Microwave Energy Transmission Program for SSPS

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Abstract

Institute for Unmanned Space Experiment Free Flyer, USEF, has been studying Space Solar Power System, SSPS, as future electricity alternative energy source. From 2009, USEF started new research and development project of the Microwave Ground Wireless Power Transmission under a support of Ministry of Economy, Trade and Industry, METI. This project includes the study for high efficient and thin structured phased array antenna, and the study for high efficient rectenna element. Also this project plans to test ground wireless power transmission as a previous stage to the next space proof of SSPS. In this paper, outline and progress of this project are introduced.

1. Introduction

USEF has been studying Space solar power system (SSPS) under a support of METI and the other related agency since 1990s.[1][2][3] These studies have covered from basic laboratory testing level to the practical power plant level, See Fig.1. Based on these efforts, USEF is now conducting a new project with related agencies and companies. KW class ground power transmission test is planned at final phase of this project.

2. Summary of SSPS activities

The feasibility study of SSPS was carried out from FY2001 to FY2003. The Working Committee has investigated a simple, technically feasible, and practical configuration SSPS which consists of a large power generation /transmission panel or sandwich panel suspended by multi-tether wires from a bus system above the panel. See Fig.2.

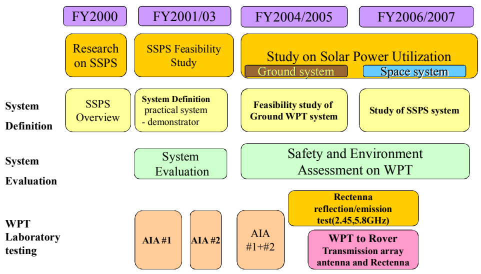

Fig.1 SSPS activities by USEF

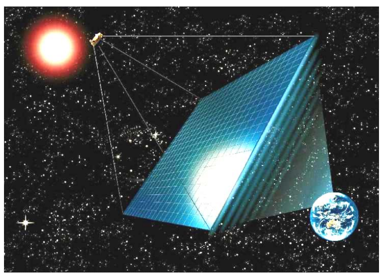
Fig.2 USEF SSPS reference model

In order to utilize wireless power transmission, we have to consider three main elements. First element is generation of RF energy from the electric power. The second element is to transmit the energy to the point of interest. The last element is the receiving RF energy and converting it to direct current electric power. We have covered these elements in our testing in some extent.

The beam control experiment was initiated from 2001. The active array panel with phase shifters, AIA#1[4], and the hardware retro-directive active integrated array panel, AIA#2[5], were developed and tested. The purpose of the development was to understand the issue derived by the microwave beam steering with integrated panels. And its

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evaluation was carried out in the anechoic chamber. In 2007, high accurate beam control experiment was carried out using the phased array antenna (5.8GHz, one-dimensional, 12 elements, about 40 cm wide). Also, experiment of synchronized reference control system by closed loop technique for multiple phased array panels were carried out.[6]

The WPT to remote object is a preferable application of SSPS technology. The rectenna array for rover, light weight phased array panel for transmitter on 5.8GHz had been developed. We also confirmed the low power command communication, 10mw, in 100W level microwave power transmitting condition. [7][8]

3. Japanese New Space Policy, and the New Project

The Japanese new space policy was enacted in 2008 and the basic plan for space policy was established in 2009. They have summarized 9 space systems and programs for the social demands to be realized through the use and R&D of space and a specific goal to correspond to each demand for the next 10 years. Space Solar Power system program was selected as one of the research development programs. After it was selected in the space policy, METI had initiated the research and development of microwave power transmission ground testing project. Though Space Solar Power System was selected as an important project, the Large Space system was not yet declared to be supplied. In this project, we lead the progress of the technology for the next space experiment phase, and conduct electric power transmission demonstration at the end of this period.

3.1 The Objective of the Project

In the previous study as described in paragraph 2, we have already been clarifying the issues to be studied.

For the power transmission section, there are five key phrases to realize the SSPS. They are Large, High Efficient, High Accurate, Light Weight and Low Cost. Therefore, we are trying to realize Light Weight thin phased array antenna (thickness is some centimeter) by using High Efficient HPA(High Power Amplifier) that applied GaN HEMT and F class amplifier. As the SSPS has to be large system, multiple small power transmission sections shall be combined and synchronized operation has to be realized with High Accurate beam steering. Power transmission section is composed of four power transmission modules. To synchronize the phase of the transmitting microwave of these power transmission modules, this subsystem has reference signal control function. The power transmission output power should be 1kW or more.

In the receiving section, there are two objectives. One is the stable operate system construction. The receiving panel assumes plural receiving modules connected in series parallel and taking out stable electricity. And the other is highly effective rectifying element development. The target efficiency of element is more than 80%.

A precise beam direction control of the microwave is an important issue for SSPS microwave transmission from 36,000km above. Japan Aerospace Exploration Agency (JAXA), that jointly executes this project, share this part of research and development. The element electric field vector rotation method (REV method) will be applied to maximize the received electric power. Also software retro directive method will be applied to transmit the microwave beam in that direction are planned. Target number of the angle accuracy for ground experiment is 0.5 degrees as a beam control in the transmission.

These sections will be combined at the final phase of this project, and we will demonstrate the wireless power transmission.

4. Progress of the Project

Overall architecture of the system was determined in 2009, functions and performance of the subsystem to constitute the system was defined. After that study, basic design and element examination work were pushed forward. These summaries are shown below.

4.1 Power Transmitting Section

GaN HEMTs with F-class power amplifiers was applied to the power transmission section. GaN HEMT has attracted much attention as the state-of-the-arts microwave power transistor due to its high voltage and high power density capability. F-class operation was applied for high efficient power amplifier operation. In this work, an internally matched GaN HEMT high efficiency amplifier is developed, in which 2^{nd} harmonic at input side and 2^{nd} and 3^{rd} harmonic at outside are tuned with internal matching circuit. Very high Power Add Efficiency, PAE 70%, with 7W output power was successfully obtained. Fig.3 is the photograph of hermetic sealed metal packaged GaN HEMT high efficiency amplifier.[9]

The output power from HPA is fed to antenna elements which have four elements sub-array structure via filter and the distributor, and the many sub-array antennas consist the power transmission module, which size is 60cm x 60cm. Furthermore, four transmission modules consist a power transmission phased array antenna, the total size is 120cm x 120cm.

For space application, antenna thickness is very important parameter. That is because the huge sized SSPS is required light weight transportation size and also required the expansion in space. Fig.4 is the ideal image of thin sub-array structure. Reducing the thickness is attempted by vertically doing the circuit transmitted from the micro wave circuit board to the antenna array substrate. The achievement of the thickness is 44.4mm in our current design. We are trying to reduce the thickness with keeping low loss performance.[10]

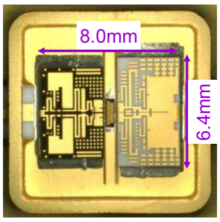

Fig.3 Metal packaged GaN HEMT amplifier

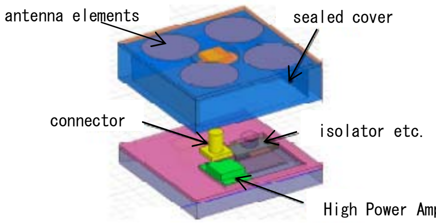

Fig.4 Sub-array radiation part structure image

4.2 Power Receiving Section

The receiving section has function to rectify and convert the transmitted microwave energy to DC electricity. The total efficiency from transmitted power to the converted power mainly depends on the beam shape and the size of receiving antenna. The technological issue of receiving section is to predict the electricity flux density distribution, and to take out the energy with appropriate antenna arrangement using series/parallel connection. To take stable electrical energy at high conversion efficiency is very important.

Fig.5 is the typical block diagram of rectenna. Rectenna is remarkably simple in structure, which is composed of antenna and rectifying circuit. For SSPS System, transmitting microwave has just one frequency, 5.8GHz. So, broadband characteristic is not required. Patch antenna is suitable than linear antenna because it has miniaturizing potential. Self-bias rectifying circuit is used in a rectenna. This circuit has Input filter, rectifying diode and output filter. Most of the power loss might be caused by the loss in rectifying diode. We are considering improvement of efficiency with studying both parameters.

The input power into rectifying circuit is composed by multiplying input microwave power density into the antenna and effective aperture area of antenna element or sub-array antenna. We are also studying the antenna arrangement. Fig.6 is just a sample of antenna arrangement study.

For the receiving antenna for the ground wireless power transmission demonstration, we are considering Φ2.5m sized receiving panel consisted of tens of square shaped receiving module.

In parallel to the receiving antenna development described above, we are trying to develop a high effective shottky barrier diode for rectifier using GaN material. In this development, an experimental evaluation of the manufacturing process and the manufacturing condition are done. [11]

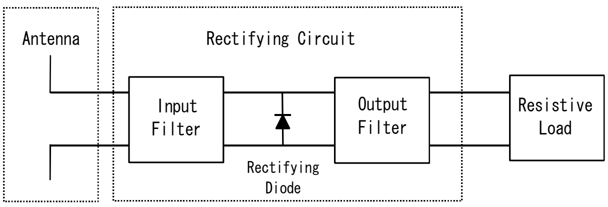

Fig.5 Rectenna block diagram

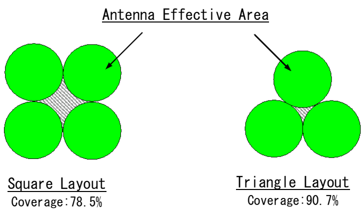

Fig.6 Antenna arrangement study

4.3 Wireless Power Transmission Demonstration Test

As described before, phased array transmitting antenna size is 120cm x 120cm and the output power is 1.3kw. The energy electricity flux density at the receiving position center is calculated in Fig.7. We are assuming the 50m distance according to the relationship between distance and energy.

An energy distribution at 50m point is analyzed as shown in Fig.8. The black flame in the figure is shape of the receiving panel being assumed now, and the electric power collection efficiency (energy that physically hits the receipt panel when the gross energy transmitted is assumed to be one) remains in about 58%. This energy enters the receiving module, and then it is taken out as electricity. Around several hundred watts power can be taken out from the current examination.

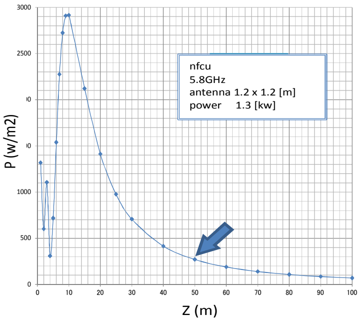

Fig.7 Electricity flux density

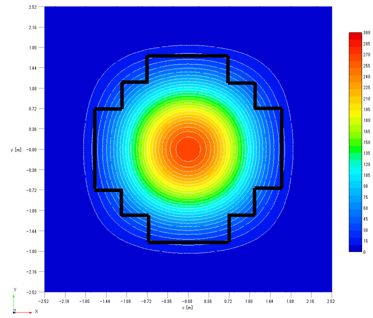
Fig.8 Energy distribution at 50m point

5. Conclusion

Microwave power transmission project is now conducting. In this project, we lead the progress of the technology for the next space experiment phase, and conduct electric power transmission demonstration at the end of this period. We shall always consider the next coming space experiment step during this project.

6. Acknowledgments

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