RECENT SPS PROJECTS IN JAPAN

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Abstract: Solar Power Satellite/Station (SPS) is one of important energy system in future, which is supported by radio wave technologies. The electric power which is generated in the SPS is transmitted to the Earth by microwave or laser. We need a high efficiency and light weight for microwave power transmission (MPT) system in order to reduce total cost of the SPS. There were some MPT phased array, for example, a phased array in the MILAX experiment in 1992 in Japan, a magnetron phased array in MPT airship experiment in 2009 in Japan, and a phased array in the Hawaii experiment in 2008 in US and Japan. However, there were not enough for the future SPS. Recently in Japan, there are two trials to develop a MPT phased array. One is a new phased array for collaborative inter-universities researches, which has been developed in Kyoto University in FY2010. The other is the SPS research and development project, in which we are developing thin and high efficiency phased array for MPT from FY2009. The Japanese SPS projects are based on 'Basic plan for space policy' which was established by Strategic Headquarters for Space Policy in June 2009. Beam forming and target detecting algorisms and technologies are also as important as the development of the high efficiency and light weight phased array. There are various beam forming and target detecting techniques for the SPS, for example, retrodirective target detecting with a pilot signal, Rotating Electromagnetic Vector (REV) method, Position and Angle Correction (PAC) method, etc. The Japanese SPS projects involve the verification of the various beam forming and target detecting techniques. In this paper, I show mainly developments of phased array and beam forming and target detecting techniques in the recent Japanese SPS projects.

1 INTRODUCTION

In June, 2009, Japanese Government established 'Basic plan for space policy' in order to expand Japanese space activities and technologies. In the plan, the SPS was selected on measure nine systems and programs for the utilities and R&D of space as follows;

"As a program that corresponds to the following major social needs and goals for the next 10 years, a Space Solar Power Program will be targeted for the promotion of the 5-year development and utilization plan." and "Government will conduct ample studies, then start technology demonstration project in orbit utilizing "Kibo" or small sized satellites within the next 3 years to confirm the influence in the atmosphere and system check."(Basic plan for space policy1, 2009) (Basic plan for space policy2, 2009).

Three years passed from the establishment of the Basic plan for space policy. During three years, Japanese government has changed from the Liberal Democratic Party, which had political power for a long time, to the Democratic Party of Japan. Unfortunately, there was less progress of the space policy by the Democratic Party of Japan in Japan in this three years. However, in June 20th, 2012, Japanese government established new law concerning space development which is called "Law of partly improvement of law of establishment of Cabinet Office". In the new law, they declare that Cabinet Office will have jurisdiction over Japanese space development instead of several Ministries, including Ministry of Education, Culture, Sports, Science and Technology which has jurisdiction over JAXA, which had jurisdiction over the Japanese space development simultaneously. They also declare that new space policy decision commission

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will be established instead of old Space Activities Commission which leaded the Japanese space activities. Seven members of new space policy decision commission are selected in July 26th, 2012. Prof. Hiroshi Matsumoto of Kyoto University, Prof. Hiroshi Yamakawa of Kyoto University, and Prof. Shin-ichi Nakasuka of University of Tokyo are the members of new space policy decision commission.

Under the tempestuous circumstance of Japanese space policy, the Japanese SPS project and related development of a microwave power transmission (MPT) are making our way.

2 DEVELOPMENT OF PHASED ARRAY IN JAPAN

From FY2009, J-spacesystems (former USEF) starts the SPS and the MPT R&D project(Fuse, 2011). The author is committee chair of the assessment committee of the project. The purposes of the project are (1) development of high efficiency phased array and rectenna array, and (2) field MPT experiment with the developed phased array and rectenna. A historical review of the phased array is shown in Fig.1. There are two kinds of the phased array. One is a phased array with semi-conductors. The other is a phased array with magnetrons which are mainly developed in Kyoto University, Japan. There are a lot of the phased array for radar and SAR in the world. However, the phased array for the MPT and the SPS requires higher accuracy of beam forming with higher efficiency of DC-RF conversion than those for the radars. The newest phased array, which will be developed in J-spacesystems' SPS project in FY2013, will have thinnest thickness (<4cm), highest efficiency (>70% at HPA) at 5.8GHz with GaN semi-conductor and MMIC technologies.

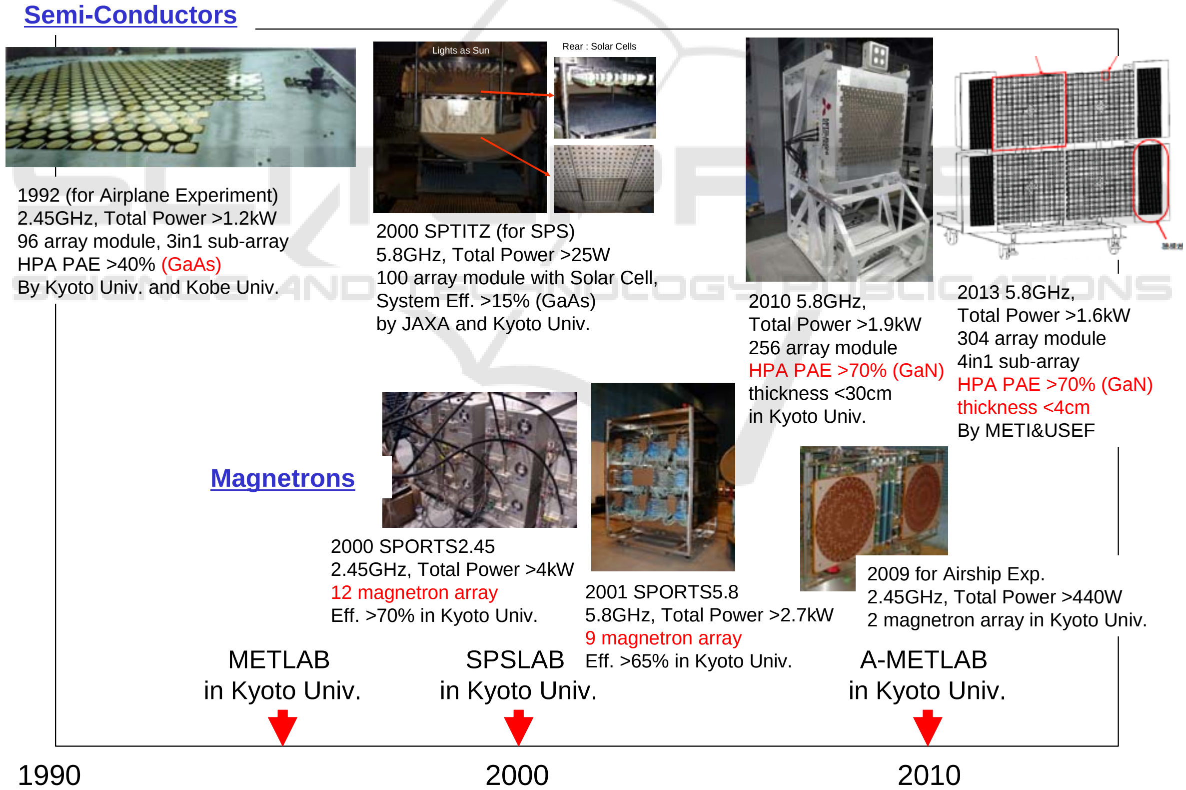

Fig.1 History of Developed Phased Array for MPT

At the end of FY2010, a new phased array was installed in Kyoto University as multipurpose research equipment(Honma, 2011)(Yamanaka, 2010). The characteristics of the phased array in Kyoto University are as follows:

1) 5.8 GHz CW, no modulation.
2) Separated module antenna/active circuits system.
3) Rigid antenna plane.
4) 256 elements.

5) Active phased array with one active circuit for one antenna.
6) 1.5 kW output microwave power.
7) F-class power amplifiers with GaN FETs.
8) >7 W output in high-power amplifier as final stage.
9) >70% power added efficiency in microwave high-power amplifier as the final stage (Fig. 21).
10) >40% as total DC-microwave conversion efficiency.
11) 5-bit MMIC phase shifters.
12) <30 cm thickness as universal experimental equipment.

The phased array system consists of phased array equipment, beam control units, and a cooling unit. The beam control units consist of an antenna control unit, a PC, and the retrodirective equipment. The rectenna array system consists of the rectenna array, a DC/DC converter, a load, and the retrodirective equipment. Figure 2 shows a simulated beam pattern, and Fig. 3 shows measured beam patterns when the main beam is steered to EL = (−15, −10, −5, 0, 5,10, 15) degrees. In each beam steering angle, the obtained steering accuracy was within 0.1 degrees.

Figure 4 shows measured azimuth-elevation beam pattern which is measured by near field scanner in Kyoto University. The near field scanner is installed in new anechoic chamber called Advanced METLAB with the phased array at the same time (Fig.5). It is plane-polar type near field scanner. It can measure the multi-beam pattern with control of beam direction of the phased array simultaneously. It can also measure the 10mϕ and 10kWCW phased array of satellite for the SPS. The phased array and the near field scanner are open for use by inter-universities and international collaborative studies. We would like use the research facilities in Kyoto University in order to advance the Japanese SPS project.

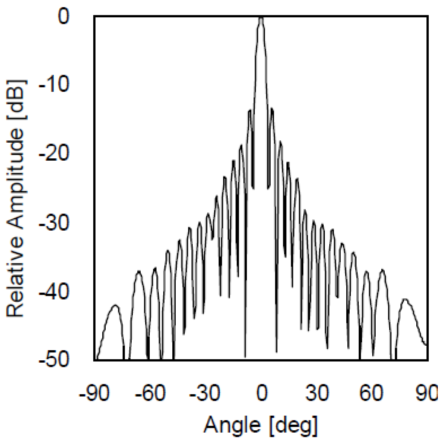

Fig.2 Simulated Beam Pattern of the Phased Array in Kyoto University

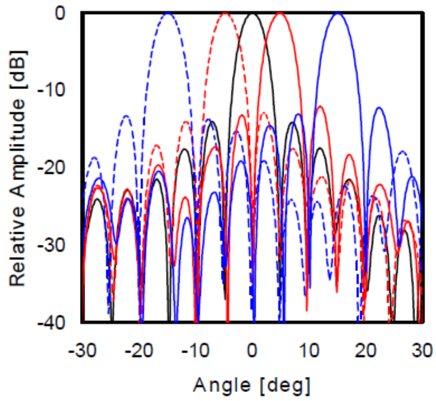

Fig.3 Measured Elevation Beam Pattern of Phased Array (Beam Steering Angle: EL=-15, -5, 0, 5, 15 Degrees(AZ=0 Degrees)).

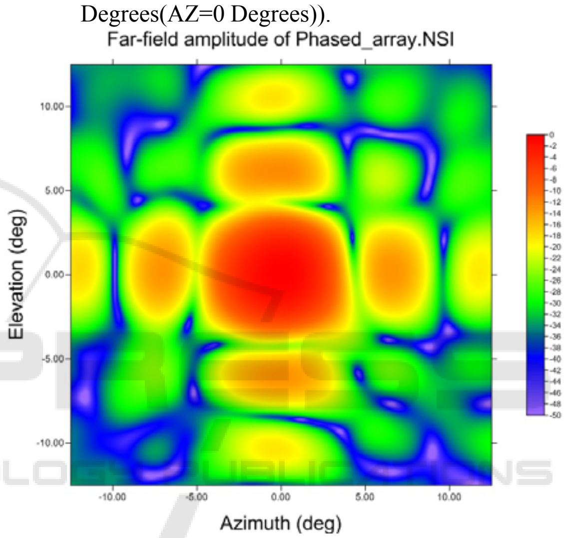

Fig.4 Measured Azimuth and Elevation Beam Pattern of the Phased in Kyoto University

Fig.5 Anechoic Chamber A-METLAB and Plane-Polar Type Near Field Scanner in Kyoto University

3 NEW ALGORISM OF BEAM FORMING AND TARGET DETECTING FOR SPS

The panel-structure SPS is designed by Japanese SPS committee. It consists of a large number of power generation/transmission panel modules. This type of SPS is suitable for mass production and easy to maintenance. However, joints of the panel modules are flexible and the panel-structure SPS is difficult to maintain flatness of the transmission antenna surface. In order to achieve the high beam direction control accuracy, we have to correct the output phase errors caused by the antenna surface distortion.

Mitsubishi Heavy Industry's SPS research group proposed new beam correction methods which is called a PAC (Position and Angle Collection) method. The PAC method is one of the beam correction methods for the panel-structure SPS. In the PAC method, we measure phases of a pilot signal, which was sent from a power receiving site on the Earth, on every panel module. We estimate the panel module positions by using the measurement phases. Then, considering the panel module positions, we correct the output phases of pilot signal.

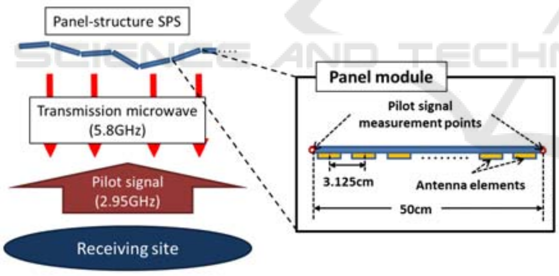

Fig. 6 Schematic Diagram of a SPS 1D Array Model.

In Kyoto University, we simulated the PAC method by a 1D array model shown in Figure 6. Taking account of the SPS system, we set these parameters. At first, we simulated the accuracy of the PAC method. From the simulations, the pilot signal measurement points have to be put on the both ends of each panel module in order to achieve the high beam direction control accuracy. However, the spacing of two measurement points is much longer than the half wavelength of the pilot signal and ambiguities occur in the panel position estimation method. Because of the ambiguities, we can correct the output phase errors only when the panel module gradients are in the range of -5 degrees to 5 degrees. Thus, we propose an improved panel position estimation method. By using this estimation method, we can use the PAC method even if the panel module gradients are in the range from -50 degrees to 50 degrees(Ishikawa, 2012).

4 CONCLUSIONS

There is no experimental satellite project for the SPS in the world. Based on the developments of the new phased array for the MPT, we hope the first experimental satellite will be launched in Japan.

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BRIEF BIOGRAPHY

Naoki Shinohara received the B.E. degree in electronic engineering, the M.E. and Ph.D (Eng.) degrees in electrical engineering from Kyoto University, Japan, in 1991, 1993 and 1996, respectively. He was a research associate in the Radio Atmospheric Science Center, Kyoto University from 1998. He was a research associate of the Radio Science Center for Space and Atmosphere, Kyoto University by recognizing the Radio Atmospheric Science Center from 2000, and there he was an associate professor since 2001. he was an associate professor in Research Institute for Sustainable Humanosphere, Kyoto University by recognizing the Radio Science Center for Space and Atmosphere since 2004. From 2010, he has been a professor in Research Institute for Sustainable Humanosphere, Kyoto University. He has been engaged in research on Solar Power Station/Satellite and Microwave Power Transmission system. He is a member of the IEEE, URSI, the Institute of Electronics, Information and Communication Engineers (IEICE) and the Institute of Electrical Engineers of Japan (IEEJ).