



Hybrid Power Processing Unit

The Next Cornerstone in Spacecraft PMAD Systems



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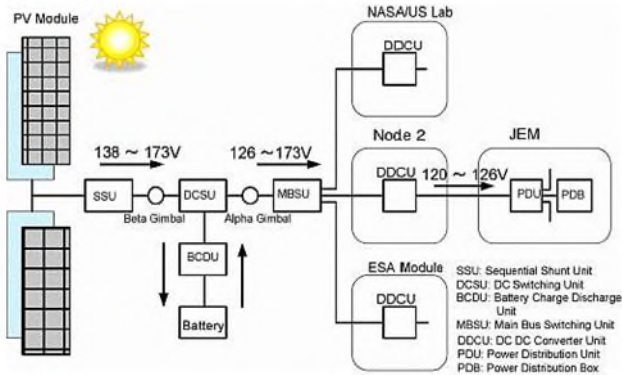
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Space Power Workshop - April 21st 2021

Agenda

- Introduction and Background
 - Aerojet Rocketdyne Background (A hybrid company)
 - Aerojet-Electric Propulsion
 - Rocketdyne-ISS Power System
- 13kW AEPS & 100kW NextSTEP XR-100 EP System
- Hybrid PPU Development, Success Criteria and Test Results
- Benefits to PMAD & Range of potential capabilities
- Conclusion

Aerojet + Rocketdyne Background



4.08 kW 100V Arcjet PCU



Switch Gear



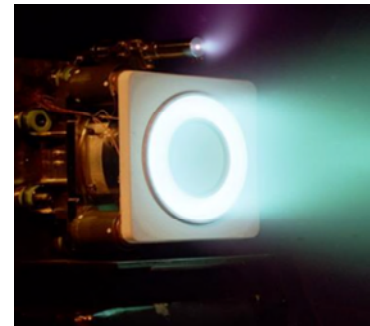
6.5kW DC-DC Converter Unit



15kWhr Li-Ion Battery



3.5A to 50A Remote Power Controller Circuit Breaker



HALL THRUSTER PROPULSION SYSTEM
4.5 kW PPU



Plasma Contactor



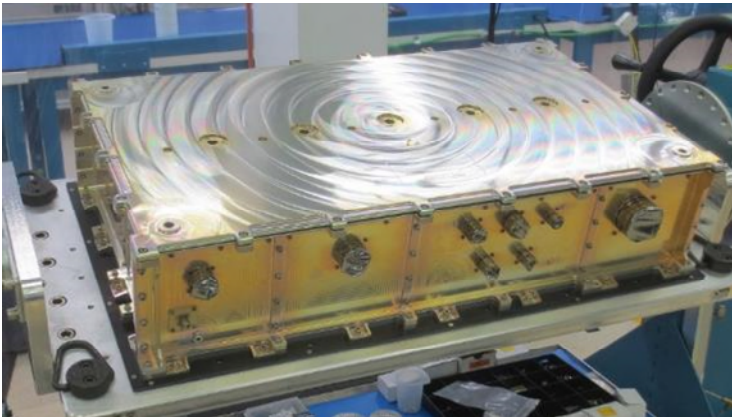
Dream Chaser EPS

AR's Synergistic past provides bases for a Hybrid Approach

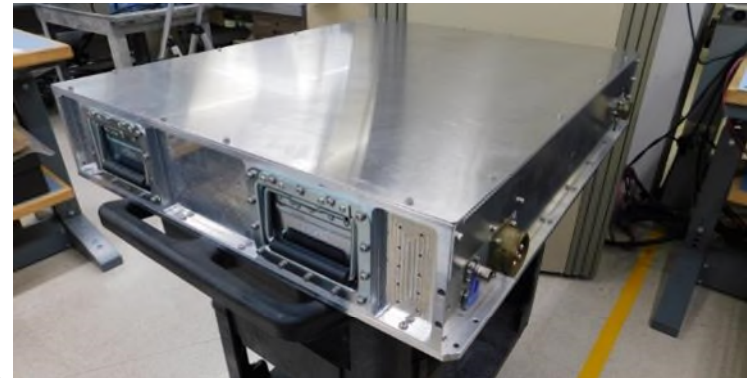
NextSTEP XR-100 and AEPS Programs



AEPS PPU Development



XR-100 Development



	AEPS	XR-100
Input Voltage	90 – 150	95-130
Output Voltage	300-630	350-400 700-800
Output Current	22	38 / 19
Output Power	13KW	15kW

Each Program Provide Unique Features the HPPU

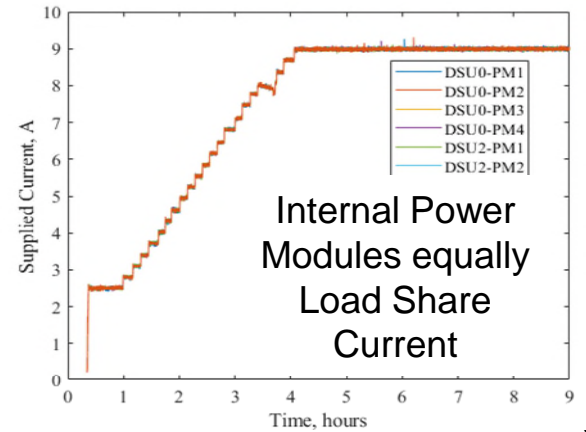
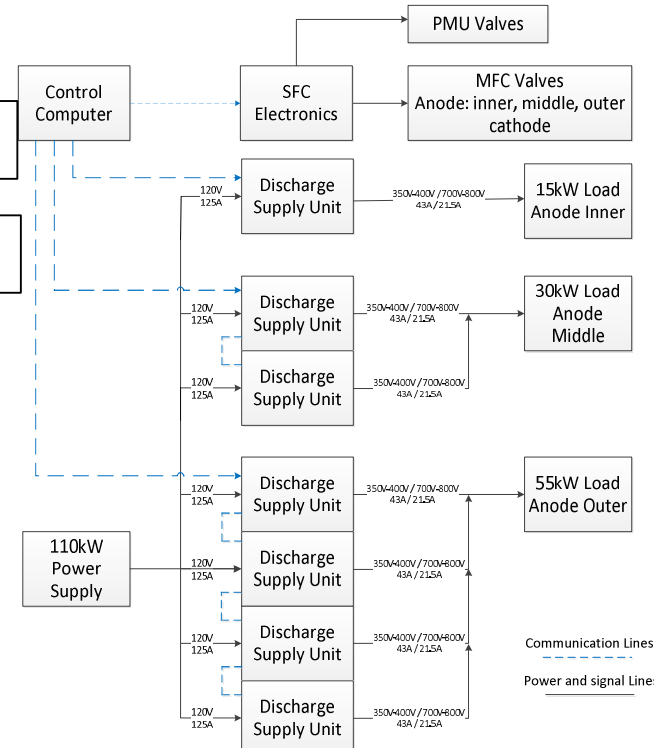
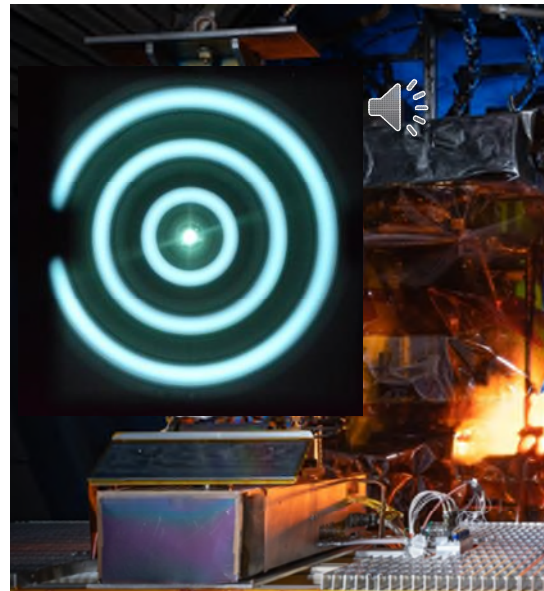
XR-100 Nested Hall Thruster System



Input Voltage	Input Current	Input Power	Output Voltage	Output Current	Output Power	Efficiency
107.0 V	99.6 A	10,657 W	400.4 V	25.56 A	10,234 W	96.0%
103.6 V	103.8 A	10,753 W	400.4 V	25.94 A	10,386 W	96.5%
104.0 V	85.6 A	8,902 W	602.0 V	14.37 A	8,650 W	97.1%
105.8 V	97.2 A	10,283 W	705.6 V	14.16 A	9,991 W	97.1%
105.9 V	97.0 A	10,272 W	800.0 V	12.50 A	10,000 W	97.3%

400V

800V

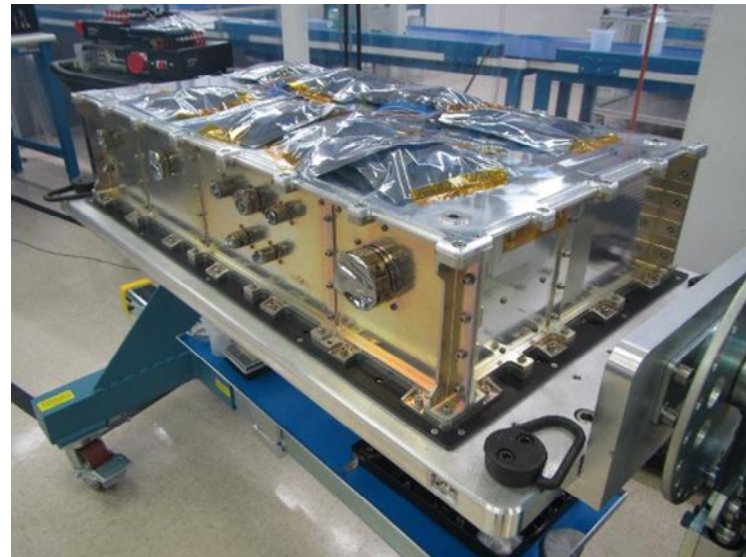
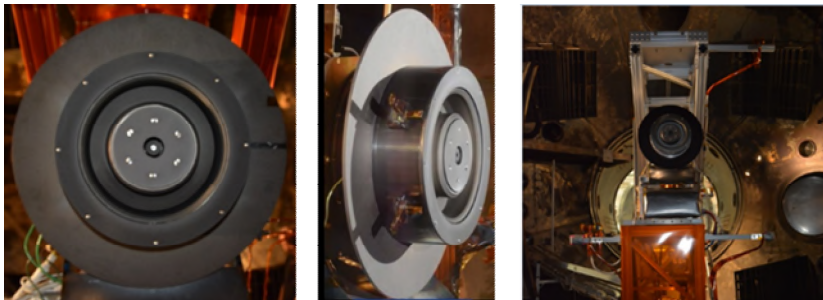
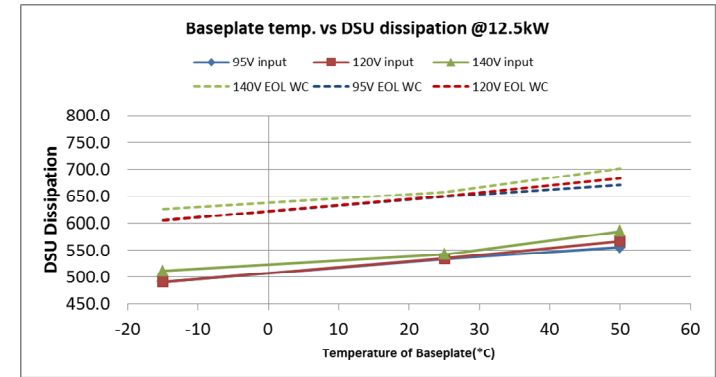
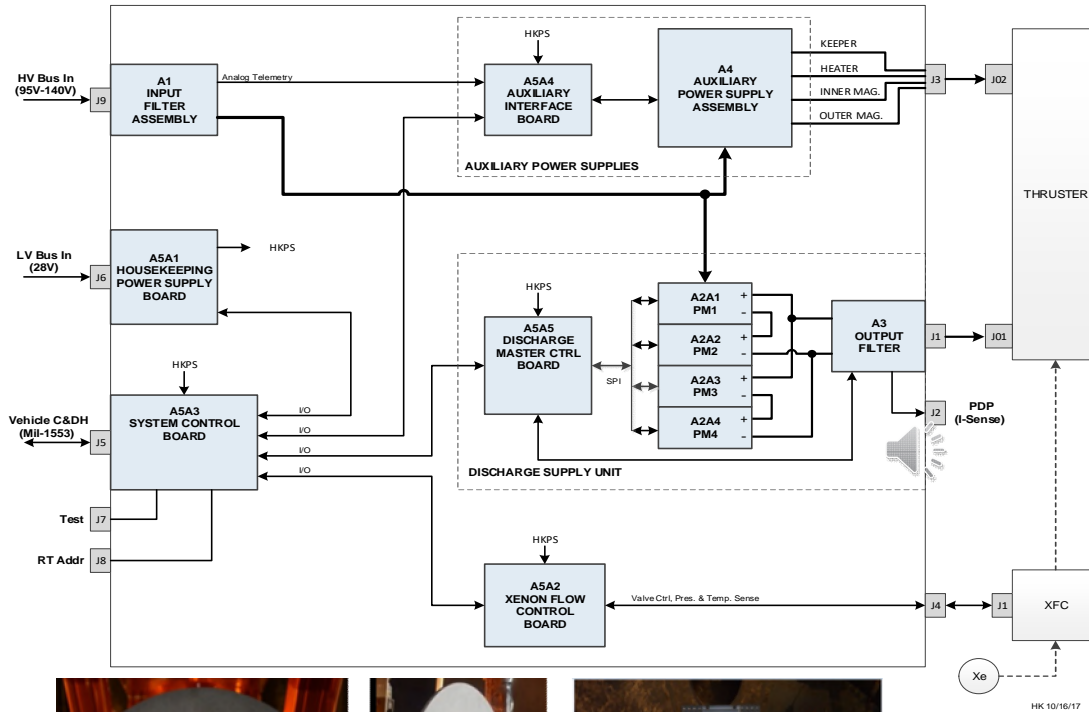


The Configurable 400V or 800V Output Set the Stage for HPPU Development

13kW Advanced Electric Propulsion System PPU



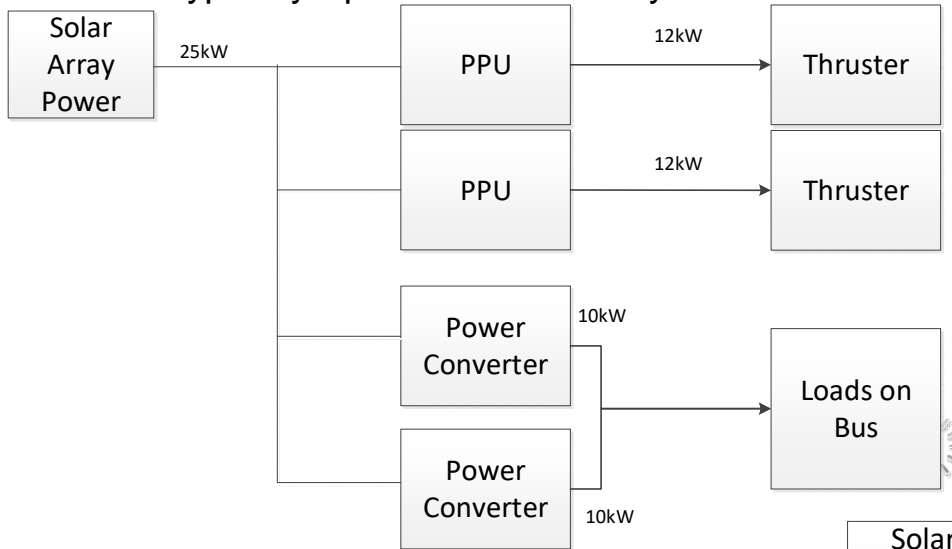
AEPS PPU BLOCK DIAGRAM



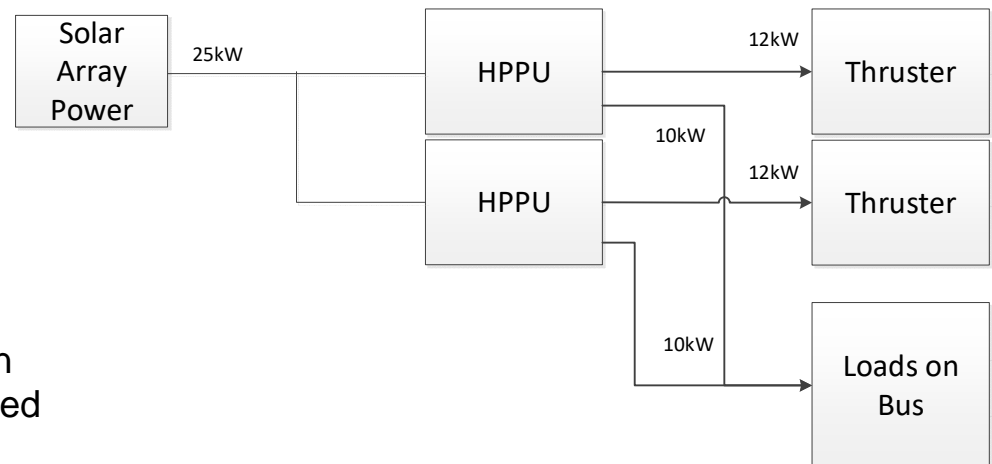
The AEPS PPU Established Wide Variable Output for HPPU Development

What does a Hybrid PPU do?

Typically Spacecraft Power System



HPPU Spacecraft Power System




Generally Loads Exceed Solar Power Available
Therefore Loads are managed and not always on
Leaving Parts of the Power System Under utilized

HPPU Power Thruster and Loads on the Spacecraft

Hybrid PPU Configurations



	AEPS	XR-100	HPPU
Input Voltage	90 – 150	95-130	95-130
Output Voltage	300-630	350-400 700-800	75-150, 150-300, or 300-600
Output Current	22	38 / 19 	88 / 44 / 22
Output Power	13KW	15kW	13kW

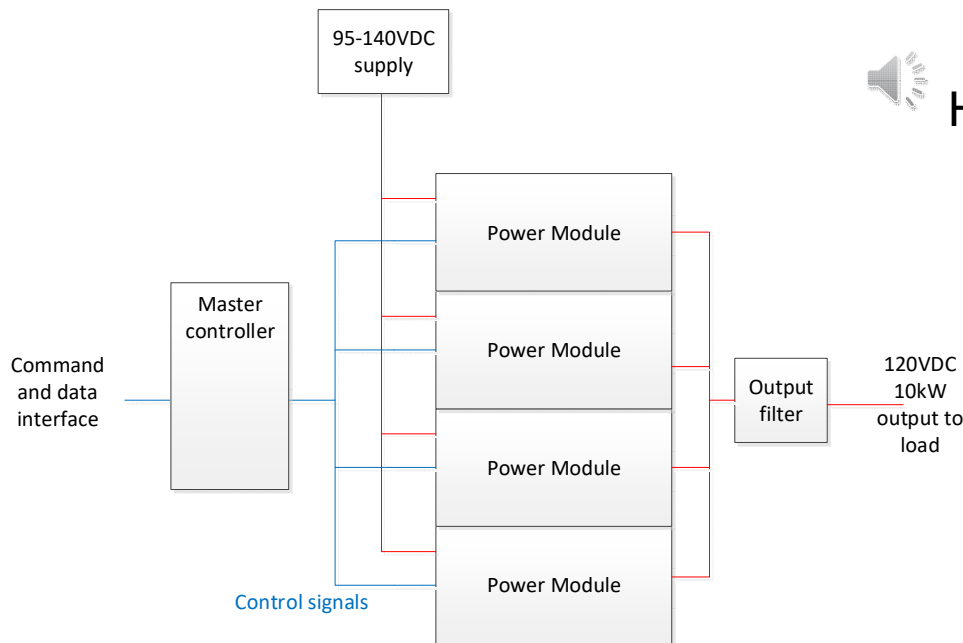
SAE AS5698
SSP 52051, Volume 1

Space Power Standard, issues 2012-04
User Electric Power Specifications and Standards for ISS REV A

Functional Output Ranges for HPPU Established

HPPU Efficiency Test

Configured Output Mode	Input voltage (V)	Input Current (A)	Output Voltage (V)	Output Current (A)	Input Power (W)	Output Power (W)	Efficiency
S/C Bus mode	95.232	106.108	119.94	80.168	10105	9615	95.2%
	129.04	78.272	119.86	80.05	10100	9595	95.0%
Thruster mode	94.131	112.698	600.35	17.008	10608	10211	96.3%
	128.98	82.534	600.37	16.99	10645	10200	95.8%

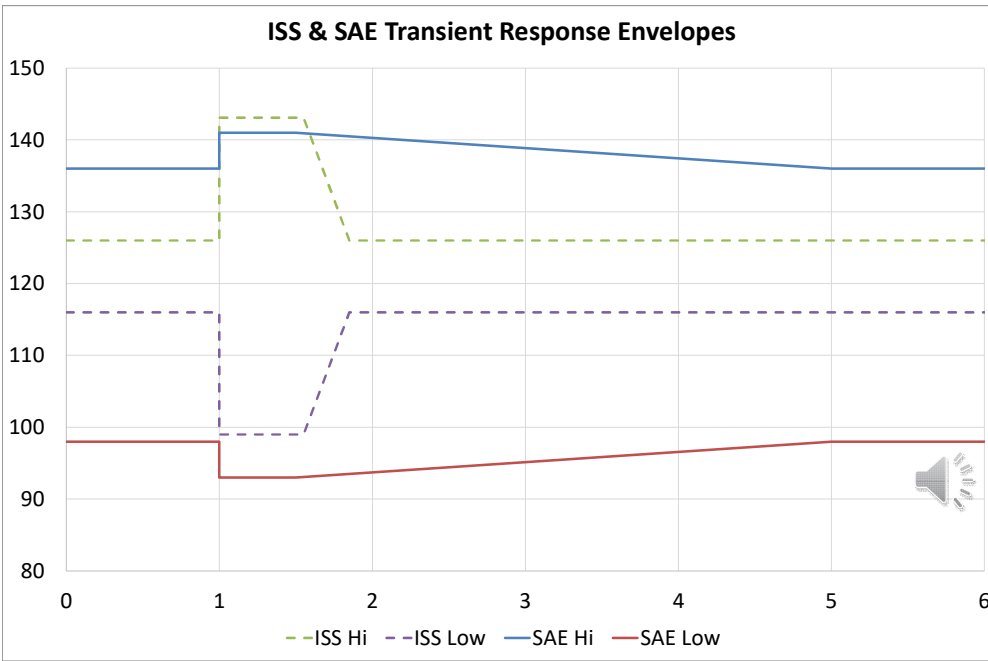


HPPU exceeds 95% Efficiency

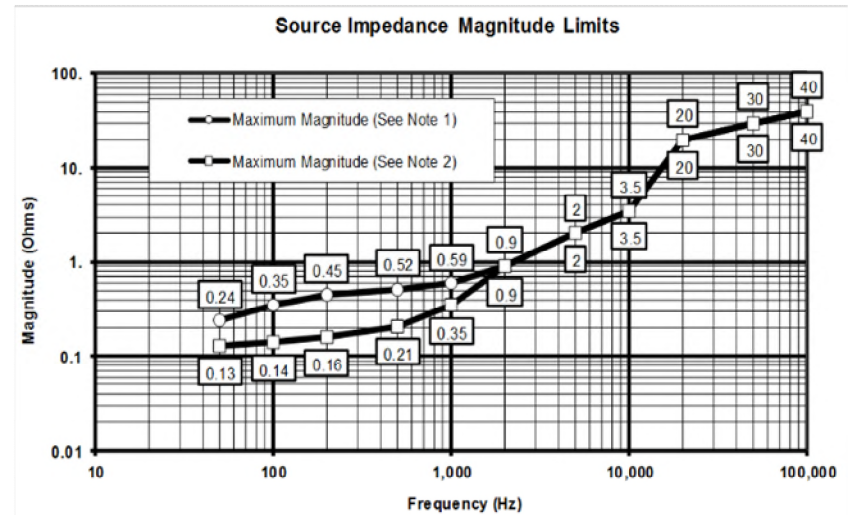
Hybrid PPU Meets Efficiency Needs for Thruster (600V) and Spacecraft (120V) Modes

HPPU Power Quality Evaluation Criteria

ISS & SAE Transient Response Envelopes



Source Impedance Magnitude Limits

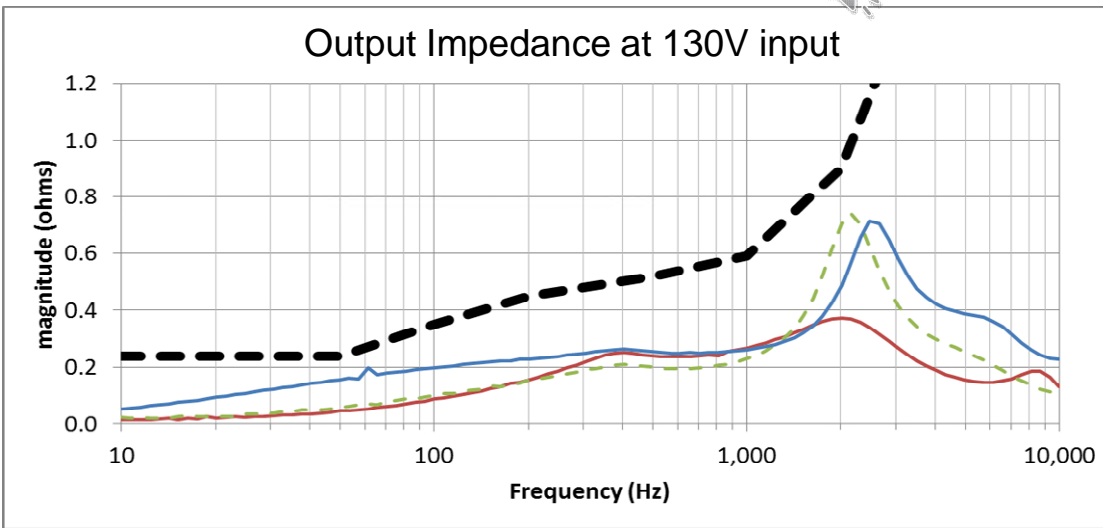
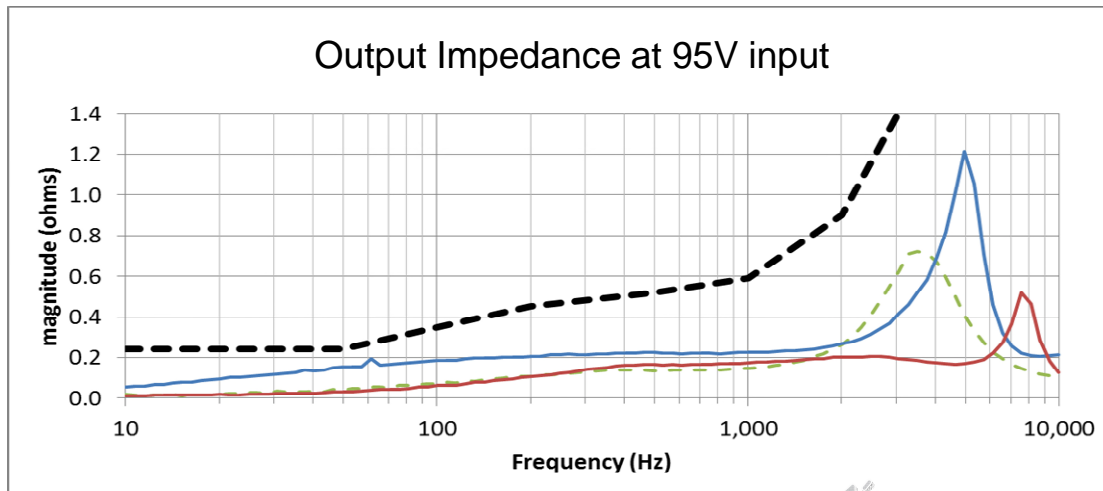


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Transient and Output Impedance Ensure System Stability and Robustness

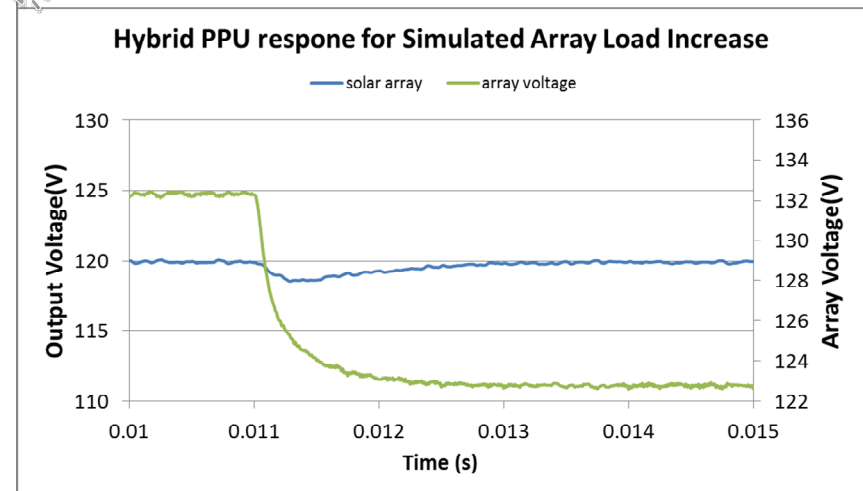
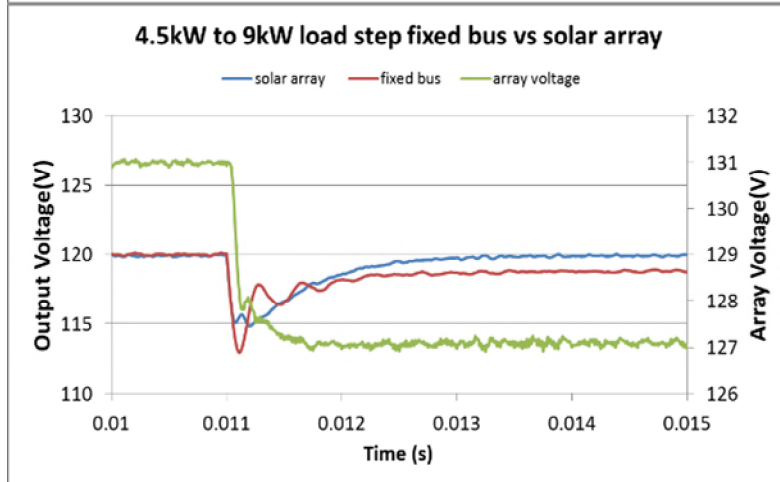
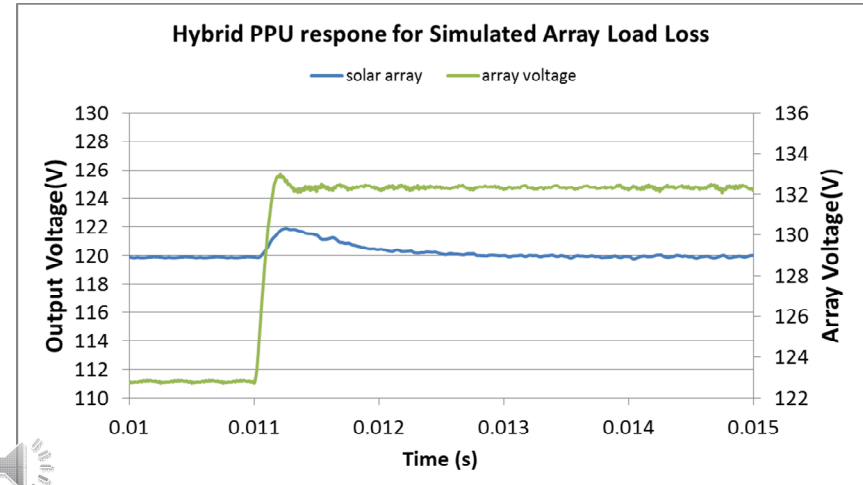
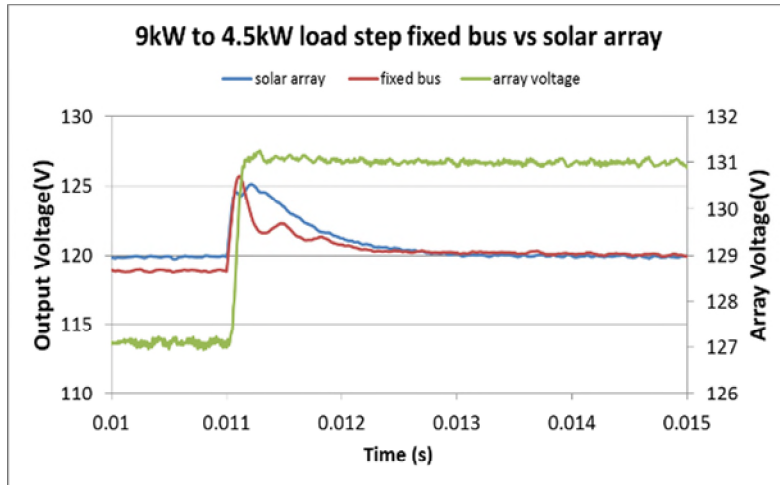
HPPU Output Impedance at Input Voltage Limits



Controls were tailored to maximize Output Impedance and Transient response

HPPU Meets Output Impedance of SSP and SAE Specifications

HPPU Analyzed with 4.5kW Step loads

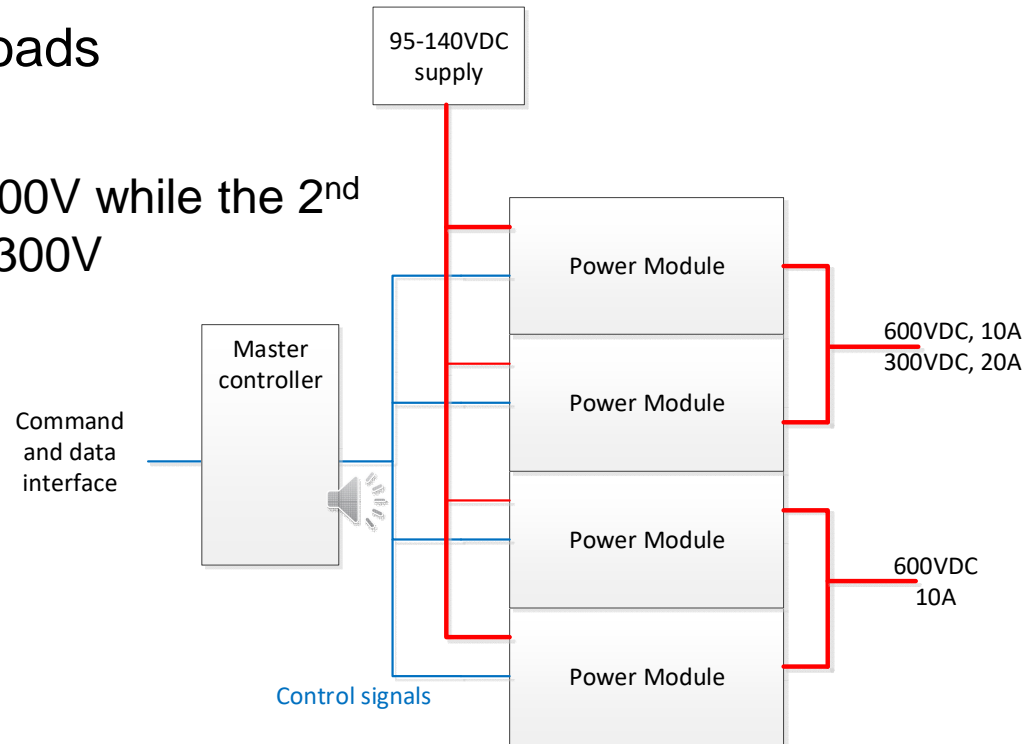


HPPU Meets Transient Performance of SSP and SAE Specifications

HPPU Dual Output Mode

- Power 2 different Loads simultaneously

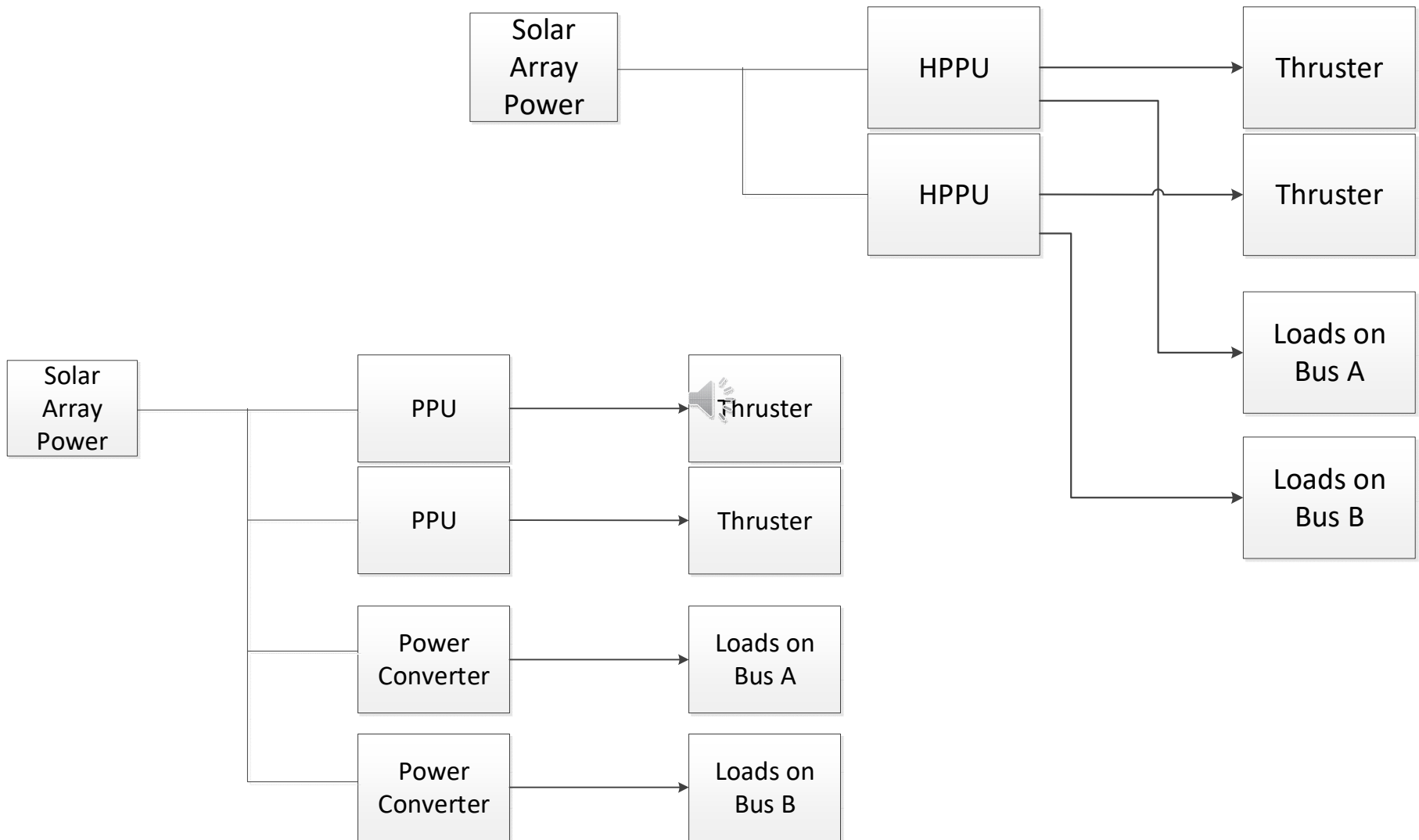
– 1 Output Set to 600V while the 2nd is set to 2 Set to 300V



Vin (V)	Iin (A)	Vout1 (V)	Iout1 (A)	Vout2 (V)	Iout 2 (A)	Pin (W)	Pout 1 (W)	Pout 2 (W)	Eff (%)
119.5	103.5	297.8	19.9	600.2	10.0	12362.4	5936.0	5978.3	96.38%
112.3	110.3	298.3	20.0	600.1	10.0	12386.3	5955.8	5981.0	96.37%
122.1	109.1	449.2	15.2	299.9	19.9	13324.9	6817.7	5975.4	96.01%
119.3	102.2	598.0	9.6	299.8	19.9	12189.1	5752.5	5973.1	96.20%

HPPU in Dual Output Mode Exceeds 95%

HPPU Benefits to Future Missions

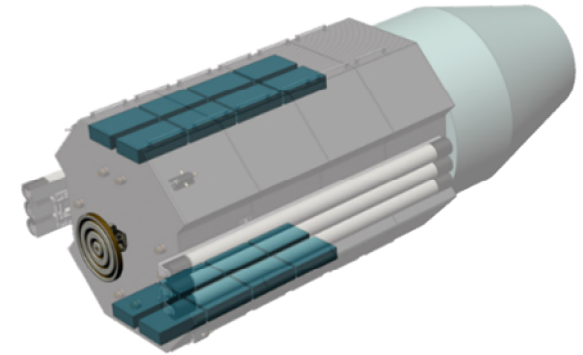
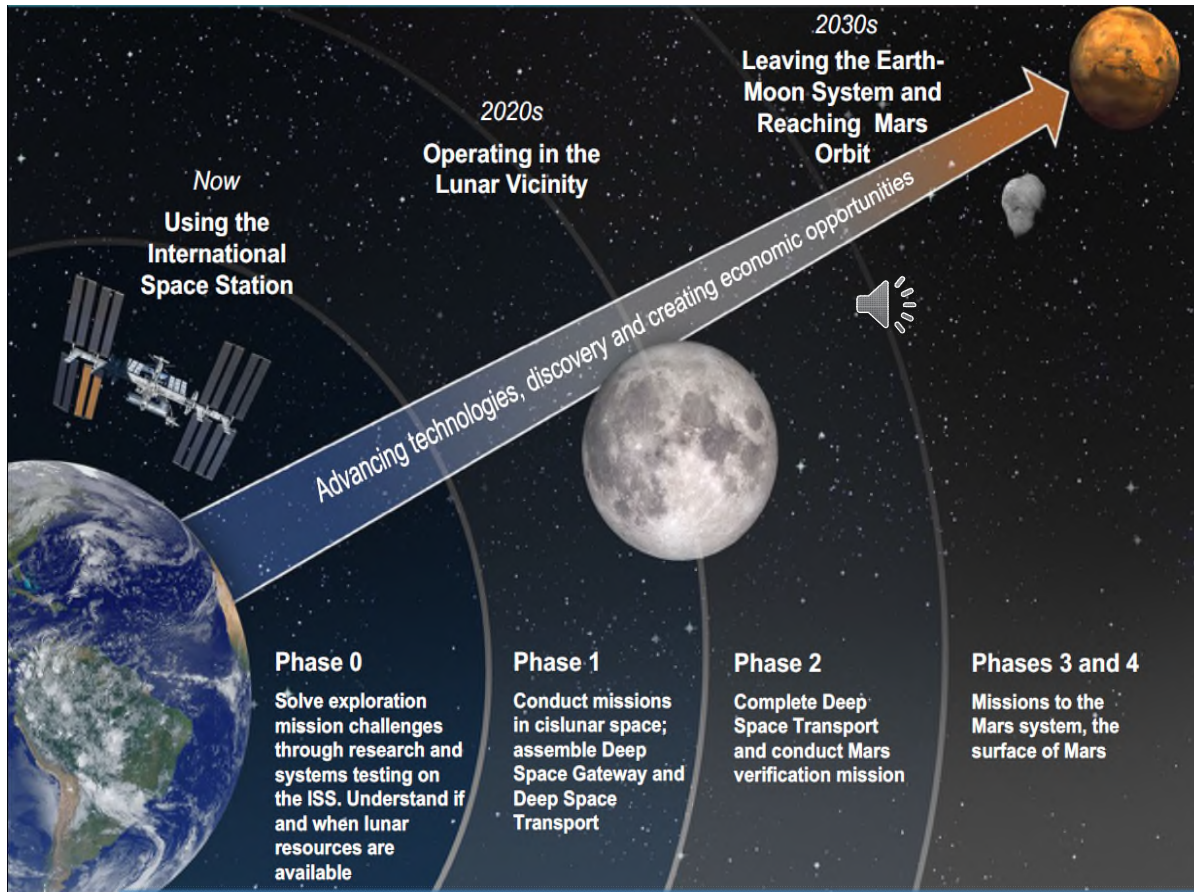


Two HPPU Can Increase the Utility of the Power System while saving 80kg

NASA VISION FOR DEEP SPACE EXPLORATION



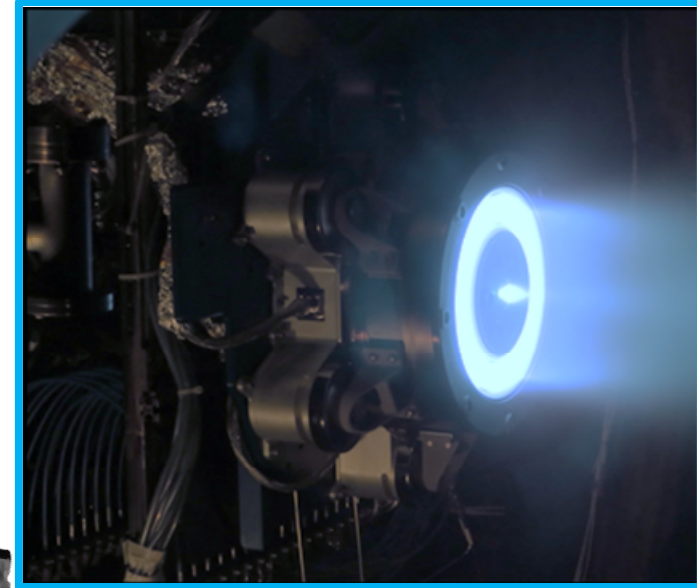
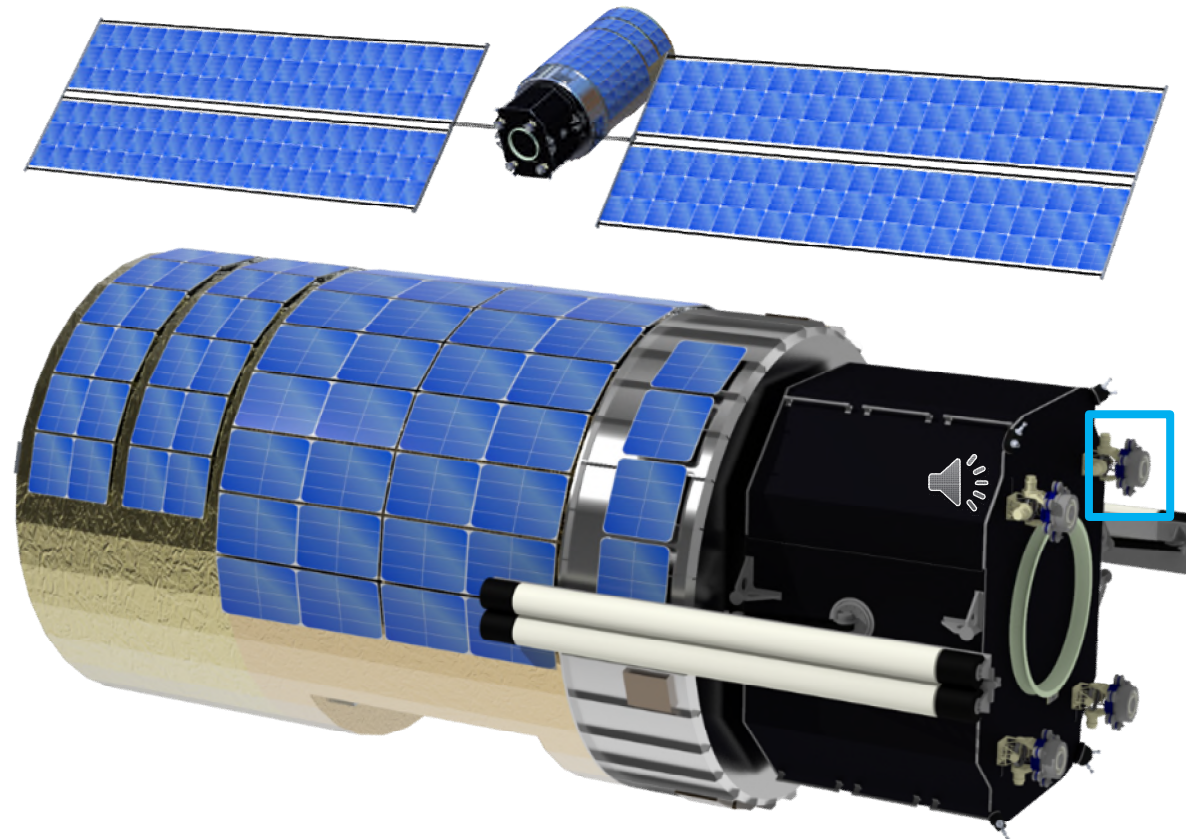
A High power Nested Hall Thrusters is an integral part of the In-Space Propulsion Technology road map enabling science missions



Scale-able Propulsion System for Multiple Mission Applications

The HPPU could provide 160kW of capability while saving 640kg of mass

SEP HTV with 13.5 kW AEPS Thruster



Advanced Electric Propulsion System (AEPS)

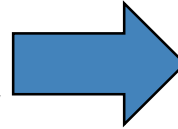
I_{sp} : 1900 – 2800 s
Thrust: 386 – 589 mN
TRL: 6 (Gateway PPE)

The HPPU could provide 40kW of capability and save over 160kg of mass

HPPU Conclusion

HPPU Development has demonstrated:

- Mission Extensibility
 - Through Configurability
 - 600V, 13kW for Thruster Power
 - 120V, 10kW for Spacecraft Power
 - Power Quality



Benefits

Lower Mass
Greater Functionality



	Mode-1	Mode-2		Mode-3		Key Feature
Type-1	600V 22A	120V 88A		300V 44		Dual Output Single Control
Type-2	600V 22A	600V 11A	600V 11A	600V 11A	300V 22A	Dual Output Dual Control

Hybrid PPU is Next Cornerstone in PMAD Architectures