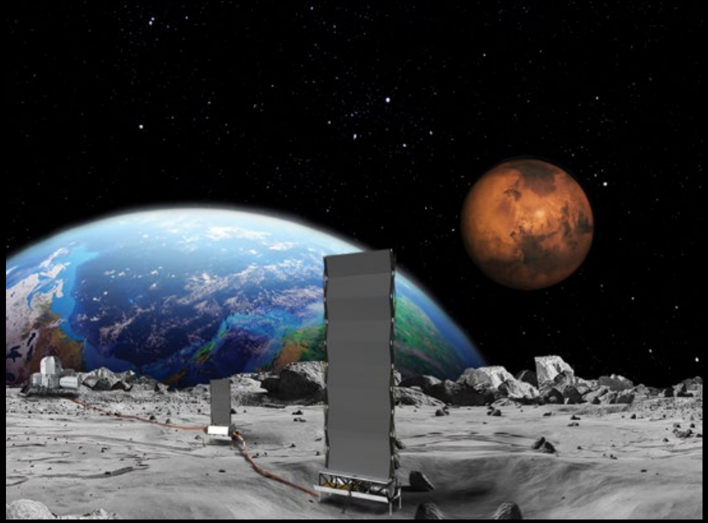
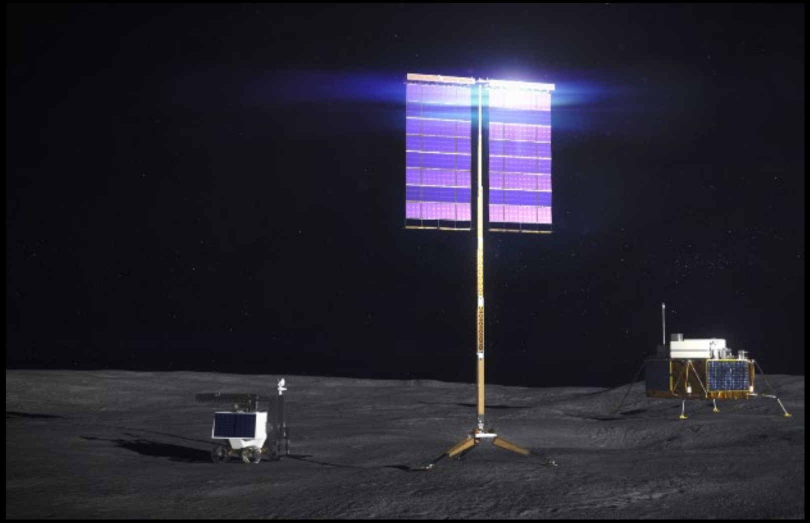
National Aeronautics and
Space Administration

Tethered Power Transmission in the Lunar Environment
LSIC Joint Surface Power and Crosscutting Focus Group Monthly

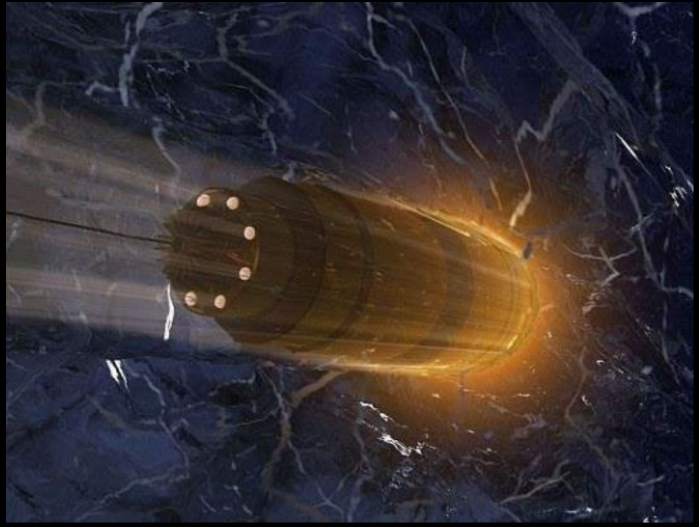
Ansel Barchowsky, NASA Jet Propulsion Laboratory – 06.27.2024

Motivation





Connecting nuclear and solar power generation to remote payloads is essential for a sustained Human and robotic presence on the Moon and Mars



Long distance power transfer, communications, and extreme terrain mobility allow robotic missions to explore new worlds

Motivation

Power Delivery

200 W – 10 kW

To support everything from small rovers like large HEO, we need to deliver scalable power in small form factors, pushing the design towards a high voltage, modular architecture.

Communications

1-10 Gb/s fiber

For autonomous control and big data capabilities, we need high bandwidth and low error rates. This includes communications without line of sight, so the most extreme terrain can be reached.

Transmission

1 – 10 km

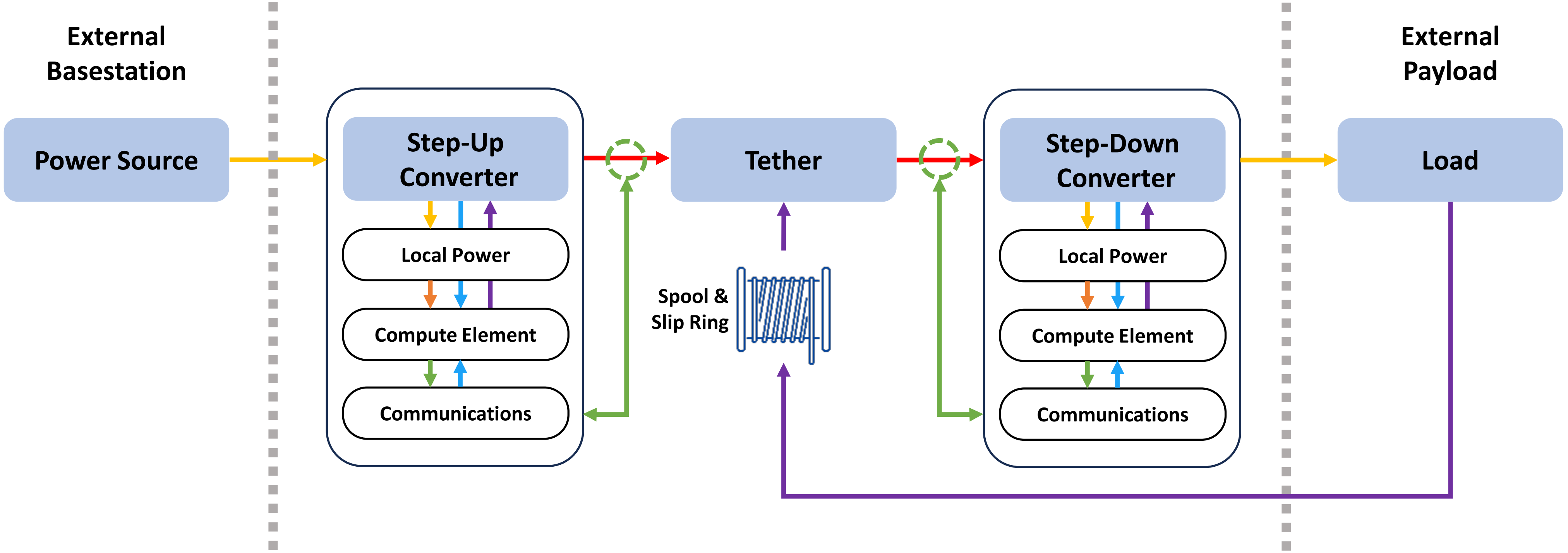
Many human and robotics missions require distances above 1 km to connect source to load. That means we need compact cables or efficient power beaming to avoid large landed sources.

	Mission	Potential Launch	Power (W)	Comm (Mb/s)	Length (m)	Tensile Load (N)	Duration (days)	Tether Management	Temp Min (C)	Temp Max (C)
Moon	Moon Diver	2020s	54	0.18	300	200	14	Active	-30	130
	ISRU Proc. Demo	2020s	1,000	TBD	5,000	TBD	1,000	TBD	-173	130
	ISRU Proc. Pilot	2020s	2,000	TBD	5,000	TBD	1,000	TBD	-173	130
	ISRU Proc. Full	2020s	150,000	TBD	5,000	TBD	1,000	TBD	-173	130
	FARSIDE	2030s	72	1,000	12,000	-	1,825	Active	-173	130
	PSR Rover	2020s	TBD	TBD	1,000	TBD	14	Active	-250	130
Icy Moons	EELS Enceladus	2040s	500	1,000	5,000	100	3,650	Hybrid	-240	-128
Venus	Venus Aerobot	2030s	-	1,000	50	50	365	Hybrid	-50	125
Earth	EELS Earth	2020s	2,000	1,000	250	1,000	-	Active / Offboard	-23	23

Tethered Power and Communications

NASA needs end-to-end tether and electronics systems, which provide human and robotic missions with power, communications, and tensile support to traverse extreme terrain. These systems must be **modular**, have **common interfaces**, and be **compatible** with solutions from around the industry. They also must survive **years** in the lunar environment, all while providing:

- High-efficiency power transmission for surface nuclear or solar array power generation, providing 10s of kW, and end-to-end efficiency above 90%
- Easy deployment, connectorization, and mobility for robotic assets in support of human encampments. Cables must be tolerant to the dusty environment and to extreme bends.



Electronics Limitations - Radiation

The Lunar surface is a challenging environment. For electronics, the toughest challenge is radiation effects, which limit performance of high voltage FETs. Combined with the thermal environment, our challenge grows. **We must design systems that can last 10s of years in the TID and SEE environment and have robust fault containment.**

SLS-SPEC-159 → Solar Particle Events + Galactic Cosmic Rays → Planetary Shielding → Neutron Surface Effects → 2x Derating → Radiation Requirement

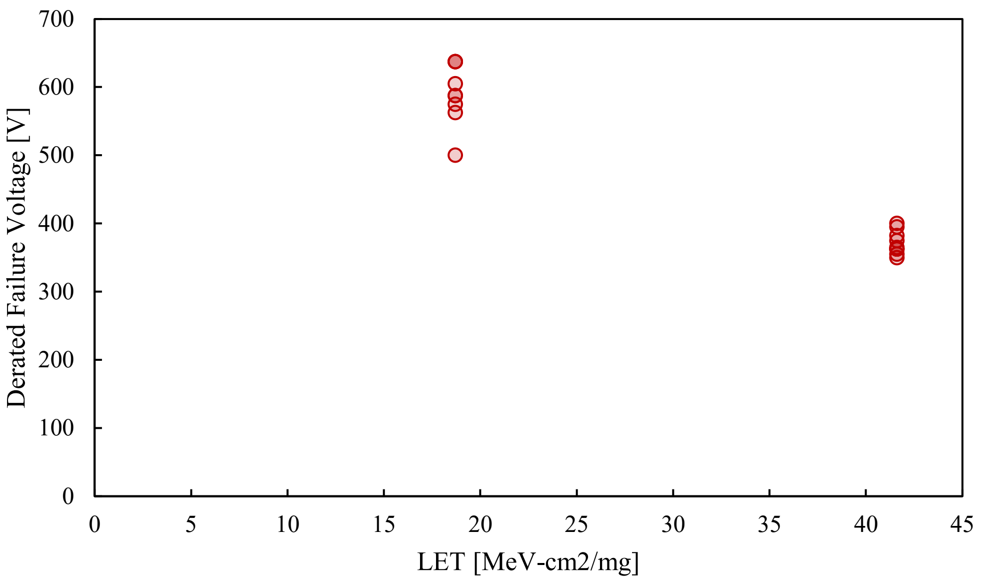
CLPS Technology Demonstrations
10 – 14 day mission, <1 krad

COTS GaN HEMTs
- **Tolerant to TID and SEE**
- **Automotive screening**

COTS Plastic ICs
- **Known good processes**
- **Tolerant to TID and SEE**
- **Automotive screening**

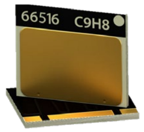
Automotive Grade Passives
- **Automotive screening**
- **High Energy Density**
- **Automotive Derating**

Results of Single Event Burnout Testing on GaN Systems GS65006T 650 V HEMT Device



Sustained Surface Operations
10 year mission, 100 krad

Upscreened GaN HEMTs
- **Tolerant to TID and SEE**
- **Upscreened for Flight**



Rad Hard Ceramic ICs
- **Hardened to TID and SEE**
- **Flight screening**

Class S Passives
- **Space screening**
- **Lower Energy Density**
- **Flight Derating**

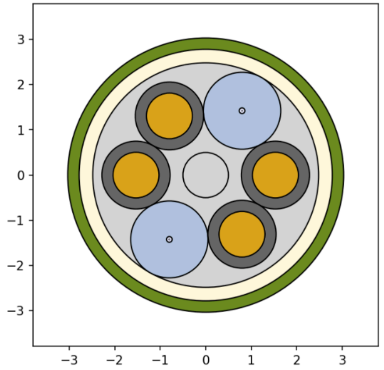
Assess radiation effects early in development, **test components or systems** when needed, and **share your results**!

Tether Limitations - Environment

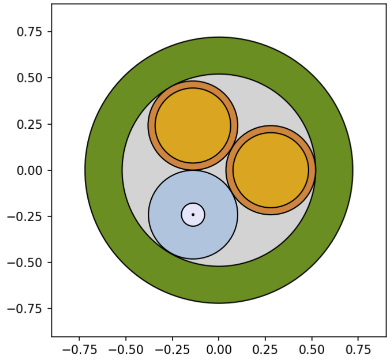
For cable systems, the Lunar surface compounds challenges we face on earth by adding **extreme thermal ranges, abrasive dust, and charged particles**. The Lunar tether design space includes:

- Length
- Voltage
- Losses
- Power
- Communications
- Tensile Strength
- Outer diameter constraint
- **Thermal Range**
- **Minimum Bend Radius**
- **Abrasion Resistance**

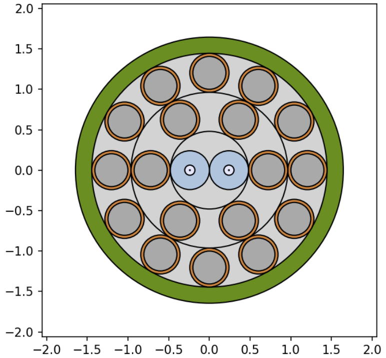
TetherCAD, an open-source tool developed by NASA JPL for STMD, aids in tether design for mission planners, using off-the-shelf parts to form cable assemblies. It is available here: https://github.com/nasa-jpl/TetherCAD



Ruggedized Tensile Tether
1 kW, 1km, 5.9mm, 55 g/m

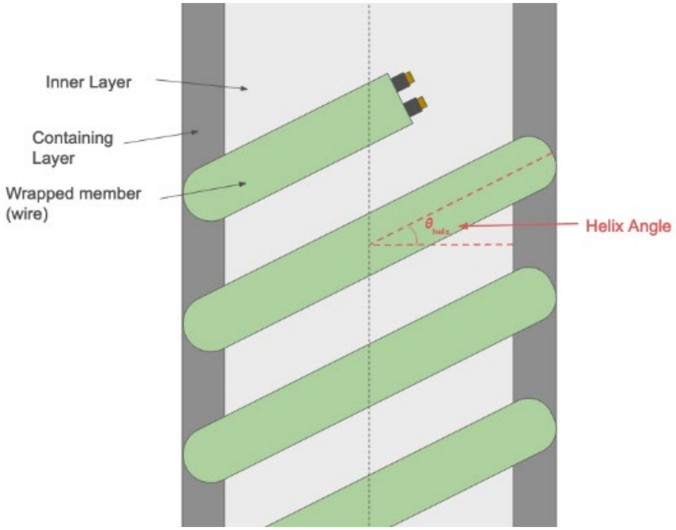


Microrover Mobility Tether
1 kW, 1 km, 1.5mm, 5.2 g/m

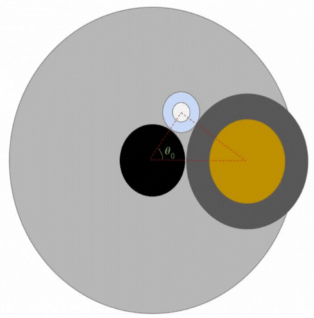


VSAT Surface Tether
10 kW, 1 km, 4.9mm, 40 g/m

Helical Winding Analysis

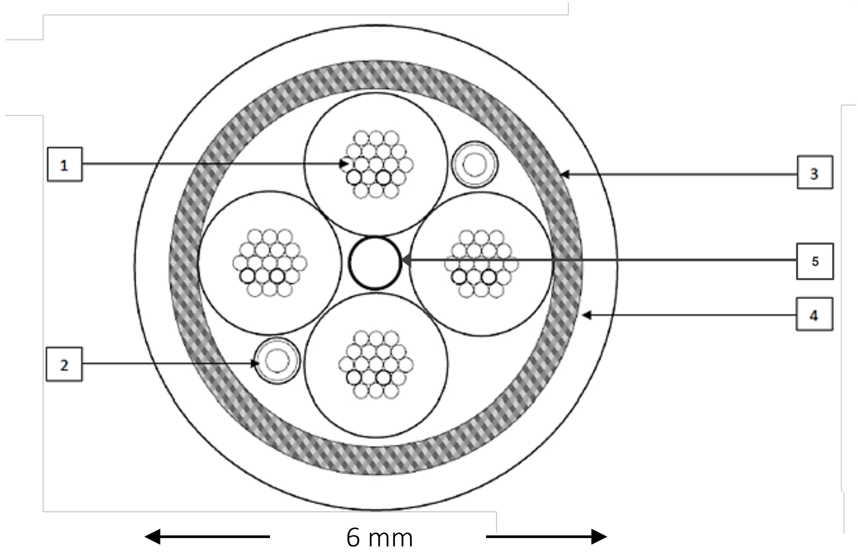


Geometric Optimization

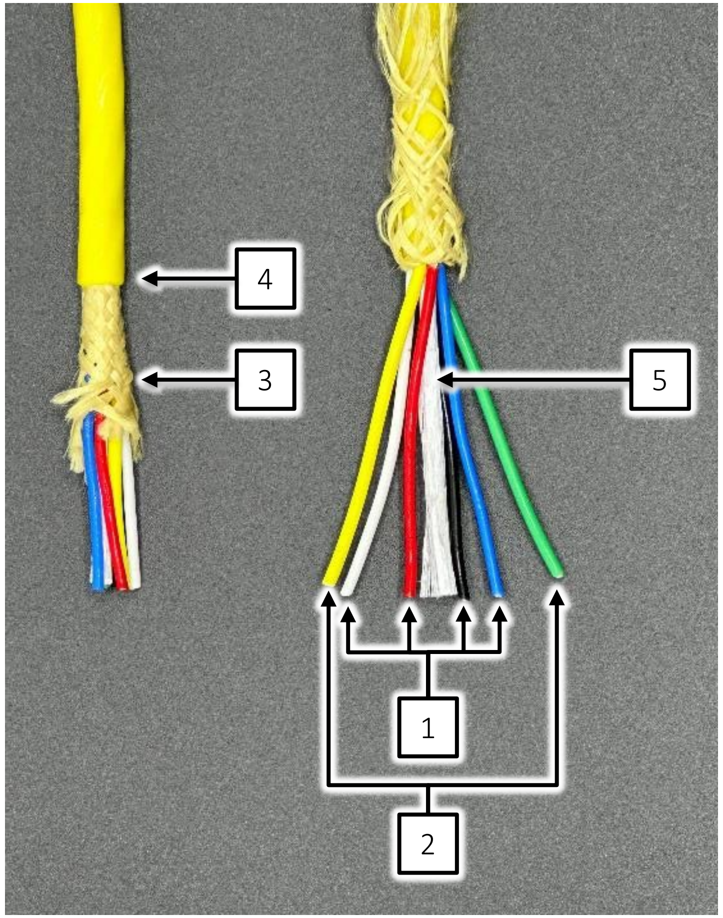


The Criticality of Environmental Testing

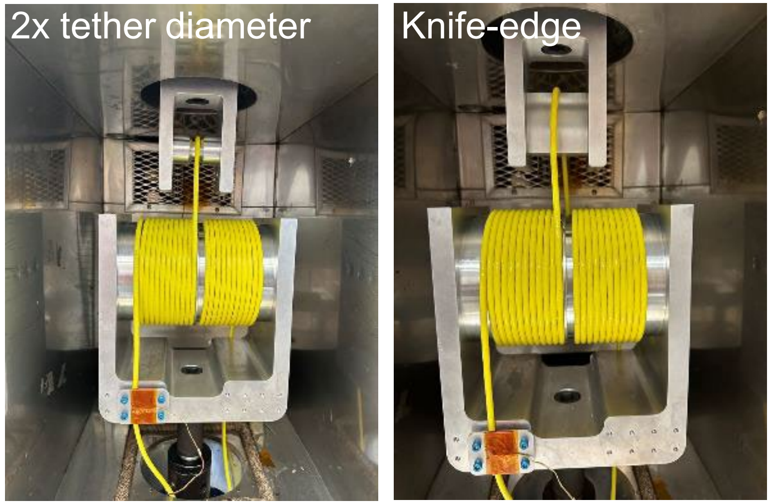
After an optimization process, a**6 mm diameter, 55.5 g/m** tether was fabricated with Linden Photonics. The tether combines **22 AWG conductors and radiation hardened fiber**. We tested it in liquid nitrogen in a pull test and liquid helium in an abrasion test, taking it to Lunar thermal and environmental extremes. These facilities can be used to test community-developed tethers.



1. Four 22 AWG Teledyne conductors, with 18 kV_{DC} insulation
2. Two Linden radiation-hardened singlemode fibers
3. Aramid fiber providing 200 kg breaking strength
4. FEP outer jacket, for abrasion resistance and rounding
5. Inner core for helical wire and fiber optic wrapping



TYMPO Tether, fabricated by Linden Photonics



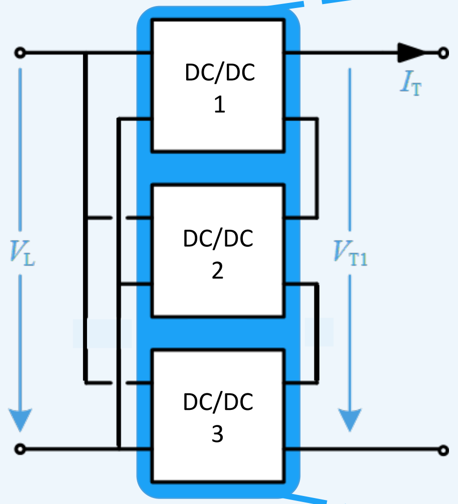
Strain testing of tether in Lunar thermal environment

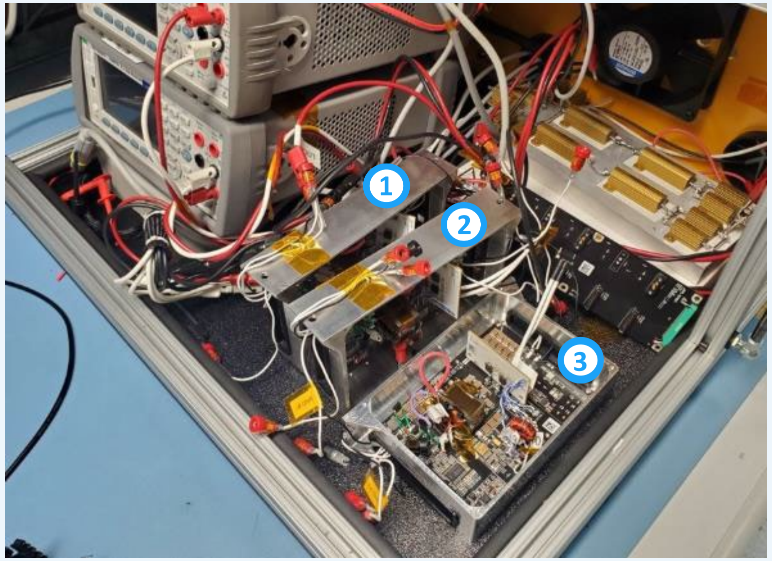
Abrasion testing of tether in Lunar thermal environment

Conversion System Example - TYMPO

Configuring power modules in input-parallel, output-series, we achieve a conversion ratio equal to the 3N, where N is the number of active modules. This makes the system fully scalable, so that while we are processing high voltage, each semiconductor only experiences voltages within it's derated limits.

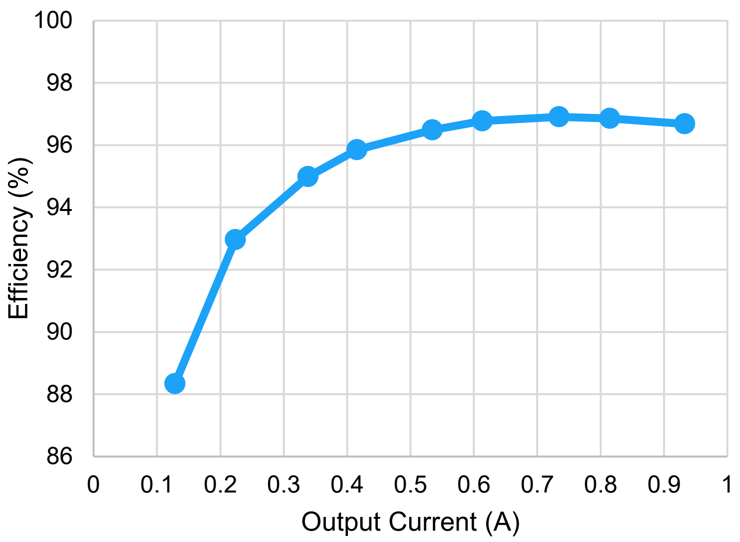
The efficiency remains constant regardless of the number of modules in series. Here, with 3 modules, we **processed 100 V to 900 V at up to 1 kW, with 97.5 % efficiency.**



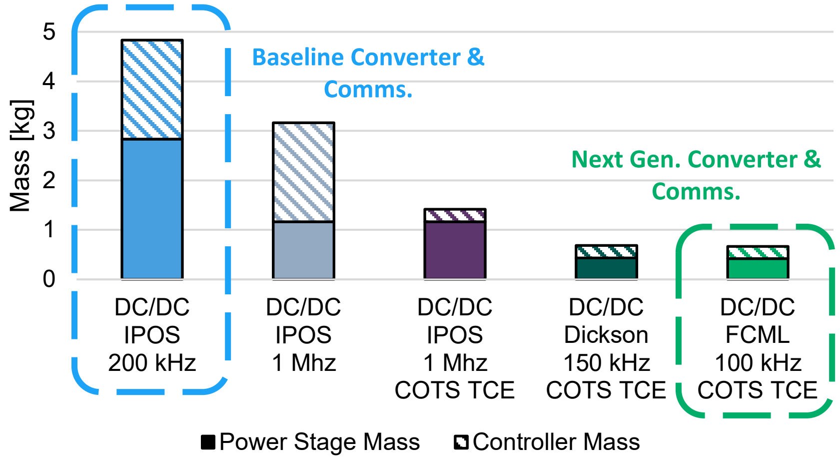


JPL-Designed 3 Module DCX Converter Stack

3 Module DCX Stack Efficiency: 100 V-to-900 V



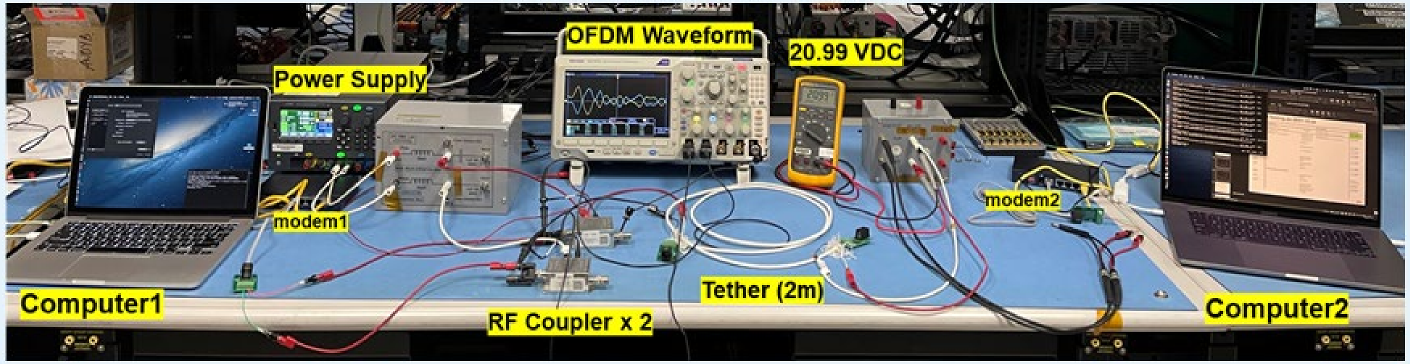
Power Stage and Controller Mass



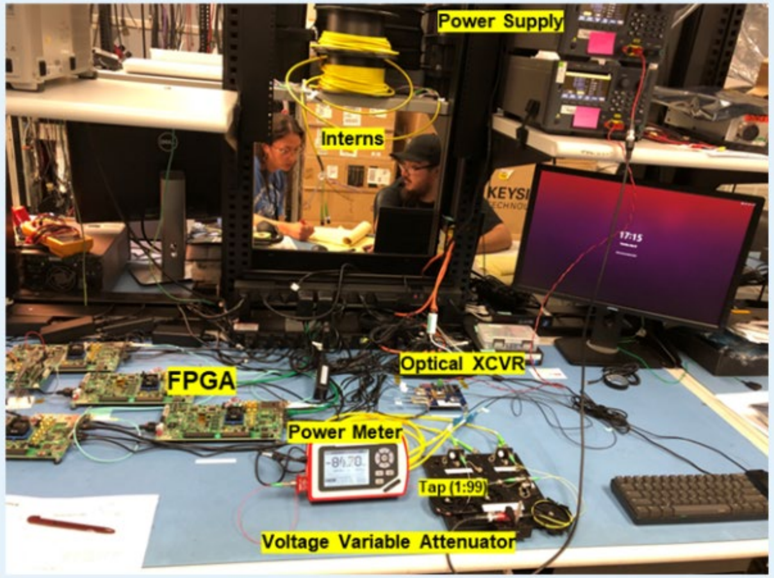
Communications System Example - TYMPO

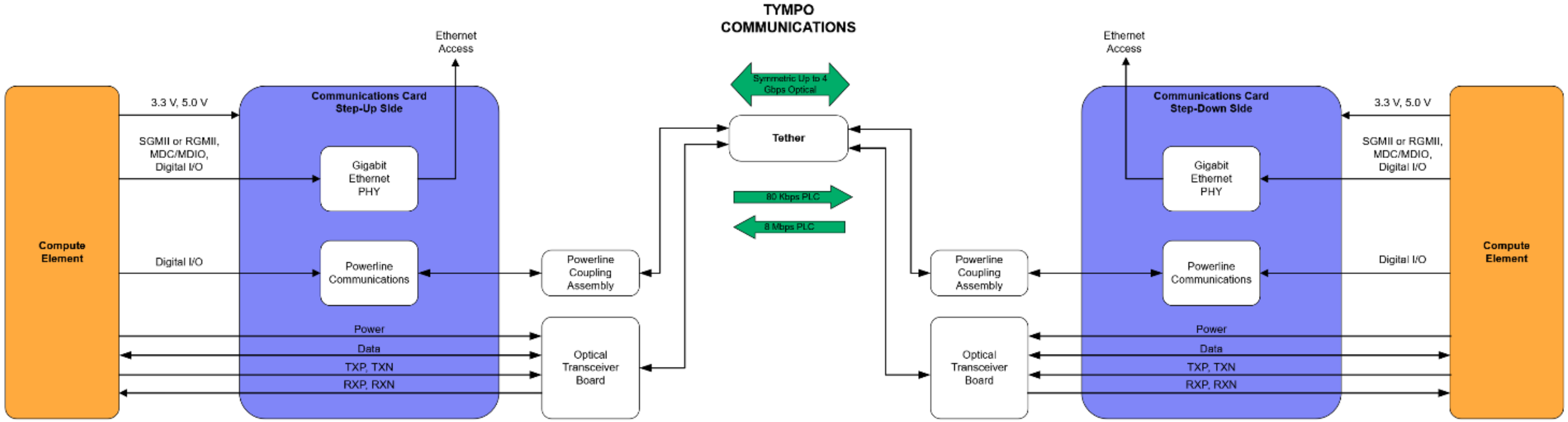
TYMPO provides **two communications platforms**. The primary system is a **fiber optic link**, which provides a 1 Gb/s ethernet link, supporting high data rates from Lidar, video, and other payload systems. The secondary system is a **power line carrier link**, which only provides 10 Mb/s at 1km but can tolerate knife edge bends.

Power Line Carrier Testbed



Fiber Optic Testbed

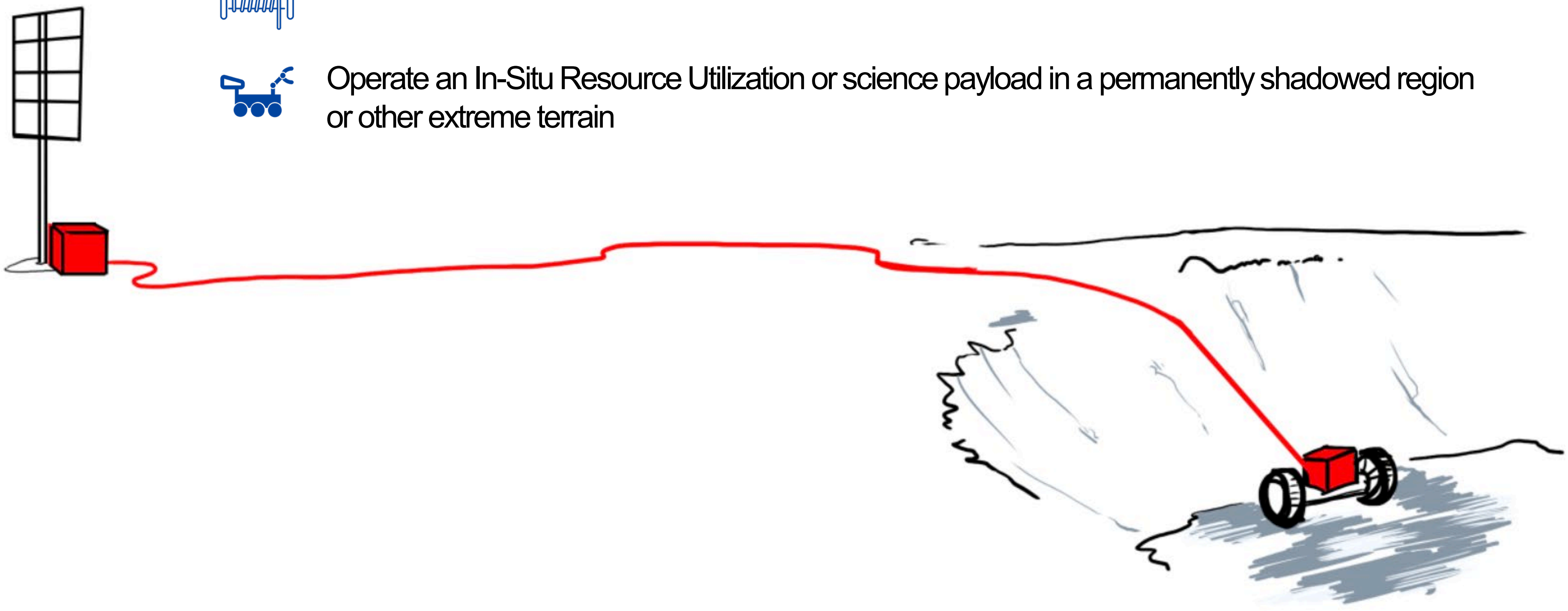




Tethered Power – In Situ Resource Utilization

CLPS demonstration with VSAT and Lunar payload

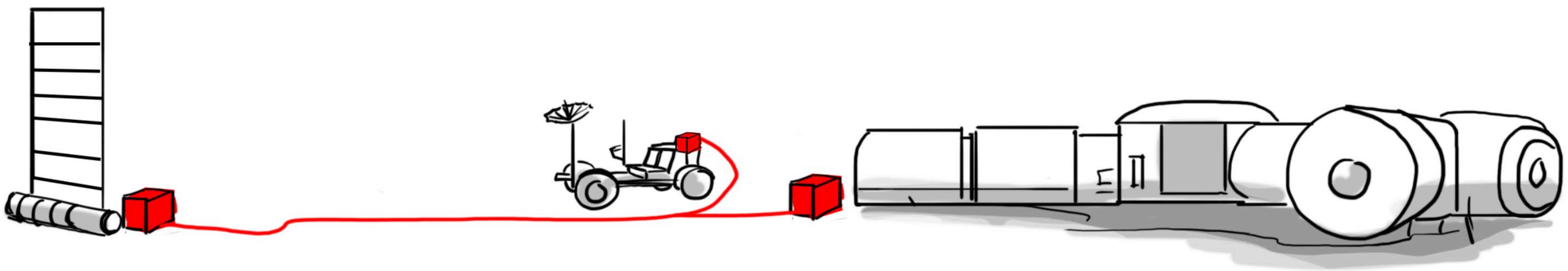
- Land a Vertical Solar Array system on the Lunar surface, with 10 kW source power
- Deploy a 10 kW tether system from a mobility platform designed for Lunar crater exploration
- Operate an In-Situ Resource Utilization or science payload in a permanently shadowed region or other extreme terrain



Tethered Power – Human Encampments

Surface power transfer for Artemis Moon-to-Mars sustained presence

- Land a Vertical Solar Array or Fission Surface Power system on the Lunar surface, with 40 kW source power
- Deploy a 40 kW tethered system from a mobility platform designed for surface power transfer
- Support sustained human presence through power transfer to habitat and surface vehicles



Jet Propulsion Laboratory
California Institute of Technology

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