Hybrid Switched Capacitor Anode Supplies for 1 kW-Class Hall Effect Thrusters

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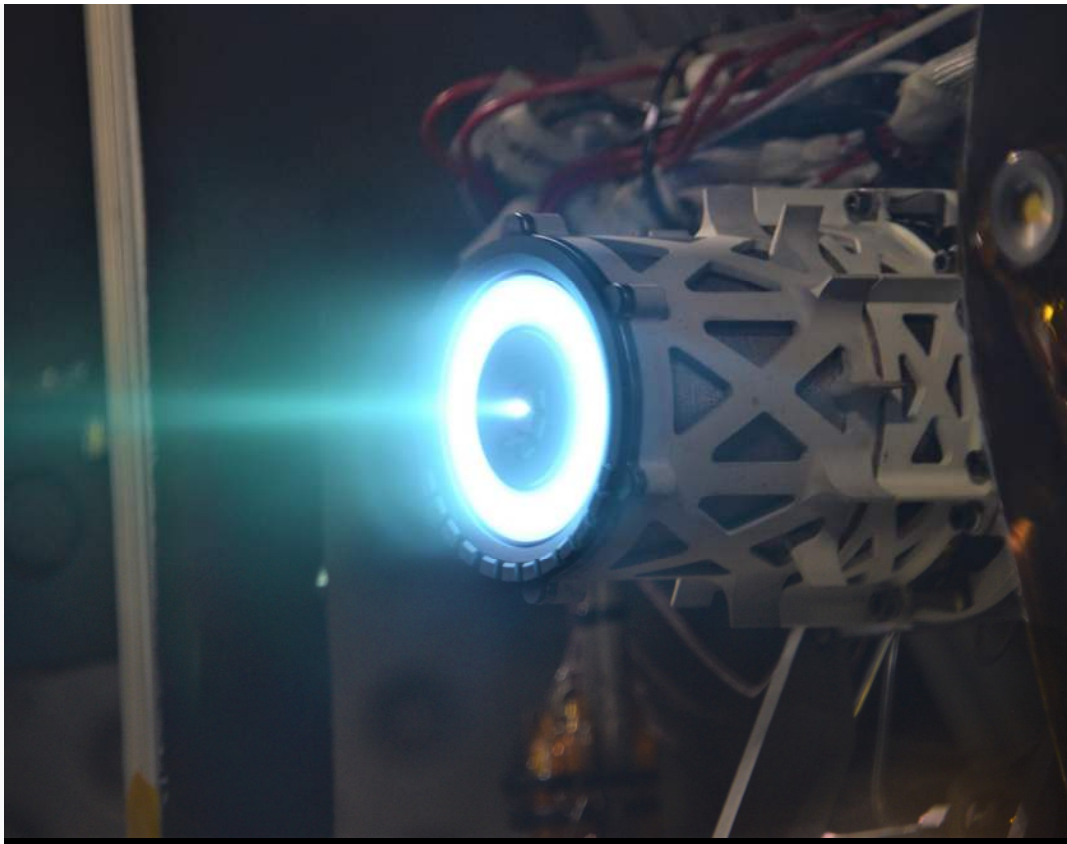

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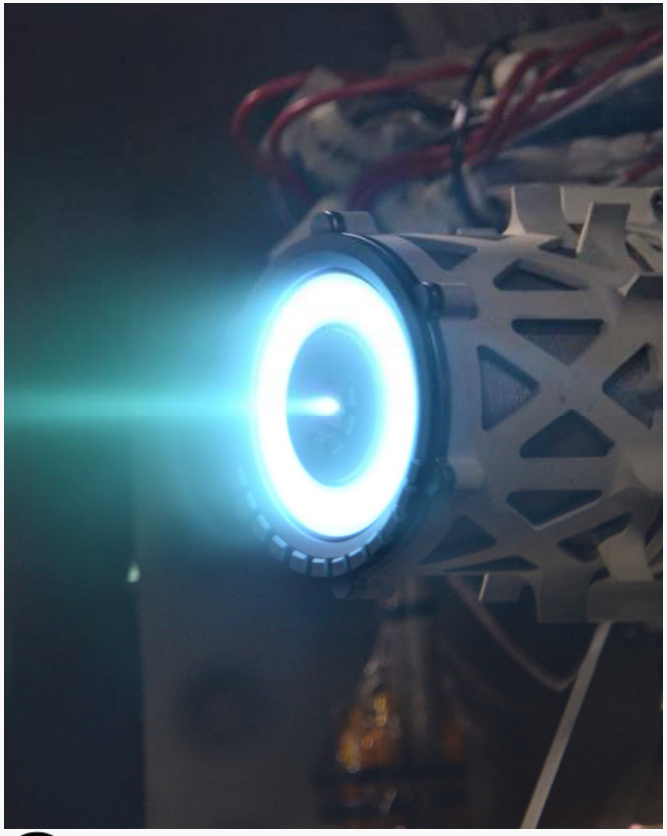
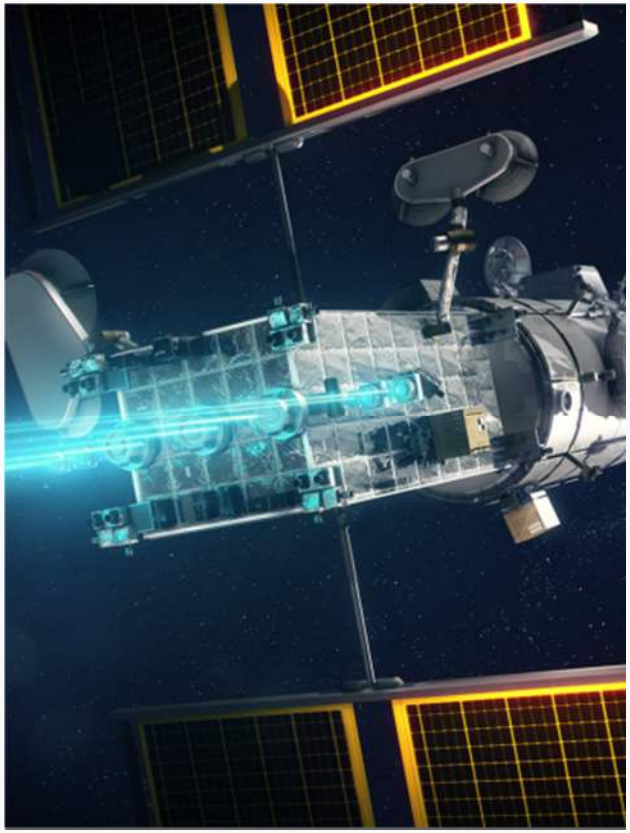
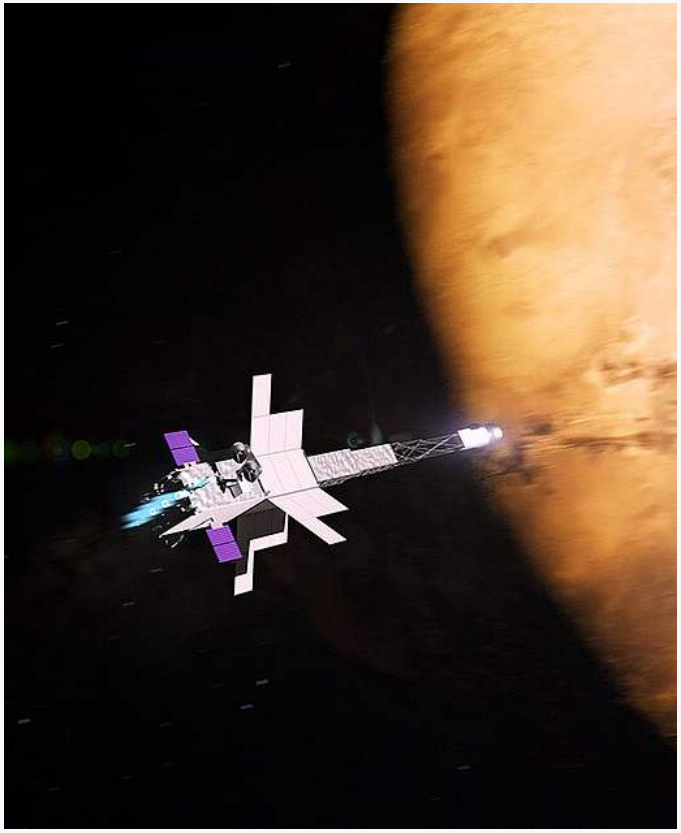
Motivation

Solar and nuclear electric propulsion provide high delta-V, enabling rapid transit to the Moon, Mars, and beyond.



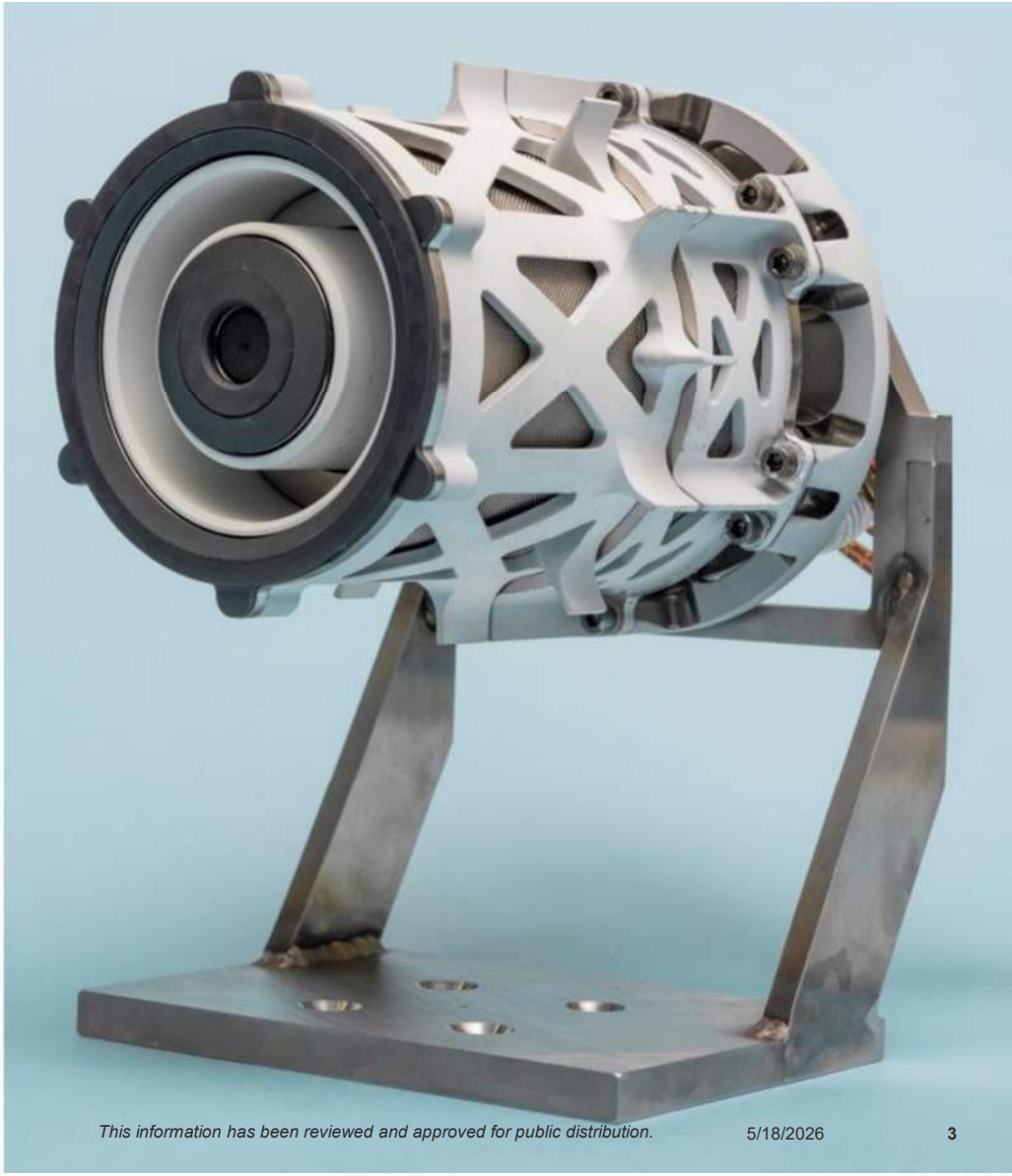




Hall Effect Thrusters

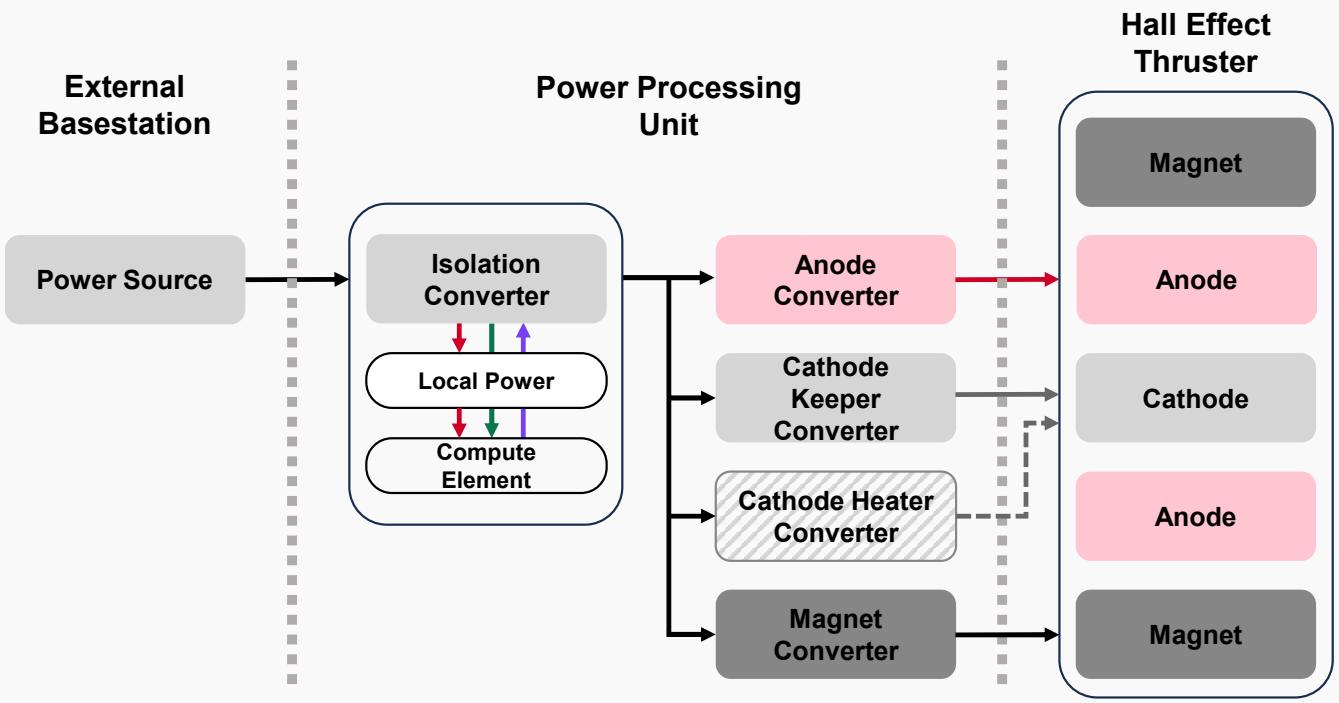
Hall thrusters are electrostatic thrusters that accelerate ions to high velocities using the Hall effect. They achieve high I_{SP} and relatively high thrust, enabling vehicles to rapidly explore the solar system with small amounts of fuel.

- **1 kW-class:** small missions to maximize payloads
  Applications: Constellations, smallsats, commercial lunar and mars
- **10 kW-class:** large vehicle maneuverability
  Applications: Gateway, orbital transfer vehicles, SR-1 Freedom
- **50 kW-class:** high power systems for deep space
  Applications: Mars transfer, human spaceflight, large NEP systems

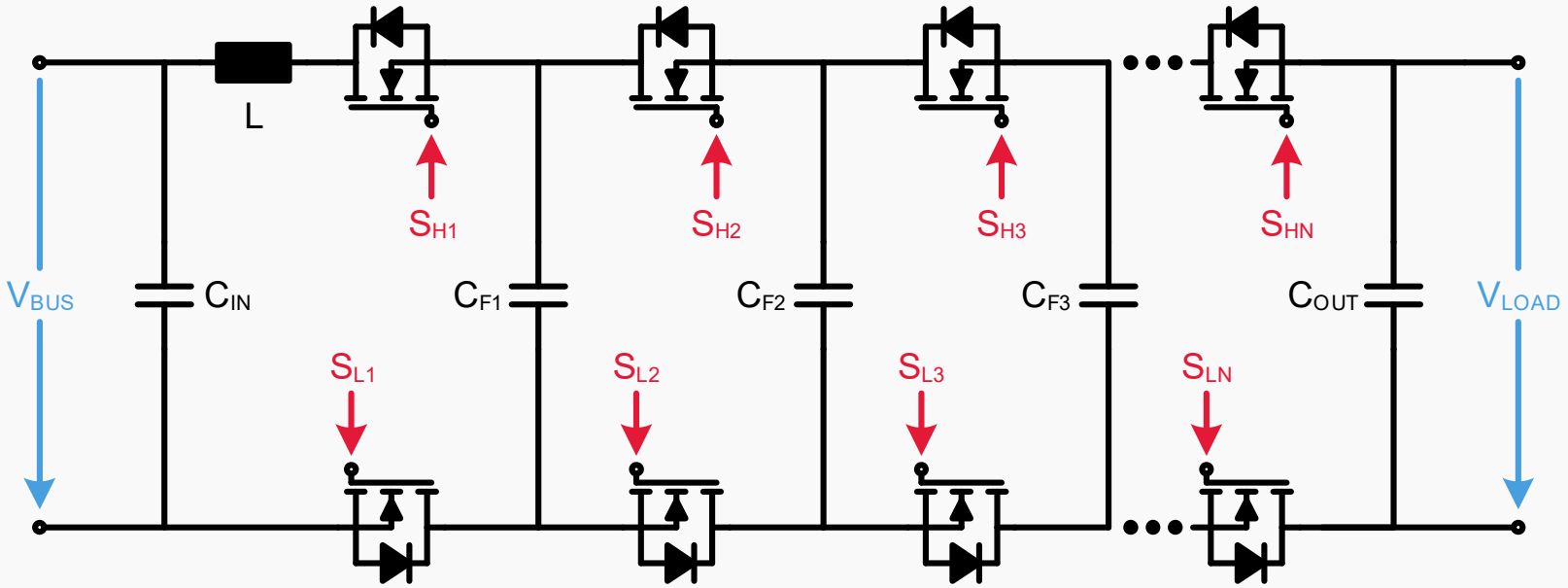


Power Processing Units

The best thrusters in the world deserve the best power supplies in the world. Compact PPUs are essential to improve system efficiency, minimize mass, and reduce radiator size.



Parameter	Specifications
Isolation Converter	1.5 kW 100 V
Anode Converter	1 kW 200 – 500 V
Cathode Keeper Converter	100 W 20 – 1000 V
Cathode Heater Converter (Thruster Dependent)	50 W 28 V
Magnet Converter	100 W 0 – 28 V



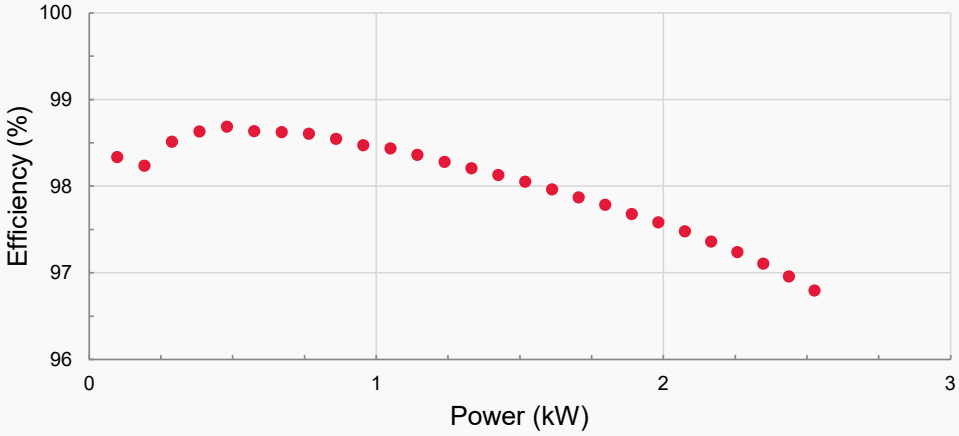
Flying Capacitor Multilevel Converters

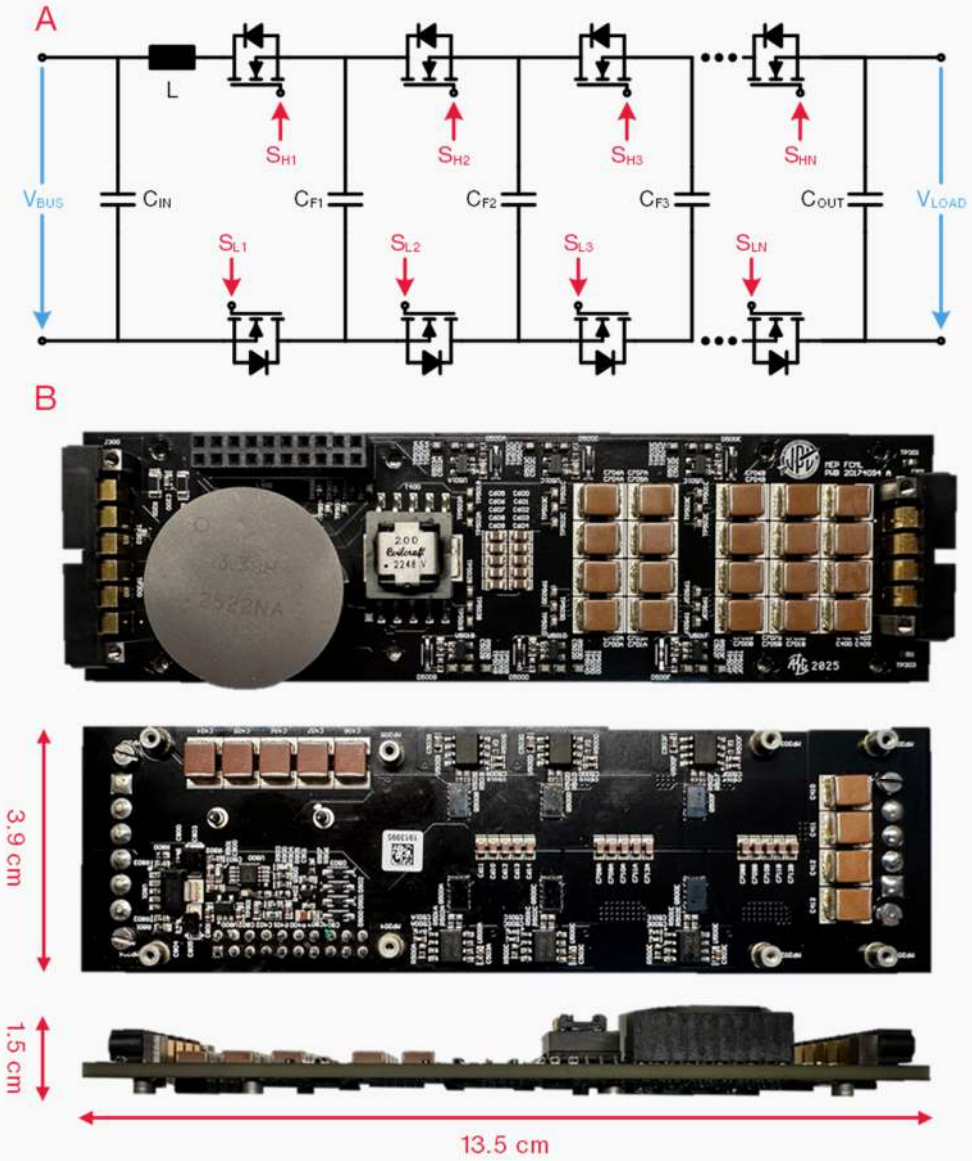
Flying Capacitor Multilevel (FCML) converters, like all hybrid switched-capacitor converters, take advantage of the high specific energy of capacitors to reduce converter mass and volume.

For PPUs, FCMLs enable high-density, low-mass, high-efficiency anode supplies, providing the wide throttling range needed to optimize thruster performance in deep-space electric propulsion missions.

FCML Power Stage Evaluation

Parameter	Specifications
Input Voltage	50 V
Output Voltage	100 V
Output Power	2.5 kW
Switching Frequency	150 kHz
Peak Efficiency	98.7%
Mass	116 g
Volume	78.9 cm^3

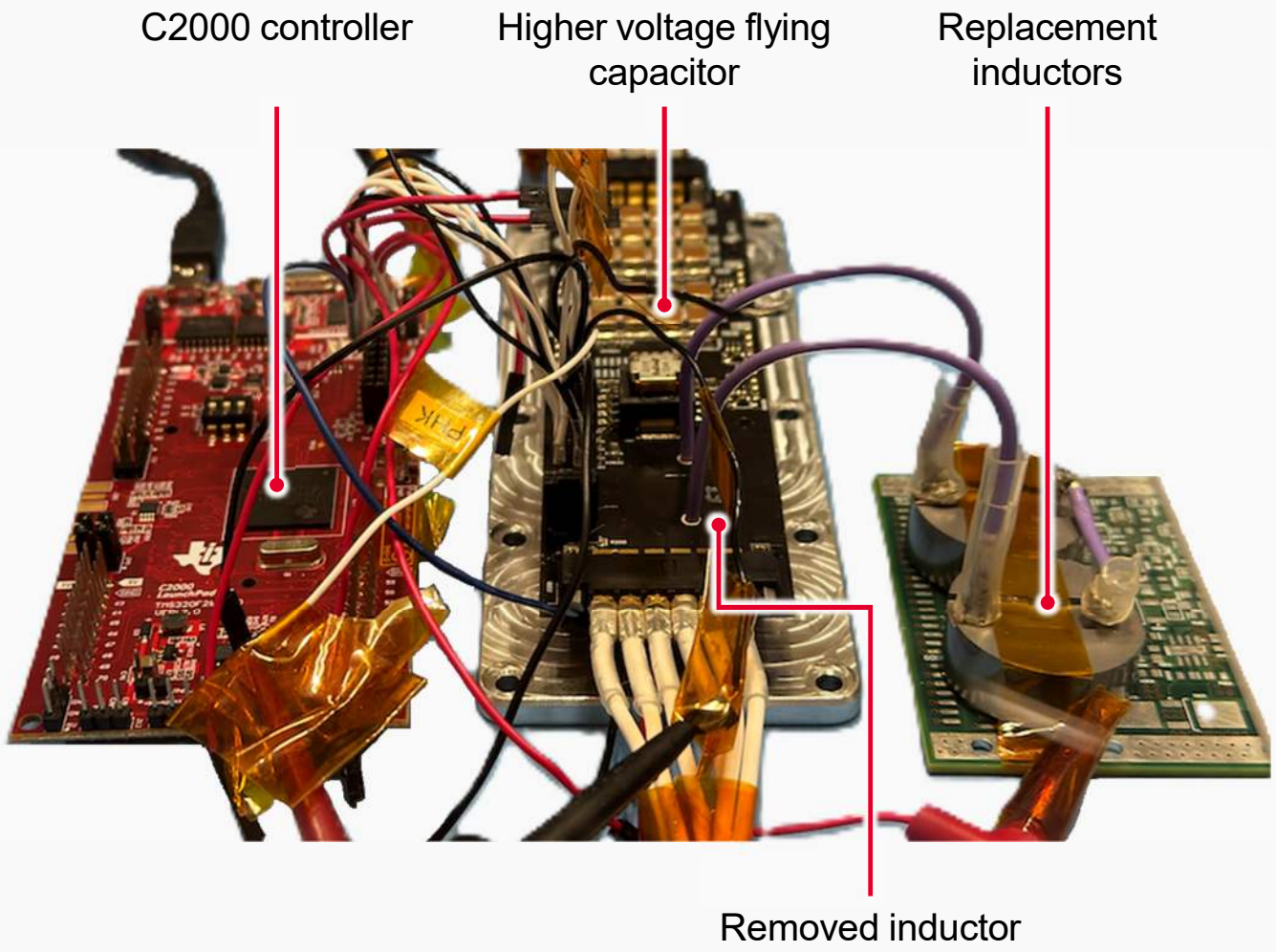




Modified FCML for Anode Power Conversion

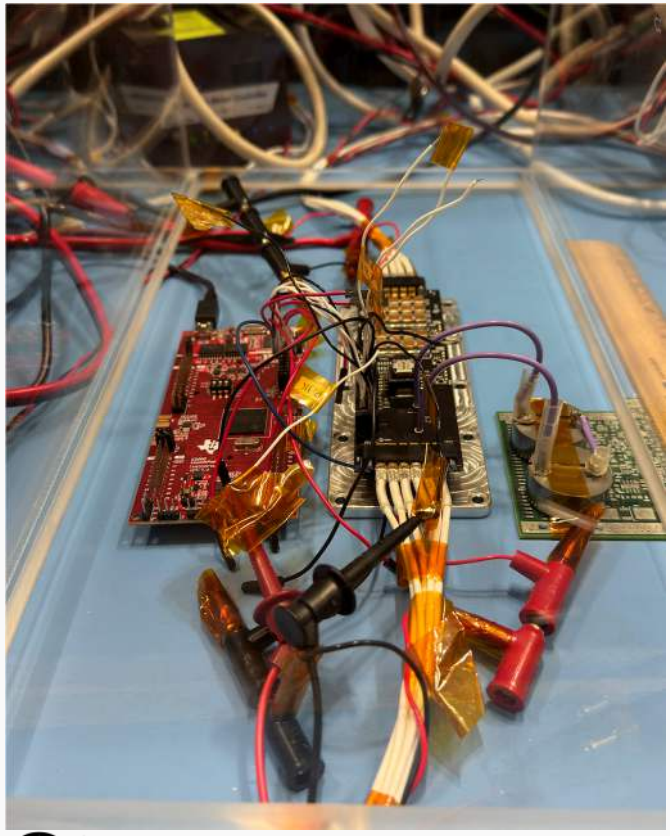
To fire a Hall thruster using the FCML for the anode, we adapted the demo hardware for a wider voltage range, modifying the inductor, flying capacitors, and controller.

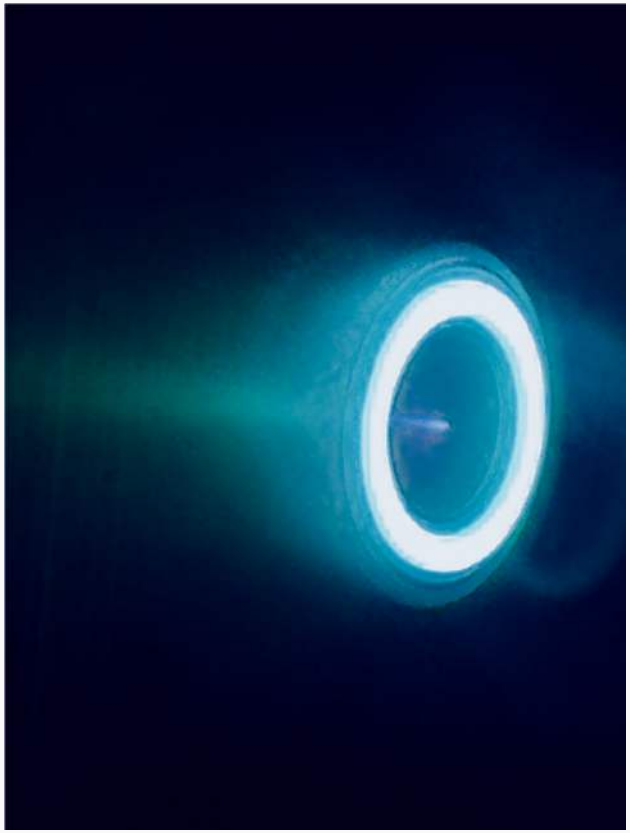
Parameter	Specifications
Input Voltage	100 V
Output Voltage	200 V
Output Power	2.5 kW
Switching Frequency	150 kHz
Peak Efficiency	98.7%
Mass	116 g
Volume	78.9 cm^3

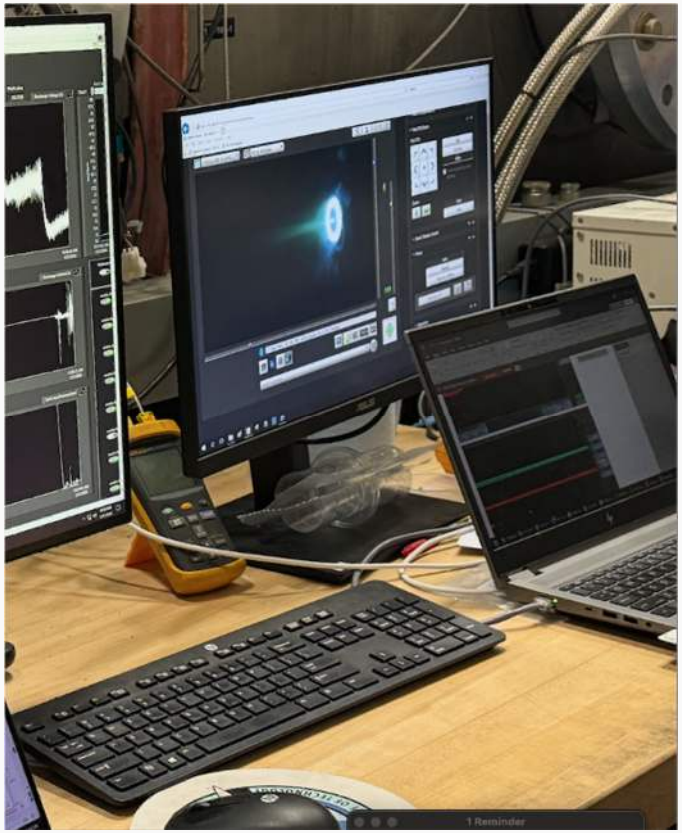


MaSMI Hall Thruster Anode Converter Firing Test

We integrated the FCML Anode Converter to the MaSMI 1 kW Hall effect thruster and demonstrated firing at 750 W, 250 V, and 96% efficiency

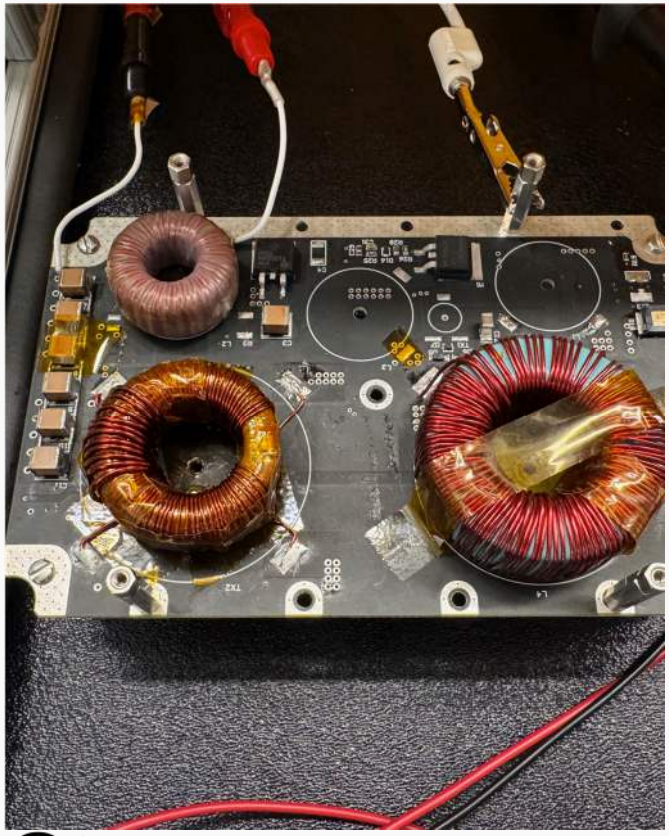


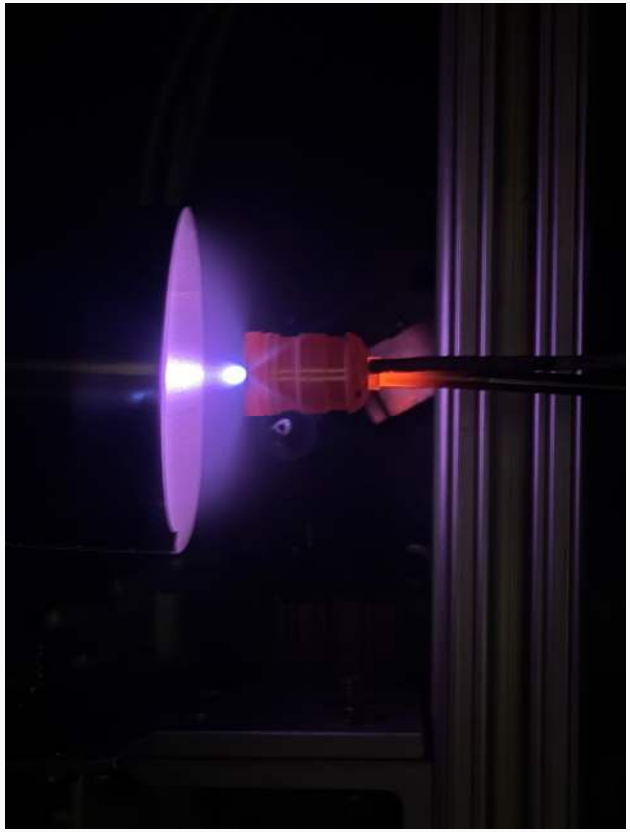


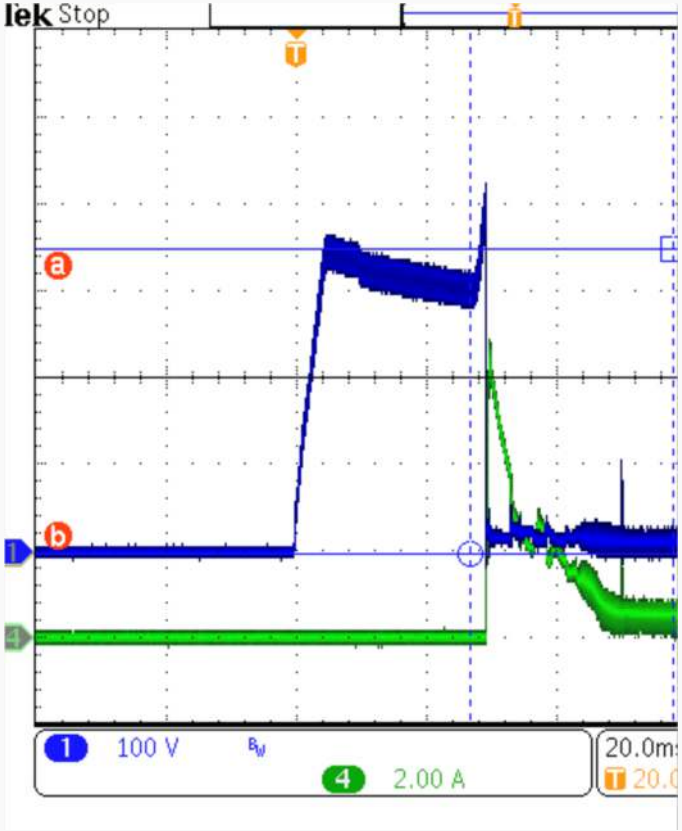


MaSMI Cathode Keeper Converter Firing Test

To achieve consistent ignition of 1 kW-class thrusters, JPL has developed a cathode keeper converter that has been demonstrated on the MaSMI heaterless cathode







Integrated PPU Development

A fully integrated FCML PPU, including the Cathode Keeper Converter, Magnet Converter, valve drives, and system controller dramatically improves **specific mass** and **efficiency** when compared to the state of the art.

Parameter	Specifications
Converters	Anode: 2.5 kW, 200 – 500 V Keeper: 100 W, 20 – 1000 V Magnet: 100 W, 0 – 28 V
Communications	Ethernet, UART, CAN, RS-422/485
TID	30 krad or 100 krad
SEE	37 MeV-mg/cm^2
Peak Efficiency	97%
Mass	2 kg
Volume	8450 cm^3

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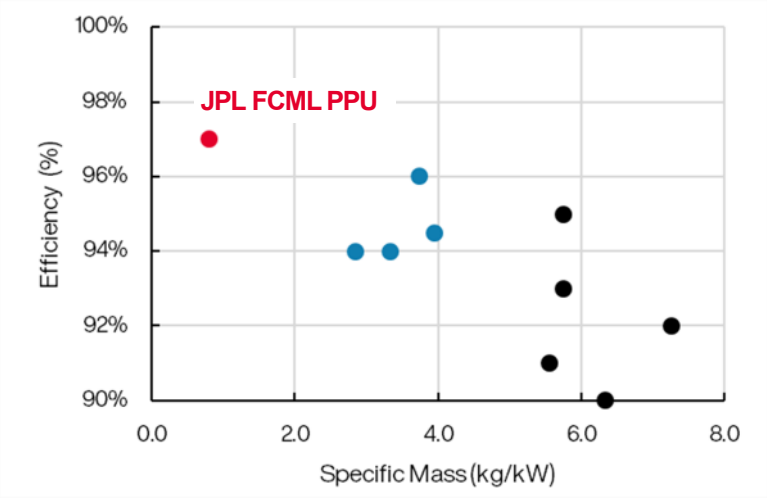

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A Efficiency (%) and Specific Mass (kg/kW) comparison of **this work** to existing PPU systems

B Prototype of targeted packaging design for developed PPU system

Let’s explore deep space together!

To work together, reach out to us! We’re here to support NASA and industry in building the future of spaceflight:

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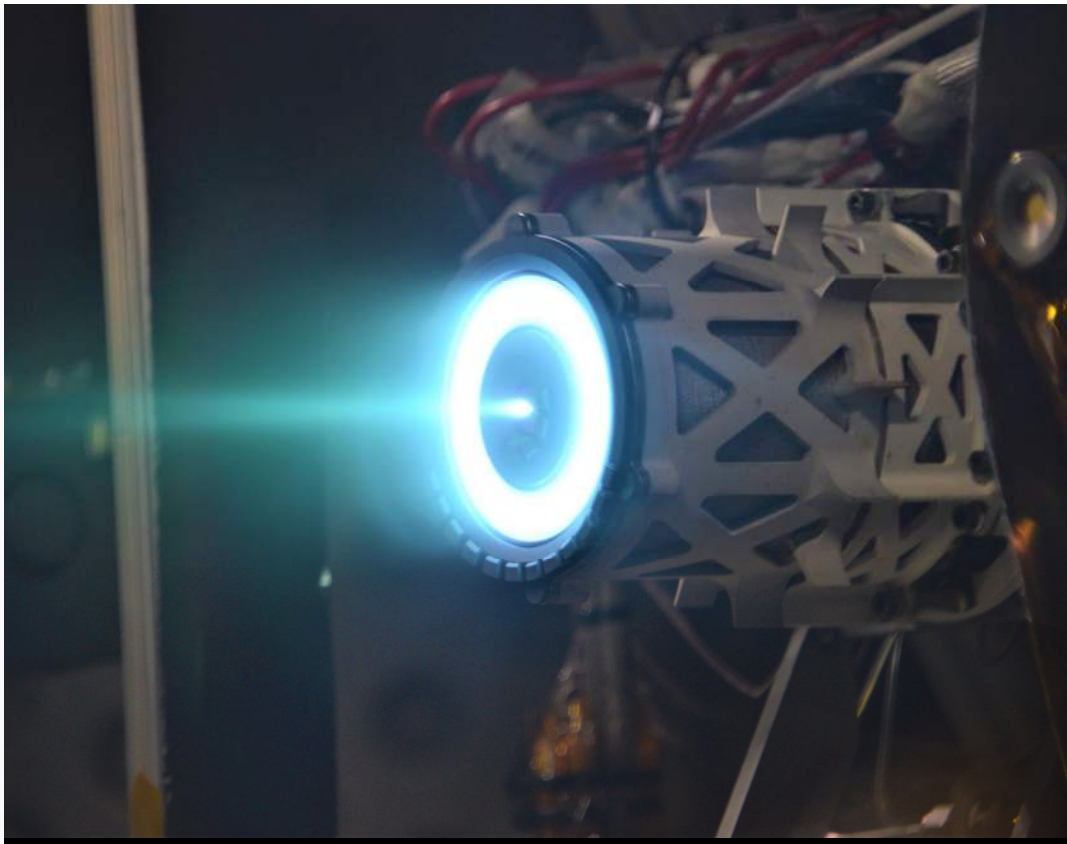

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