Feasibility study of a large-scale WPT system formed by a modular structure

Tanaka laboratory

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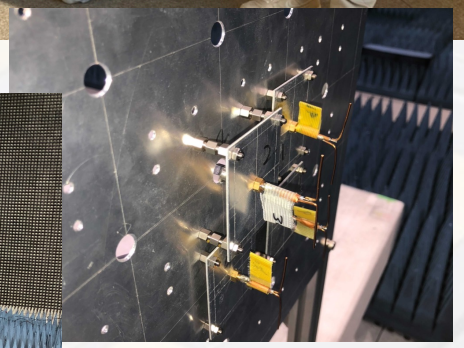
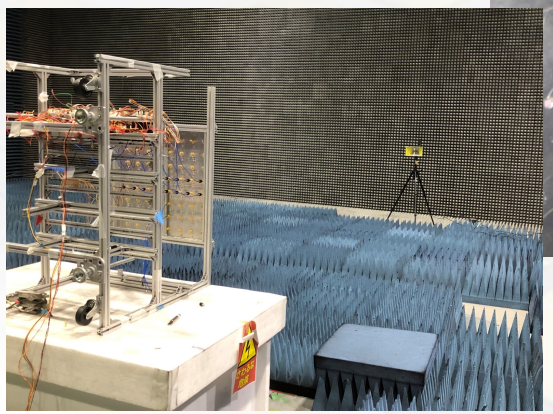
About us





We are...

“Tanaka laboratory Members”

What is Tanaka laboratory...?

Our laboratory is in ISAS / JAXA

Our main research subjects are...

1. **Study of WPT**
2. **Study of Structure of SPS**
3. **Study of Discharge Phenomena**

and more...

Members

Our members are from several universities.
Therefore, we have many backgrounds.
And we are the educational volunteer of SPS for high school students.

Backgrounds

Over 15 years have passed since the birth of Tethered SPS model, in Japan.

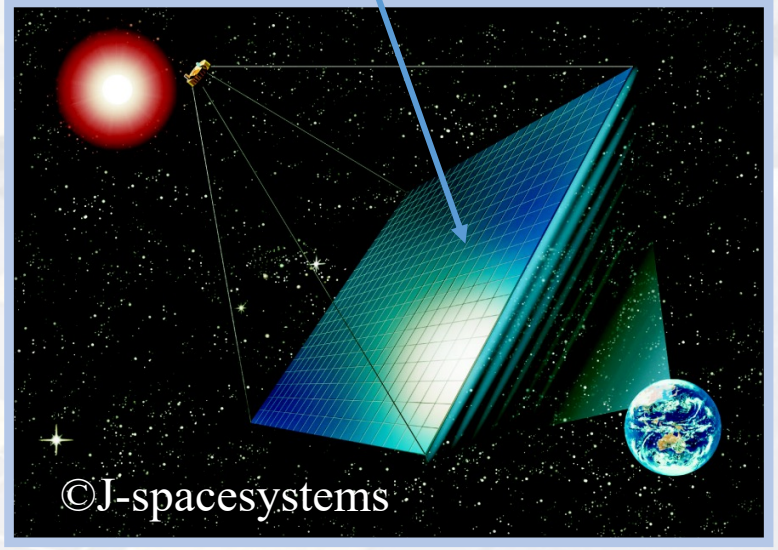
Tethered SPS was proposed

Many R&D activities

1968, Power from the Sun: Its future

The latest technologies

✓ 2,375,000 Generation/Transmission panels,
✓ All panels are equivalent spec. and independent.



Commercial SPS

We are facing the phase;
to review the ever R&D activities,
to clarify unsolved issues and promote the development toward the commercial system.

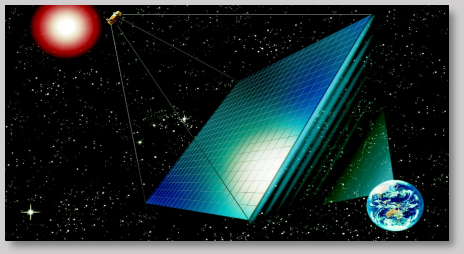
What is our project?

The purposes and goals of this project is:

to clarify unsolved issues from our feasibility study,
to promote the development of the WPT system,

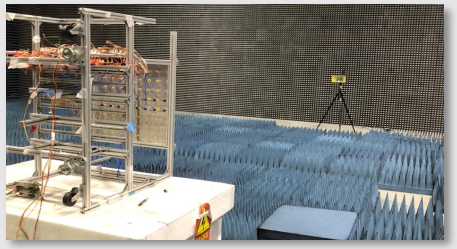
toward realizing a large-scale modular structure SPS.

Our steps toward goals



Feasibility study

Step①:**Summarize** the original concept of the Tethered SPS
Step②:**Reviewing** the recent R&D activities
Step③:**Clarifying** unsolved issues of modular WPT system

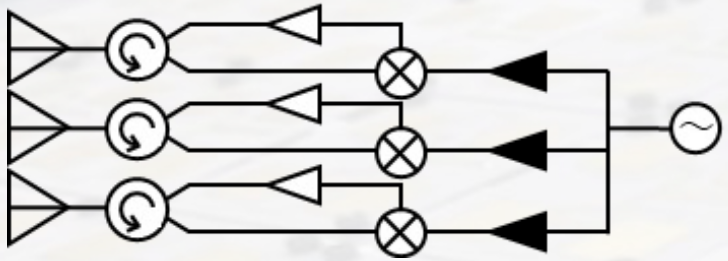


Promotion R&D

Step④:**Apply** the latest technologies for system improvement
Step⑤:**Study** of a new method regarding WPT in ISAS/JAXA

Recent R&D activities

Hardware retro-directive



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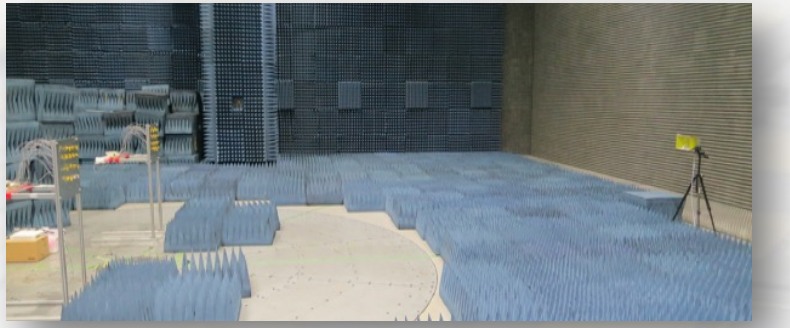
Software retro-directive



- Generate phase conjugation waves by electric circuits
- Fast processing and scanning
- Flexibility of the frequency and functions are poor

- Direction finding and beam forming via signal processing
- Safety, security and other functions are available

Ref.	Years	Description
[1]	2010	-Position and Angle Correction (PAC) method
[1]	2010	-Parallel method
[2]	2015	The horizontal WPT experiment uses: -The amplitude mono-pulse method, -Rotating Element Electric Field Vector (REV) method.
[3]	2019	-The vertical WPT experiment using the drone in outdoor uses: -The amplitude mono-pulse method, -REV method.

Phase correction method

Software retro

Software retro

Recent WPT technologies

Software retro-directive method,

must find a target direction and adjust phases of all antennas for precise control of beam.

- Direction finding method can detect the direction of the target from pilot signal.
- Phase correction method can correct phase errors caused by antenna deformation and temperature raises.

Phase correction method

Phase-correction methods	Descriptions
REV method:	can point beam within 0.15° rms. Many processing time is required [2].
Parallel method:	can detect phase errors within 1° [1].
PAC method:	can detect phase errors within 1° [1].

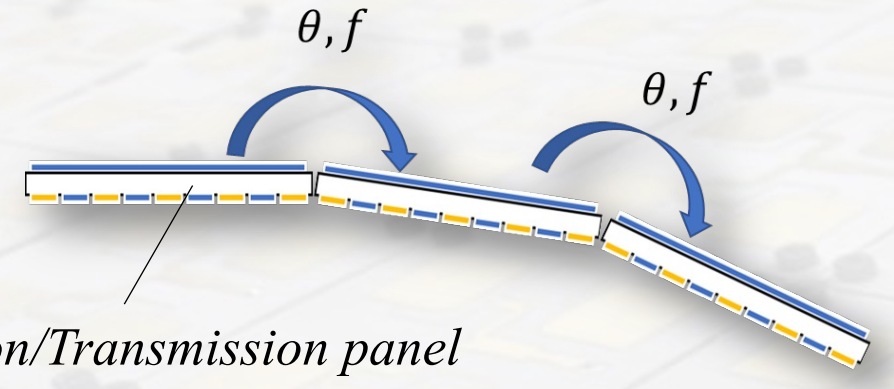
Direction-finding method

Direction Finding (DF) method	Descriptions
Mono-pulse method (phase/amplitude comparison):	• will realize simplified DF, • will not have a few flexibilities as compared to Software retrodirective.

MUSIC, ESPRIT and other methods are being studied for more precise direction-finding.

Unsolved issues for current WPT technologies

We are focusing on 2 big issues of the recent technologies such as Software Retro and REV method.



1. Synchronization of the phase and frequency

The reference signal must be shared among all equivalent modules, in modular structure system.

2. Long processing time to adjust the phases

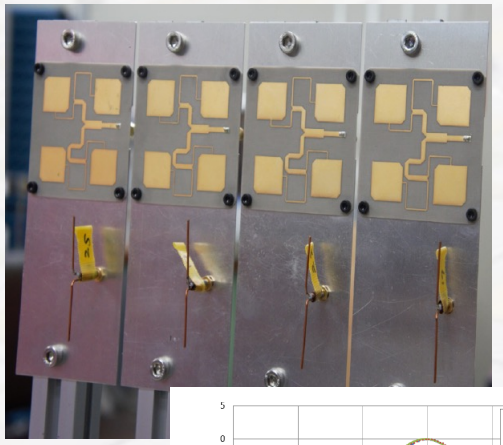
The REV method, promising phase-correction method, requires too long processing time to steer the beam.

We consider solving these issues by: **①Applying the latest technologies, ②Installing digital signal processing.**

Solution as a new method in JAXA/ISAS

For an example, we introduce a new method in ISAS/JAXA in Japan!

【*Digital Retro-directive Method*】



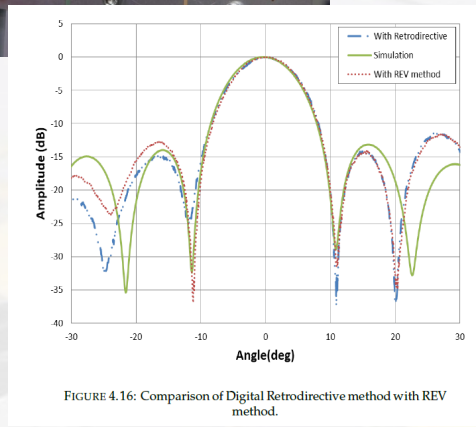
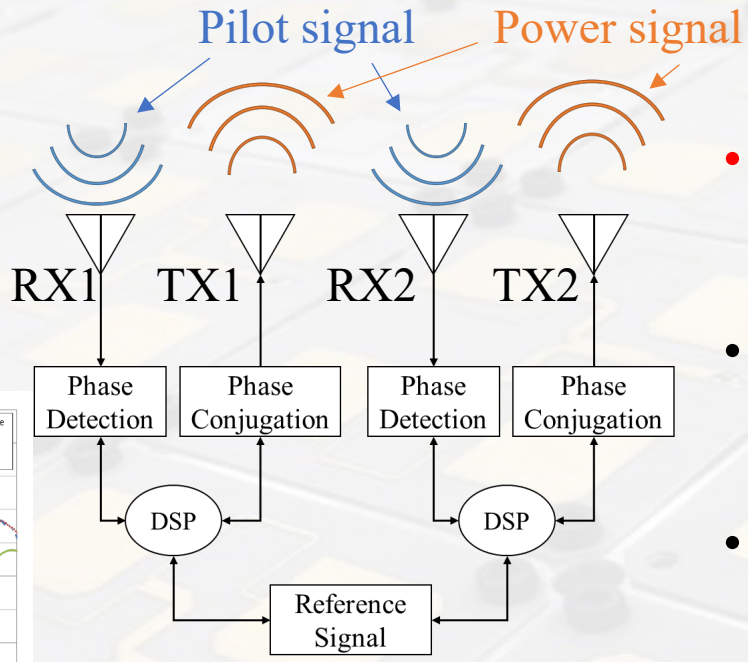


FIGURE 4.16: Comparison of Digital Retrodirective method with REV method.



- **Digital Signal Processing (DSP)** is used for: detecting phase and generating Conjugate phase.
- **Synchronization** among panels is not required. (Rx antenna and Tx antenna is same number)
- Digital retrodirective method correct errors with **shorter time** **than** **REV method**.
- Digital retrodirective method could correct errors with the same accuracy of REV method.

We will demonstrate this method with a simplified model.

Future works of Digital retro-directive

Followings are issues should be confirmed and be solved of Digital retro-directive

- Accuracy of phase correction with antenna deformed.

  【 ***Forward of backward deformation case*** 】

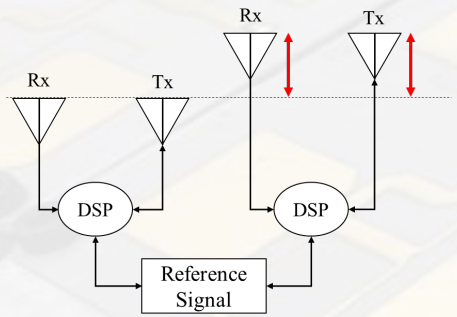
  The traditional study in our laboratory has achieved with the accuracy of **0.98° rms. [4]** .

  【 ***Angular deformation case*** 】 (Rev method: **0.15° rms. [2]**)

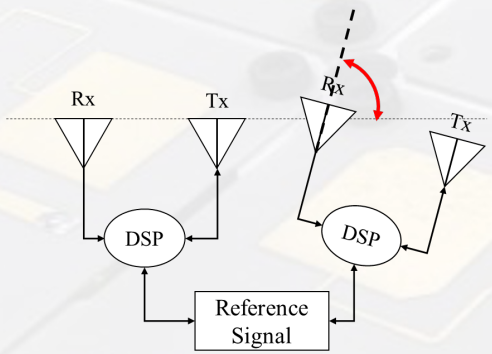
  It should be confirmed.

- Provision the reference signal among groups of Tx and Rx antenna.

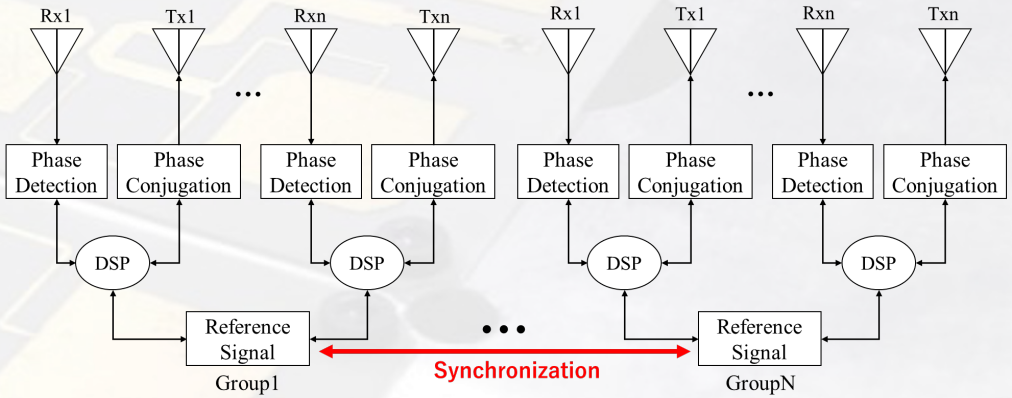
  It should be confirmed.



Forward of backward deformation

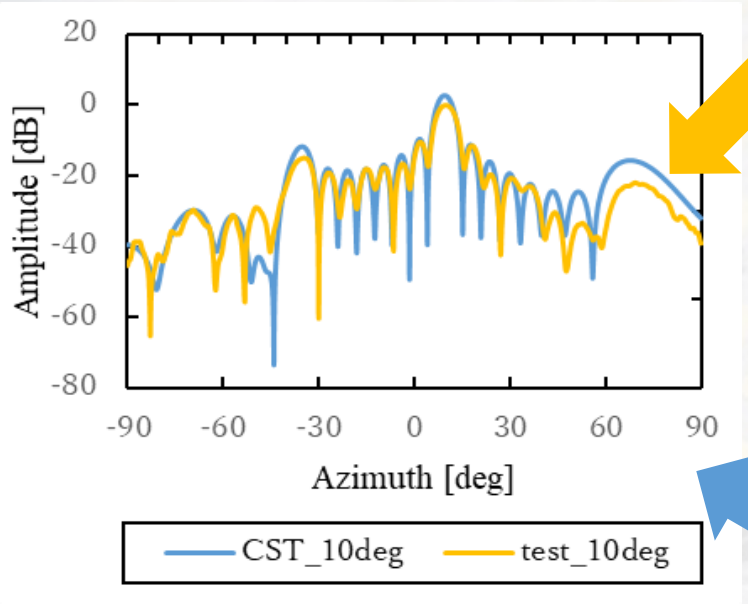


Angular deformation

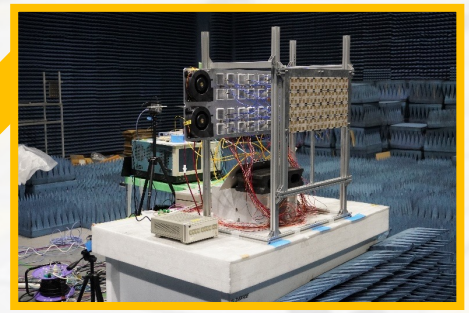


Progress from 2022 ISDC

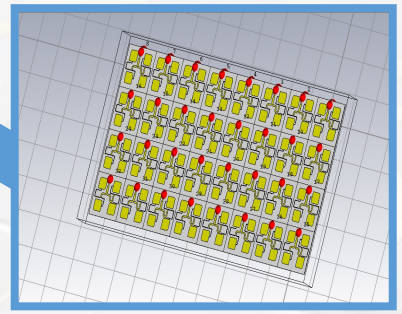
- We performed on a preliminary experiment for demonstration of **Digital retro-directive**.



Azimuth radiation pattern with beam 10° steering



Phased array system



Numerical simulation by CST studio

<Experimental condition>

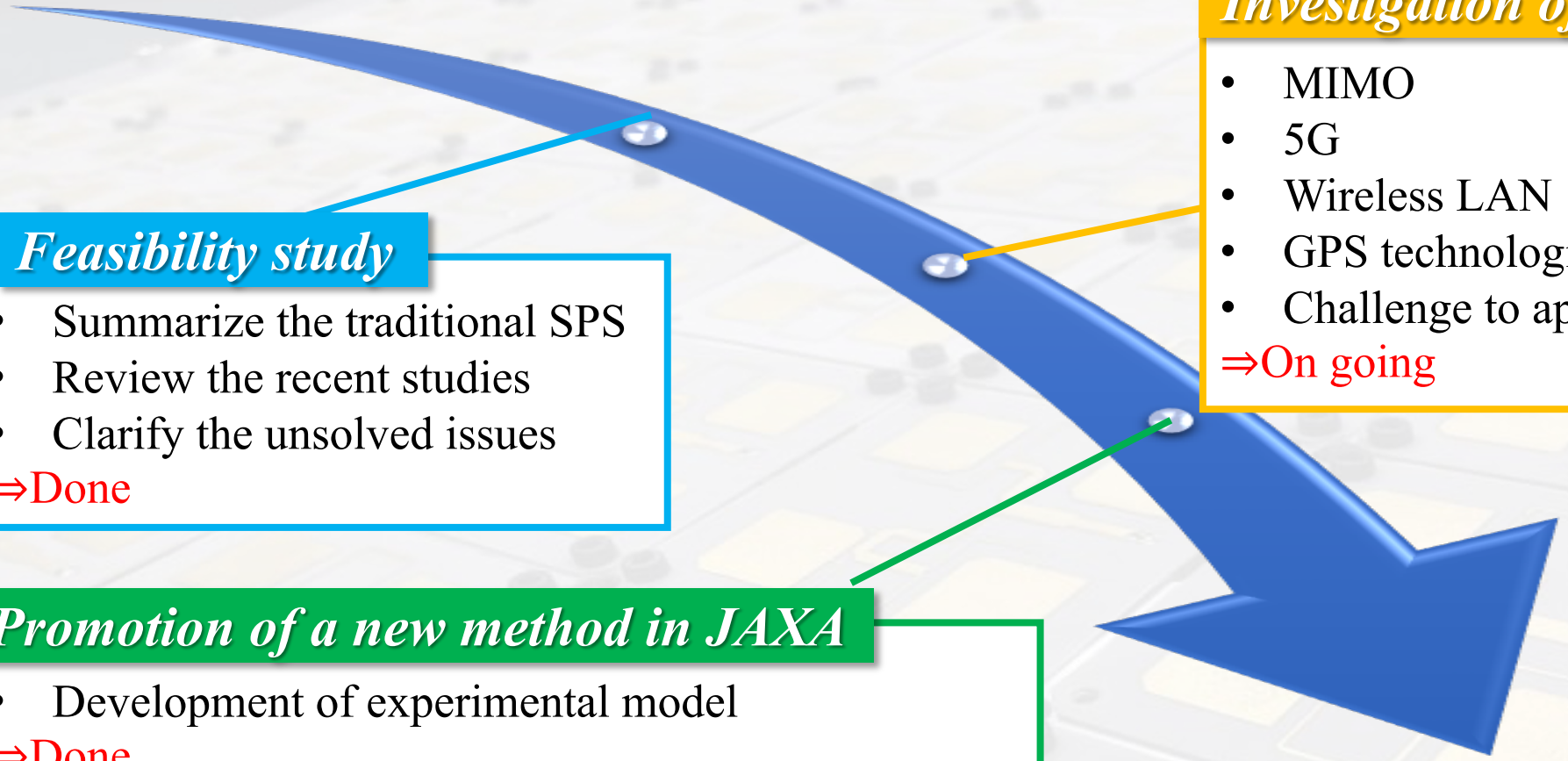
- 32 subarray with 2x2 patch elements
- 32 high power amplifiers and phase shifters
- Frequency: 5.8 GHz
- Beam steering direction: 0° ,5° ,10°
- In anechoic chamber at Kyoto Univ.

<Comparation between the test and CST result>

	Test	CST	unit
Main lobe direction	9.80	10.0	deg.
MSLL	-10.39	-12.6	dB
HPBW	5.75	4.9	deg.

- The results of the test and the numerical simulation have good agreement.
- This preliminary experiment confirmed the ability to control microwave beam of this phased array system.
- Next, we will confirm future works of digital retro-directive method base on this phased array system.

Our future process and goals toward next year



Feasibility study

- Summarize the traditional SPS
- Review the recent studies
- Clarify the unsolved issues

⇒Done

Investigation of the latest technologies.

- MIMO
- 5G
- Wireless LAN
- GPS technologies
- Challenge to apply the latest techs for WPT

⇒On going

Promotion of a new method in JAXA

- Development of experimental model

⇒Done

- Demonstrate a new method in ISAS/JAXA
- Verify a new method applied the latest technologies
- Promote the WPT system for a modular structure

⇒On going

Next competition

Our project goals are:

Feasibility study and improvement,

Promotion of development for SPS.

Reference

[1]

Takanari Narita, et al., Development of High Accuracy Phase Control Method for Space Solar Power System, 2011 IEEE MTT-S International Microwave Workshop Series on Innovative Wireless Power Transmission: Technologies, Systems, and Applications, 2011, 157-160.

[2]

Tomohiro Takahashi et.al., Phased Array System for High Efficiency and High Accuracy Microwave Power Transmission, 2016 IEEE International Symposium on Phased Array Systems and Technology (PAST), 2016

[3]

Mihara, S., et al., Current Status of the SSPS Development and the Result of Ground to Air Microwave Power Transmission Experiment. IAC Proc., IAC-2019-C3.2.1, 2019

[4]

Raza Mudassir, Precise Beam Control System for Solar Power Satellite, doctoral thesis, SOKENDAI, Japan,2021