

Goddard Modular SmallSat Architecture (GMSA) Hardware Presentation

James Fraction – GMSA C&DH Lead

NASA Goddard Space Flight Center

Code 561: Flight Data Systems and Radiation Effects Branch



Acronym List

AB:	Actuator Board
ACS:	Attitude Control System
ADC:	Analog-to-Digital Converter
BCR:	Battery Charge Regulator
BCRX:	Battery Charge Regulator Extender
BP:	Backplane
CAN:	Controller Area Network
C&DH:	Command and Data Handling
cFE:	Core Flight Executive
cFS:	Core Flight System
CID:	Current Interrupt Device (CID).
COTS:	Commercial Off-The-Shelf
CSS:	Coarse Sun Sensor
DET:	Direct Energy Transfer
GMSA:	Goddard Modular SmallSat Architecture
GPIO:	General Purpose Input Output
FPGA:	Field Programmable Gate Array
I2C:	Inter-Integrated Circuit
LVDS:	Low-Voltage Differential Signaling
MRAM:	Magnetoresistive Random Access Memory
NAND:	Not And
PDU:	Power Distribution Unit
PSB:	Power Switches Board
PSE:	Power System Electronics
PTC:	Positive Temperature Coefficient (PTC)
SCEB:	SmallSat Common Electronics Board
SPI:	Serial Peripheral Interface
SRAM:	Static Random Access Memory



Content Summary

- **Introduction – Pages 4 through 6**
- **GMSA C&DH Information – Pages 7 through 17**
- **GMSA PSE Information – Pages 18 through 27**
- **Environmental Testing – Pages 28 through 30**
- **Future Work – Pages 31 through 32**
- **Point of Contact – Pages 33 through 34**



INTRODUCTION



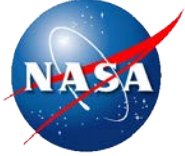
Introduction

- The Goddard Modular SmallSat Architecture (GMSA) is an in-house initiative that addresses the need for developing high reliability SmallSat technology within a minimum 6U SmallSat volume.
- The purpose of GMSA is to have a spacecraft architecture that can enable high reliable, long duration SmallSat missions that operate in harsh radiation environments.
- Typically commercial off-the-shelf (COTS) hardware that is currently available does not provide the overall reliability and radiation tolerance that is needed for certain types of missions.
- GMSA is an in-house development effort that is focused on meeting these mission needs.



Introduction

- **GMSA follows a modular, flexible, and extensible small satellite implementation approach**
- **GMSA can accommodate spacecraft subsystems developed both within NASA and outside of NASA**
- **The initial GMSA hardware development involved the design and assembly of multiple board assemblies that implements the Command and Data Handling (C&DH) subsystem the Power System Electronics (PSE) subsystem functionality within the satellite.**



GMSA C&DH INFORMATION



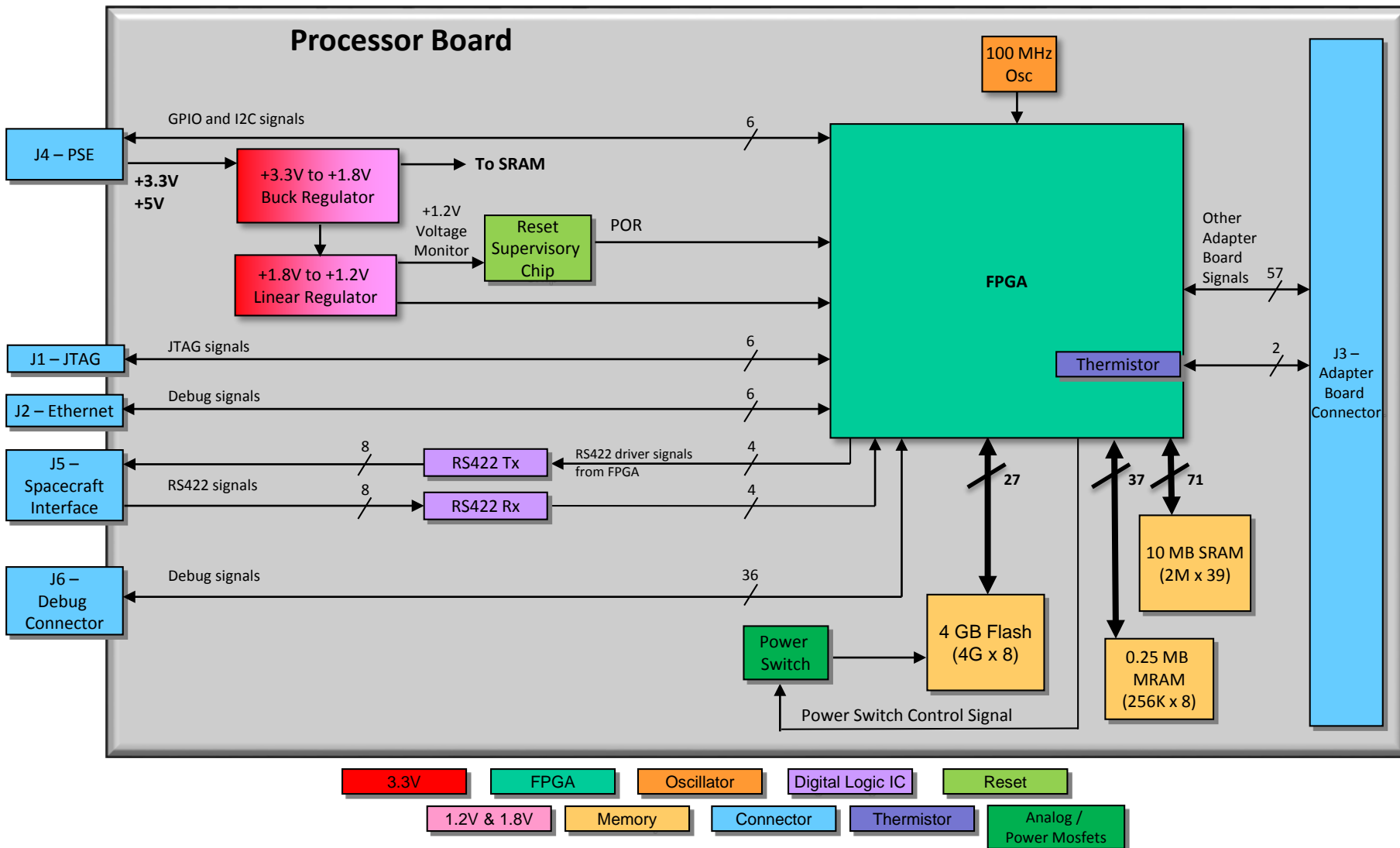
C&DH Primary Functions

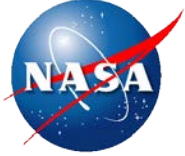
- **C&DH hardware consists of the following two boards:**
 - SmallSat Common Electronics Board (SCEB)
 - Adapter Board

- **GMSA C&DH supports the following features:**
 - TID > 20 krad
 - SEL immune
 - 2 years mission including activation and checkout (does not include storage)
 - Uses flight qualified parts for higher reliability.



SCEB Architecture Block Diagram





SCEB Primary Functions

- **RTG4 FPGA supports the following features:**
 - TID > 100 krad
 - SEL immune
 - Host embedded soft processor core and core flight executive (cFE)
 - Currently using an embedded Cobham Gaisler LEON3FT
 - Host Attitude Control System (ACS) electronics algorithms
 - Discrete I/O interfaces
 - Built-in RX clock recovery block with good jitter tolerance for SpaceWire
 - JTAG connector interface

- **On board voltage regulation**
 - Use a point-of-load converter to generate +1.8V for SRAM core voltage and linear regulator voltage input
 - Use a linear regulator to generate +1.2 V for FPGA core voltage

- **Supervisory Reset Circuit**



SCEB Primary Functions

● Multiple memory modules

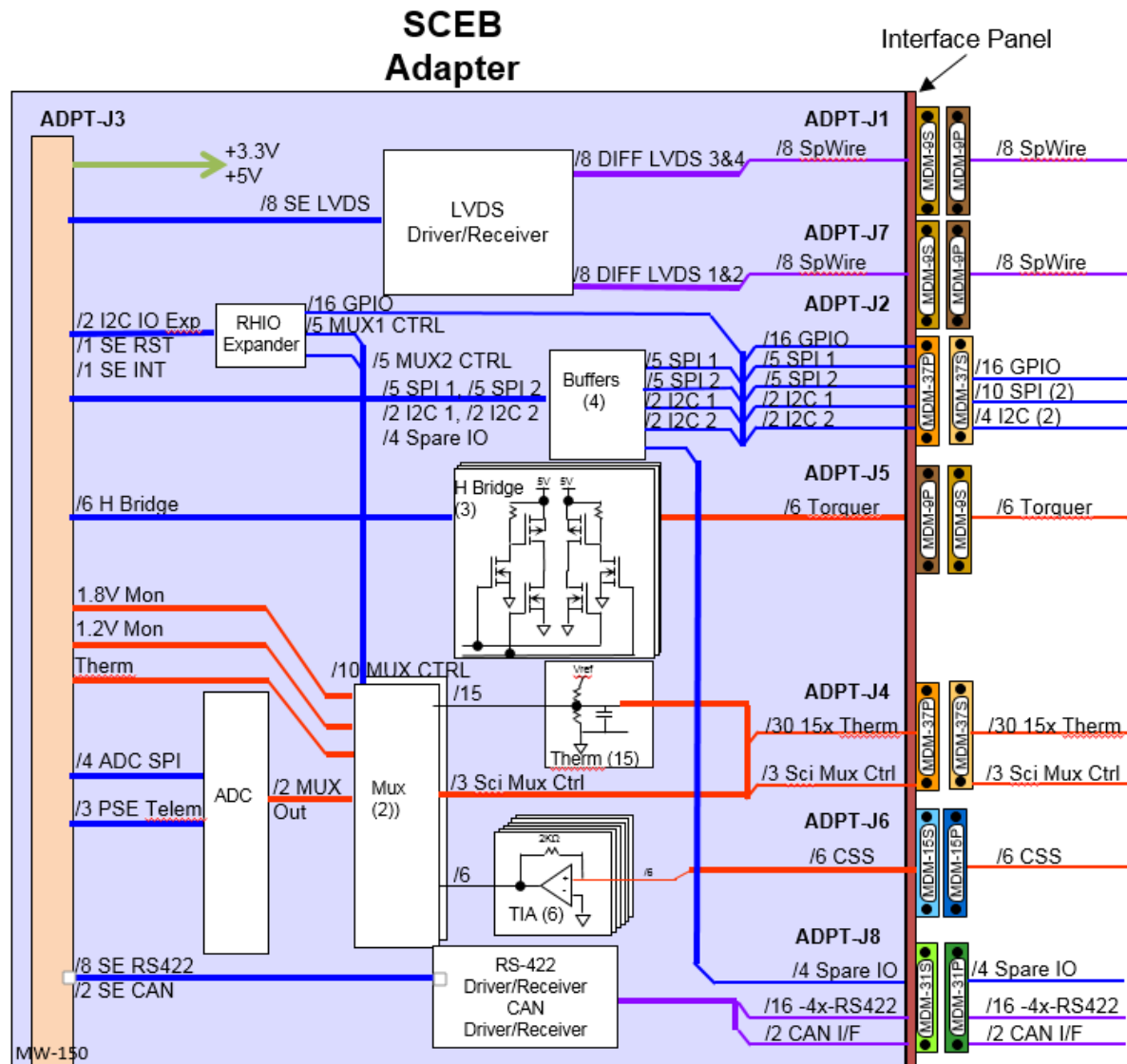
- Cobham 10 MB SRAM
 - Run FSW applications
- 3D-Plus SEU immune 0.25 MB MRAM
 - Store FSW boot code and emergency FSW recovery applications
 - Substitute for PROM in typical C&DH architecture
- 3D-Plus 4 GB NAND Flash
 - Store multiple FSW images, HK data, and science data
 - Flash device shall have a power switch to mitigate SEFIs

● Multiple I/O options

- 4 RS-422 drivers and 4 RS-422 receivers
 - Interface for up to 4 additional RS-422 drivers and 4 RS-422 receivers populated on the Adapter Board
- Interface for 4 LVDS drivers and 4 LVDS receivers populated on the Adapter Board
- 1 dedicated CAN bus interface
- 2 dedicated spacecraft SPI interfaces each with 2 slave select signals
- 2 dedicated spacecraft I2C interfaces
- 1 dedicated I2C interface to the PSE
- 1 dedicated I2C interface to the SCEB Adapter Board for controlling multiple multiplexers and 16 general purpose inputs / outputs (GPIO)
- 4 inputs from the SCEB Adapter Board that are +5V tolerant
- ADC I/Os
- Driver signals for 3 H-bridge drivers on the SCEB Adapter Board



Adapter Board Architecture Block Diagram





Adapter Board Primary Functions

- **Housekeeping functionality**
 - 16 thermistor interfaces (using voltage divider circuit)
 - Voltage monitoring interface (+1.2V and +1.8V from SCEB)
 - Voltage and current monitoring (+3.3V, +5V, +12V, and battery voltage from PSE)
 - 3 science instrument multiplexer inputs
 - 3 PSE multiplexer inputs
 - One 32-bit I/O expander to control two onboard multiplexers
 - One 12-bit serial output analog-to-digital converter (ADC)

- **Magnetorquer H-Bridge Driver Interface**

- **6 Coarse Sun Sensor (CSS) current-to-voltage conversion circuits**

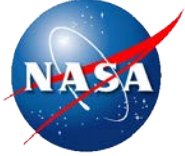
- **Connector interface to SCEB**

- **Connector(s) interfacing to the rest of the spacecraft**



Additional Information

- **Target C&DH Assembly Power Consumption: < 3 Watts**
- **C&DH Total Mass = 419.86 g**
 - SCEB (Processor Board): 135 g
 - Adapter Board: 258.55 g
 - C&DH Assembly Hardware: 26.31 grams
- **Temperature Ranges:**
 - C&DH survival temperature range: -40C to +65C
 - C&DH operating temperature range: -20C to +50C
- **Individual Board Dimensions: 90 mm x 90 mm**
- **C&DH Assembly Dimensions: 116.56 mm x 44.35 mm x 92.51 mm (LxWxH)**

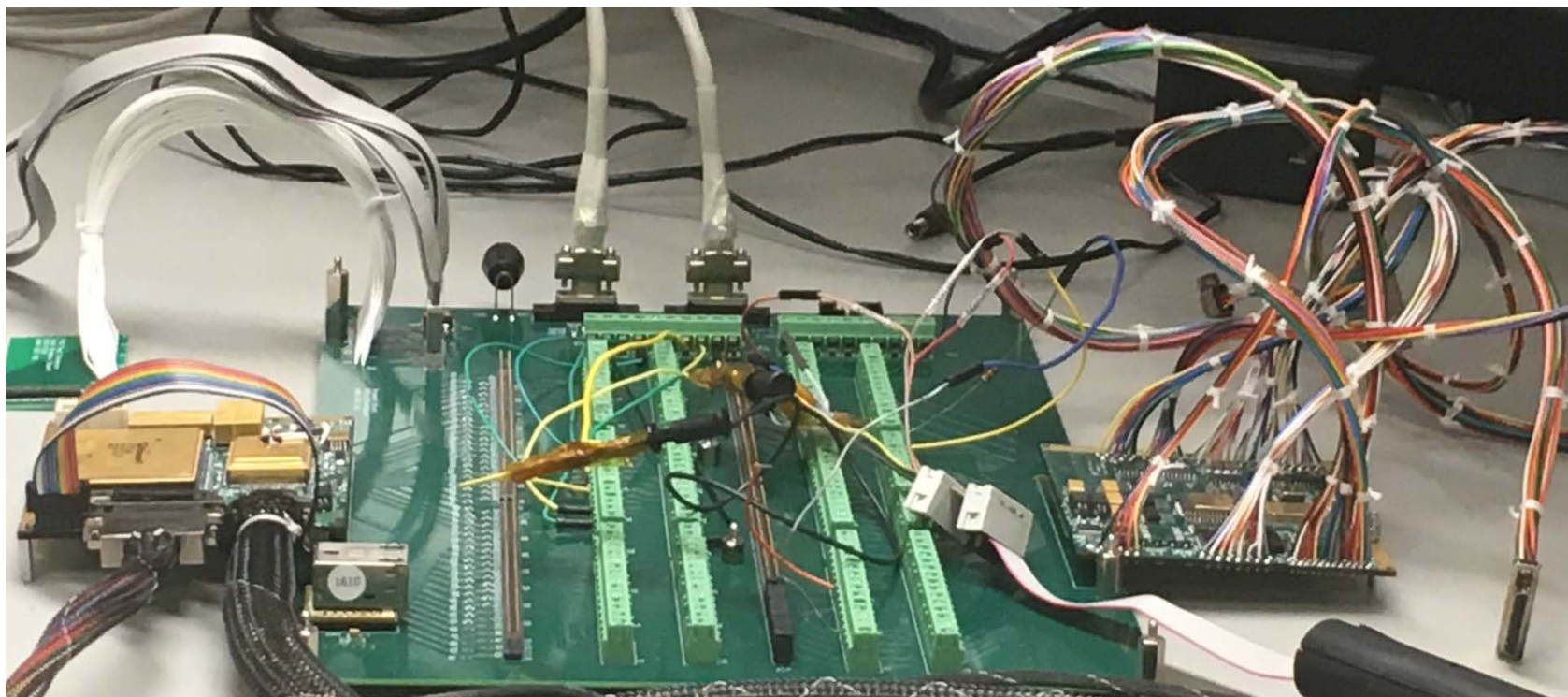


Reconfiguration in Flight

- **Capability to reprogram MRAM device while in flight to reload cFE/cFS apps stored in it.**
- **Evaluated the potential of reprogramming the RTG4 FPGA design while in flight**
 - **At the time of development Microsemi was still in the process of completing radiation testing of this functionality.**
 - **We took the conservative approach and assumed that once the RTG4 was programmed on the ground prior to flight it would not be changed after launch.**



GMSA C&DH Test Configuration Photo



SCEB

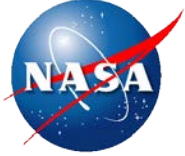
Breakout Board

Adapter Board



GMSA C&DH Mechanical Assembly Photos





GMSA PSE INFORMATION



PSE Primary Functions

- **GMSA PSE supports the following features:**

- TID > 20 krad
- SEL immune
- 2 years mission including activation and checkout (does not include storage)
- Uses flight qualified parts for higher reliability.
- PSE is a Direct Energy Transfer (DET) system with the battery connected directly to the electrical bus. Any excess solar array power that is not needed for battery recharge or Spacecraft loads is shunted.
- PSE provides charging capabilities for a Li-Ion battery utilizing voltage and current charge control. The shunt control technique is a linear sequential full shunt which provides a simple solar array interface.
- This DET topology can support both 3-axes stabilized and spinner SmallSat.
- The PSE includes all the circuits needed to perform telemetry and command function using I2C interfaced with the C&DH.
- The PSE is designed, tested, and verified to meet launcher vehicle safety requirements.
- 6U size SmallSat. PSE manages and distributes 6 Amp maximum input current from Solar Array in a volume of 1U (10cm x 10cm x 10cm).
- Works compatibly with GMSA Li-Ion battery that provides 80 Watts power.



PSE Primary Functions

● Unregulated Primary (Bus) Voltage

- Un-Switched Vbus in the range of 10.8V to 12.6V, nominal voltage of 11.1V: used at Actuator Card.
- Switched Vbus:
 - Quantity 1: 1A S/C Heater and Quantity 1: 1A Transmitter RF
 - Deployment Bus (at Actuator Card): Provide 3A pulse for deployable loads: Antenna, Magnetic Boom, Solar Array.
 - Propulsion System: 3A pulse.

● Regulated Secondary Voltage

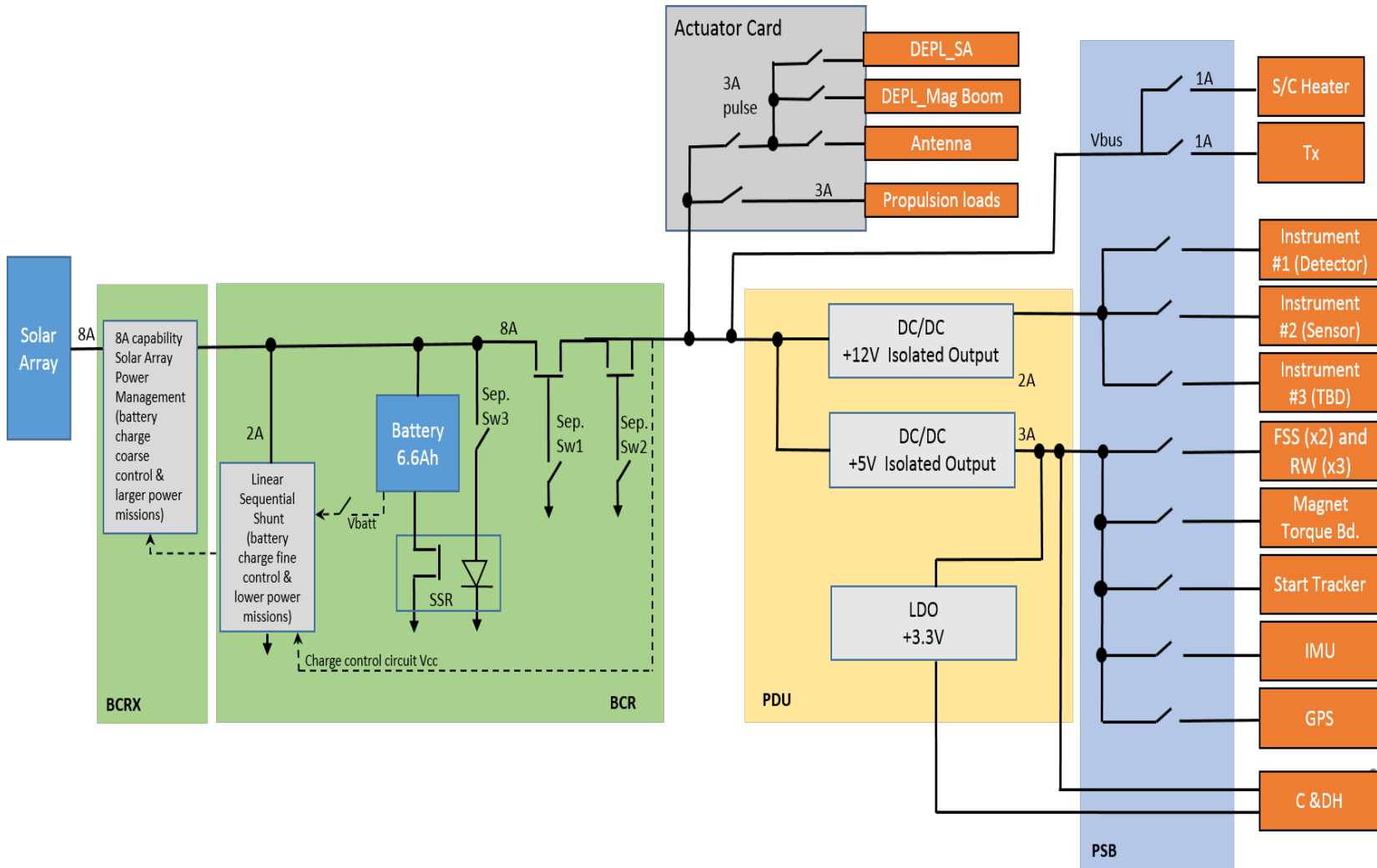
- +12V @2A max, Quantity 3 switched services to instruments.
- +5V @ 1.5A max, Quantity 1 un-switched service to C&DH, Quantity 5 switched services to ACS.
- +3.3V @1.5A max, Quantity 1 un-switched service to C&DH, optional services to ACS.
- Current sense (monitor) : Solar Array, Battery, Loads (+12V, +5V, +3.3V).

● Thermistor Sensor

- There're thermistors located on Solar Array, Battery, BCR, PDU, and PSB for temperature monitor.



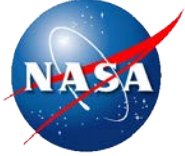
PSE Architecture Block Diagram





PSE Card Assembly Description

- Battery Charge Regulator Extender (BCRX) card expands the power input handling capabilities for missions with high input power (2A-6A) from solar array.
- Battery Charge Regulator (BCR) card provides battery charge control to commanded voltage and current levels. Any excess power that is not used by the spacecraft or to recharge the battery is dissipated in linear sequentially operated shunts.
- Power Distribution Unit (PDU) card converts and distributes all load secondary voltages which include: +12V, +5V, and +3.3V.



PSE Card Assembly Description

- Power Switches Board (PSB) card distributes primary and secondary voltages to the un-switched essential and switched non-essential loads. This board provide 10 switches, each switch can provide max output current of 1A.
- Actuator Board (AB) card distributes primary Battery (Bus) voltage for deployable loads (like the solar array or magnetic boom) and high power primary loads (like the transmitter and/or propulsion sub-system).
- Backplane Board (BP)card connects all the PSE cards together to share the power Bus, secondary power, and I2C lines.



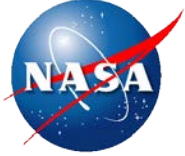
Li-Ion Battery Description

- The GMSA Li-Ion battery is an in-house design with nine Li-Ion rechargeable type 18650 cells.
 - It is packed in 3S3P configuration with 3 strings in parallel.
 - Each string has 3 cells in series.
 - The battery will provide power to SmallSat during eclipse period and will sustain a bus voltage in the range of 10.8V to 12.6V.
- The GMSA Battery is packed with ICR18650J cells.
 - This cell is manufactured by MoliCel, this cell was tested and recommended by NASA Johnson Space Center.
- Each battery cell used in GMSA Battery has an internal positive temperature coefficient (PTC) current limiting device. The PTC is used to limit short circuit current on an individual cell level.
 - This device is completely passive and functions without any inputs from the rest of the battery pack systems.



Li-Ion Battery Description

- Each battery cell used in the GMSA Battery has an internal Current Interrupt Device (CID).
 - This device serves to protect the cell from excessive internal pressure.
 - In such a case the CID will break and electrically disconnect the cell.
 - High internal pressure is generally caused by over-temperature or other failures that then result in over-temperature.
- Battery capacity 80W, nominal voltage of 11.1V.
- Battery pack mass: 580 g
- Battery dimensions: 90mm x 90mm x 80mm (W x D x H)



Additional Information

- **PSE Total Mass = 542 g**

- **Secondary Voltage:**
 - Regulation: $\pm 5\%$ for each secondary output.
 - Voltage Ripple: 100mV Pk-Pk for each secondary output.

- **Temperature Ranges:**
 - PSE survival temperature range: -40C to +65C
 - Battery charging limited below 10C
 - PSE operating temperature range: 0C to +40C
 - Battery operating temperature range: +10C to +30C

- **Individual Board Dimensions:**
 - PSE Backplane: 100 mm x 90 mm
 - All other PSE cards: 100 mm x 90 mm

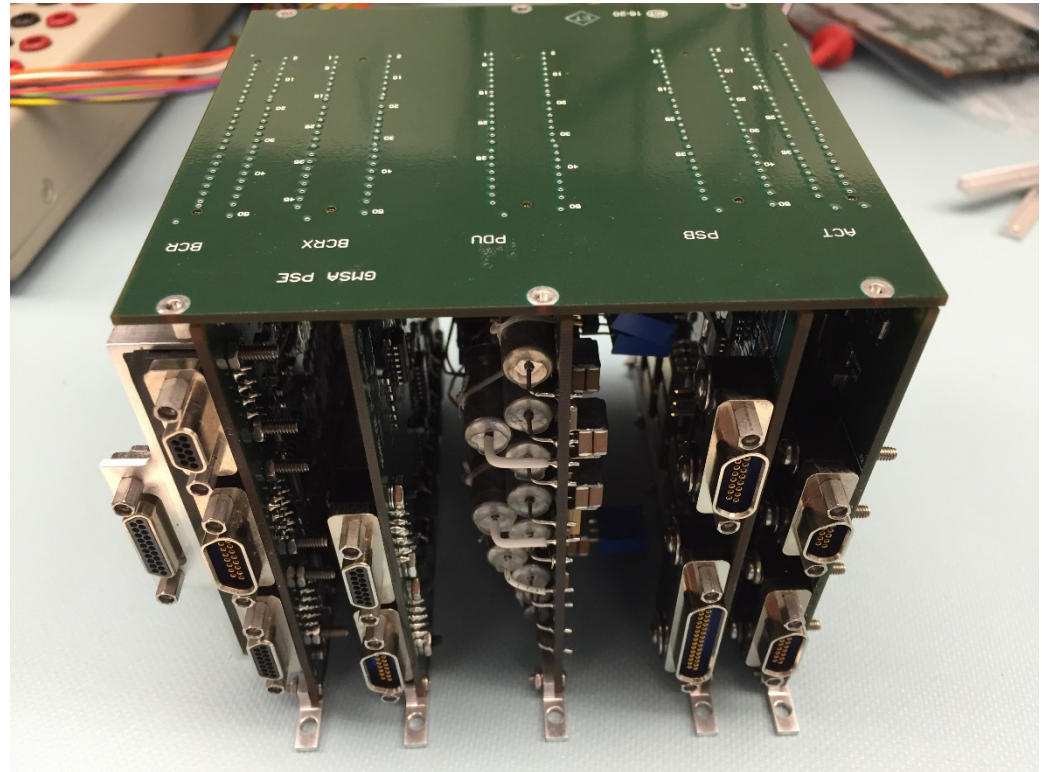
- **PSE Assembly Dimensions: 134 mm x 125.65mm x 96.39mm (LxWxH)**
 - Between 94 mm to 96.39 mm for the height (depending on BP screws used)
 - These dimensions include the bracket for the battery connector (10 mm)



PSE and Battery Assembly



GMSA Li-Ion 80W Battery



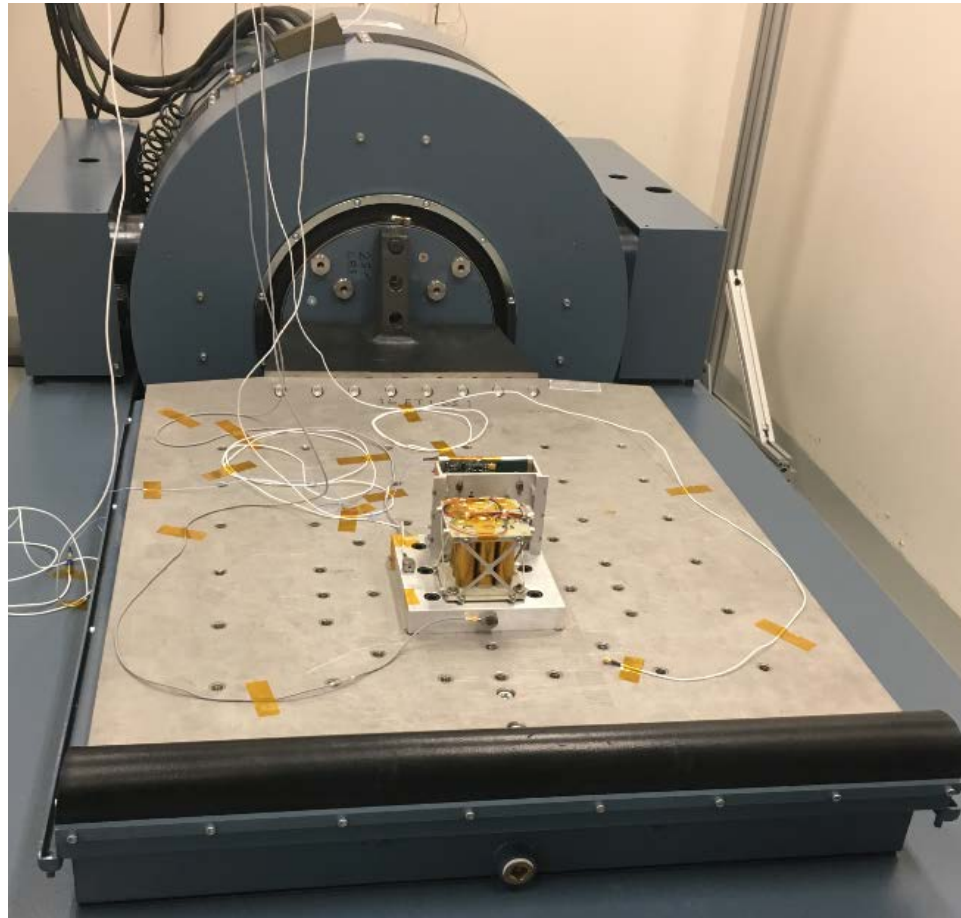
GMSA Power System Electronics (PSE)



ENVIRONMENTAL TESTING



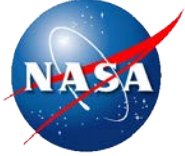
GMSA C&DH Vibration Test Photo





GMSA Hardware Thermal Vacuum Testing Photo





FUTURE WORK



Future Work

- Integrate multiple COTS devices and NASA science instruments to the GMSA C&DH and PSE hardware in a Flatsat environment
- Use GMSA C&DH hardware as a flight software test string to develop cFE/cFS apps conducive with SmallSat missions
- Evaluate alternative processor core options that can be implemented to do the following:
 - Enhance GMSA C&DH FPGA design options
 - Provide different cost options for customers
- Evaluate part selection and qualification options for future missions



POINT OF CONTACT



Contact Information

- For more information about the GMSA C&DH boards and the Memory Card please contact:

James Fraction

NASA – Goddard Space Flight Center

Code 561: Flight Data Systems and Radiation Effects Branch

Telephone Number: 301-286-2094

E-mail Address: james.e.fraction@nasa.gov

- For more information about the GMSA PSE boards please contact:

Hanson Nguyen

NASA – Goddard Space Flight Center

Code 563: Power Systems Branch

Telephone Number: 301.286.4776

E-mail Address: hanson.nguyen@nasa.gov