R&D Activities on Solar Power Satellite in Japan

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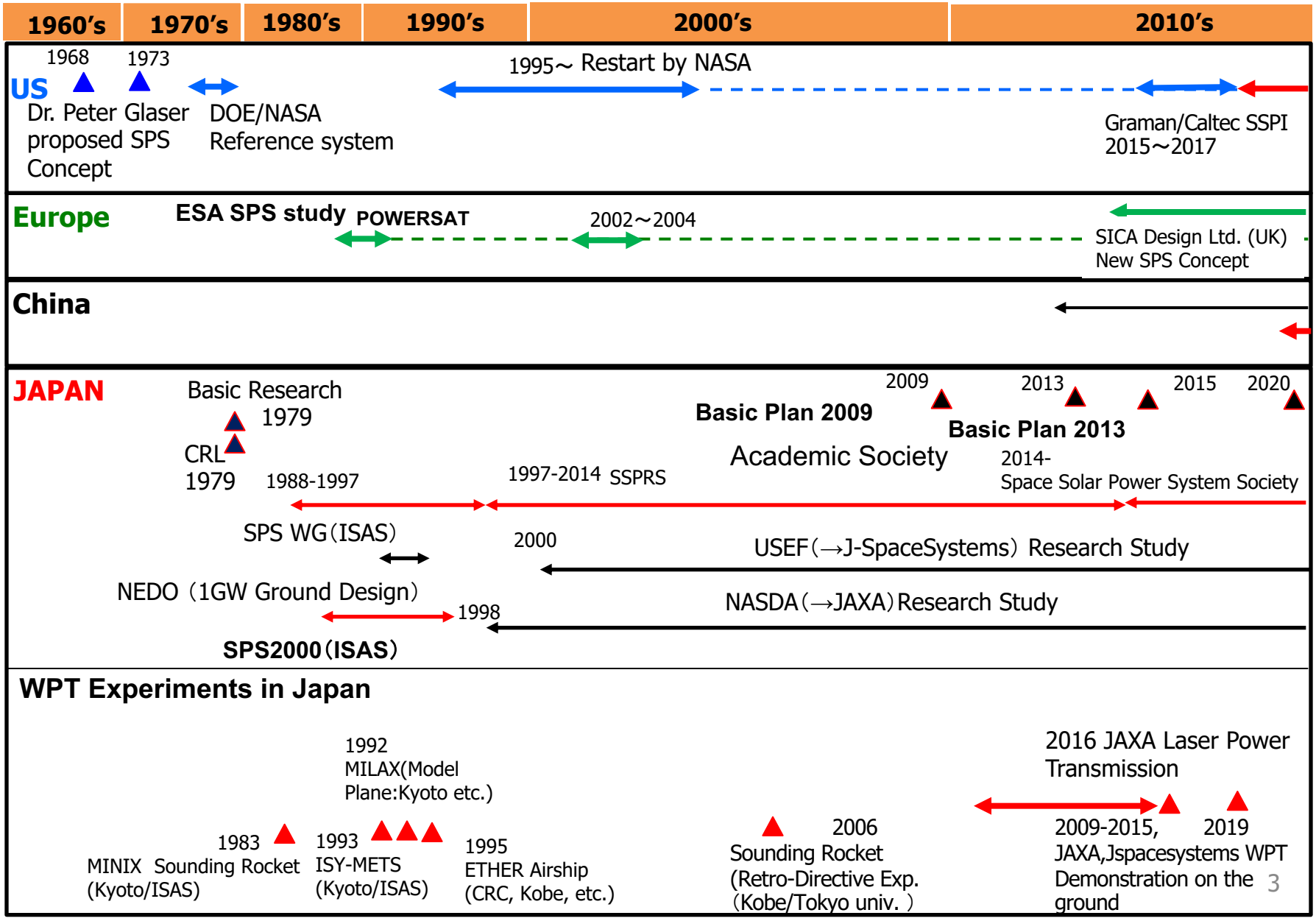
- History and Background of SPS Study in Japan
- Activities on SPS in Japan
- Activities of JAXA
- Toward SPS (Activities of J-spacesystems)
- Summary

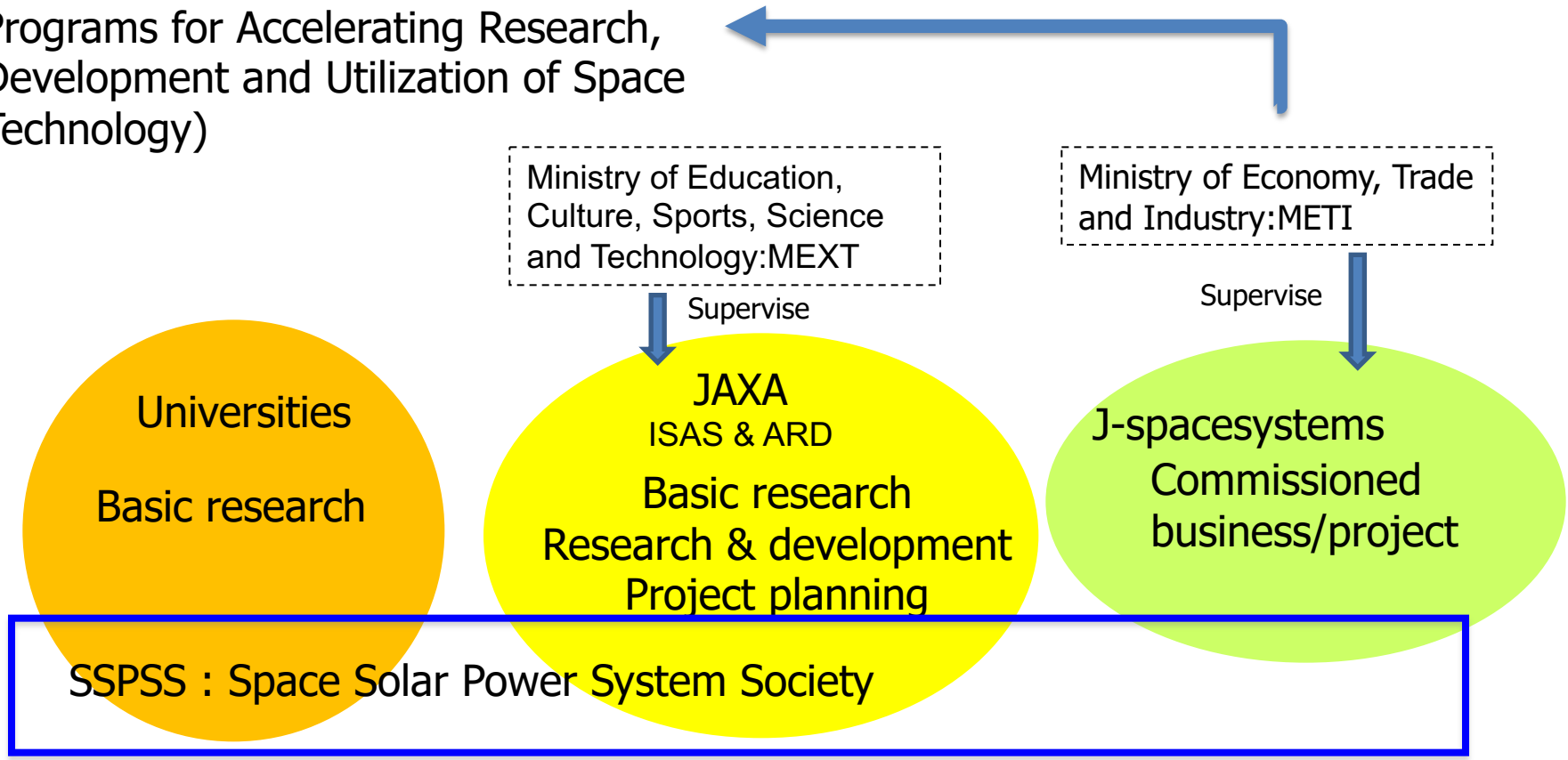
宇宙太陽発電の歴史


1960's
1970's
1980's
1990's
2000's
2010's
US
1968
1973
Dr. Peter Glaser proposed SPS Concept
DOE/NASA Reference system
1995～ Restart by NASA
Graman/Caltec SSPI 2015～2017
Europe
ESA SPS study
POWERSAT
2002～2004
SICA Design Ltd. (UK) New SPS Concept
China
JAPAN
Basic Research 1979
CRL 1979
1988-1997
1997-2014 SSPRS
2009
2013
2015
2020
Basic Plan 2009
Basic Plan 2013
Academic Society
2014- Space Solar Power System Society
SPS WG（ISAS）
2000
USEF（→J-SpaceSystems）Research Study
NEDO（1GW Ground Design）
1998
NASDA（→JAXA）Research Study
SPS2000（ISAS）
WPT Experiments in Japan
1983
MINIX Sounding Rocket (Kyoto/ISAS)
1992
MILAX(Model Plane:Kyoto etc.)
1993
ISY-METS (Kyoto/ISAS)
1995
ETHER Airship (CRC, Kobe, etc.)
2006
Sounding Rocket (Retro-Directive Exp. （Kobe/Tokyo univ.）
2016 JAXA Laser Power Transmission
2009-2015,
2019
JAXA,Jspacesystems WPT Demonstration on the ground

Activities on SPS in Japan

Basic Plan on Space Policy
was designed in 2009, revised in 2015, 2020.
SPS is one of programs to pursue the potential of the future development and utilization of space.

Stardust Program (the Strategic Programs for Accelerating Research, Development and Utilization of Space Technology)



Basic Plan on Space Policy

- The Basic Plan on Space Policy determined by the Strategic Headquarters for Space Policy in 2009, and revised 2015 and 2020.

- SSPS is mentioned as one of the important items.

- May 20, 2022

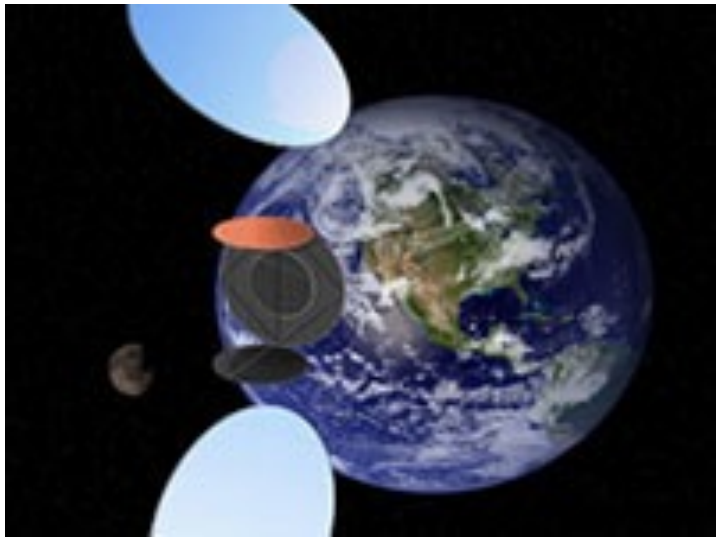
Priority items for revision of the process chart of the basic plan on space policy

→Space demonstration experiment by microwaves at LEO by 2025 was mentioned.

R&D Activities in JAXA

Conceptual Study

Conceptual study was performed by JAXA in the 2000s. Studies on power generation, WPT, large structure were conducted.
The system consists of two reflecting mirrors as a solar battery, and a microwave transmission device.



Advanced Microwave-type Model (JAXA/MEXT)

WPT by Microwave

Before an Practical SSPS is constructed in space, technological demonstrations should be conducted in both space and on the ground. JAXA has been conducting ground demonstrations of technologies for **microwave wireless transmission**, wireless power transmission by laser, and the assembly of large-scale structures.

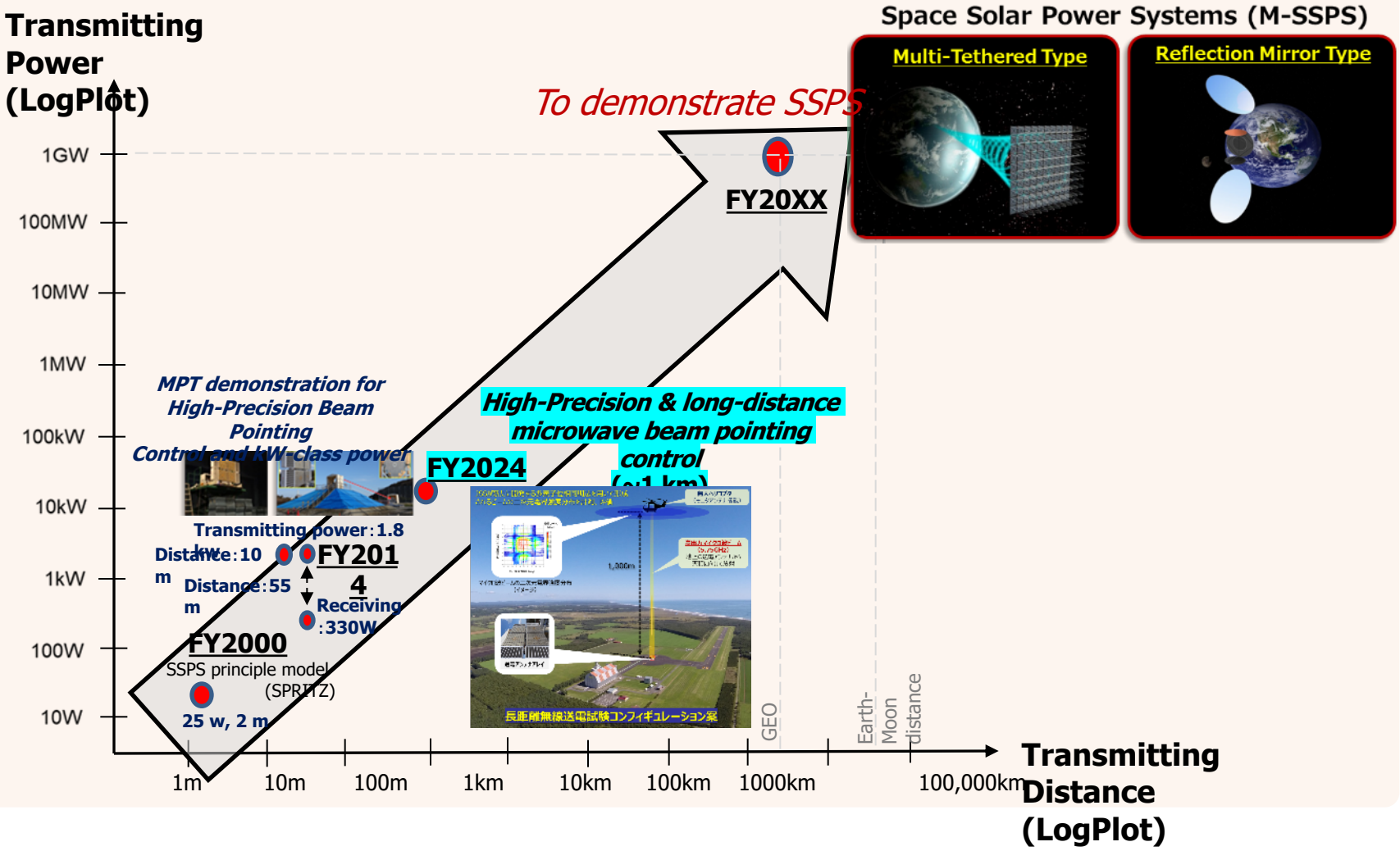
WPT by Laser

Lase WPT is superior for space applications. A lunar rover is one of the target applications.

On-orbit Demonstration for large scale structure

A space experiment is being prepared for the demonstration of **large scale structures** using HTV-X.

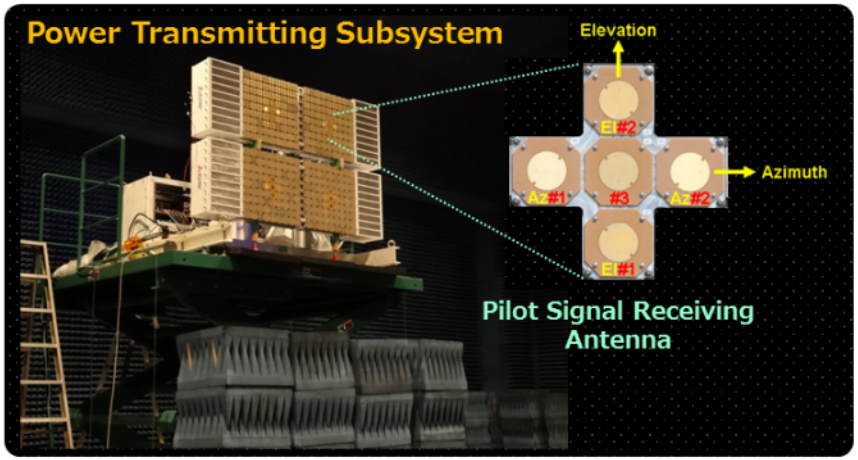
Roadmap for M-SSPS



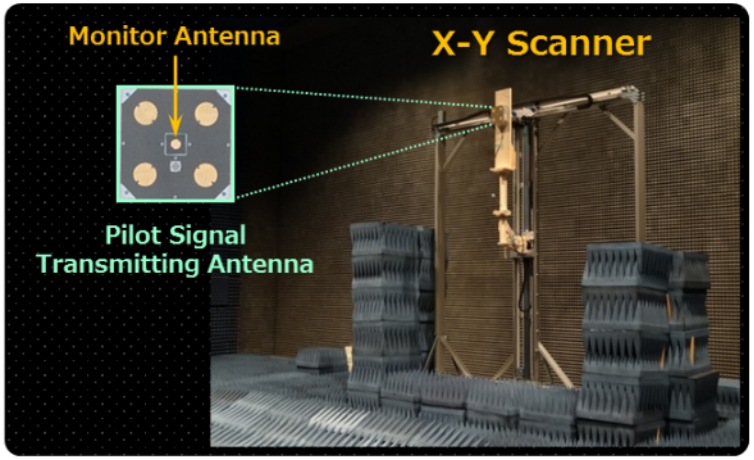
Previous Ground Demonstration of Microwave Wireless Power Transmission

◆ **Evaluation test of Beam-Pointing Control Precision with kW-class high-power microwave power Transfer**

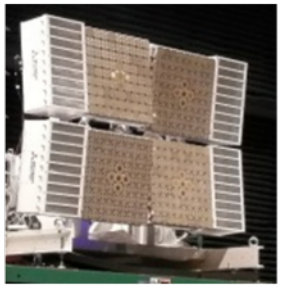
Success Criteria : Beam-Pointing Control Precision not exceeding 0.5degree(RMS) with Transmitting Distance over 10meter



Power Transmitting Side



Power Receiving Side



← The simulation of huge antenna panel deformation by thermal distortion and gravity gradient torque in space (example)

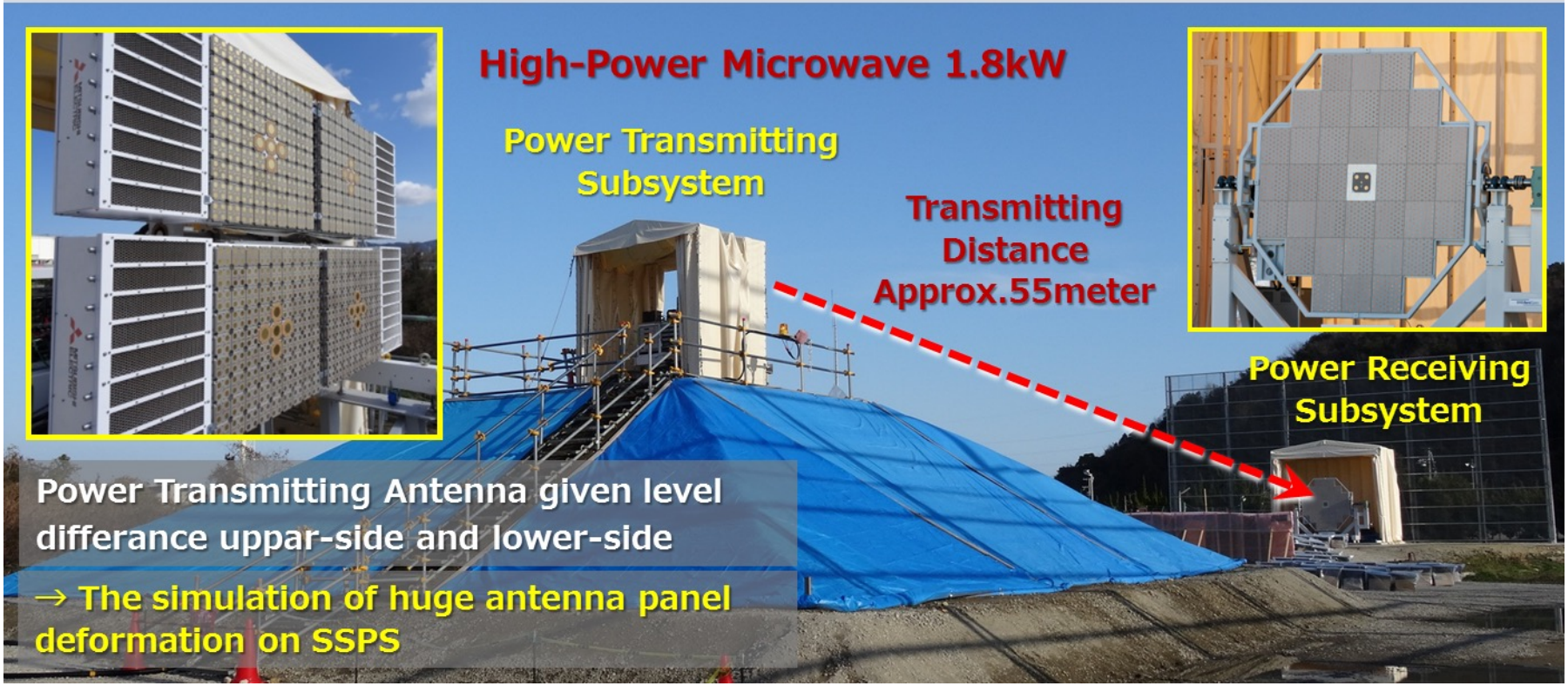
Beam Pointing Control Precision

Measured : 0.15degree (RMS)

Previous Ground Demonstration of Microwave Wireless Power Transmission

The improving of test condition is not so good as that ditection of pilot signal arrival direction opreate correctly, therefor power transmitting panel was setting toward power receiving panel manually and REV control only is effective.

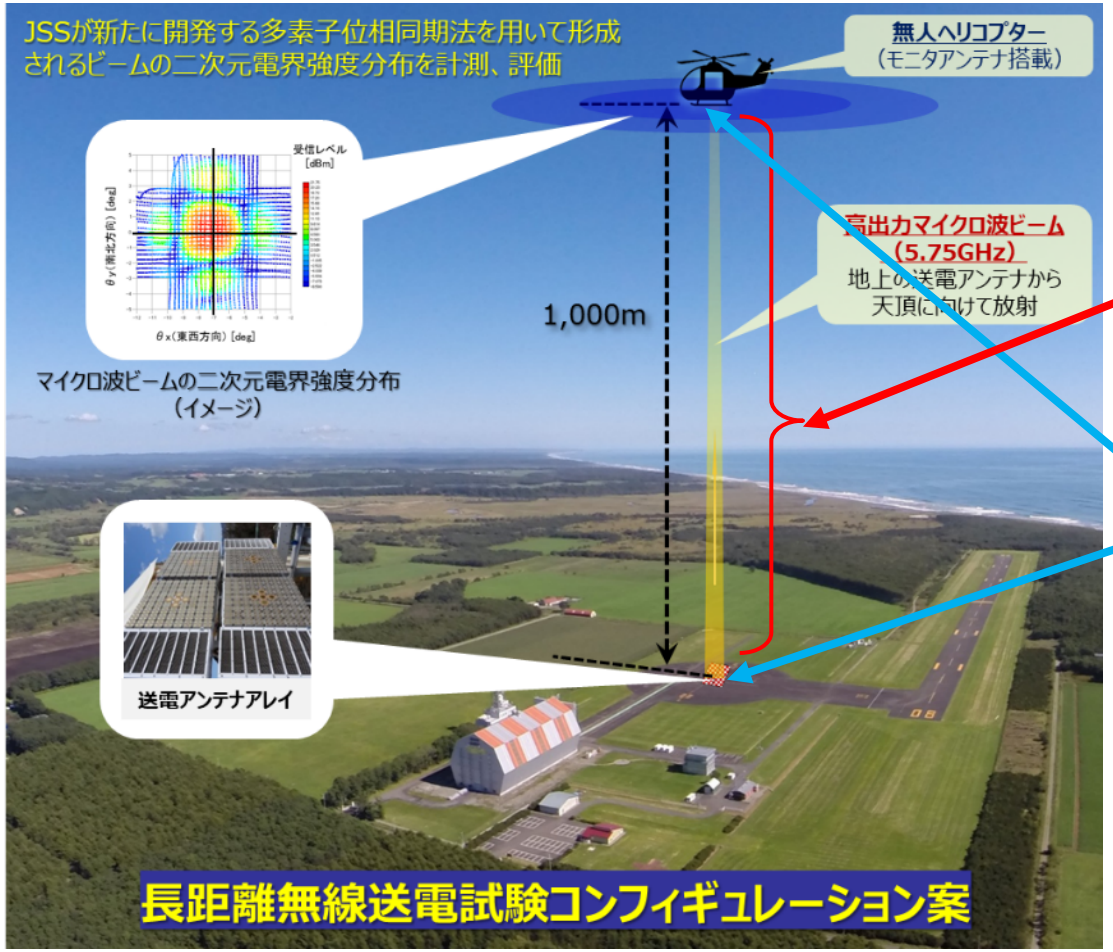
The Power taken out from Power receiving subsystem :
approx. 95W (REV Control OFF), approx. 340W (REV Control ON)



Ground Demonstration of Microwave Wireless Power Transmission

Collaboration of JAXA and Japan Space Systems (J-spacesystems)

On going project

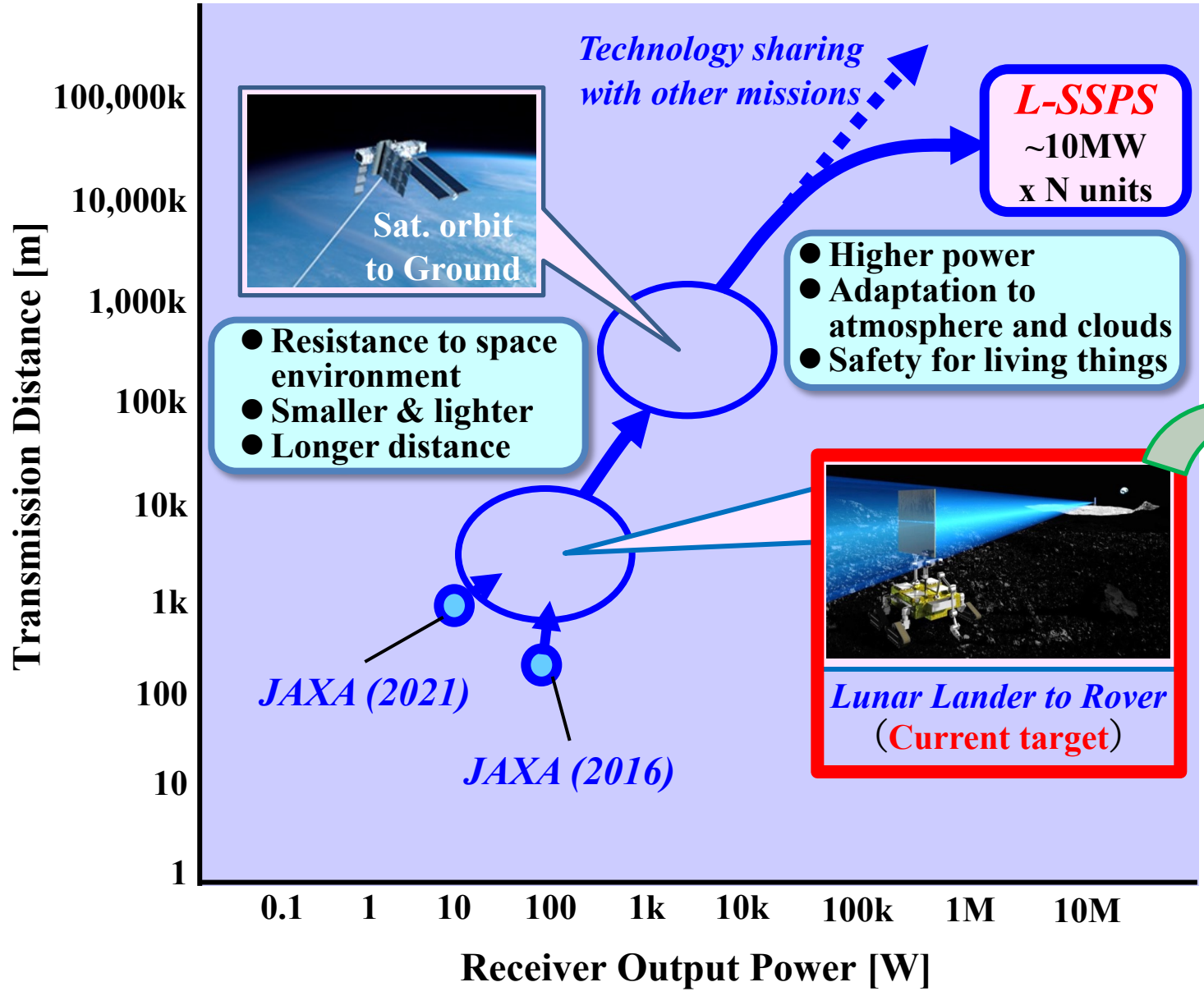


JAXA
Beam-pointing-control subsystem

J-spacesystems
Power transmitting subsystem
Power receiving subsystem

- Transmission distance: **1 km**
- Supplied Power: **kW-class**

R&D Roadmap for Laser-based SSPS (L-SSPS) & Laser WPT



Spin-off plans:

- Robot for inspection/ maintenance of infrastructures.
- Small satellites, Free flyers, etc.

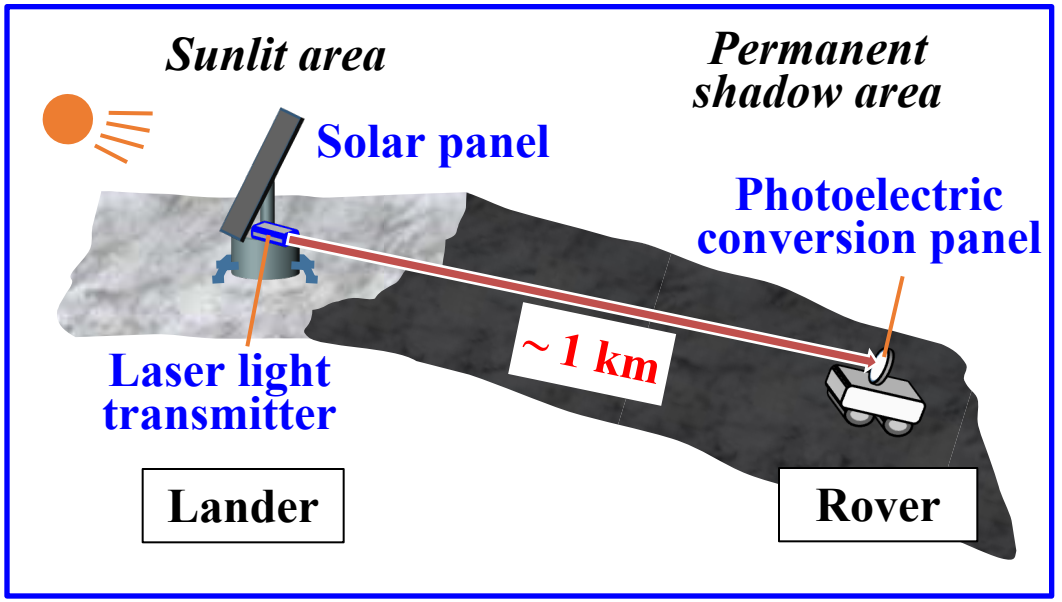
Laser WPT to Lunar Rover in "Permanent Shadow" Area

Problems

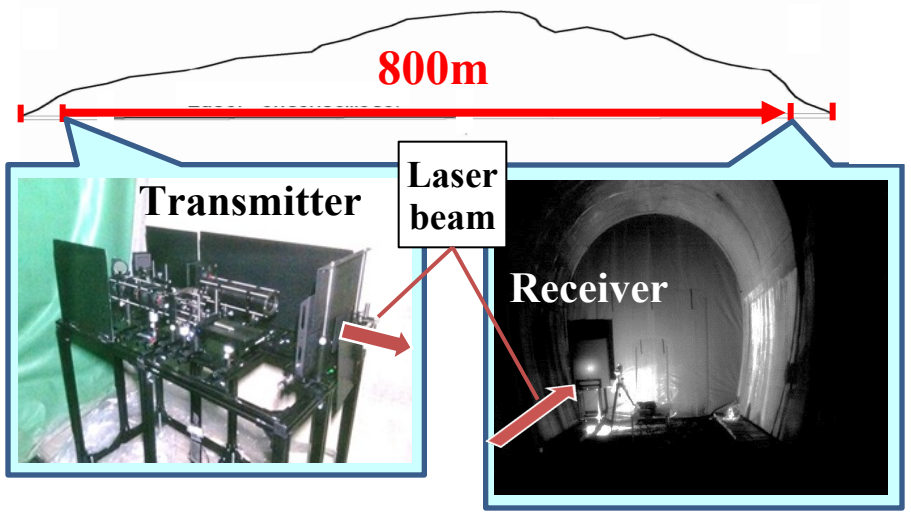
- ✔ Solar power is not available.
- ✔ Power cable is unrealistic.
- ✔ Battery capacity is limited due to weight & volume limitations.

Laser WPT

Time and risk of accidents for rover charging at sunlit area can also be reduced.



Experiment in tunnel (FY 2018 ~)



Technical challenges:

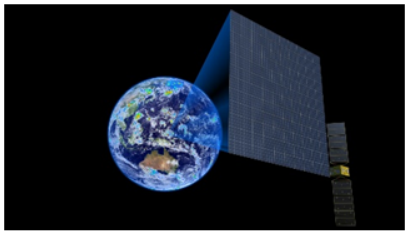
- High-power laser for space.
- High-efficient photoelectric conversion.
- Precise control of laser-beam propagation.
- Smaller size & lighter weight.

Scenario of the development of large-scale structures towards SSPS

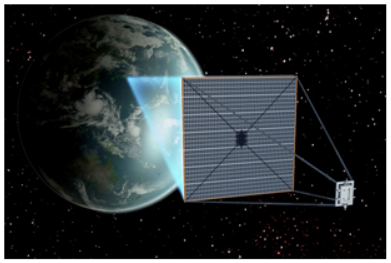
Final Goals

Target for the near future

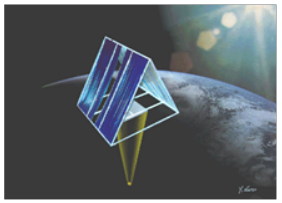
30 m class
Planar Antenna

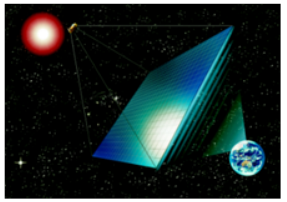


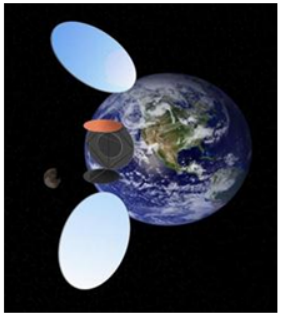
100 m class
Large scale structure



several 100 ～ several km class
Large scale structure







Current Status

Planar Antenna
10m x 3m

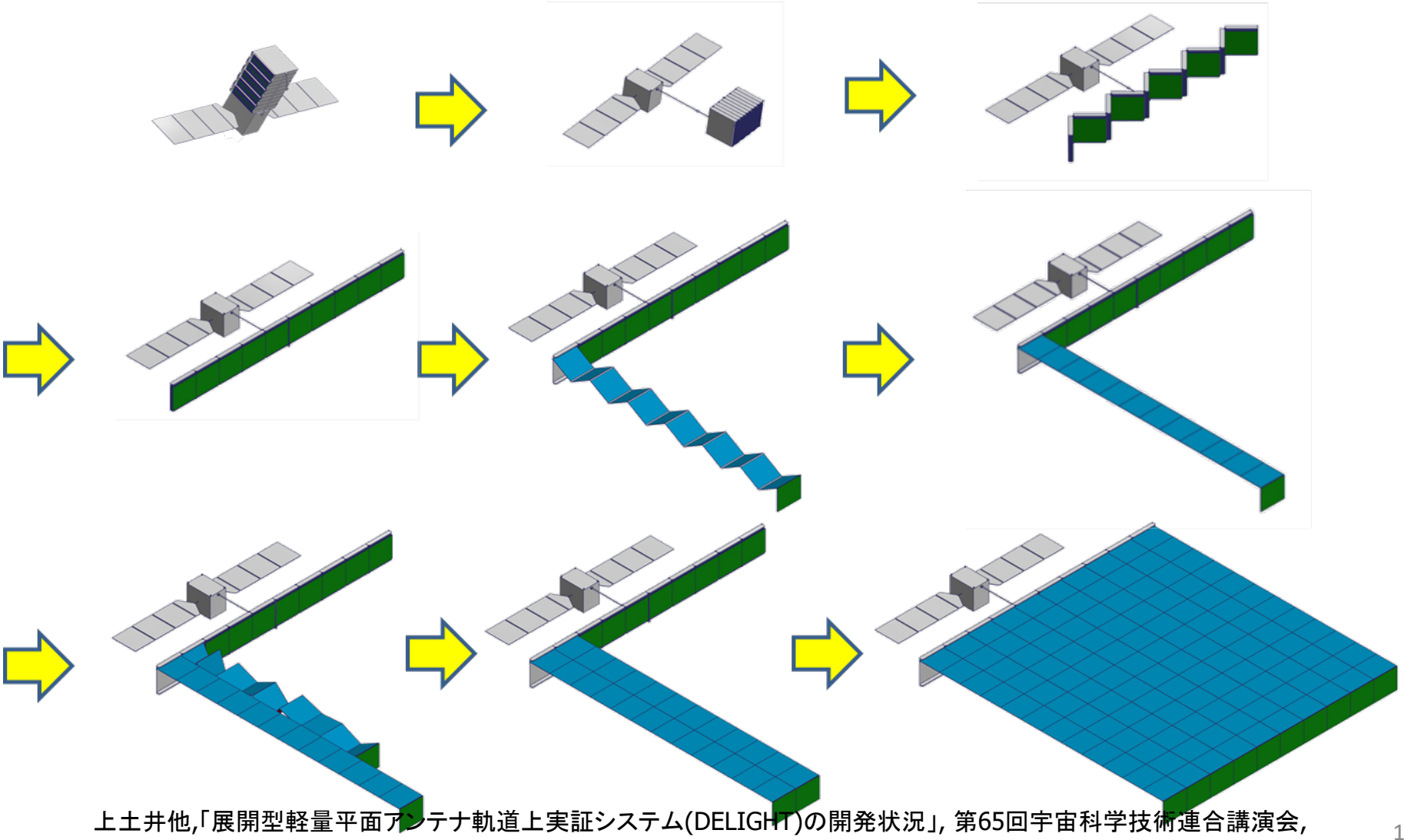
Social Return

Geosynchronous Precipitation Radar

上土井他,「展開型軽量平面アンテナ軌道上実証システム(DELIGHT)の開発状況」, 第65回宇宙科学技術連合講演会, 3J10, 2021, 山形.

Idea of 30m class large-scale antenna structure

Deployment and Connection of panels



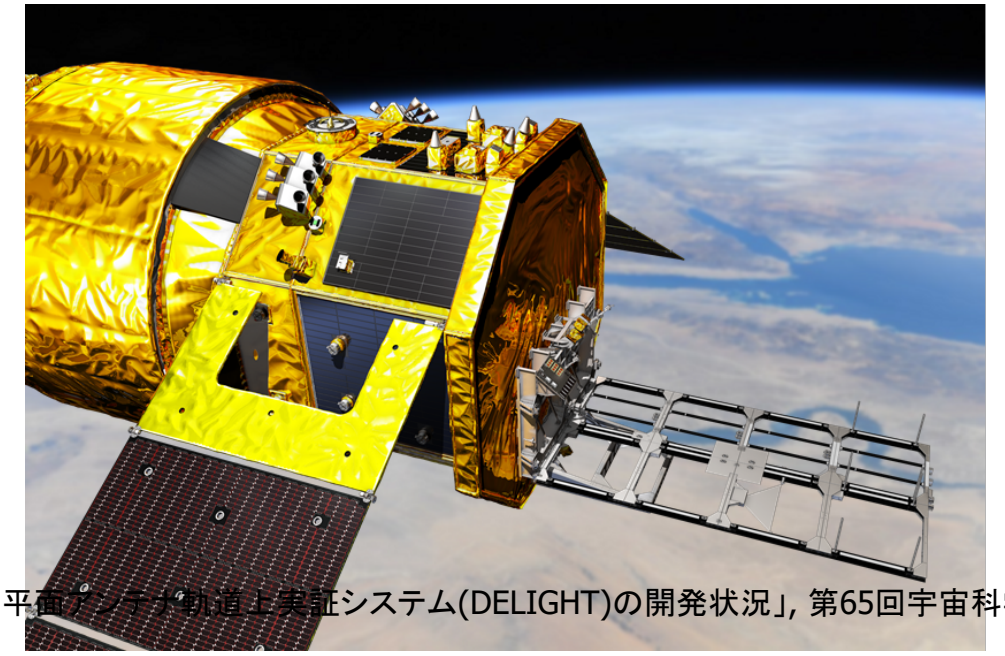
上土井他,「展開型軽量平面アンテナ軌道上実証システム(DELIGHT)の開発状況」, 第65回宇宙科学技術連合講演会, 3J10, 2021, 山形.

Purpose of Mission

DELIGHT: DEployable LIGHtweight planar antenna Technology demonstration

① Demonstration of 2D planar antenna deployment in orbit
- ✓ Developed panel deployment and connection mechanism
- ✓ Light weight planer antenna

② Confirmation of the mechanism, structure and thermal analysis of the planar antenna in the space environment



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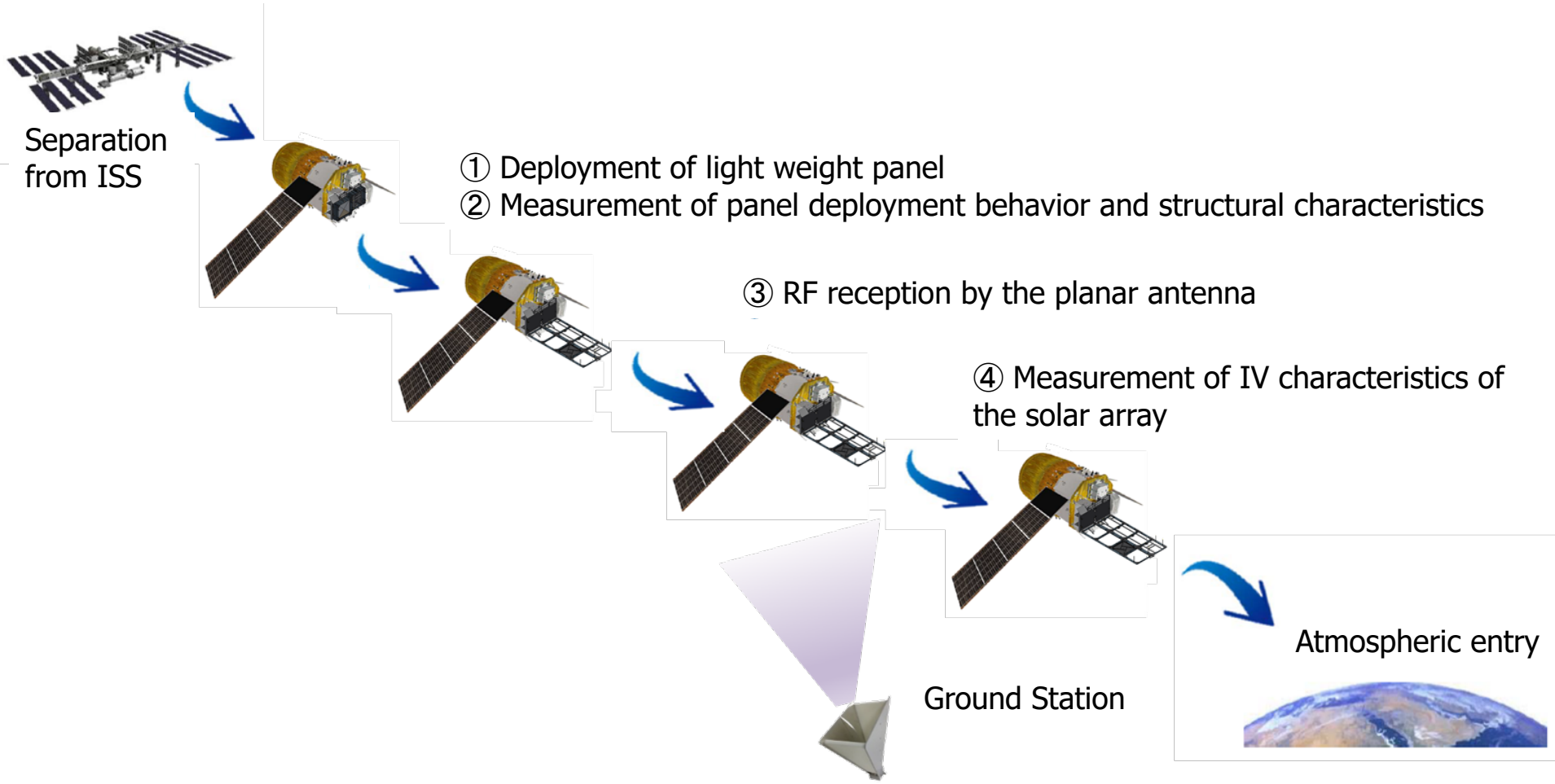
Outline of the Mission



上土井他,「展開型軽量平面アンテナ軌道上実証システム(DELIGHT)の開発状況」, 第65回宇宙科学技術連合講演会, 3J10, 2021, 山形.

Activities of J-spacesystems

- J-spacesystems, in collaboration with universities, JAXA and manufacturers, is implementing the SSPS development project defined in the METI's roadmap.

- METI started feasibility studies on the power system for Lunar utilizations last year. So, JSS is conducting research on power systems on the moon and from orbit.

METI's Road map of the SSPS development

Previous road map
All basic development shall be completed until 2015.
(From Ground WPT experiment to Small Satellite experiment)
→ Current situation: Ground WPT experiment only

(New road map 2016, based on **SSPS 2006 model**)

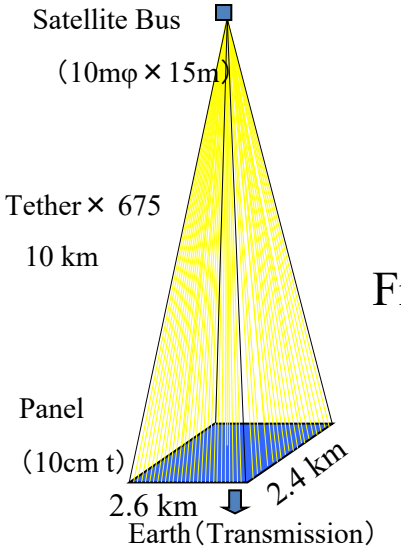
Update achieved and expected level of key technologies.
State of the art levels shall be taken in account.

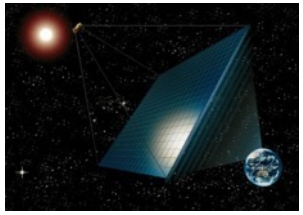
Set Experiments as milestone goals
Clarify performance index and level to be satisfied.
Ground transmission demonstration: A.Vertical , B. Long distance

Utilization of SSPS technology to daily life as spin off technology
Take into account what technology can be applied to daily life.

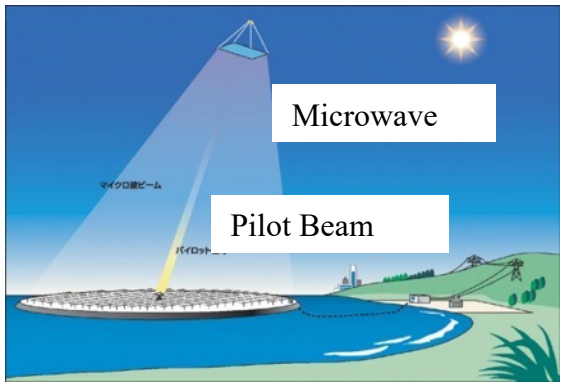
* SSPS 2006 model (System to be realized by **road map 2016**)

Baseline Concept (2001)



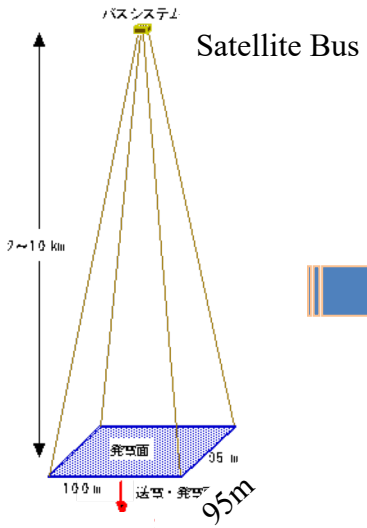


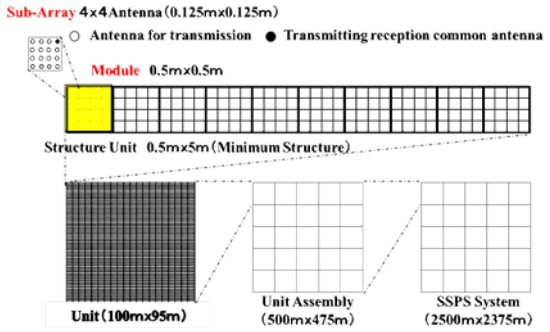
Freq:5.8Ghz



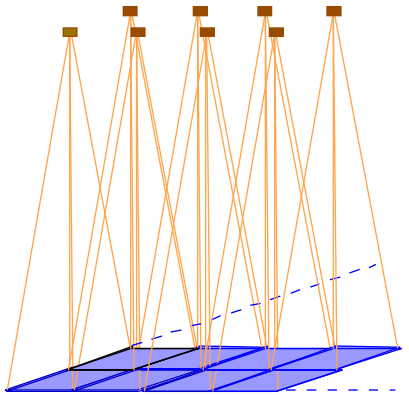
Growing Tethered SSPS Concept (2006)

SSPS Basic Unit





Growing Tethered SSPS with multiple SSPS Units



SSPS System (2.5km x 2.3km)

Stabilization:
Gravity Gradient
Sandwich panel:
Solar cells on both sides, Antenna on earth side. Retrodirective system.

Revised road map 2016 for SSPS development (Based upon SSPS 2006)

2015 2020 2025 2030 2035 2040 2045 2050

Demonstration phase on the ground

Demonstration phase in space

Decision of Space Dem

Feasibility

Demonstration and Evaluation

2015

WPT Horizontal

50m Horizontal

2018

WPT Vertical

Ground to above 50m vertical Drone target

2023–

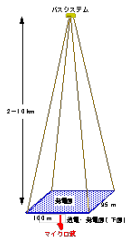
WPT Long distance

Sky to Ground 1～5km vertical Light weight sandwich panel with power gen and transmission

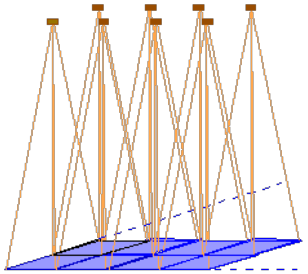
Demonstration on Space

Micro satellite Small satellite

Evaluation plant model



Commercial SSPS



Application

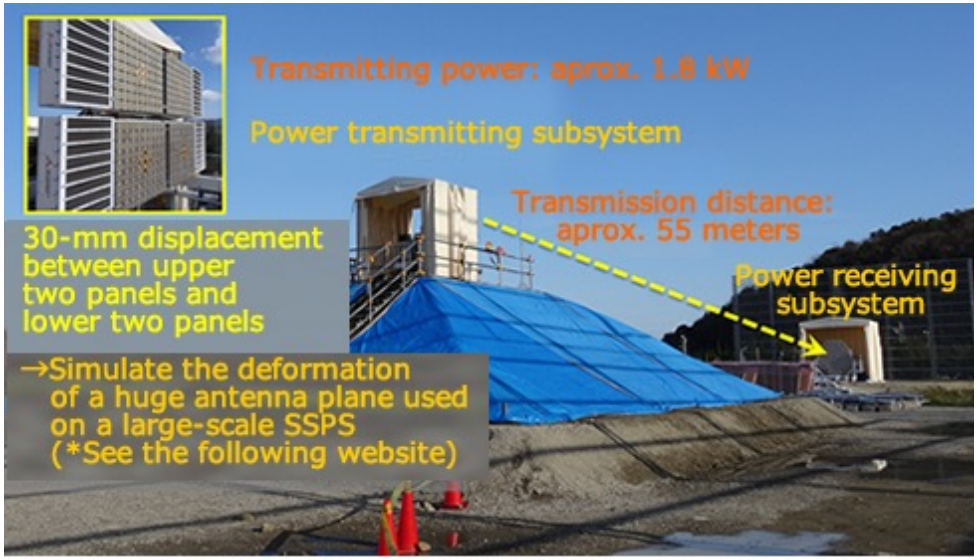
WPT to drone, robot, IOT sensor, Cellar phone and sensor network

WPT to Running EV, Remote islands, Stratospheric drone, Communication platform, etc. WPT in disaster, Offshore Wind power plan.

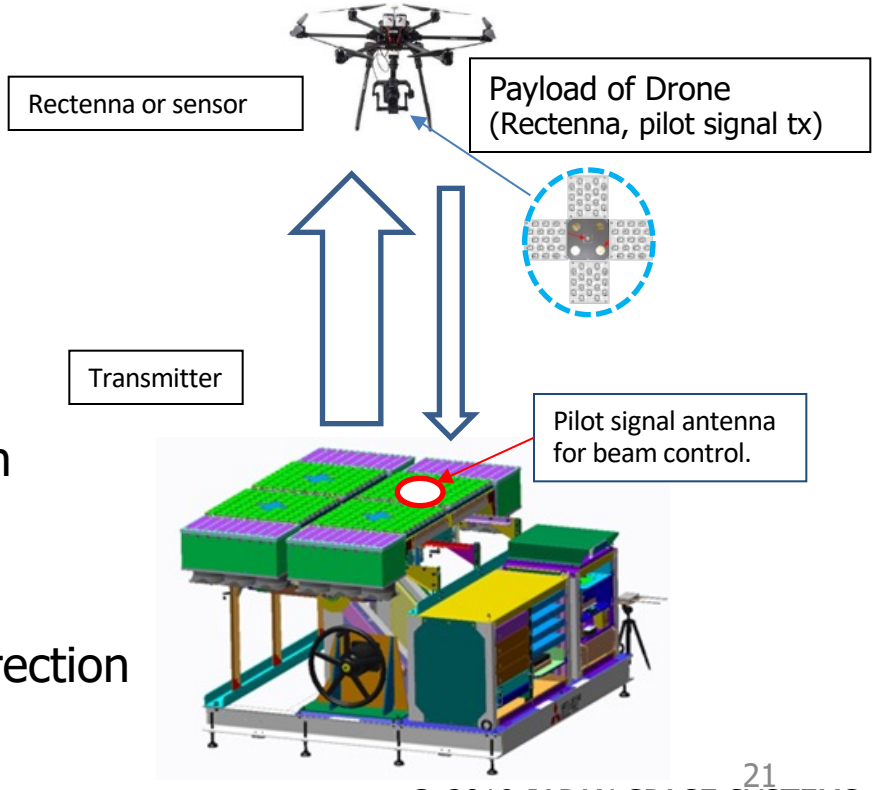
WPT to Large scale sensor network, debris collection satellite system. Large phased array radar. Orbit transfer vehicle. Large space structure.

WPT demonstration by JAXA & J-spacesystems

J-spacesystemsand JAXA developed the WPT demonstration system on the ground from 2009 to 2014.
Demonstration was successfully performed in March 2015 and 2019.



2015 WPT experiment for horisontal Direction



2019 WPT Experiment for vertical direction (from ground to the drone)

WPT (for Drone)

2019. 05. 24 in Japan

ワイヤレス電力伝送公開実験

Demonstration of Wireless Power Transfer

The Current Development Phase Activities started on the year 2019

- Objectives are:

= The first: Development of the Power Generation and the Transmission Panel (PGTP), which consist of the solar array on one side and the solar cells with antenna element on the other side. The size of the panel is about 50cm by 50 with the thickness of 10cm, and within 9kg.

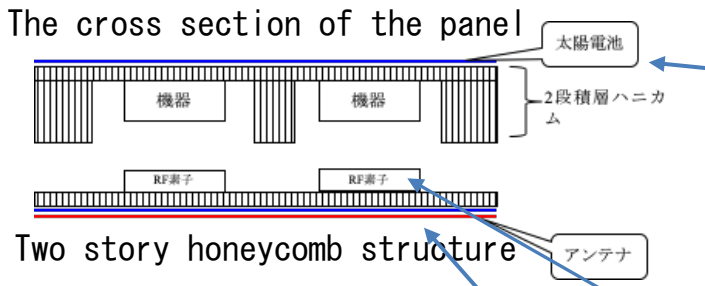
= The second: Improvement of the total efficiency of the power transmission by the improvement of the efficiency of power amplifiers and also the consideration of the their configuration. The target of the total efficiency, which is the ratio of input DC and transmitted RF power, of 60%.

= The third: The long distant power transmission demonstration experiment with large scale phased array control technology demonstration and beam pattern measurement via vertical 1km microwave transmission test with the transmission panels.

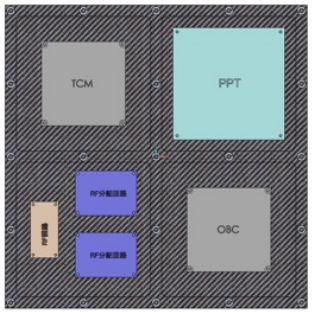
Power Generation and Transmission Panel

Examples of the issues to be solved with this phase development are:

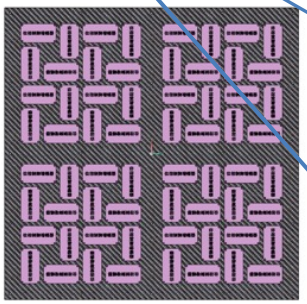
= The panel structure and thermal design considering the components arrangement with the characteristics of the components and parts
= Thermal design to accommodate LEO operation
= The characteristics estimation of the components including temperature dependance
= Realization of the antenna-on-solar cells power generation device
= Environment characteristic evaluation of the components including the radiation

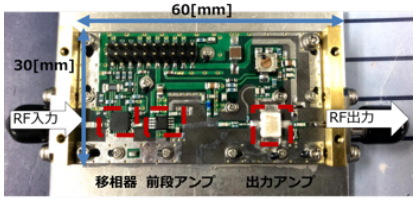



Solar array module

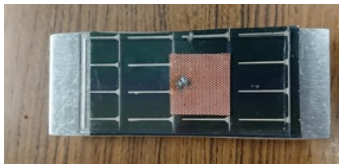


Component arrangement

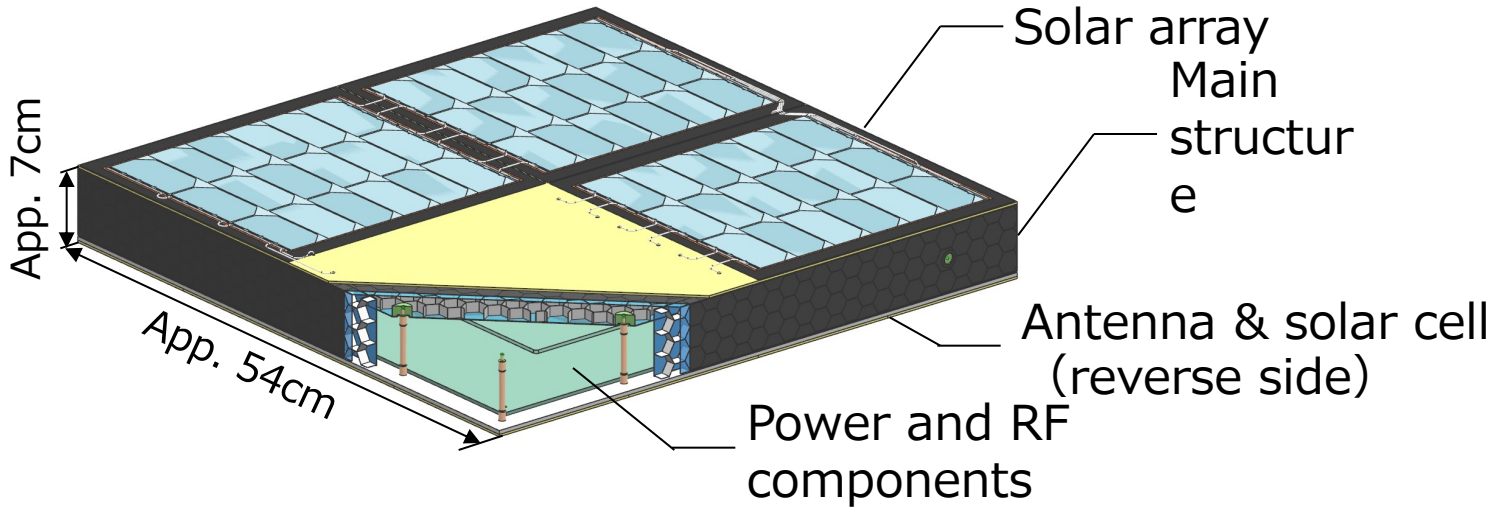

Phase control amplifier arrangement



Phase controlled amplifier

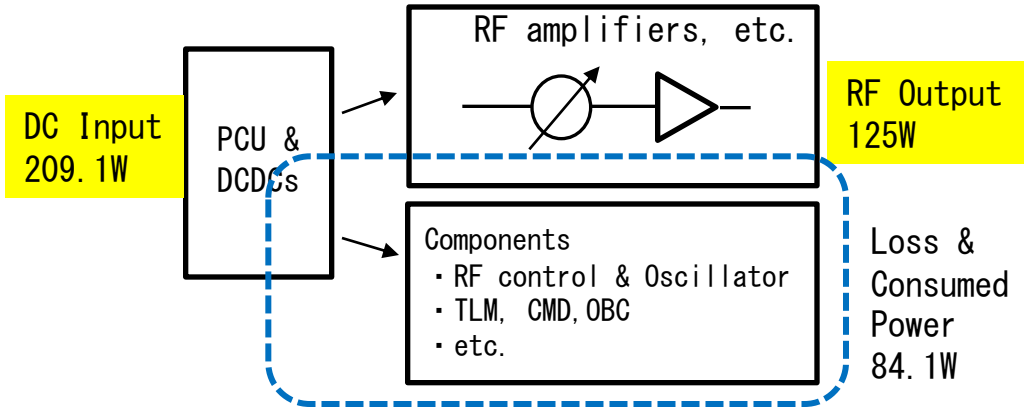

Antenna on solar cells

Schematic Drawing of PGTP



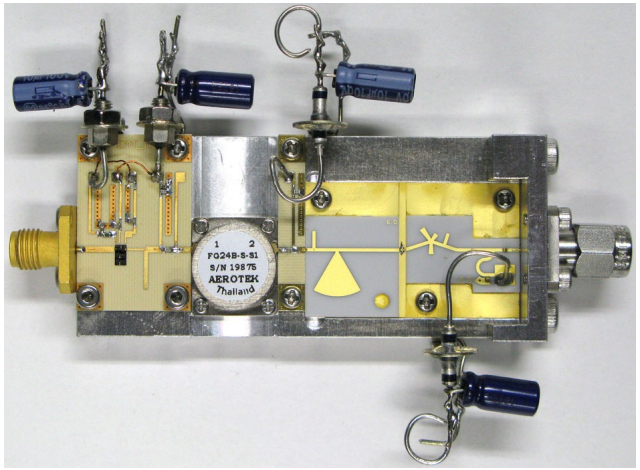
According to the current estimation based on the analysis, the mass density is app. 34.4kg/m2, which exceeded the requirement of 36kg/m2

Development of -Efficiency C-Band Amplifier



Input DC power	209.1 W
RF output	125.0 W
Total Efficiency (%)	59.8

The target total efficiency to achieve within this project phase is 60% vs 44.8% at the year of 2018



RF power amplifier module of 69% PAE with 32dB gain and 33.8dBm output power at 5.75GHz

Power system diagram of the PGTP and current estimated total efficiency

The development of the driver and final stage unified amplifier

Summary

- SPS has been studying in JAXA, J-spacesystems and universities in Japan.
- SPS was mentioned in the basic plan on space policy, and SPS experiment in LEO using microwaves by 2025 was stated.
- R&D scenario toward practical SSPS by METI is ongoing. Jspacesystems is conducting.
- JAXA implements three items, WPT by microwave, WPT by Laser and structure, related to SPS.

  JAXA is preparing a space demonstration experiment using HTV-X, and is conducting basic research and SSPS-related technology application research.