Photonic Extension Cords – Directed Energy for Lunar Power Distribution

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Introduction: In order to sustain extended operations on the lunar surface, a scalable method of power distribution is required. As part of our NASA-supported power beaming program, we propose the development of directed energy (DE) power distribution systems capable of transmitting power across kilometer-scale distances for difficult-to-reach and mobile applications on the Moon. Such applications include beaming power from crater rims into permanently shadowed regions (PSR) where large deposits of water have been shown to exist (illustrated in Figure 1), as well as beaming power from stationary sites to mobile assets such as rovers and other surface vehicles. The system we propose is effectively a "photonic extension cord" which beams near-infrared laser light to distant assets, at which it is converted via tuned high-efficiency photovoltaics (PV) into useful electricity. Such DE systems are now efficient, low-mass, practical, cost-effective, and continue to rapidly improve due to exponential growth in photonics which is driven by vast consumer and industry demand. [1] A wide range of other applications can be enabled by a scalable DE power distribution system: tower-to-tower "photonics power lines" with distances exceeding 100km and power levels exceeding 10kW; lunar surface-to-orbit or orbit-to-surface power beaming; and ultra-high speed laser communications for all of the above configurations. Even longer ranges and higher powers are possible with coherent combining of single mode lasers.

Current Labwork: We have designed, built, and tested 1064nm Yb fiber high-power single mode systems with 43% (emitter, from 50% pump efficiency and 85% conversion) wall plug efficiency pumped at 976nm in our lab. Including PV conversion efficiencies, end-to-end efficiencies of ~20% is currently possible, with 25-30% appearing feasible in the modest future. Our group has worked for 10 years developing the technology to allow extremely long range power projection, and we have already built lab-scale power beaming demonstrations up to 120W (optical) with both Si and InGaAs/metamorphic PV devices at wavelengths of 808, 880, 976, and 1064nm.

Periscope Beam Director. We have developed a demonstration laser power beaming and tracking system capable of near-4π FOV steering and active target tracking. It is compact (<30cm cube), low mass (5kg including laser), highly capable with optical power output of up to 400W, with extension to >1kW, and can operate in either single or multi-mode. If multi-mode, a 10cm aperture can project an ~80cm diameter spot at 1km distance, and a similar unit with a 1m aperture operating in single-mode could be used to project power at 100km range with a sub-meter diameter spot.

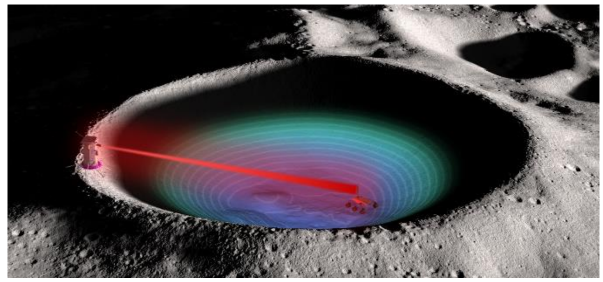

Figure 1: Example of power beaming from a lunar lander (Intuitive Machines Nova-C shown) to a rover within a PSR. Shackleton Crater is shown, with a depth of 4.2km and width of 21km. We can provide power across the entire diameter, if necessary.

Laser-Tuned PV. We have built laser PV converters in our lab using Si and InGaAs (Spectrolab) cells including novel low mass compact high speed (10kHz) maximum power point tracking (MPPT) electronics, which allows maximizing power in time-varying conditions.

Thermal Energy Capture & Storage. In addition to electrical power, the photon energy not converted to electrical energy can be harvested as thermal energy, which is critical in many applications, including operating at low temperatures during the lunar night or in PSR's. Properly done, capturing and storing this energy can greatly increase the overall efficiency of the system.

Future Goals: We intend to further develop all of the above sub-systems in order to perform power beaming demonstrations at power levels relevant for lunar operations. This will include optical beacons on the transmit/receive sides for pointing, wide and narrow FOV visible/NIR imaging, and optical + RF communications. We are working on Si and InGaAs PV arrays capable of 0.1-1kW electrical output in a lab demonstrator system that has the essential functionality required for outdoor testing and lunar operation.

References:

[1] P. Lubin (2016) *arXiv:1604.01356.*