Space solar power demonstrator wirelessly transmits power in space

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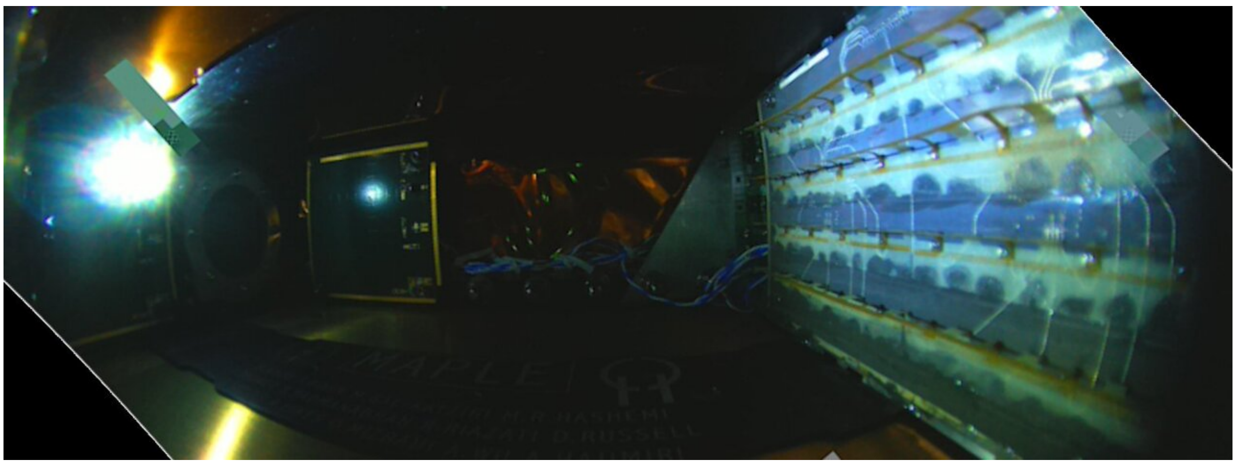

Photo from space of the interior of MAPLE, with the transmission array to the right and the receivers to the left. Credit: SSPP

A space solar power prototype that was launched into orbit in January is operational and has demonstrated its ability to wirelessly transmit power in space and to beam detectable power to Earth for the first time.

Wireless power transfer was demonstrated by MAPLE, one of three key technologies being tested by the Space Solar Power Demonstrator (SSPD-1), the first space-borne prototype from Caltech's Space Solar Power Project (SSPP). SSPP aims to harvest solar power in space and transmit it to the Earth's surface.

MAPLE, short for Microwave Array for Power-transfer Low-orbit Experiment and one of the three key experiments within SSPD-1, consists of an array of flexible lightweight microwave power transmitters driven by custom electronic chips that were built using low-cost silicon technologies. It uses the array of transmitters to beam the energy to desired locations. For SSPP to be feasible, energy transmission arrays will need to be lightweight to minimize the amount of fuel needed to send them to space, flexible so they can fold up into a package that can be transported in a rocket, and a low-cost technology overall.

MAPLE was developed by a Caltech team led by Ali Hajimiri, Bren Professor of Electrical Engineering and Medical Engineering and co-director of SSPP.

"Through the experiments we have run so far, we received confirmation that MAPLE can transmit power successfully to receivers in space," Hajimiri says. "We have also been able to program the array to direct its energy toward Earth, which we detected here at Caltech. We had, of course, tested it on Earth, but now we know that it can survive the trip to space and operate there."

Using constructive and destructive interference between individual transmitters, a bank of power transmitters is able to shift the focus and direction of the energy it beams out—without any moving parts. The transmitter array uses precise timing-control elements to dynamically focus the power selectively on the desired location using the coherent addition of electromagnetic waves. This enables the majority of the energy to be transmitted to the desired location and nowhere else.

MAPLE features two separate receiver arrays located about a foot away from the transmitter to receive the energy, convert it to direct current (DC) electricity, and use it to light up a pair of LEDs to demonstrate the full sequence of wireless energy transmission at a distance in space.

MAPLE tested this in space by lighting up each LED individually and shifting back and forth between them. The experiment is not sealed, so it is subject to the harsh environment of space, including the wide temperature swings and solar radiation that will be faced one day by large-scale SSPP units.

"To the best of our knowledge, no one has ever demonstrated wireless energy transfer in space even with expensive rigid structures. We are doing it with flexible lightweight structures and with our own integrated circuits. This is a first," says Hajimiri.

MAPLE also includes a small window through which the array can beam the energy. This transmitted energy was detected by a receiver on the roof of the Gordon and Betty Moore Laboratory of Engineering on Caltech's campus in Pasadena. The received signal appeared at the expected time and frequency, and had the right frequency shift as predicted based on its travel from orbit.

Beyond a demonstration that the power transmitters could survive the launch (which took place on January 3) and space flight, and still function, the experiment has provided useful feedback to SSPP engineers. The power transmission antennas are clustered in groups of 16, each group driven by one entirely custom flexible integrated circuit chip, and Hajimiri's team now is assessing the performance of individual elements within the system by evaluating the interference patterns of smaller groups and measuring difference between various combinations. The painstaking process—which can take up to six months to fully complete—will allow the team to sort out irregularities and trace them back to individual units, providing insight for the next generation of the system.

Space solar power provides a way to tap into the practically unlimited supply of solar energy in outer space, where the energy is constantly available without being subjected to the cycles of day and night, seasons, and cloud cover—potentially yielding eight times more power than solar panels at any location on Earth's surface. When fully realized, SSPP will deploy a constellation of modular spacecraft that collect sunlight, transform it into electricity, then convert it to microwaves that will be transmitted wirelessly over long distances to wherever it is needed—including locations that currently have no access to reliable power.

"The flexible power transmission arrays are essential to the current design of Caltech's vision for a constellation of sail-like solar panels that unfurl once they reach orbit," says Sergio Pellegrino, Joyce and Kent Kresa Professor of Aerospace and Civil Engineering and co-director of SSPP.

"In the same way that the internet democratized access to information, we hope that wireless energy transfer democratizes access to energy," Hajimiri says. "No energy transmission infrastructure will be needed on the ground to receive this power. That means we can send energy to remote regions and areas devastated by war or natural disaster."

SSPP got its start in 2011 after philanthropist Donald Bren, chairman of Irvine Company and a lifetime member of the Caltech Board of Trustees, first learned about the potential for space-based solar energy manufacturing as a young man in an article in the magazine Popular Science.

Intrigued by the potential for space solar power, in 2011, Bren approached Caltech's then-president Jean-Lou Chameau to discuss the creation of a space-based solar power research project. In the years to follow, Bren and his wife, Brigitte Bren, also a Caltech trustee, agreed to make the donation to fund the project. The first of the donations to Caltech (which will eventually exceed $100 million in support for the project and endowed professorships) was made through the Donald Bren Foundation.

"The hard work and dedication of the brilliant scientists at Caltech have advanced our dream of providing the world with abundant, reliable and affordable power for the benefit of all humankind," Bren says.

"The transition to renewable energy, critical for the world's future, is limited today by energy storage and transmission challenges. Beaming solar power from space is an elegant solution that has moved one step closer to realization due to the generosity and foresight of the Brens," says Caltech President Thomas F. Rosenbaum. "Donald Bren has presented a formidable technical challenge that promises a remarkable payoff for humanity: a world powered by uninterruptible renewable energy."

"Demonstration of wireless power transfer in space using lightweight structures is an important step toward space solar power and broad access to it globally," says Harry Atwater, Otis Booth Leadership Chair of Division of Engineering and Applied Science; Howard Hughes Professor of Applied Physics and Materials Science; Director of the Liquid Sunlight Alliance; and one of the principal investigators of the project.

"Solar panels already are used in space to power the International Space Station, for example, but to launch and deploy large enough arrays to provide power to Earth, SSPP has to design and create solar power energy transfer systems that are ultra-lightweight, cheap, and flexible."

Individual SSPP units will fold up into packages about 1 cubic meter in volume and then unfurl into flat squares about 50 meters per side, with solar cells on one side facing toward the sun and wireless power transmitters on the other side facing toward Earth.

A Momentus Vigoride spacecraft launched aboard a SpaceX rocket on the Transporter-6 mission carried 50-kilogram SSPD to space. Momentus is providing ongoing hosted payload support to Caltech, including providing data, communication, commanding and telemetry, and resources for optimal picture taking and solar cell lighting. The entire set of three prototypes within the SSPD was envisioned, designed, built, and tested by a team of about 35 individuals—faculty, postdocs, graduate students, and undergrads—in labs at Caltech.

SSPD has two main experiments besides MAPLE: DOLCE (Deployable on-Orbit ultraLight Composite Experiment), a structure measuring 6 feet by 6 feet that demonstrates the architecture, packaging scheme, and deployment mechanisms of the modular spacecraft; and ALBA, a collection of 32 different types of photovoltaic cells to enable an assessment of the types of cells that are the most effective in the punishing environment of space.

The ALBA tests of solar cells are ongoing, and the SSPP has not yet attempted to deploy DOLCE as of press time. Results from those experiments are expected in the coming months.

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