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The Overview of JAXA Laser Energy Transmission R&D Activities and the Orbital Experiments Concept on ISS-JEM

Daisuke Goto, Hiroyuki Yoshida, Hiroaki Suzuki, Katsuto Kisara, and Kazuo Ohashi
JAXA (Japan Aerospace Exploration Agency)
Aerospace Research and Development Directorate
Innovative Technology Research Center
Advanced Mission Research Group
Tsukuba Space Center, Tsukuba city, Ibaraki prefecture, Japan

Yoshinori Arimoto *1
National Institute of Information and Communications Technology
Koganei city, Tokyo, Japan

***Abstract*— The SSPS (Space Solar Power System) is a potential energy supply infrastructure which uses laser or microwave to transmit energy from spacecraft to the ground facilities. The Laser SSPS (L-SSPS) has the following advantages: (1) smaller spacecraft designs and (2) smaller ground facilities, as well as the following disadvantages: (3) significantly affected by the atmospheric disturbance and weather and (4) eye safety issues. JAXA has continued R&D programs of laser energy transmission to help resolve the technological difficulties of L-SSPS. The first step of the L-SSPS demonstration is the 500m horizontal laser energy transmission experiments, which were conducted in 2013 and technological data were obtained. The second step will be the 100-200m vertical laser energy transmission experiments, which will be conducted in 2015. The orbital laser energy transmission experiments, from the ISS (International Space Station) –JEM (Japanese Experiment Module, Kibo) to the ground, are expected to constitute the third step.**

Keywords—SSPS, L-SSPS, laser energy transmission, ISS, JEM, Kibo

I. SSPS CONCEPTS AND BASIC PLAN ON SPACE POLICY

The first image of the Space Solar Power Systems (SSPS) was conceived by Dr. Peter Glaser in the 1960s.[1] In his concept, solar energy is transferred to microwave on the spacecraft in geostationary orbit, transmitted to the ground facility, and finally transferred and supplied to ground electric power networks. The R&D activities started after Dr. Glaser's Paper and have mainly continued in the U.S., Europe and Japan. Japanese activities started in the 1980s and continued at several Universities or space agencies.

In the Basic Plan on Space Policy, as determined by the Japanese central government in January 2013, the SSPS is described as one of the three programs for pursuing the possibility of the development and utilization of space in future, which has a potential to be an infrastructure for power supply, and it is also described that the research focusing on wireless power transmission technologies will be conducted steadily.

Based on the Basic Plan on Space Policy, JAXA will continue energy transmission R&Ds of both Microwave and Laser.

The Microwave SSPS (M-SSPS) is better known than L-SSPS and has the following characteristics:

1) The appropriate wavelength microwave beam is unaffected by clouds or fog. (The supplied power is unaffected by the weather.)
2) The size of the spacecraft and ground facilities become so large to realize high efficient energy transfer.

The L-SSPS has the following characteristics:

1) The spacecraft and ground facilities are made compact, and a larger space system can be constructed by assembling small independent L-SSPSs.
2) The laser beam is significantly affected by atmospheric disturbances and the weather.
3) The intense laser beam can damage human eyes.

II. CONCEPTS OF L-SSPS AND ITS DIFFICULTIES

In our L-SSPS concepts, there are plans to use infrared wavelength CW fiber laser as an energy transmission medium. A laser wavelength comparison of the 1.07 and 1.55μm bands is shown in Table 1.

The 1.07μm band is chosen because it is easier to develop a larger output-power laser than with a 1.55μm band laser, and there is increased technological potential for high-efficiency energy transfer from laser to electricity.

The schematics of L-SSPS are indicated in Fig. 1. The solar energy is transferred to electrical energy by PV (photovoltaic) means, and then transferred to an infrared laser beam. The direction of the fiber laser beam to the ground PV facilities is precisely controlled by the fast-steering mirror and pilot laser beam from the ground, while the laser energy from the space segment is transferred to an electrical energy beam at the ground PV, and supplied to electric power networks.

*1 Present Address: Space Systems Division, NEC Corporation, Fuchu City, Tokyo, Japan

Table 1 Wavelength comparison of 1.07 and 1.55μm bands

	Yb-fiber laser (1.07μm band)	Yb-Er fiber laser (1.55μm band)
Larger Output Power	Better e.g. laser welding tools	Worse
Energy Transfer from laser to electricity	Better e.g. InGaAs, CIGS	Worse
Eye safety	Worse	Better
Transparency of atmosphere	Good	Good
Overall evaluation	Better	Worse

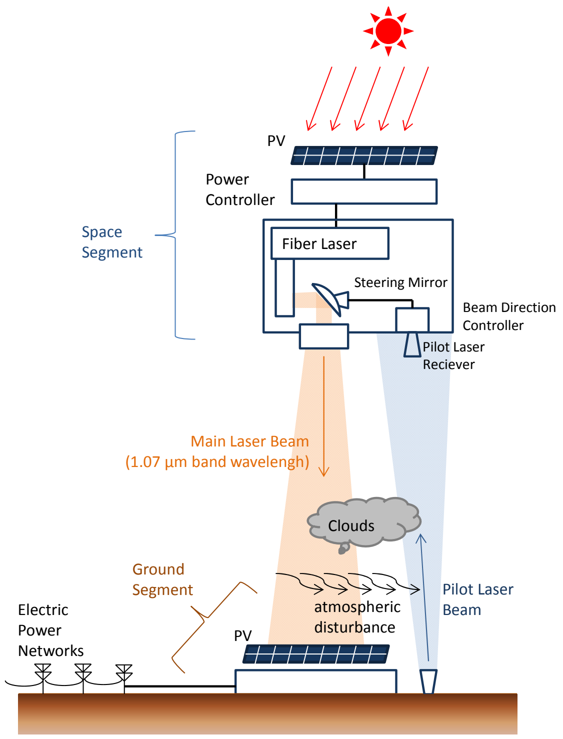

Fig. 1 The Conceptual Schematics of L-SSPS

The system is similar to mutual laser communication between satellites and the ground. The atmospheric disturbance will result in beam scattering or beam direction displacement. To offset the atmospheric disturbance effect, the space segment optics, ground PVs and pilot laser beam system must all be appropriately designed.

There are several differences between L-SSPS and laser communication .

1) The L-SSPS ground segment PV must receive the majority of laser energy arriving to the ground, while this is not necessary for laser communication.

2) The L-SSPS laser power far exceeds that of laser communication, which will affect the optical instrument thermal design.

3) The main laser beam output diameter must be determined to maximize the received energy of ground PVs, under the effect of atmospheric disturbances and laser beam diffusion.

The technological design of L-SSPS is significantly dependent on the orbit of space segments, while the GEO (Geostationary Earth Orbit) is a common orbit for SSPS. This is because the GEO L-SSPS has a simple optical tracking system due to the stationary spacecraft position, and need not store electrical energy in the battery because the spacecraft can obtain solar energy at virtually any time while in operation. However, the transmission distance exceeds 36000km and controlling the laser beam direction becomes much difficult. The LEO (Low Earth Orbit) L-SSPS has different characteristics. A more complex optical tracking system (e.g. laser gimbal) is necessary, but the precision requirements for controlling laser beam direction are relaxed due to the short transmission distance. The LEO L-SSPS must have large batteries if energy supply is sought in the shadow region of the Earth.

Focusing on L-SSPS from a technological perspective, JAXA constructed a development roadmap. (Table 2) Via two ground demonstrations, laser energy transmission fundamental technology will be achieved, whereupon the orbital systems of LEO or GEO will be launched.

Table 2 JAXA L-SSPS roadmap

	Ground Demo#1	Ground Demo#2	L-SSPS LEO	L-SSPS GEO
Year	2012-2013	2015-2017 (scheduled)	2019 ?	Undecided
Place	Terrestrial (Horizontal)	Terrestrial (Vertical)	LEO e.g. ISS-JEM	GEO
Energy Transmission Distance	500m	100-200m	400km	36000km
PV in space	N/A	N/A	PV for Space	PV for Space
Fiber Laser (Power)	COTS Laser (5W max)	COTS Laser (500W)	Laser for Space Use (approx. 500W)	Laser for Space Use (kW over)
Laser Beam Angle Precision	1μrad	1μrad	1μrad with the Laser gimbal for LEO	0.1μrad
Main Laser output diameter	φ42mm	φ200mm	φ200mm	φ1000mm
Effects of Clouds	N/A	N/A	Limited under the clear sky condition	Weather forecasting and multi ground site system
Effects of atmospheric disturbance	Technological Data Acquisition	Technological Data Acquisition	Mutual Laser Link and Energy Transmission under the disturbance	Mutual Laser Link and Energy Transmission under the disturbance
PV on the ground	N/A	Si-PV (Demonstration)	Efficiency Target 50%	Efficiency Target 60%

III. TERRESTRIAL DEMONSTRATION (500M HORIZONTAL)

As the first demonstration experiment of laser energy transmission with the beam direction control system, 500m terrestrial horizontal experiments were conducted in 2012 and 2013. The laser beam direction controller is based on the laser communication terminal developed by NICT, and combined with the 1.064µm infrared fiber laser (maximum output 5W).[2, 3]

Fig. 2 shows the laser beam direction controller. The optical antenna (lens) diameter is 42mm, and the laser direction is controlled by a fast-steering mirror (FSM) using the quadrant photodetector (QPD) signal. After the 0.982/0.972 µm mutual beacon laser link is established, the main laser beam was transmitted. Although the terminal design of the main beam transmitter and receiver are almost the same, the 1.064µm fiber laser was settled at the transmitter, and the power meter at the receiver, which measures the laser energy.

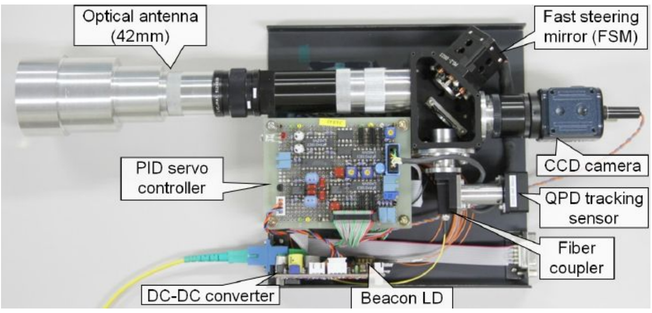

Fig. 2 The laser beam direction controller

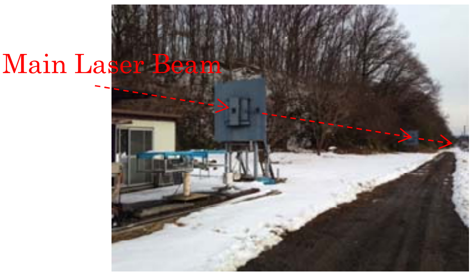

Fig. 3 Test Site (JAXA Kakuda Space Center)

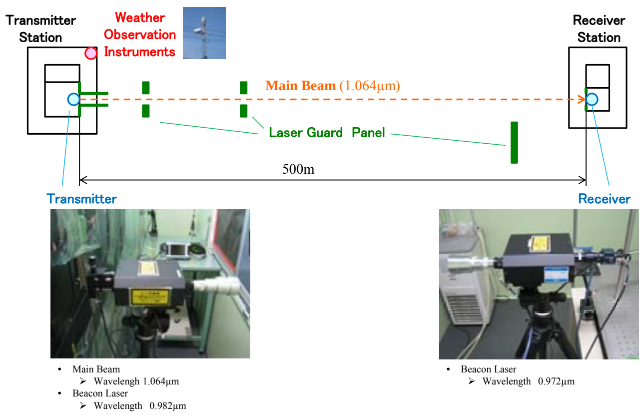

Fig. 4 Configuration of the Laser Transmission Demonstration Experiments

The outdoor demonstration experiments were conducted at the JAXA Kakuda Space Center Test Site. The 0.982 and 1.064µm beacon and main laser beams were transmitted from the transmitter station and the 0.972µm beacon laser beam from the receiver station. They are going through the holes of the guard panels, while weather data, such as solar irradiance, visibility etc. are obtained by instruments at the transmitter station.

Initially, the beacon laser mutual link with laser beam angle control to precision of around 1µrad was successfully established. Subsequently, the 1.064µm, 70µW fiber laser was added to the transmitter terminal and several attempts at main laser beam transmission were made. Approximately 50% of energy transmitting efficiency was successfully achieved and maintained for 90 minutes without intense sunshine. However, transmitting significant energy with the 1.064µm, 5W laser beam was not successful due to the rigidity of the supporting structure of the transmitting terminal which is caused by the rigid laser cable.

The results of the 500m horizontal demonstration were discussed, and we have the following opinions:

1) It will be possible to transmit the significant energy, if the arrangements of laser cable and the rigidity of transmitter terminal is improved.

2) The intense sunshine caused a strong atmospheric disturbance at the laser beam pathway, which is 3m above ground, and occasionally interfered with the beacon link and the main laser transmission.

3) The appropriate laser output diameter have to be pursued for a more stable laser direction under the daytime condition, because the effects of atmospheric disturbance tend to be mitigated with a larger diameter laser.

IV. TERRESTRIAL DEMONSTRATION (100-200M VERTICAL)

As the second demonstration experiment, concepts of vertical laser energy transmission experiments were considered. To mitigate the effects of near-ground atmospheric disturbance, the vertical downlink transmission direction from the 100-200m height tower is planned. Brand new equipment with a laser output diameter of φ200mm will be developed and the main laser output power will be up to 500W.

The functions and fundamental structures of the new equipment will be very similar to the laser terminal that is used in the 500M horizontal demonstration. The beacon laser signal from the transmitter, and the pilot laser signal from the receiver are detected by QPDs in each device and the laser direction is controlled by each of the FSMs, whereupon a mutual link is established. Finally, the energy of the main laser beam from the transmitter is transferred to electricity by the Si-PV in the receiver.

This experiment will be started from 2015.

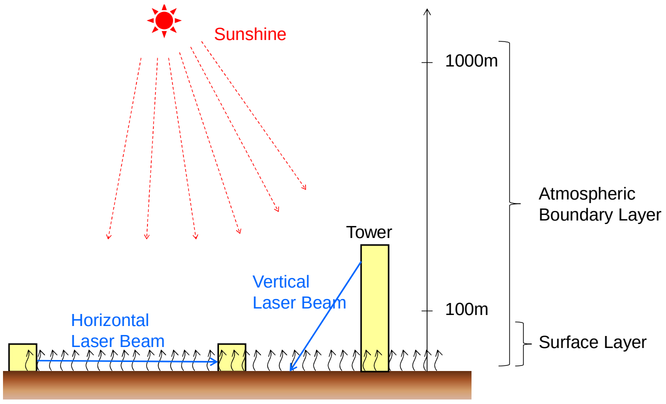

Fig. 5 Conceptual Schematics of the Laser Energy Transmission Demonstration

V. ORBITAL DEMONSTRATION ON THE ISS-JEM

Following the terrestrial vertical transmission, an orbital demonstration is considered the next technological step. The Japanese Experiment Module (JEM) of the International Space Station (ISS) is considered a suitable demonstration venue, because the electric power supply, coolant supply, several transportation methods and the telemetry / command communication link is available. The normal mass of an exposed facility (EF) payload is 500kg, which is adequate for storing the experimental equipment.

The output diameter (φ200mm) and output power (500W max.) of the main laser resemble those of the vertical experiment. If 50% of the energy transfer efficiency from laser to electricity is achieved, electrical power of approximately 80W will be obtained at the ground site.

The target of the main beam direction angle precision is 1μrad, and the laser footprint on the ground will be 10m. Therefore, a φ10m light condensing PV system is necessary for energy transfer from laser to electricity.

The ground test site must meet residence and aviation safety requirements. The intensity of the main beam from the ISS is not a problem for naked eyes, but the manned airplane must avoid the region near the ground site due to the pilot beam intensity. We are going to choose several domestic and overseas places for the ground sites.

This mission's target launch year is 2019 and the experimental period is one year, although this depends on the budget.

CONCLUSION

The concept of the L-SSPS and JAXA's development roadmap of laser transmission technology is introduced. A terrestrial vertical demonstration experiment is planned to be started from 2015, and the orbital demonstration is under conceptual study.

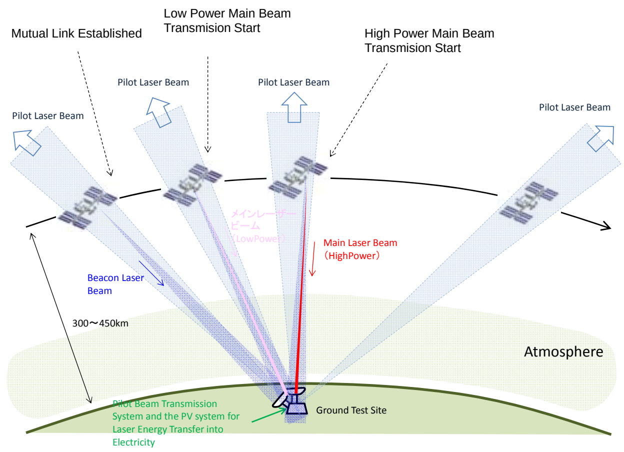

Fig. 6 The Concept of the L-SSPS Orbital Demonstration from the ISS-JEM

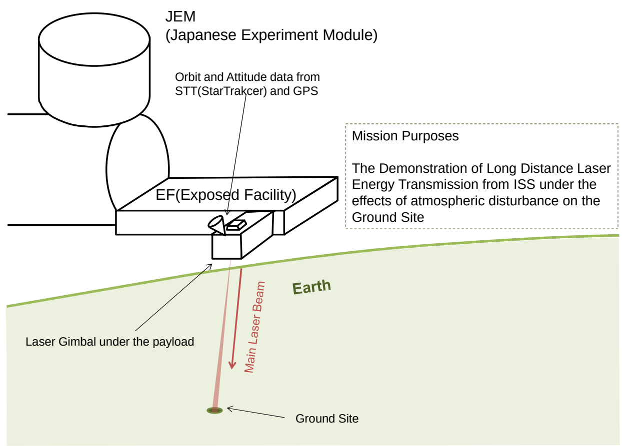

Fig. 7 The Image of the L-SSPS Orbital Demonstration Equipment on the JEM-EF

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