Virtual Research Presentation Conference

Gan-based Power Bus Converter with Autonomous Adaptive Control for Deep Space Small Spacecraft Power Subsystems

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Program: Topic

Jet Propulsion Laboratory
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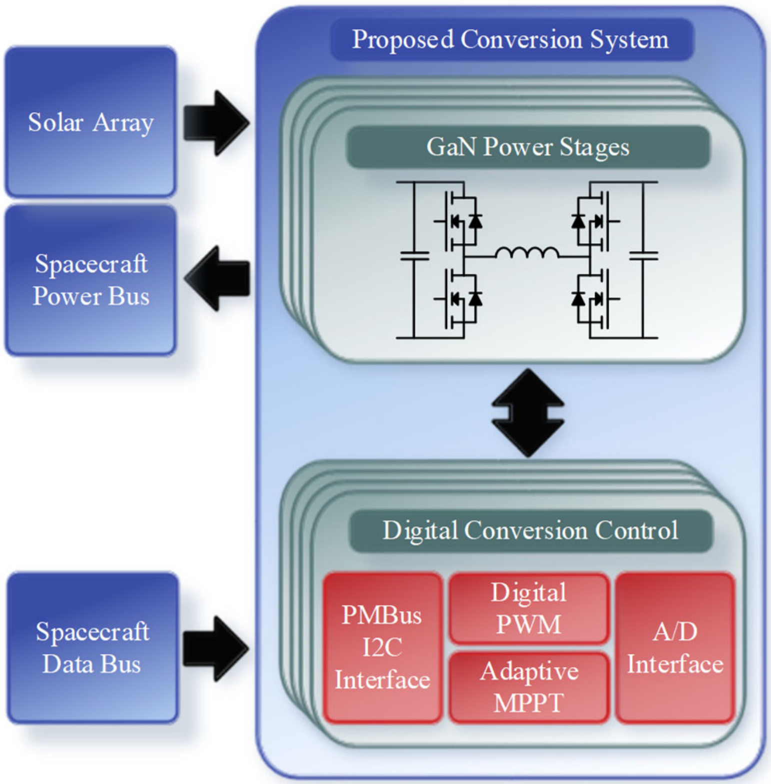
Assigned Presentation # RPC-237

Tutorial Introduction

Solar array power conversion is essential to the vast majority of spacecraft, converting the power produced by the solar array to useable voltages for the battery and payloads. We aim to improve the state of the art in solar array power conversion for JPL and NASA spacecraft by:

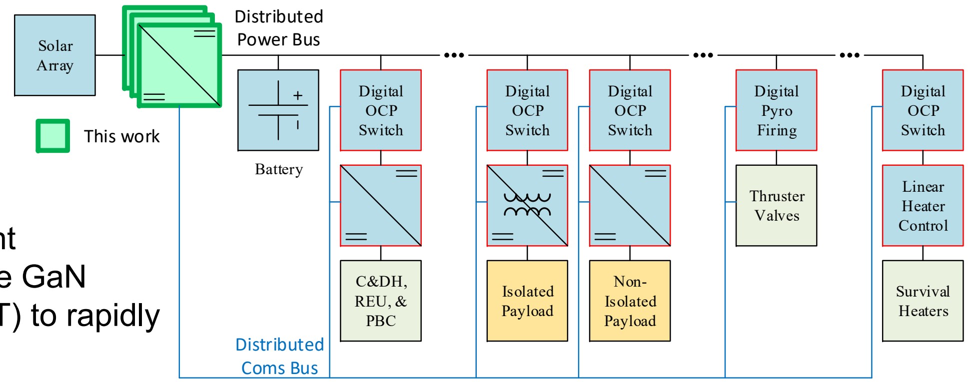
- **Developing new power converters that improve the efficiency of solar array power conversion from 90% to 97%**
- **Utilizing new semiconductor technologies that minimize losses while reducing volume and mass**
- **Developing new control algorithms that force the solar array to operate at its maximum power point, without introducing perturbations into the system**
- **Design common interfaces, form factors, and communications protocols to make building power subsystems simple for spacecraft designers**



Problem Description

Context

- This work aims to bridge the gap between COTs and Flight converters for photovoltaic (PV) based spacecraft. We use GaN HEMTs and digital Maximum Power Point Tracking (MPPT) to rapidly track the MPP and provide efficient bus conversion.

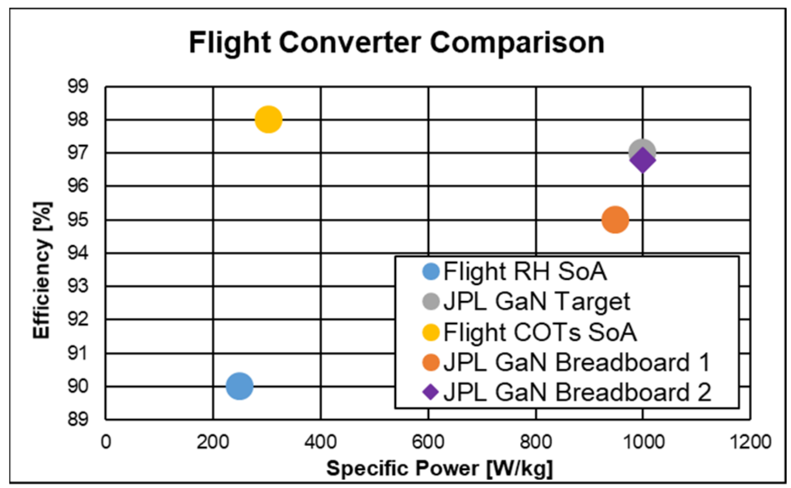


Block Diagram of Distributed Power System

State of the Art Comparison

- Provides efficiency and power density rivaling COTs systems, while improving reliability through the use of flight components

	JPL Flight SoA	Other Flight SoA	Other COTs SoA	This Work
Efficiency	90 %	86 %	98 %	97 %
Power Density	0.3 W/cm3	N/A	0.5 W/cm3	2 W/cm3
Specific Power	250 W/kg	250 W/kg	304 W/kg	1 kW/kg



Efficiency vs. Specific Power for COTs and Flight Power Systems

Relevance to JPL and NASA

- Dramatically reduce SWaP-C for power converters for future PV-based Cubesat, Smallsat, and Flagship missions
- Provide toolset to develop full power subsystem based around digital control and communications

Methodology

The Four-Switch Buck-Boost

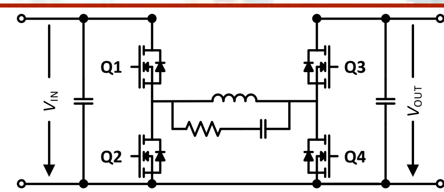
- The wide PV voltage range on deep-space missions overlaps with the unregulated battery bus range, requiring buck-boost functionality from the PV converter
- The non-inverting, four-switch buck boost provides high efficiency (> 90%) in either buck mode or boost mode. This work improves on boundary condition operations, reaching > 95% efficiency to the bus.

Hysteretic MPPT Control

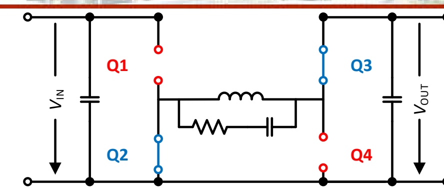
- Ripple correlation control (RCC) is a method of Maximum Power Point Tracking (MPPT) that utilizes inherent converter ripple to avoid system perturbations typical of traditional MPPT methods
- Hysteretic control of the buck-boost stage, coupled with RCC MPPT, reduces mode transitions, maximizing efficiency of the power stage when near unity gain

GaN HEMT Reliability

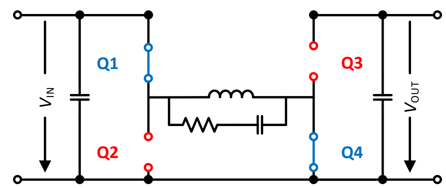
- GaN HEMTs, in both NASA and commercial testing, have been demonstrated to be hardened up to 1 Mrad
- Single Event Burnout testing has demonstrated that GaN devices do not suffer radiation-induced failure when below 75% of rated V_{DS}
- Europa Clipper MASPEX has developed path to flight for commercial GaN, including full qualification campaign that can be leveraged for future missions



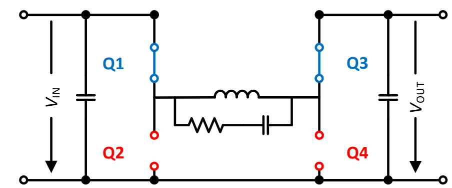
Four-Switch Buck-Boost Topology



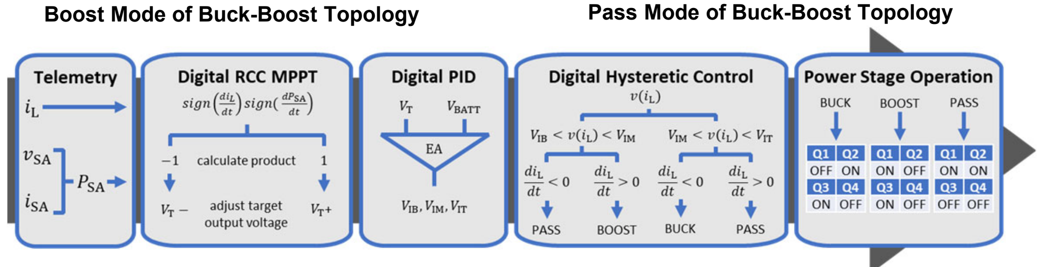
Buck Mode of Buck-Boost Topology



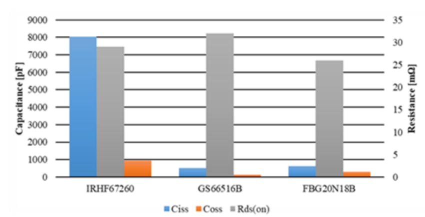
Boost Mode of Buck-Boost Topology



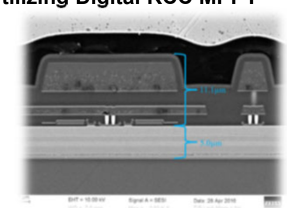
Pass Mode of Buck-Boost Topology



Hysteretic Converter & PV Array Control Utilizing Digital RCC MPPT



Comparison of Flight Si vs. GaN FETs



GaN HEMT Cross Section

Results

A breadboard was developed based around a 250 W system, targeted at platforms from Cubesats, to Smallsats, to future Flagships. Developed to TRL 4, this PCB provides the following converters:

- PV GaN Buck-Boost Converter(22 – 100 V_{IN}, 22-36 V_{OUT}, 250 W)
- Isolated GaN Push-Pull Converter (22 – 36 V_{IN}, 12 V_{OUT}, 100 W)
- PoL Buck Converters (12 V_{IN}, 3 & 5 V_{OUT}, 25 W)

The platform also provides these Power Subsystem features:

- Solar Array telemetry and Maximum Power Point Tracking
- Battery telemetry and control
- Telemetry for spacecraft bus, 12 V bus, 5 V bus, and 3.3 V bus
- Switched heater services

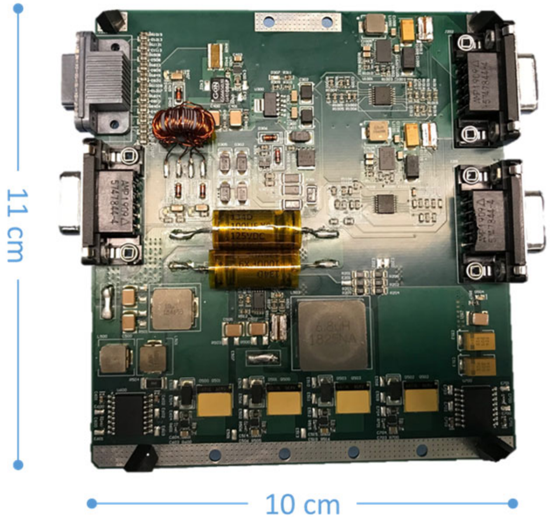
The platform also provides these Power Subsystem features:

Parameter	Minimum	Maximum
Output Power	0 W	250 W
Input Voltage	22 V	100 V
Output Voltage	22 V	36 V
Output Current	0 A	12 A

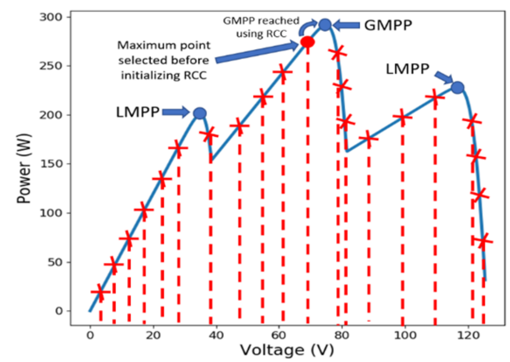
Breadboard PV Converter Specifications

Component Type	Part Number
Switching FETs	GS66516T
Inductors	SGIHLP60HEB6R8M81S
Bulk Input Capacitance	T550B756M075AH
Bulk Output Capacitance	T510X337K010CH641C
Microcontroller	UT32M0R500

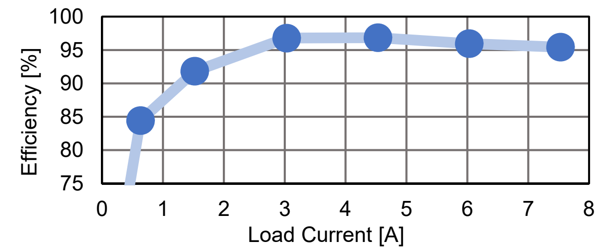
Breadboard PV Converter Components



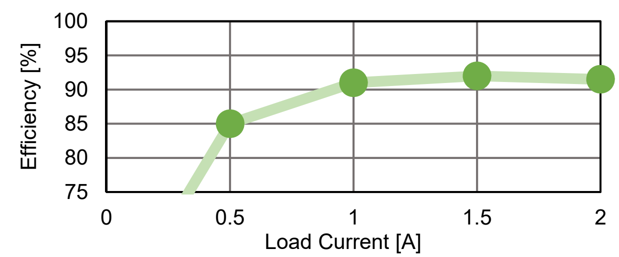
Breadboard PV Converter & Power Subsystem PCB



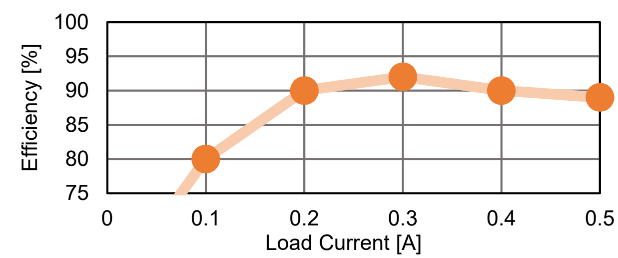
Ripple Correlation Control MPPT Performance



PV Buck Boost Converter Efficiency



Point of Load Converter Efficiency



12 V Isolated Converter Efficiency

Future Work

NASA Game Changing Development – “Breakthrough Distributed Power Architecture for In Situ Lunar Missions”

NASA Game Changing Development – “Tethered Power Systems for Lunar Mobility and Power Transmission”

Publications and References

S. Mahmud et al., "A GaN-based Four-Switch Buck-Boost Converter using Ripple Correlation Control for Maximum Power Point Tracking in Dynamic Deep Space Environments," AIAA Small Satellite Conference, Virtual, 2020

T. Cook et al., "Soft-Switching GaN-Based Isolated Power Conversion System for Small Satellites with Wide Input Voltage Range," AIAA Small Satellite Conference, Virtual, 2020

A. Barchowsky et al., "GaN-Based, Ultra-Compact Power Conversion System for the PUFFER Autonomous Mobility Platform," AIAA Small Satellite Conference, Virtual, 2020

A. Barchowsky et. al, "GaN-Based Distributed Power Electronics Architecture for In Situ Lunar Mission", Deep Space Power Conference, Virtual, 2020

M. Sadab et. al, "Enhanced Digital Ripple Correlation Control for Maximum Power Point Tracking in Dynamic Partial Shading Conditions", IEEE Applied Power Electronics Conference (APEC) 2021 [Submitted]