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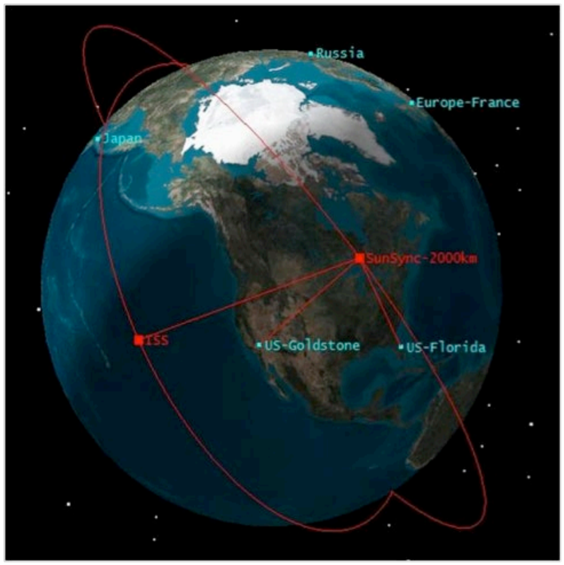


# Wireless Transfer of Power: Proposal for A Five-Nation Demonstration by 2020

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Abstract

A multinational mission architecture is proposed as a way to jump-start development of a global space solar power (SSP) industry. Solar power generated on the International Space Station (whose orbit is roughly 400 km above the Earth) will be converted to millimeter waves and beamed to ground receivers located in five or more nations, providing measurements of dynamic beam pointing and atmospheric propagation in various parts of the globe. A second spacecraft in a polar orbit at nearly 2000 km, launched by a consortium of nations, will be used as a relay for beamed power delivery from the ground and from the ISS to other ground stations.

The power transfer will employ one or more of several frequency windows for atmospheric transmission. The millimeter wave regime is chosen as a near-term option reachable by current research, on the road to a possible conversion to the more compact laser optics regime. This mission architecture seeks logical buy-in from the various entities that are essential partners in Space Solar Power, as follows: national space agencies, the terrestrial energy industry, the electronics/ communication industry, the space transportation industry, and military agencies.

The Five-Nation Demonstration paper on which this proposal is based summarizes the major technical, business and policy issues to be addressed in such a mission, and suggests the place of this experiment in a roadmap toward development of a Space-based economy. The paper will be stored on the Journal server for on-demand access.

TECHNICAL BRIEF

## Concept

Our proposal is to conduct a near-term multinational experiment of wireless power beaming that develops needed knowledge, provides a visible demonstration, and builds customer confidence in the viability of Space Solar Power (SSP). The proposal springs from the belief that to make Space Solar Power a significant component of global energy supply (4000 GWe), it must become a global endeavor.

The proposal seeks buy-in from several entities:

1. The National Space Agencies of the participating countries:

   Most space agencies of the space-faring nations are mandated to seek scientific payoff as well as technology advancements.

2. Terrestrial Energy Industry:

   The mission will help develop a Space-based power market exchange where terrestrial plants can buy and sell power to adjust to demand in real time.

3. The Electronics/Communication Industry:

   The mission will stimulate developments in the field of high-power millimeter wave generation, conversion and transmission, with the immense market potential of SSP and Space-based power exchange.

4. Military Agencies:

   The mission will help facilitate a collaborative regime where militaries can co-develop technology sectors of mutual interest. One such needed technology is the development of runway-based Space Access.

5. Public Interest in SSP: The interest and support of diverse stakeholders will be key to generating the momentum that can take us towards full-scale Space Solar Power.

## Objectives

The objectives of the proposed experiment include:

1. Scientific objectives in beaming millimeter waves through the atmosphere.
2. Technology demonstrations of high power millimeter wave technology and wireless power beaming.
3. Public policy exercise in demonstrating global collaboration in a power-beaming project.
4. Public education objectives in demonstrating the feasibility, safety and social benefits of wireless power beaming.
5. Build momentum for near-term space solar power development.

Technical Departures

Such a demonstration must be based on a viable Space Solar Power architecture. Relevant SSP-architecture elements identified at the Georgia Institute of Technology include:

1. Using primary Brayton Cycle turbomachine conversion of highly concentrated sunlight to increase the specific power (power generated per unit mass launched into orbit) that can be generated by a space solar power satellite.
2. Collecting and concentrating sunlight using an array of individually pointable optical elements placed in a sun-synchronous altitude near 2000km, such that the satellite is in continuous view of the sun. Mirrors concentrate the solar energy at a focus point, like a heliostat array, that feeds into the heater of the brayton cycle converter.
3. Using millimeter wave beaming at 220GHz to reduce the antenna diameter significantly over those employed with microwave frequencies.
4. Using tethered aerostats placed above the weather portion of the atmosphere, whereby the issue of poor atmospheric transmission through rain and fog for millimeter wave frequencies can potentially be sidestepped.
5. Establishing a power exchange with terrestrial renewable energy as a means of providing early revenue generation by exchanging power through relatively small (3000-4000kg) relay satellites. This first phase of the full-scale architecture seeks to eliminate the barrier of “large cost to first power” facing GEO-based architectures.

Experiment Components

The mission has two primary demonstrations. The first takes advantage of existing photovoltaic panels on the ISS, and beams (via a transmitting antenna sent as a payload to the ISS) its solar power to ground locations, demonstrating wireless power beaming from Space to Earth. The second beams power from the ISS to the ground via a relay satellite. The experiment components are listed below.

1. International Space Station:

   The ISS experiment is based on the 6.25kW DC standard ISS power module described by Karimi et al [2]. We expect that 5 kW will be available for conversion to millimeter waves. Three converters are proposed, with frequencies of 94 GHz, 170 GHz, and 220 GHz. A single 10m diameter external transmitting antenna, launched as cargo payload, will be mounted on the ISS, intermeshing components for the 3 frequency bands.

2. Relay Satellite:

   This spacecraft, placed in about a 2000km altitude sun-synchronous orbit, will demonstrate an alternative path for millimeter wave power being transmitted from the ISS to a ground receiver. It will also test the use of waveguides as a means of transmitting power through the spacecraft, or it may be equipped with pointable mirrors serving as reflectors for relaying power via the satellite.

3. Multiple Ground Facilities:

   As a starting point, the proposal suggests that space solar power rectennas be located in such participating space-faring nations as the United States, Japan, India, Russia, China, Australia and the European Union.

   ***For a more detailed technical analysis of the proposal, click here to view the paper "Visualizing Wireless Transfer of Power: A Five Nation Demo by 2020."

BUSINESS BRIEF

SSP Viability

Understanding and managing wireless power beaming is a necessary step in establishing viable full-scale Space Solar Power architectures. But there are other related steps to be taken into consideration. One of these is the system mass that must be launched into orbit to deliver a given amount of power. Called "the specific power," it speaks to the kWe delivered per kg launched into orbit. Traditional NASA cost estimation methods use mass to determine system life cycle costs. Thus, the more power that can be delivered per unit mass, the more viable the system architecture will be.

This demo introduces several specific innovations that could help to reduce cost and increase viability. In the Technical Brief, the following technical departures are noted:

1. By using primary Brayton Cycle turbomachine conversion, the specific power that can be achieved using solar thermal conversion has the potential to be considerably higher than what can be achieved by photovoltaic arrays, due to nonlinear scaling of mass needed at higher power levels.
2. By collecting continuous sunlight in a sun-synchronous orbit at an approximate altitude of 2,000km rather than in GEO at 36,000km, the antenna diameter required for similar beam capture is reduced by a factor of 18, and the antenna area is reduced by a factor of over 300. If antenna mass is estimated by mass per unit area, the antenna mass can be reduced by orders of magnitude.
3. By utilizing millimeter wave beaming at 220GHz, as opposed to the 5.8GHz frequency proposed in most GEO-based architectures, the antenna diameter can decrease by an additional factor of about 38. The size of the system quickly comes down. There are also no known technical risks associated with high power millimeter wave beaming, but that is a question the demonstration seeks to answer.

Benefits/Costs of Demonstration

The primary benefit of the demonstration is in reducing the significant technical risks associated with a full-scale space solar power architecture, at an acceptable cost.

The major costs of the project are those related to research, technology development and equipment launch. This demonstration will require two launches. One is to deliver a 10m-diameter antenna as a payload to the International Space Station. The other is to launch into a sun synchronous orbit a new 3000-4000kg class relay satellite. This spacecraft can be delivered into its orbit using a polar orbit launcher. The amount of mass needed to be launched for this demonstration is comparatively small. The demonstration also requires the erection of several rectennas, each about 150m in diameter, constructed at the participating ground facilities.

The total costs of the project are expected to be shared among its multiple participants as a basis for establishing ownership, commitment and benefit. When weighed against the potential long-term benefits of large-scale space solar power development, the research and development costs are relatively modest.

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****For more extensive list of references click here Visualizing Wireless Transfer of Power: Proposal for A Five-Nation Demonstration by 2020.