Advanced Power Technology Development Activities for Small Satellite Applications

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Outline

I. Introduction

II. Small Spacecraft Technology Program, Smallsat Technology Partnerships
   a) Demonstration of a Nano-Enabled Space Power System (RIT)
   b) Development of a Lightweight CubeSat with Multifunctional Structural Battery Systems (University of Miami)

III. ALBus Small Sat power demonstration at NASA Glenn

IV. Low Power Stirling Technology

V. Advanced PMAD Technology Development Efforts

VI. Summary

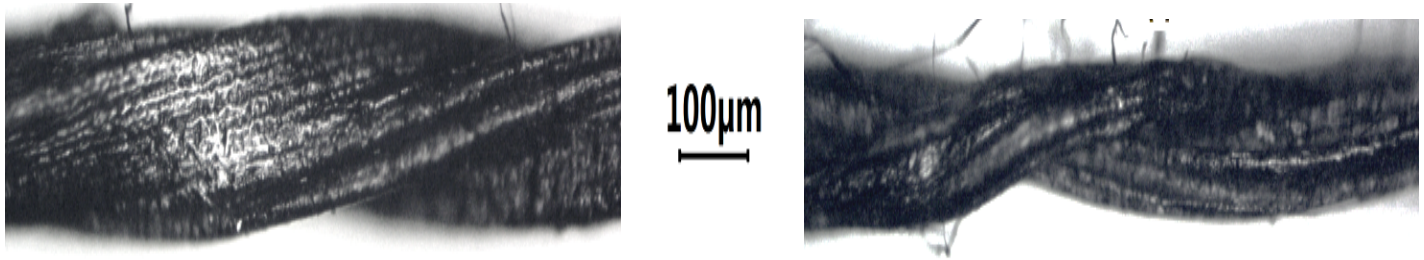
NASA Glenn Power Technology Expertise

- NASA Glenn Research Center has a long tradition of developing advanced technology for spacecraft, with particular expertise in the areas of power, in-space propulsion, communications, and materials
- Advanced power technology for space applications
  - Energy generation (photovoltaics, advanced thermal-to-electric)
  - Energy storage (batteries, fuel cells)
  - Power Management and Distribution (PMAD)
  - Power systems architecture and analysis
- Advancements in these technology areas are slowly being infused into small satellite missions and can have significant impacts on longevity and mission capability

Development of a Nano-Enabled Space Power System

- Nanomaterial-enhanced power system components to allow for reduced weight while maintaining or increasing capability.
  - Quantum dot / Quantum well solar cells
  - CNT enhanced lithium-ion batteries
  - Carbon nanotube (CNT) wire harness
  - CNT thermoelectric energy harvesting
- Nanomaterials
  - ✓ Significant weight saving
  - ✓ Minimal change in cost
  - ✓ Increase in available space

Optical Microscopy of Twisted and Braided metal-free CNT Harness, exceeding $1x10^6$ S/m in electrical conductivity



3 Ply Laid

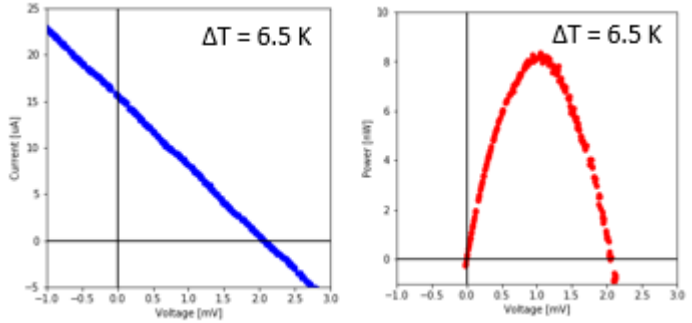
3 Ply Braid

Evolutionary advancements **in each technology when combined can translate into** ***revolutionary changes*** **at the system level to provide higher conversion efficiency and energy density to extend mission capability.**

Progress to Date

Heat Management & Energy Harvesting

Demonstrated thermoelectric power generation from SWCNT TE device, producing over 8 nW from 3 paired couples against a temperature gradient of 6.5 K

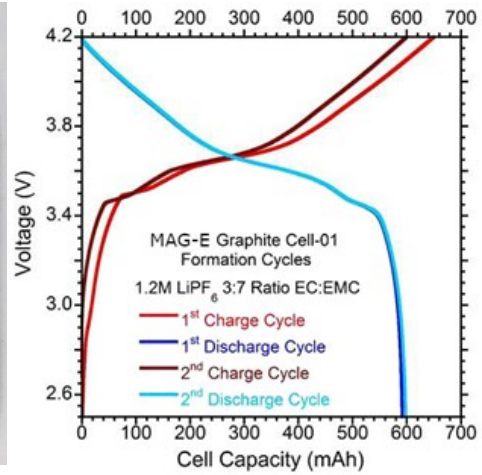


QD/QW Cells

Increased radiation tolerance extending lifetime. Spectrally tuning the middle (GaAs) cell bandgap leading to higher current densities. Highest QD V_{OC} to date. replacement PV cells to be integrated with Clyde Space boards

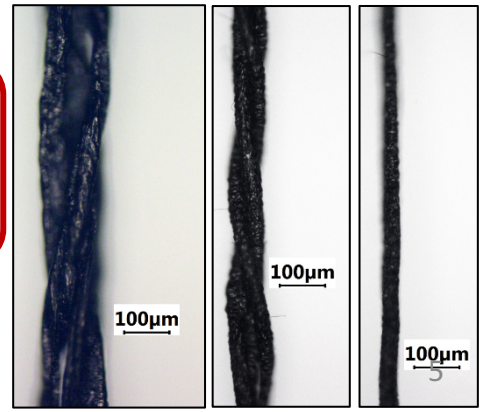
CNT in Li-Ion Batteries

Fabricated pouch cells exceed 250 Wh/kg and will serve as drop-in replacement for Clyde Space batteries (100-150 Wh/kg)



CNT Conductive Wiring

Fabricated Braided Metal Free CNT wires to compare against commercial interconnects



Approach to Integrating Nanoenhanced Components

Characterize SOA CubeSat power system components

Fabricate power system components which incorporate nanomaterials

Replace commercial devices with nanoenhanced versions

Characterize CubeSat power system components and make necessary changes

Integrate finished components into CubeSat power system. Test under space conditions

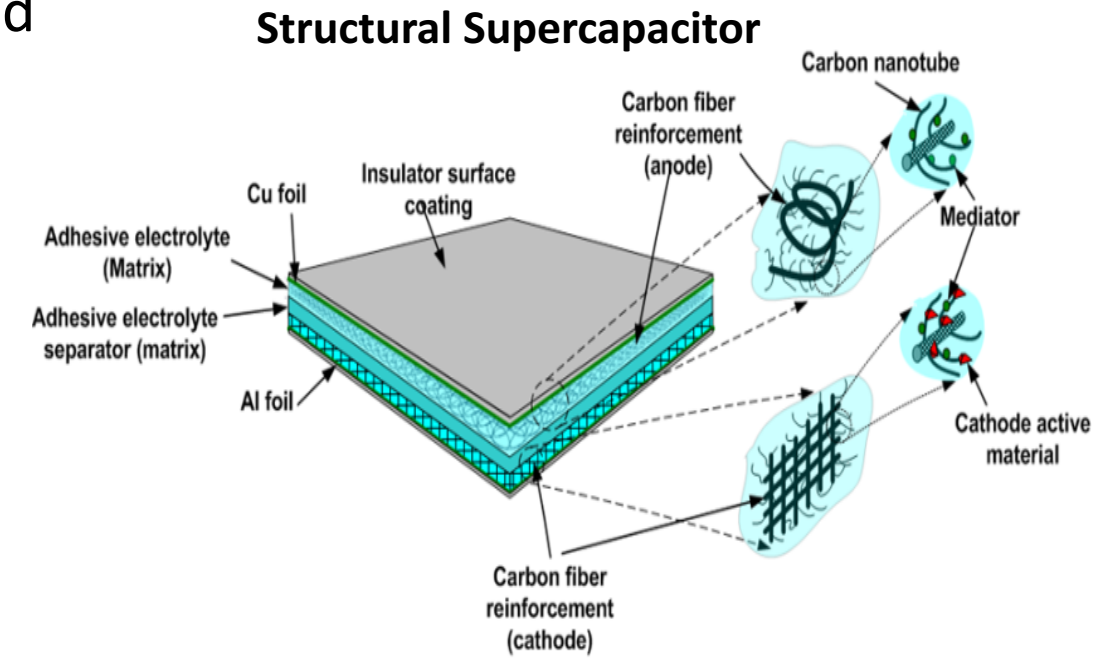
www.clyde.space

Nano Enhanced

Benefit of enhancing existing technologies through the use of nanomaterials is that the enhanced products can serve as drop in replacements to existing infrastructure, minimizing the need for new equipment and infrastructure.

Development of Lightweight CubeSat with Multifunctional Structural Battery/Supercapacitor Systems

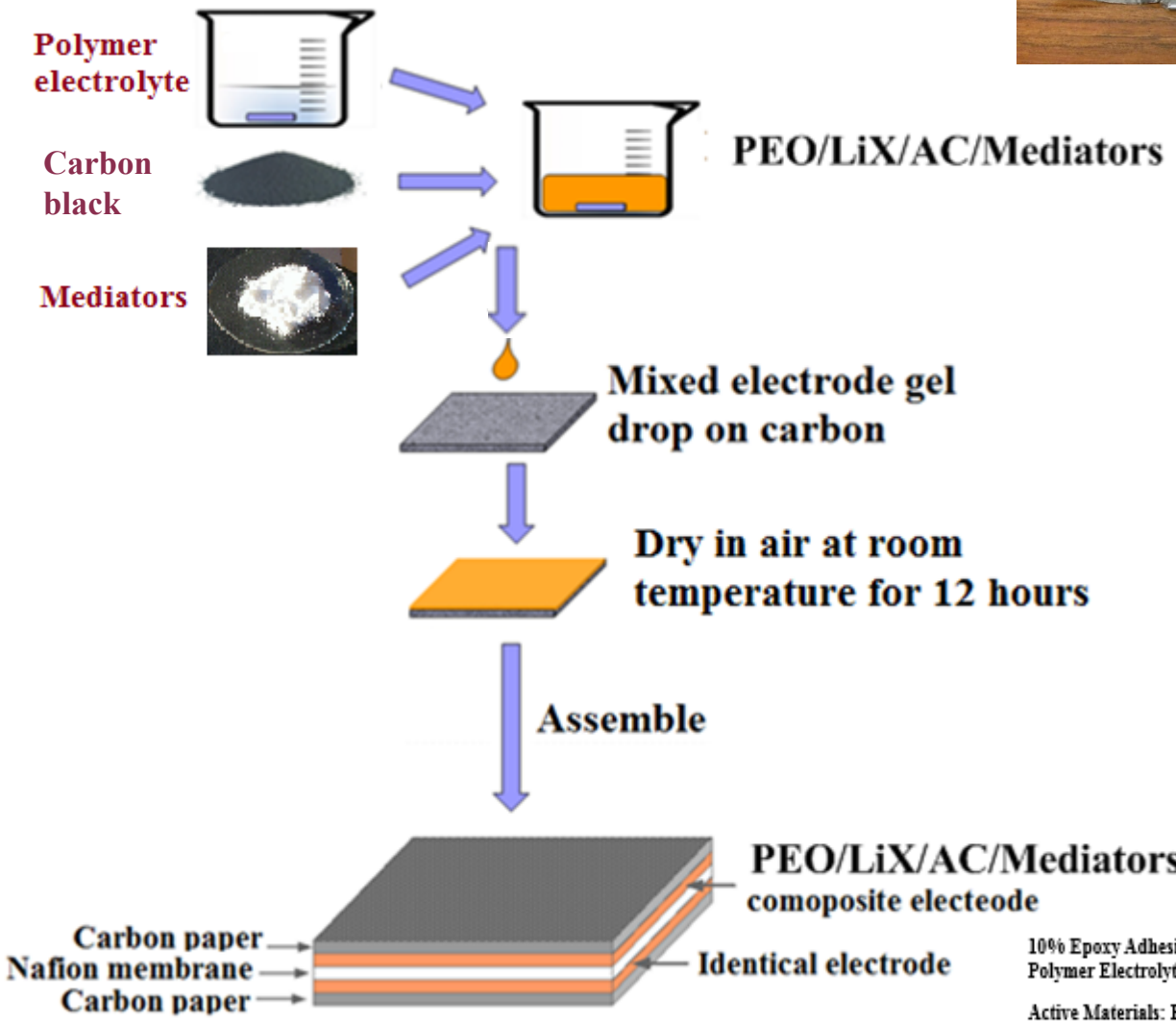
- Lightweight 1U CubeSat that utilizes fully integrated structural battery materials for mission life extension of 200-300%, larger payload capability, and significantly reduced mass of 15% or more.
- Mediator-enabled electrolytic polymer
  - ✓ Lightweight load bearing structure and an electrochemical battery system
  - ✓ High specific power and energy with fast charge rate
  - ✓ Significant weight savings
  - ✓ Increase in available volume for payloads



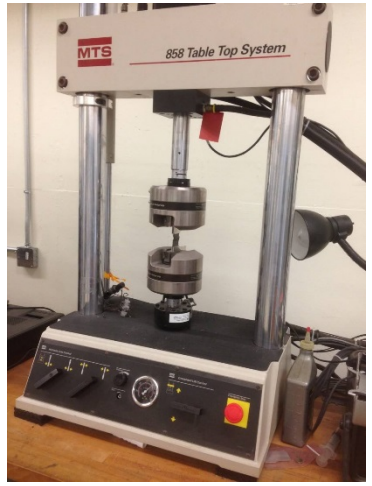
Advancements **in structural battery technology can replace parasitic structural mass with material that provides additional energy, leading to lighter weight and extended satellite mission life.**

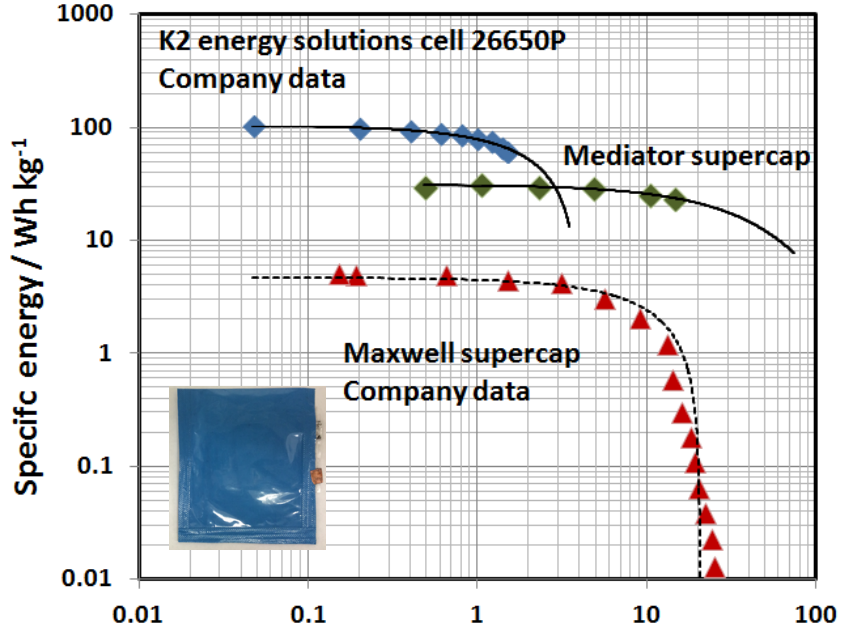
Progress to Date

Supercapacitor Fabrication

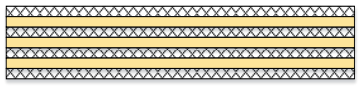


All Solid-State mediator structural supercapacitor stacks

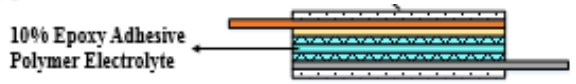




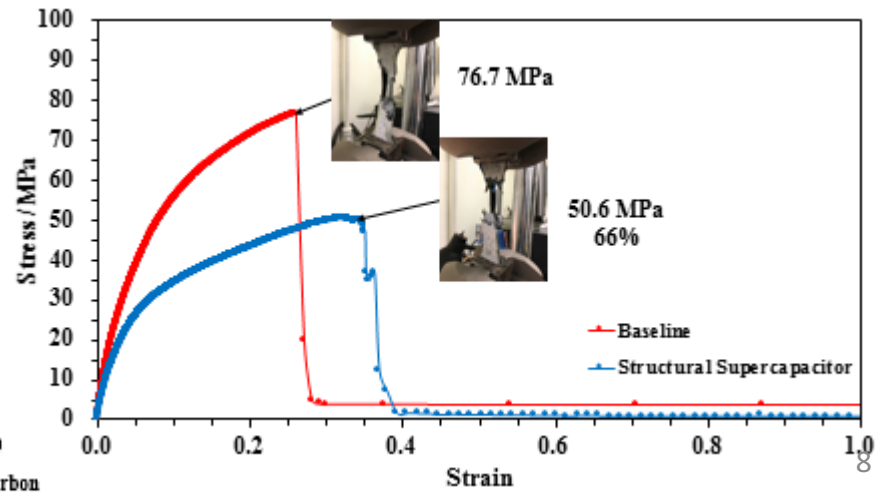
Baseline



Structural



Active Materials: PVDF+LiTFS+Activated Carbon+Conductive Carbon

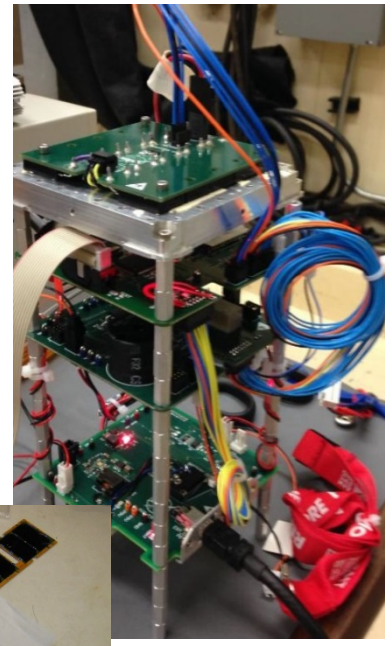


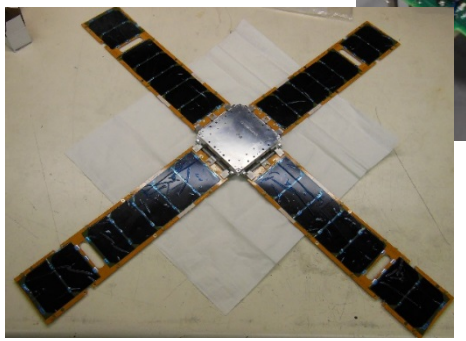
Advanced Electrical Bus (ALBus) CubeSat Technology Demonstration Mission

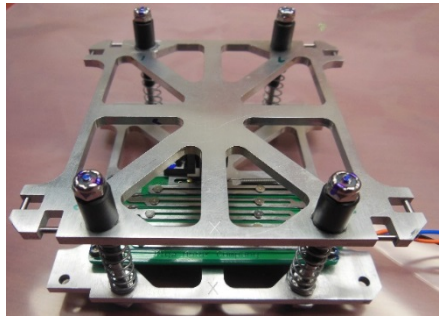
- Provide 100 W capable power management system
- Demonstrate regulated high power bus
- On-orbit demonstration of technologies required for 100 W system
- Power system efficiency ≥ 85%
- EPS shall fit in 1U volume (10x10x10 cm) or less
- CubeSat shall not exceed 4.0 kg mass
- Exhibit solar array mechanisms utilizing shape memory alloy materials

Advanced Electrical Bus (ALBus) CubeSat (Update)

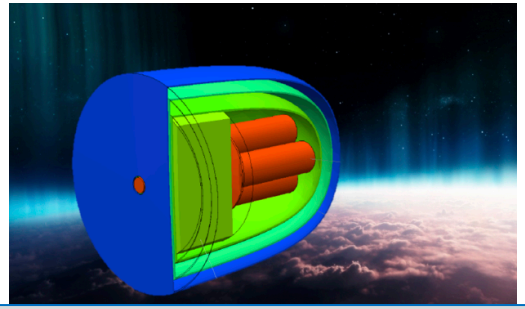
- Pathfinder mission for high power density 3-U CubeSats
  - Up to 100 W of distributed power
  - Assessment of operational duty cycle of 100 W system in a LEO environment
  - Demonstration of robust and resettable Shape Memory Alloy (SMA) Mechanism for solar array deployment
  - Demonstration of novel technique for power transfer from solar arrays through SMA deployment hinges
- Currently in final system integration and test
- Scheduled to fly on ELaNa XX mission (early 2018)







GRC Low Power Stirling Development



Future use on probes, landers, and rovers

Innovation

- New class of high efficiency RPS being developed at GRC using flight-qualified Radioisotope Heater Units (RHU)
- Previous technologies use low efficiency thermoelectrics

Applications

- Low power landers, probes, and rovers
- Science measuring instruments
- Distributed near objects of interest with low solar flux

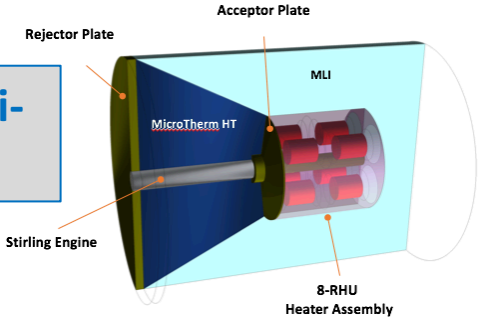
Power Conversion Research

- Stirling engine and linear alternator
- Controller and battery charger for spacecraft

Insulation

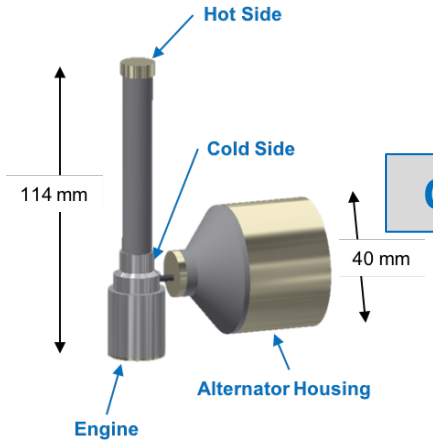
- Vacuum foil insulation is required due to low heat input
- Functions as thermal resistance and structural support

Insulation concept uses hybrid multi-layer and microporous insulation



Heater Assembly

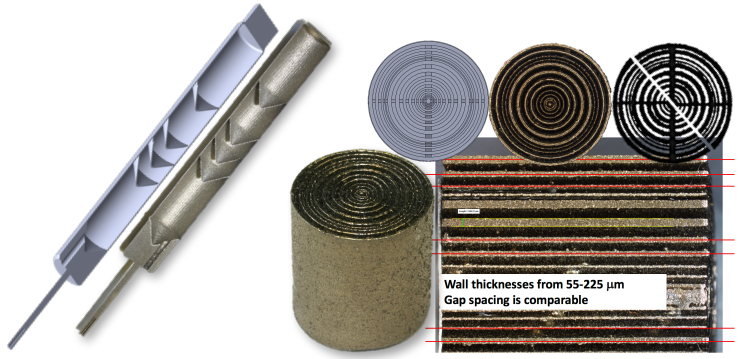
- Each RHU provides 1 watt thermal output
- Multiple RHUs selected for initial design
- Lab testing uses electric heaters to simulate RHUs



Convertor demonstration being prepared

Miniature Stirling Convertor

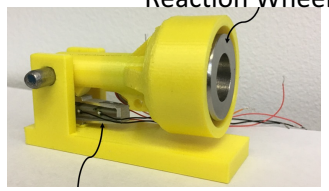
- 1 W_e power output from controller to spacecraft sensors
- 350 ºC hot side temperature, 50 ºC cold side temperature
- Flexure bearings, gap regenerator



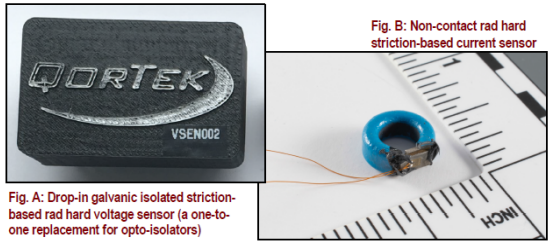
Evaluating Additive Manufacturing for production

PMAD Technologies for SmallSats

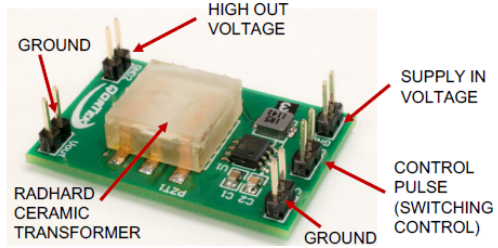
- Power Electronics SBIR work with Qortek:
  - Precision fine attitude tuning of SmallSats (GSFC)
  - Striction-based current and voltage sensors for MEO/GEO (GRC)
  - DC/DC conversion – ceramic based power supply for space bus on SmallSats (GRC)
  - Development of SiC and GaN power devices for space applications (GRC with GeneSiC)



Precision Pointing Mechanism



Voltage and Current Sensors



DC/DC Converter

Summary

- NASA GRC (along with other NASA Centers, Academia, and industry) is developing advanced space power technologies that could have a direct impact on future small satellite missions by increasing lifetime and improving spacecraft capabilities.
- These development effort cover a wide range of technologies and technology readiness levels (TRLs) in:
  - Energy generation
  - Energy storage
  - Power management and distribution