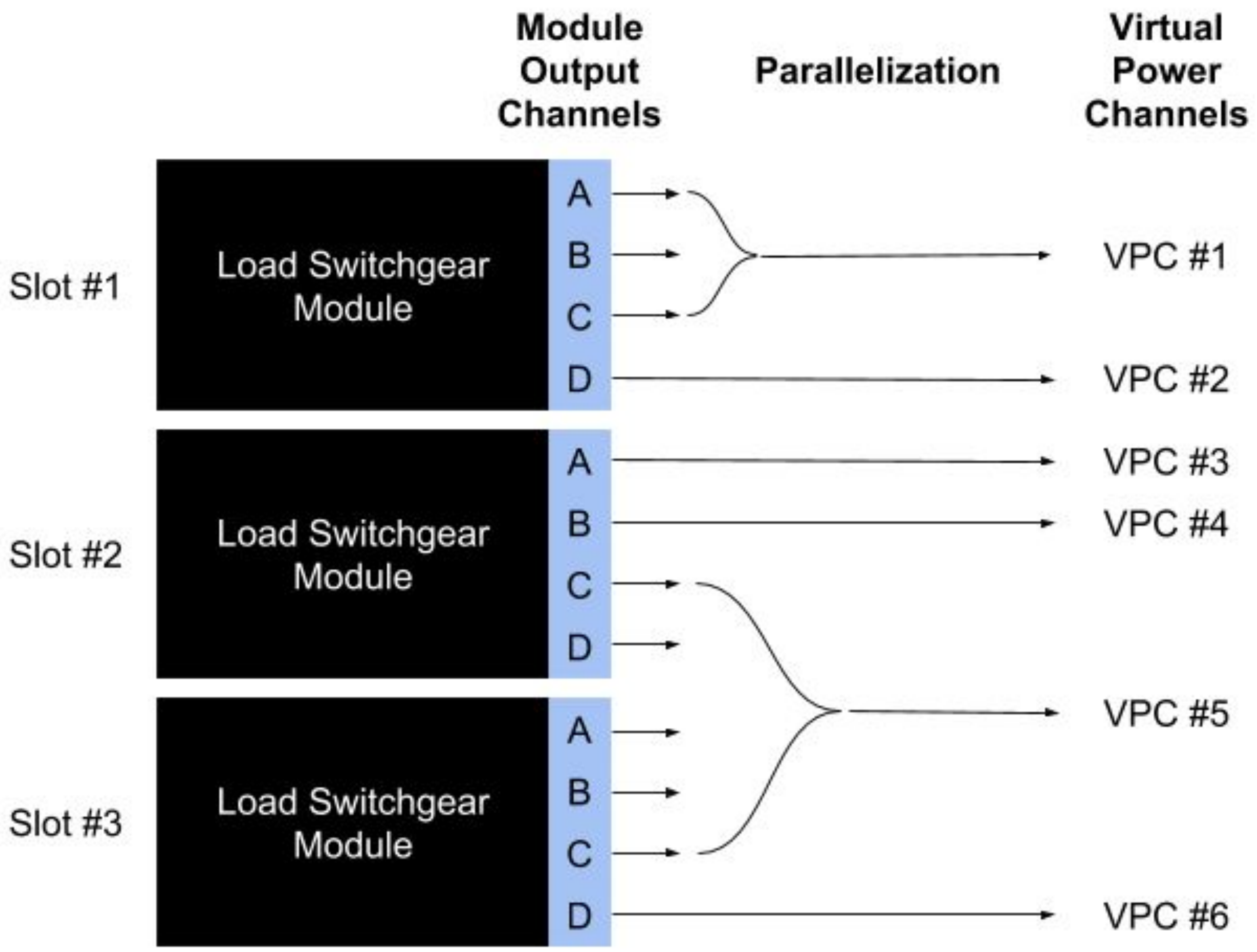
Short-Circuit Load Test (Current-Limiting)

Flexibility!

The 4x4A outputs of the Load Switchgear Modules (inside a single PDU) can be paralleled to form higher-current VPCs.

Parallelization can take place on the backplane, cables, and/or at the load.

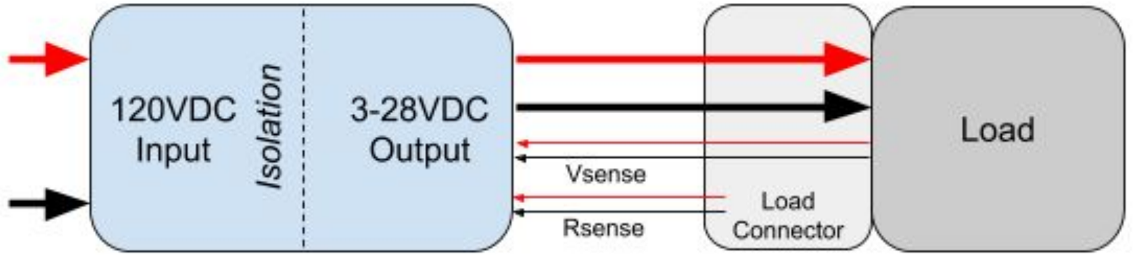
Current-limiting algorithms handle timing mismatches to prevent single-channel faults during transient events.



Portable Equipment Power Module (PEPM)

Functions:

- Variable output, isolating DC/DC converter ("universal adapter")
- Load cable or user programmable output
- Remote voltage sense



Input: 120VDC

Output: 3-28VDC @ 5.3A (up to 150W @ 28VDC)

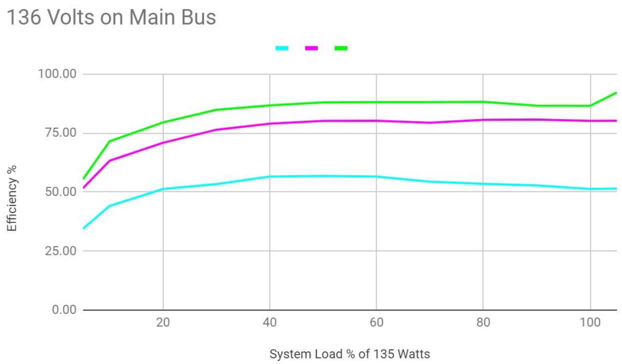
Size: 3U x 1 Slot

TRL: 4

Status:

- Jointly funded by JSC and GRC
- 3rd gen. prototypes demonstrated in chassis

Featured on Instagram @nasaglenn

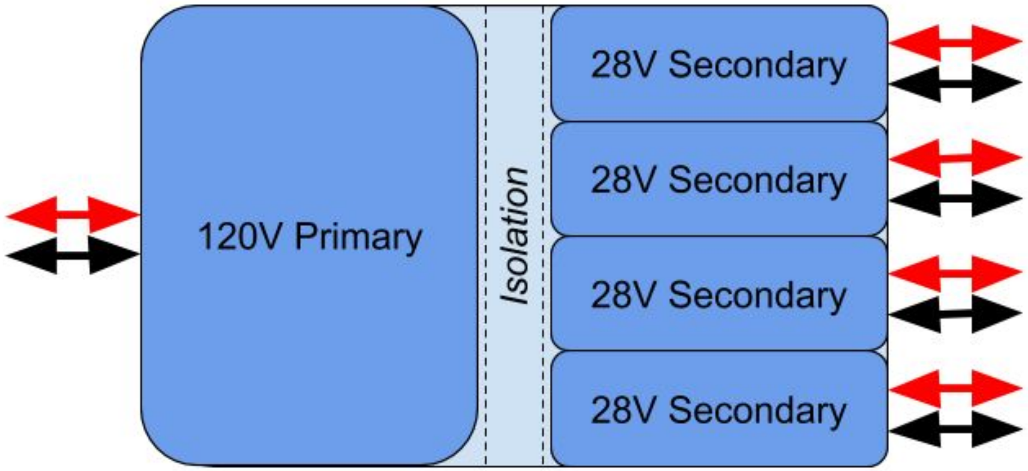


Efficiency Test

Bidirectional Converter Module (BDCM)

Functions:

- Bidirectional DC/DC converter
- Configurable current & voltage setpoints
- Configurable, resettable trip
- Configurable secondary: 120VDC or 28V
- Parallelable: synchronized, staggered switching for reduced EMI



Inputs/Outputs:

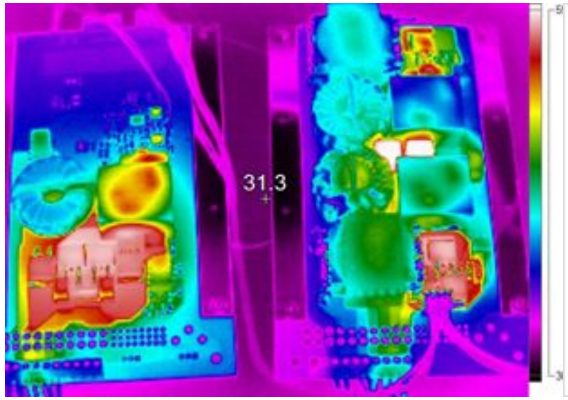
- “Primary”: 120VDC @ 10A (~1kW)
- “Secondary”: 120VDC @ 10A or 28VDC @ 40A

Size: 3U x 3 Slots

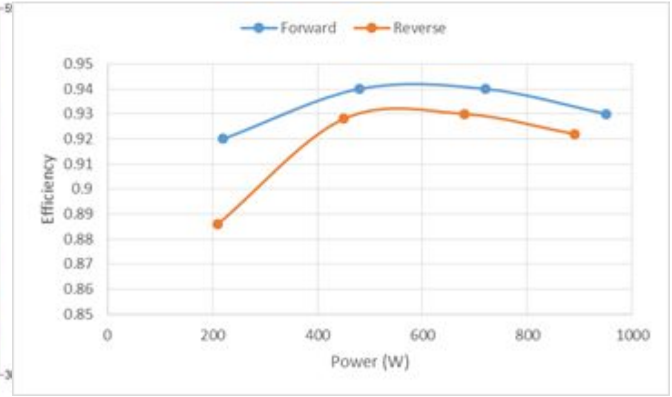
TRL: 4

Status:

- 3rd gen. prototypes demonstrated in chassis, paralleled 4 module sets @ 4kW



Thermal Test

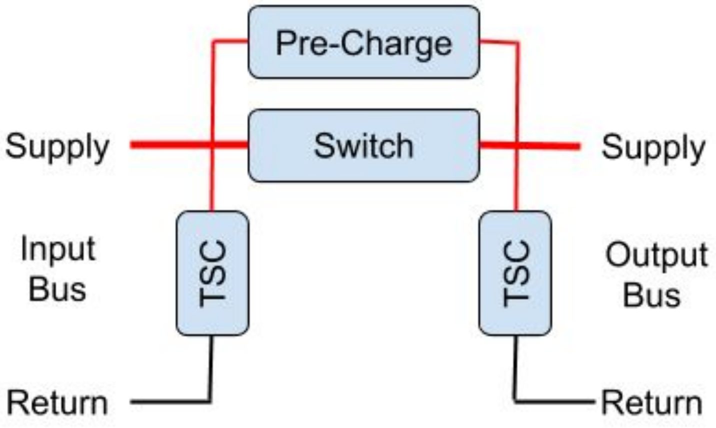


Efficiency Test

High Current Switchgear Module (HCSM)

Functions:

- Bidirectional supply-side switch
- Bidirectional pre-charge circuit*
- Configurable, resettable trip
- Transient suppression*



TSC: Transient Suppression Circuit

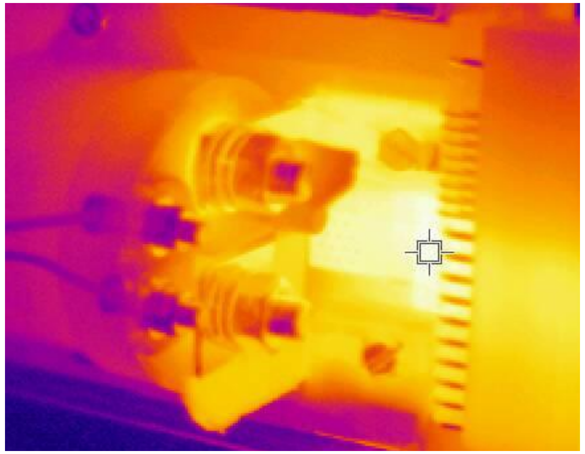
Input/Outputs: 2 ports @ 120VDC, 200A

Size: 3U x 3 Slots

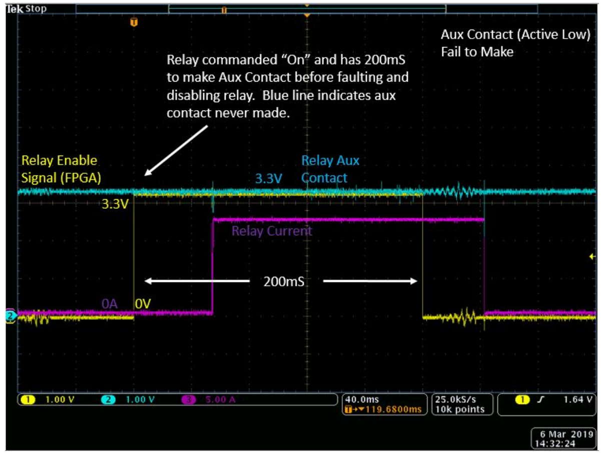
TRL: 4

Status:

- 1st gen. prototype demonstrated
- *Next: Add pre-charge, transient suppression, additional connectors; integrate into chassis



Thermal Test @ 200A



Electrical Test

Example Assembly: 2-Input, 32-Output Power Distribution Unit

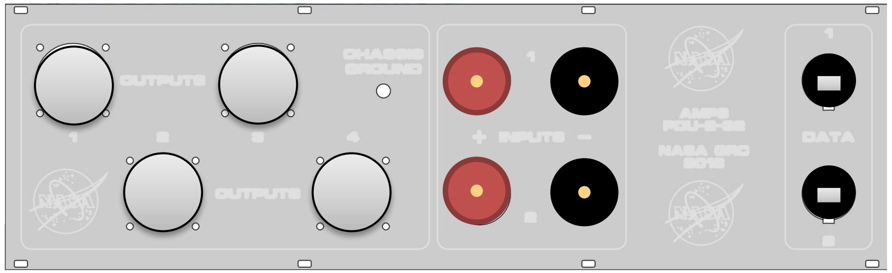
Chassis/Backplane

+

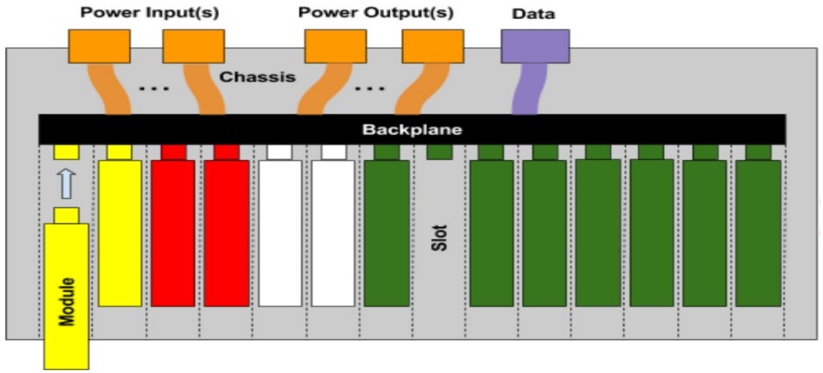
1x or 2x	Intelligent Controller
2x	Housekeeping
2x	Bus Switchgear
8x	Load Switchgear

Modules

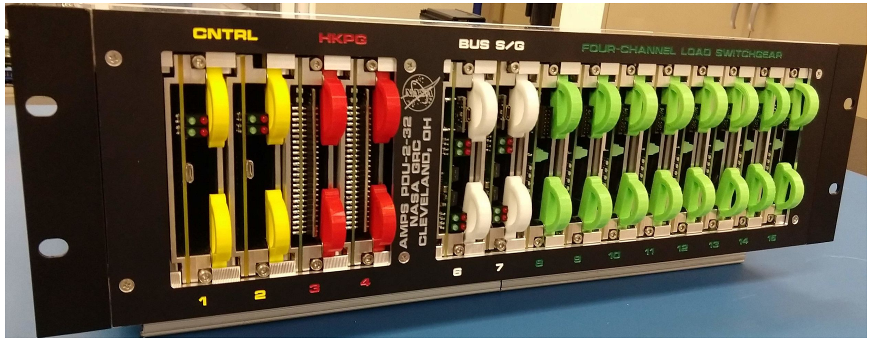
Rear



Top

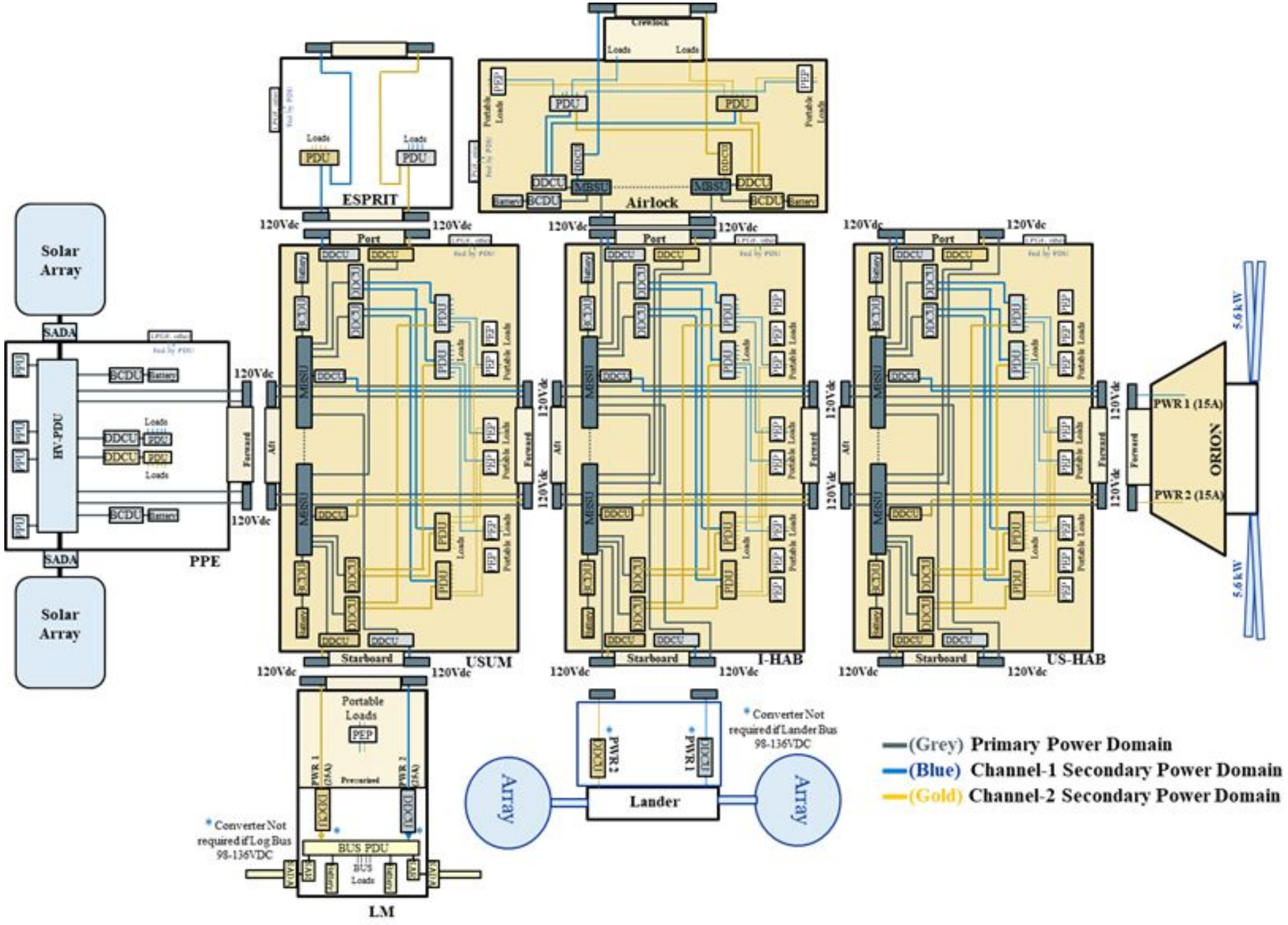


Front



Assembly

Example Spacecraft Power System



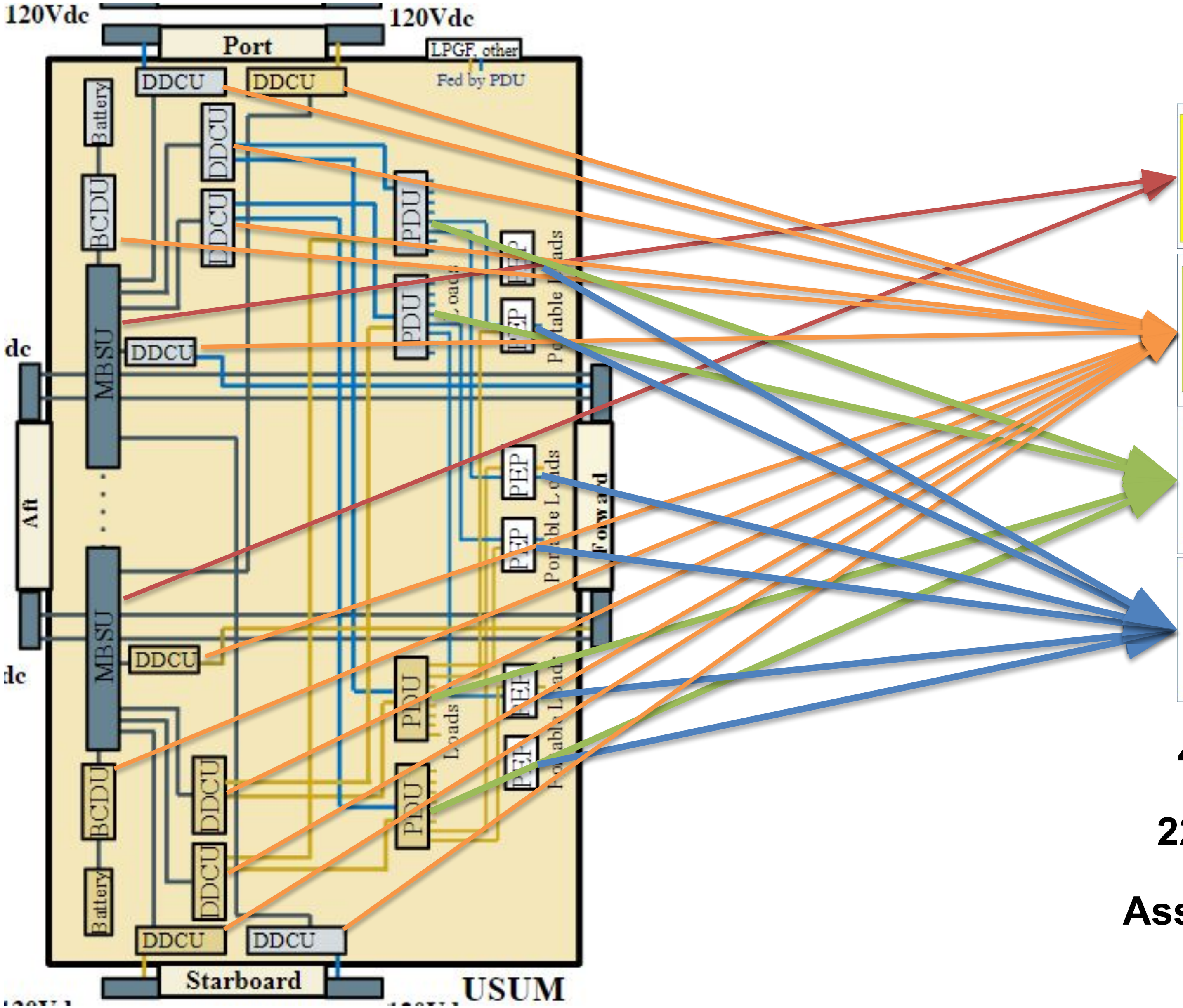
This diagram represents the power system of a notional space station.

Each large box is a separate "dockable" spacecraft, or "element".

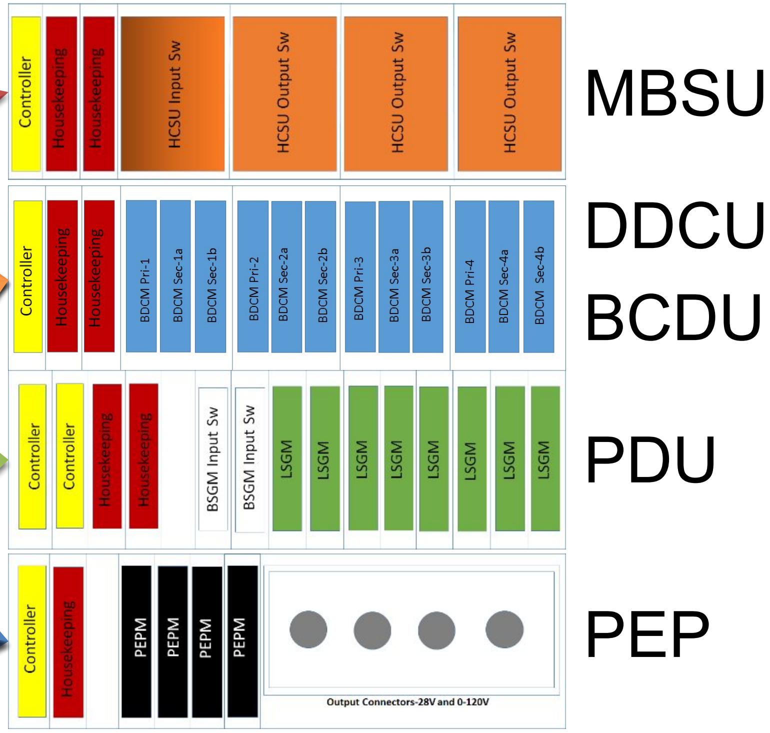
Each small box is a functional power system assembly, or "unit":

- **MBSU**: Main Bus Switching Unit
- **DDCU**: DC/DC Converter Unit
- **BCDU**: Battery Charge/Discharge Unit
- **PDU**: Power Distribution Unit
- **PEP**: Portable Equipment Panel

Example Spacecraft Power System



Assemblies



4 unique assembly designs

22 assemblies in this element

Assembly designs can be reused across entire spacecraft

Future Work

- **Verification of MESSPS with “flight” parts and designs**
  - **Advance Technology Readiness Level (TRL) from 4 to 6+**
  - **Support from one or more aerospace vendors**

- **End-to-end power distribution system testing**
  - **Validates interactions between sources, modules, and loads**
  - **Testbeds at NASA’s Glenn Research Center and Johnson Space Center**
  - **Architectures representative of planned missions**

- **Promote adoption by current and future missions**
  - **Currently challenging due to immaturity/low TRL**
  - **Current missions have shown interest, but not fully committed**
  - **Continue to involve domestic and international partners**

Conclusions

- **Standardization and modularization provide benefits to the end user**
  - **In this case, NASA and its missions are the end user**
  - **Needed to enable deep space/long duration missions**
- **NASA's AMPS project developed the MESSPS**
  - **Prototypes used to prove concepts and validate requirements**
  - **7 module types; including utility, switchgear, and converter modules**
- **AMPS project promoting adoption of the MESSPS**
  - **Near term: Lunar orbiting space station**
  - **Long term: Lunar and/or Martian surface habitat**
  - **Domestic and international aerospace agencies and commercial vendors**

Questions?