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JAXA RESEARCH STATUS FOR SPACE SOLAR POWER SYSTEMS

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ABSTRACT Space Solar Power Systems (SSPS) is a promising concept for the large-scale clean energy system in the future. JAXA (Japan Aerospace Exploration Agency) has been making scientific research for the SSPS technologies and associated environmental issues. Microwave power transmission experiment on ground is planned to demonstrate the beaming technology from the orbit to the ground. In the experiment, the microwave beam at kW class is transmitted precisely to the rectenna target 100 m apart from the transmitter. We also plan a laser power transmission experiment using a kW class laser in a range of 500 m. In addition to these demonstration experiments on ground, we are investigating the SSPS demonstration experiment in orbit, which is aimed at verifying the microwave beaming technology in 500 km range and finding the upper limit of microwave power density through the ionosphere.

Keywords: Space Solar Power Systems, Microwave Power Transmission, Laser Power Transmission

1. INTRODUCTION

"Energy" is one of the most important bases to support human life. 80 % of energy in our life comes from fossil fuels, burning a huge amount of oil, natural gas and coal. If we continue to consume the fossil fuel resources at the current rate, they will be completely lost within 100-200 years. Furthermore, the huge amount of consumption of fossil fuel will increase CO_2 concentrations, the primary greenhouse gas, in the atmosphere. If we continually depend on the fossil fuel, we will experience substantial degradation of life quality within this century. The concept of Space Solar Power Systems (SSPS) is to utilize the space environment near the earth to tap energy for human society. SSPS has a great potentiality for the large-scale clean energy system to replace the fossil energy plants. Since the NASA/DOE study of the SSPS in the 1970's [1], various types of the SSPS have been proposed in Japan, the United States, Europe, and Russia [2,3,4]. Typical examples of the system are summarized in Fig. 1.

Currently in Japan, three types of SSPS system are studied; Tethered-SPS (microwave-type) by USEF (Institute for Unmanned Space Experiment Free Flier) /METI (Minister of Economy, Trade and Industry), M-SSPS (microwave-type) and L-SSPS (laser-type) by JAXA. The laser-type has an essential problem that the power transmission is strongly affected by the local whether and the associated technologies are not matured as compared with those for the microwave-type. However, since the laser-type SSPS has a potential advantage that the system, both the space and ground segments, can be considerably small, JAXA is conducting its research as well as the microwave-type SSPS.

Figure 2 shows a road map we are proposing towards the commercial SSPS, three typical models named as basic SSPS, advanced SSPS, and laser SSPS. We are now in the basic study phase, concentrating to establishing the wireless

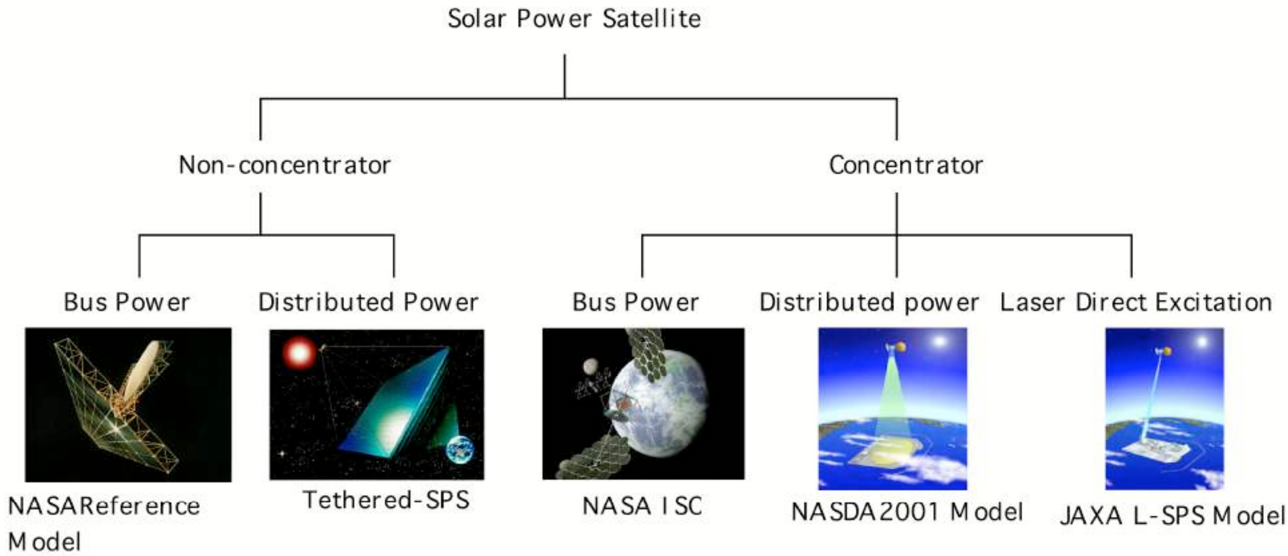

Fig.1 Classification of SSPS and typical examples of system configuration.

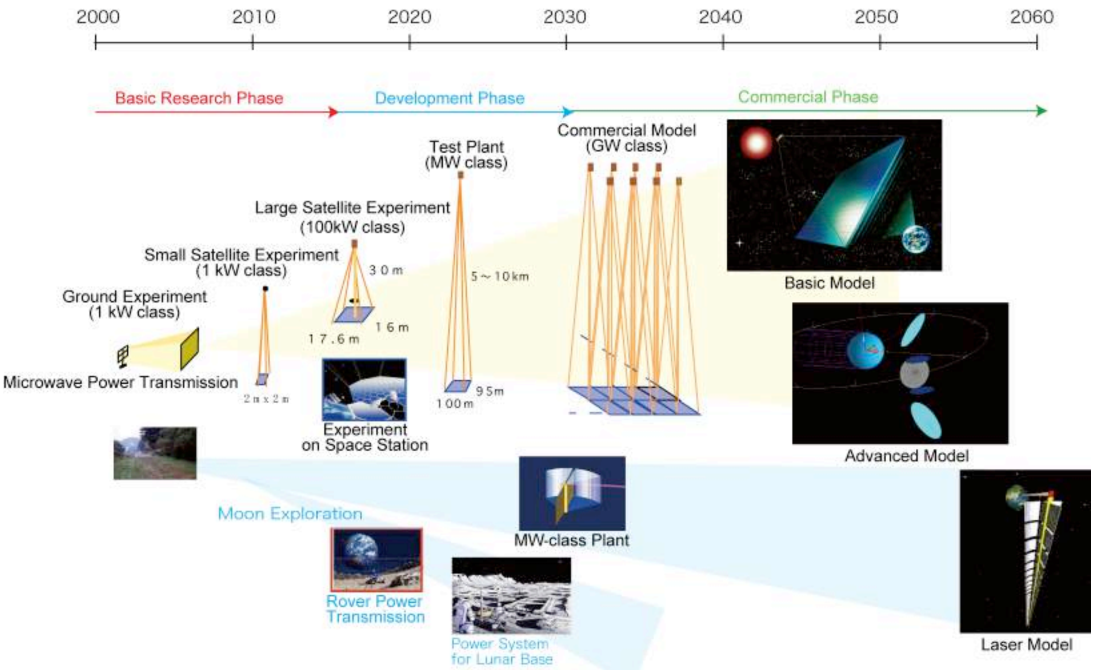

Fig.2 Road map towards commercial SSPS in 2030's.

power transmission technology on ground in a few years. For the microwave power transmission technology, we plan to make a demonstration experiment, in which a microwave beam at kW class is transmitted precisely to the rectenna target 100 m apart from the transmitter. For the laser transmission technology, we are now studying the feasibility of laser power transmission using a new technology to convert the sunlight directly to the laser power at a high efficiency more than 20 %. Once the laser conversion technology is established, we will make the laser power transmission experiment using a kW class laser in a range of 500 m. After the wireless power transmission technologies are fully verified, we will start the demonstration experiment in space. Considering the research progress expected in the next several years, we will first conduct the microwave transmission experiment in space, which is aimed at verifying the microwave beaming technology in 500 km range and finding the upper limit of microwave power density through the ionosphere. The technology demonstration in space for the laser power transmission will be conducted later to confirm the beam direction control and to verify the transmission efficiency through the atmosphere.

2. MICROWAVE POWER TRANSMISSION EXPERIMENT ON GROUND

The long-range demonstration experiment for the microwave power transmission was conducted in 1972 in the United States using the JPL large dish antenna, but the beam direction was controlled mechanically. For the SSPS application, the beam needs to be controlled electrically using a pilot signal from the rectenna site, which is called as the retro-directive beam control. After the JPL experiment, the beam control experiment using the retro-directive method has been conducted in Japan and the United States. In Japan, researchers of Kyoto University and Kobe University have state-of-art technologies in this field. But the power level in the past experiments has been less than kW and the transmission has been limited in laboratory scale in many cases.

JAXA is now planning to perform a kW-class microwave power transmission experiment in the range more than 100 m. It will be the first experiment in the world as a high-power and long-range microwave transmission experiment with the retro-directive beam control capability. The technologies developed for the experiment will be fully utilized for the in-orbit experiment in the next research phase. The microwave transmitter consists of 4 individual panels. Each panel, 0.8m x 0.8m, has an array consisting of 625 transmitting antennas, receiving antennas for the pilot signal, phase controllers, and power systems. The power level from one panel will be 700 W, totally 2.8 kW using 4 panels, at 5.8 GHz. The frequency and phase of the local oscillator in each panel are synchronized using the wireless signals from a master oscillator and the pilot signal of the rectenna site. For the power transmission experiment, an 8 m x 8 m rectenna, composed of 16 sheets of 2 m x 2m size, is prepared, which will be set more than 100 m apart from the transmitter. In order to avoid the effect of microwave reflection from the ground, the transmitter and rectenna will be installed on the roof of two buildings separating more than 100 m. The basic concept of the experiment is illustrated in Fig.3.

3. LASER POWER TRANSMISSION EXPERIMENT ON GROUND

Laser-type SSPS has been regarded as an optional idea since the initial phase of research in 1970's. However, the recent technology on the direct laser excitation pumped by concentrated sunlight can give a possible application to the SSPS. The laser of 1.06μm wavelength is excited by Nd/Cr-YAG ceramic when it is irradiated by strong sunlight, 500-1000 times solar intensity. The technology has been studied by researchers of Osaka University, Institute for Laser Technology, and Fukui University in Japan.

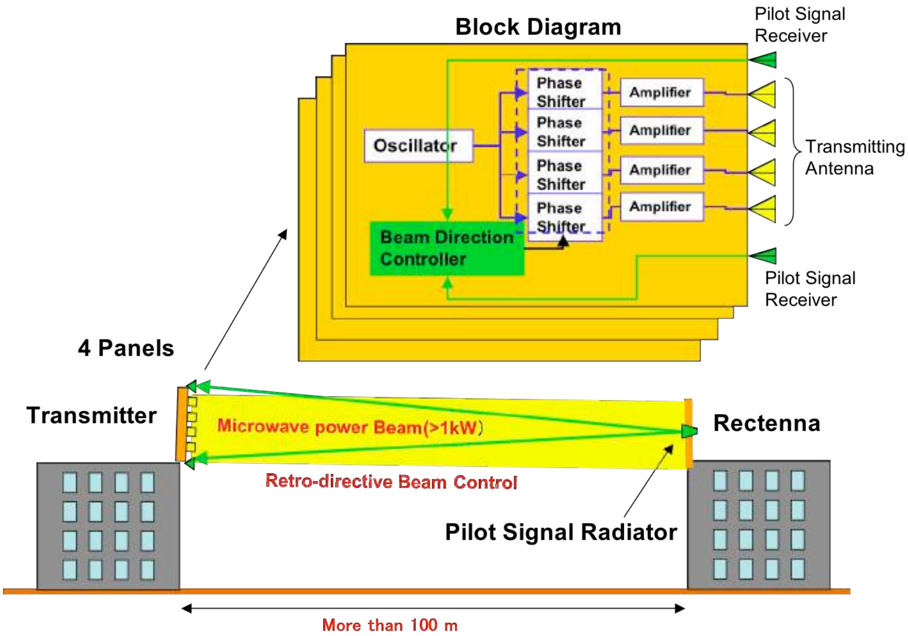

Fig.3 Basic concept of microwave transmission experiment on ground.

The demonstration experiment for the laser power transmission will be conducted using the laser transmission test facility in Kakuta of JAXA. The sunlight is concentrated up to 500-1000 times solar intensity using a solar reflector with 10 m^2 area. The Nd/Cr-YAG ceramic cell will excite 1kW laser. The direction of the beam is controlled within several μ-radian by the laser optics so as that the beam is transmitted precisely to the light receiver located at 500 m apart from the transmitter. The light receiver consists of laser optics, homogenizer, and photovoltaic cells. The total output power at the receiving site will be 0.2 kW. The basic configuration of the experiment is shown in Fig.4

4. MICROWAVE TRANSMISSION EXPERIMENT IN SPACE

The major concerns about the microwave transmission through the ionosphere are the non-linear effect for the high-energy density microwave beam and the effect of the ionospheric scintillation on the pilot signal, as shown in Fig.5. The space demonstration experiment will clarify the allowable power density for the microwave transmission and the scintillation effect on the retro-directive beam control.

JAXA has made conceptual study for the demonstration experiment in space. The weight of the SSPS demonstrator is estimated as 200 kg. The subrecurrent orbit (47 revolutions per 3 days) at an altitude of 370 km is selected to compromise the requirements from the microwave power density and orbit maintenance operation. There are two options for the configuration of the demonstration experiment; option A for 200 kg class experiment and option B for 60 kg class experiment, depending on the allowable resource. Figures 6 illustrates the configuration of the experimental system option A. The attitude of the system is stabilized by the gravity gradient force between the bus system and the power generation/transmission panel which are connected by 4 30m-tether wires. The panel consists of 4 foldable power generation/transmission module. Each module is 0.8 m x 0.8 m wide and 0.1-0.02 m thick. There is no electrical wire interface between the power modules. The bus system has a control and data management system and a propulsion system to keep the orbit. The microwave source signal is

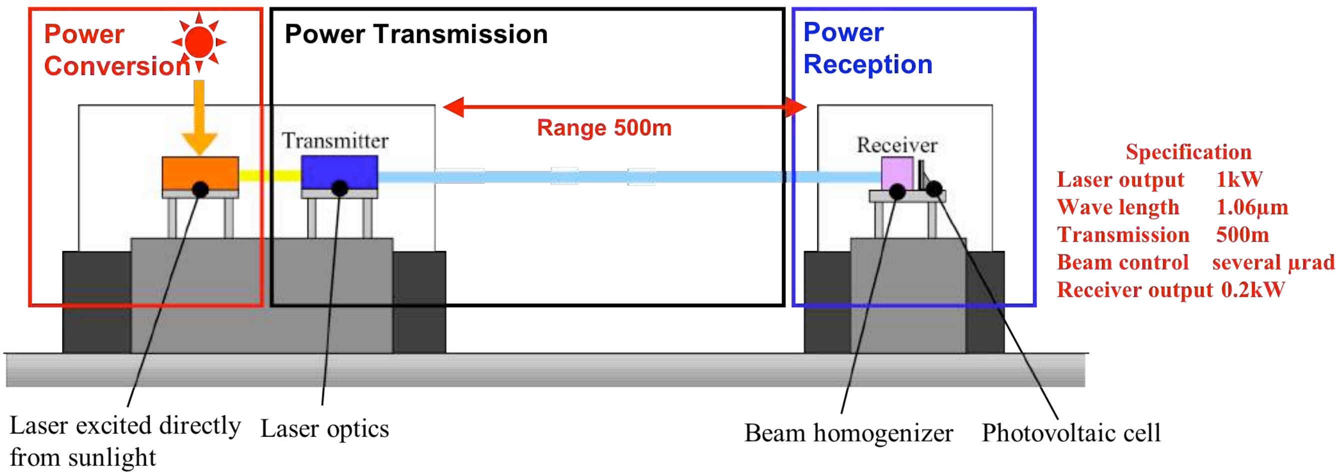

Fig.4 Basic concept of laser transmission experiment on ground.

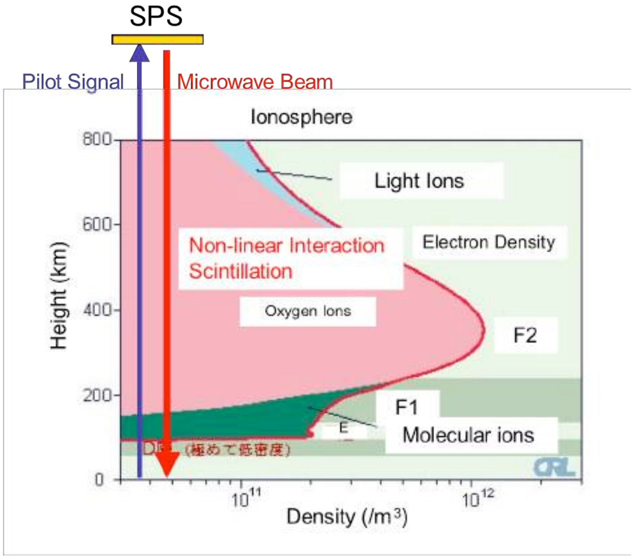

Fig.5 Possible interaction of strong microwave beam with the ionosphere.

radiated from the bus system and is amplified by the 625 sets of the active integrated antennas up to 700W in each power module. The microwave circuit is designed to control the direction of the beam ± 10 degrees from the normal line of the panel. The total microwave power injected from the power generation/transmission panel is 2.8 kW. This level of the microwave power injection will generate a power density above 100 watt/m^2 for more than 50 m in the ionosphere. The power density on the ground is calculated as 0.8 μwatt/m^2. It is necessary to use a parabola to concentrate the microwave power to be rectified by the existing diodes. About 2 m diameter antenna will give a power to illuminate one photo-diode. More conservative configuration with less resource (option B) has also been investigated, In this case, one power module (700 W) is attached directly to the main body of the satellite. The interaction of the microwave beam with the ionospheric plasma is measured by a diagnostic package consisting of plasma probes and wave receivers. The package will have a TV camera to observe the dynamic behavior of the tether.

After separation from the rocket at the altitude of 370

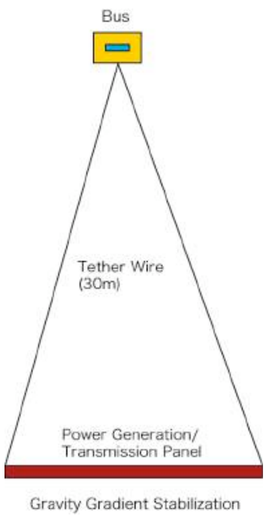

Fig.6 Configuration of the demonstration experiment (option A).

km, the experimental system is automatically controlled into the earth-pointing attitude. In case of option A configuration, the satellite and folded unit panels are separated and the tether wires are deployed by operating the thrusting system of the satellite. After the tether deployment, the folded 4 unit panels are extended to the 1.6 m x 1.6 m panel. In the experiment, the microwave beam at 10 % of the full power is transmitted to the ground for the first 2 minutes. The onboard computer controls the beam direction without the pilot signal from the ground. When the experiment system passes over the ground observation site, the microwave beam at the full power is transmitted to the ground for 16 sec guided by the pilot signal from the receiving site. The beam direction is changed in ± 10 ° from the normal line of the panel to target the receiving site. After the full power operation, the power transmission at 10 % of the full power is performed for another 2 minutes.

5. CONCLUSION

Research plan for SSPS in JAXA is introduced. JAXA will develop kW-class microwave and laser power transmission systems for ground demonstration experiment in a few years. The technologies verified in the ground experiment will be applied to the microwave transmission experiment from space to the ground. The space experiment will confirm the technology for the power beam control and verify the transmission of the power beam through the ionosphere. Once the initial space experiment in kW class is completed, we will enter the development phase in which hundreds kW class SSPS is demonstrated in space.

6. REFERENCES

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