



The COST IC1301 Meeting at Toulouse

The Local Area Microwave Power Transmission and Communication System for Space Use

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Agenda



- 1. Introduction*
- 2. The System Design*
- 3. The Components for MPT&EH*
- 4. Compatibility of MPT with Wireless Sensor
and Communication*
- 5. Applications and Demonstration*
- 6. Conclusion*



Motivation

Environmental Problems

- Energy Crisis due to shortage of fossil fuels
- Global Warming by CO2

Remarkable progress on Microwave Technology

- Wired / Wireless Communication Systems
- Sensors (ex. a Radar)
- Microwave Wireless Power Transmission (MWPT/MPT)

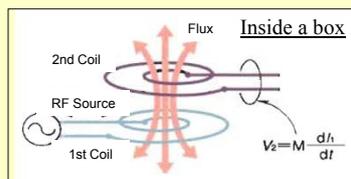


Wireless Green Eco Projects

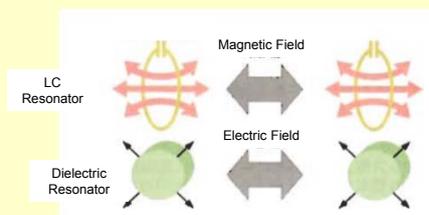


The Three Types of Wireless Power Transmission

Pairing by Tx/Rx



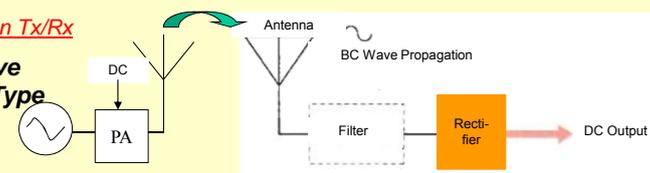
Internal Coupling Type



Resonant Type

Independent on Tx/Rx

Microwave Radiation Type (MPT)



(The Original from NIKKEI Electronics)



Power Reception / DC Power Generation

Receiving			
sorts	Source	Transferred DC Power	Structure
Scavenging	unknown (Mechanical)	μ W	simple
Harvesting	intentional & unknown (RF)	mW	medium
EM Power Receiving (Active EH)	intentional (pair with transmitting)	W	complex

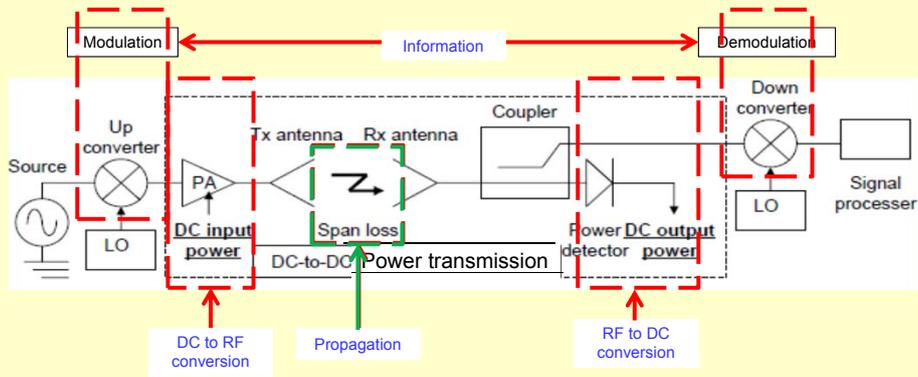


The System Design for MPT

Definition of Power Transfer



The Total Power Transmission with Communication

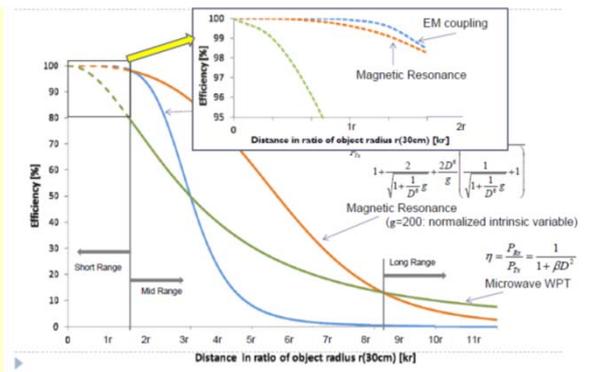


For MPT, DCin-to-DCout is important

Comparison of WPT



Comparison of power transmission rate of the three types of WPT

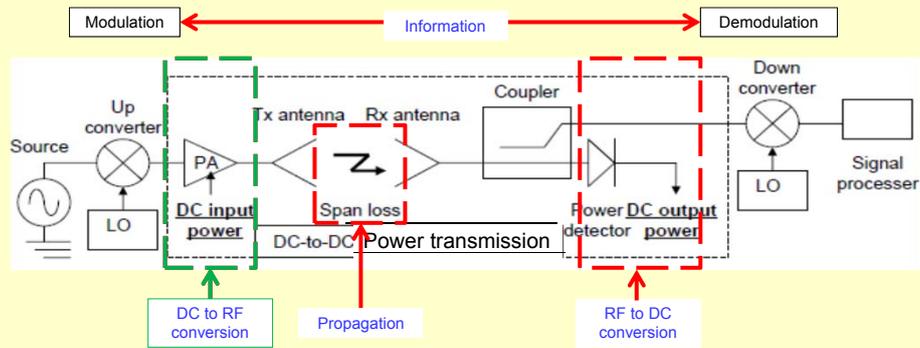


D : Diameter(60cm) of Coil/Antenna (The normalized parameter)
f : operating Frequency (common)

*Problems (Near field)-Power delivery is Limited due to very high E-field
/ (Far field)-High-sensitive scavenger is requested to response very low power density
/ (Compatibility)-Magnetic energy delivery does not possess multi-functionality of communication and sensing



The Total Power Transmission



For MPT, DCin-to-Dcout is important



High efficient non-linear circuits for MPT

Switching (the Class-F Amplifier)

The Fourier Transformer applied to distorted V_d (Pulse) and I_d (Half Sinusoidal)

$$V_d = V_{DC} - V_1 \cos \omega t + V_3 \cos 3\omega t + \langle \text{odd terms} \rangle \dots$$

$$I_d = \frac{I_{\max}}{\pi} \left(1 + \frac{\pi}{2} \cos \omega t + \frac{2}{3} \cos 2\omega t + \langle \text{even terms} \rangle \dots \right)$$

The effective DC power is derived from the product with V_d and I_d

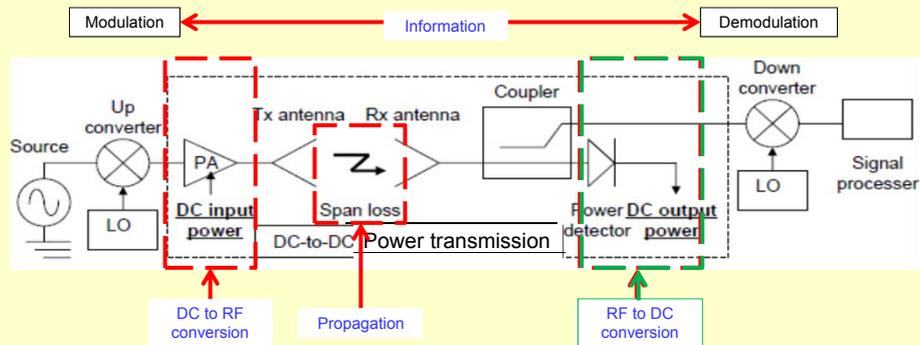
$$P_d(\text{ideal}) = [V_d I_d] = V_{DC} \frac{I_{\max}}{\pi} - V_1 \frac{I_{\max}}{\pi} \frac{\pi}{2}$$

* The Inverse Class-F Amplifier is defined as V_d (Half Sinusoidal) and I_d (Pulse)

Definition of Power Transfer

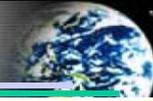


The Total Power Transmission

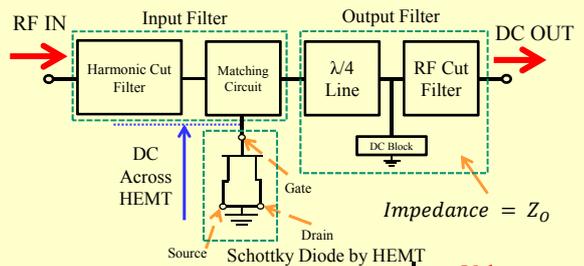


For MPT, DCin-to-Dcout is important

Power Transmission and Modulation



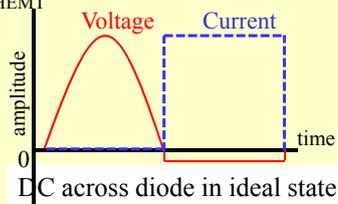
The High Conversion Efficiency Rectifier



Inverse Class-F Harmonic Processing

$$Z_0 = \infty \text{ (Even harmonics, OPEN)}$$

$$Z_0 = 0 \text{ (Odd harmonics, SHORT)}$$





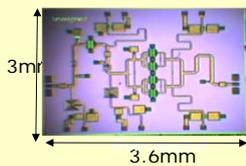
The MPT&EH Components

Microwave Components

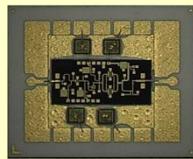


Microwave Communication and Power Transmission

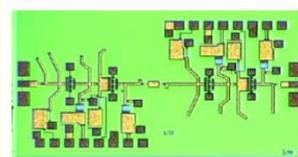
The MMICs for small size and a compact module



The C-band 2-stage MMIC power amplifier (25dBm)



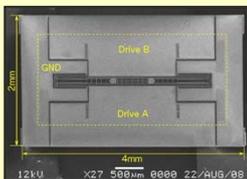
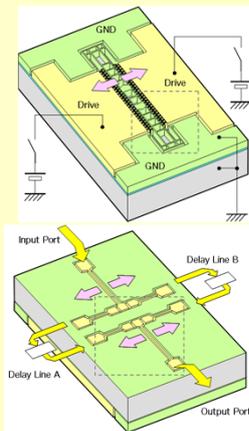
The Ku-band 3-stage MMIC low noise amplifier (NF=1.7dB) and the module



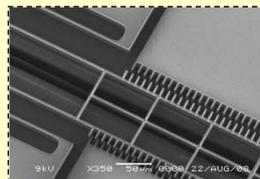
The V-band 4-stage MMIC LNA (NF: <3 dB@60GHz)



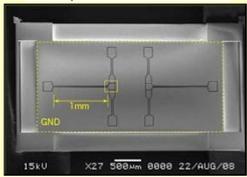
Ku-Band RF-MEMS (SPDT Switch)



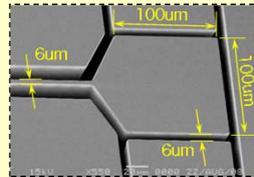
Top Side (Actuator)



Actuator (zoomed)



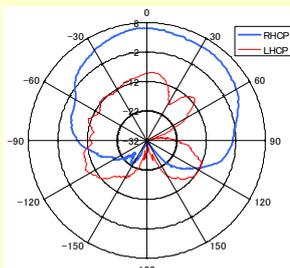
Bottom Side (Movable Waveguide)



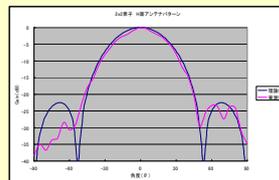
Contact Point



Antennas



The single patch (Measured AP)



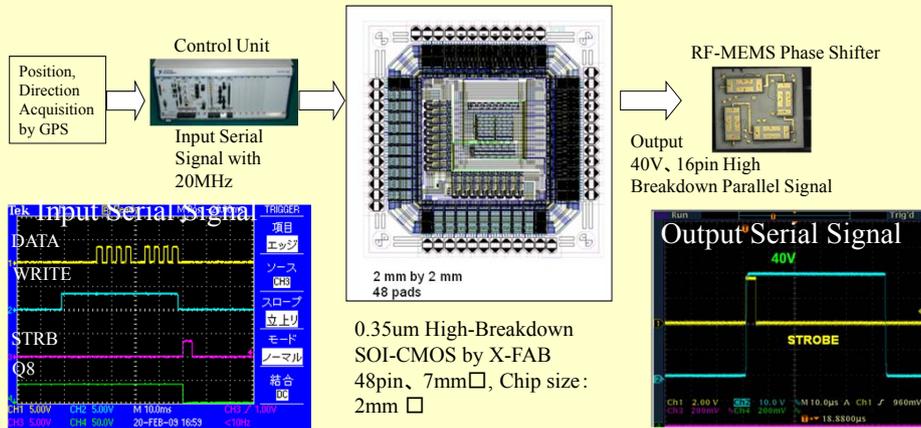
The 2x2 unit array



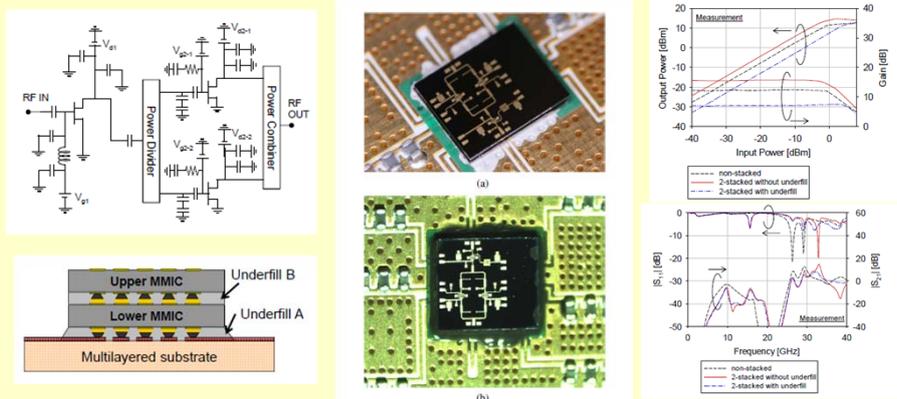
The 2x2 antenna array with a flexible print substrate



MEMS Control IC

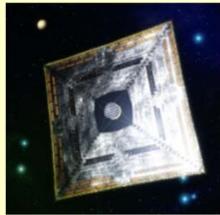


Ka-Band Double Stacked Flip-Chip Packaging

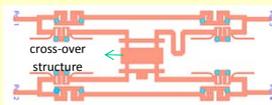
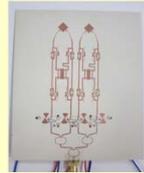
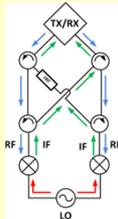




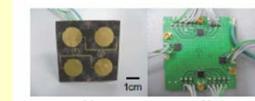
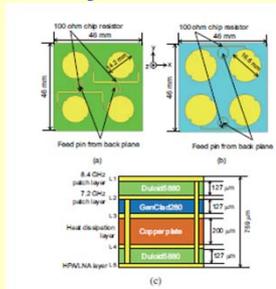
Active Integrated Antenna Arrays



The Thin Planar Antenna Array in a Solar Sail Satellite



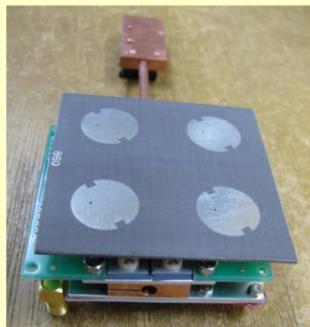
Cross-over structure along with planar diplexers



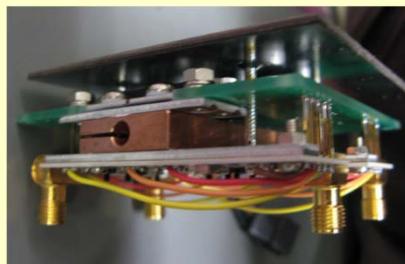
The TRx Stacked Array Antenna



The 2x2 HPA AIA Unit Array with Heat Pipe



The Top View

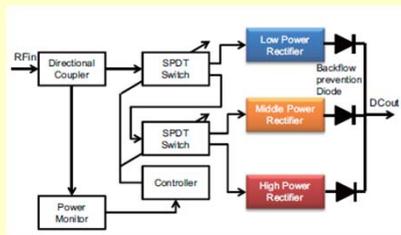


The Side View

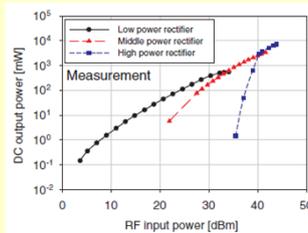
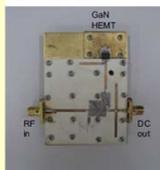
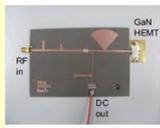
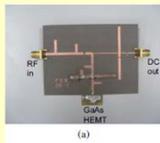
Volume : 64mmx64mmx20mm



The Rectifier Unit with Wide Dynamic Range



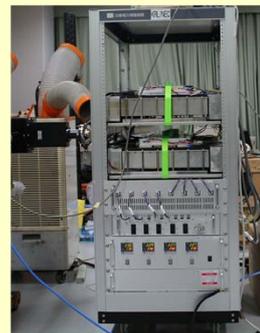
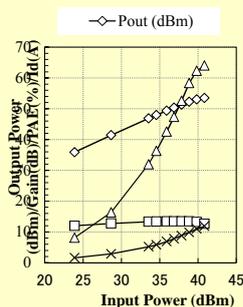
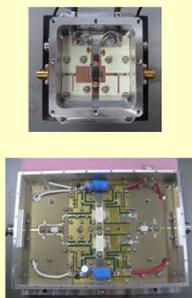
The Three Power Level Rectifier
(controlled by power monitor)



- LP Level (100uW-100mW)
- MP Level (100mW-1W)
- HP Level (1W-10W)



The Super-High Power Solid-State (GaN) Amplifier



The SSPAs with **GaN at S-band** with 20W, 200 W, Efficiency of more than 50% and SS-Cooling

The 1kW **GaN at S-band** SSPA Combiner with about 90% Combining Efficiency, and with a Cooling System



Compatibility of MPT with Wireless Sensor and Communication



Compatibility of Microwave Power Transmission

— **WiCoPT**

Wireless **I**nformation/**C**ommunication and **P**ower
Transmission

(Effective use of the carrier with signal modulation)

— **WiSEnT**

Wireless **S**ensor and **E**nergy **T**ransfer

(Batteryless and energy harvest/scavenging)


Power Transmission and Modulation


The Time Division Data / Single-Tone Power Sequence of the Wireless Data and Power Transmission System

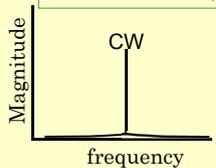
MPT requires basically same devices as wireless communication



WiCoPT (Data Transmission) with Low/High Peak-to-Average Ratio?

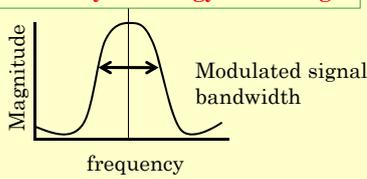
Usage of modulated signal power for WiCoPT is investigated in low P-to-A Ratio

Is the modulated signal power available for MPT?
Is the information signal such as RF power
in broadcast (high P/A) used more effectively for energy harvesting?



Common MPT Signal

➔



Spectrum for WiCoPT



Institute of Space and Astronautical Science

Kawasaki

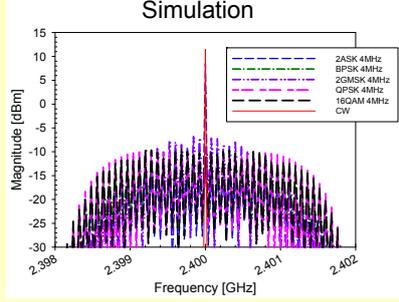
Research Laboratory


Power Transmission and Modulation

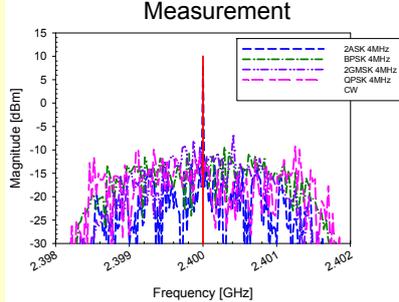

The Time Division Data / Single-Tone Power Sequence of the Wireless Data and Power Transmission System

RF-DC Conversion Evaluation Using Modulated Signals

Simulation



Measurement



4MHz Bandwidth Spectrums (Total input RF Power: 10dBm)



Institute of Space and Astronautical Science

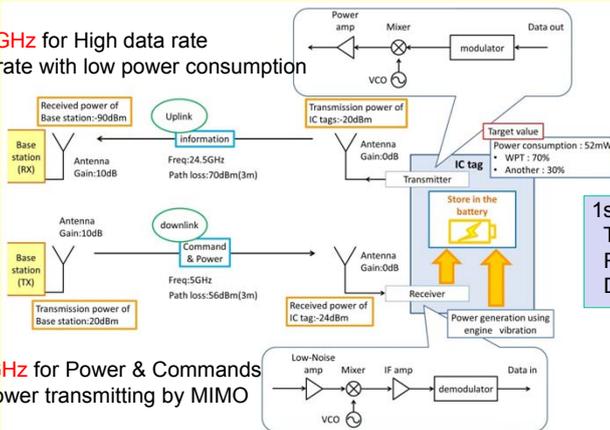
Kawasaki

Research Laboratory



The Time Division Data / Multi-Tone Power Sequence of the Wireless Data and Power Transmission System

Uplink: 24.5 GHz for High data rate
 High data rate with low power consumption



1st prototype
 TX: 10mW
 RX: 20mW
 DSP: 12mW

Downlink: 5 GHz for Power & Commands
 Effective power transmitting by MIMO



Applications

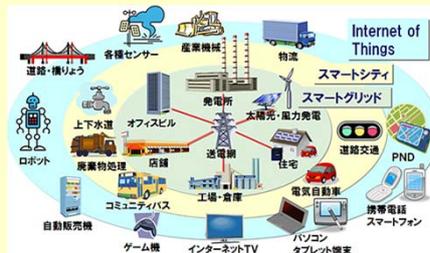
Applications



Internet of things by MPT (WiCoPT)



From EuMW (P2P -> M2M)



From NTT Data HP

* Important Items : Number of IP, Security, **Electric Power Source**

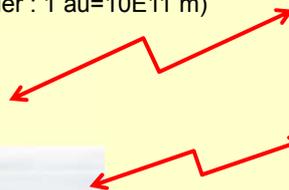
<Proposal> **Wireless Local Area Sensor Network with MPT & EH**

Space Applications



Satellite Communication and Remote Sensing

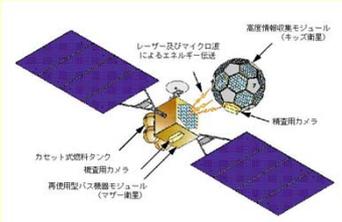
Deep Space Communication and Tracking
 (Range Order : 1 au=10E11 m)



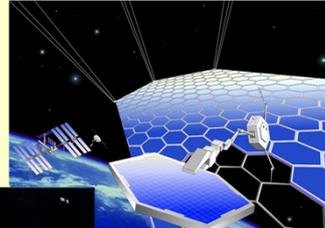
Planet Remote Sensing
 (Large Volume and High Speed)



MPT in Space Technologies



Satellite-Satellite Communication



Construction of Space Antenna

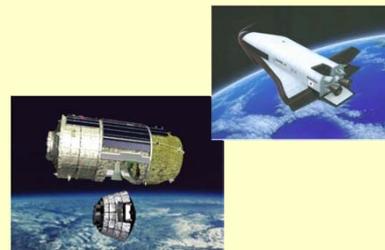


Robot Working in Planet



The Wireless Sensor System in a Spacecraft and a Rocket

• Realization of safe transportation for a spacecraft and a rocket by a wireless sensor network system.



• Health monitoring by wireless and batteryless multi-sensors with microwave wireless power transfer and energy harvesting in a spacecraft



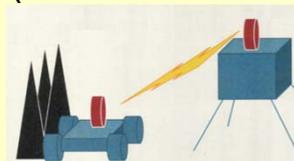
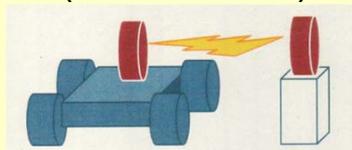
Scenario and Demonstrations

Microwave Power Transmission

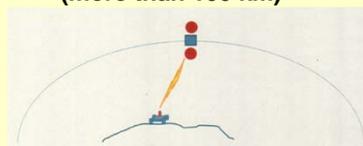


The WiCoPT to a Rover

- Hot-Spot Type (Fixed)
(a few 10 cm to 10 m)
- Lander Supply Type (Fixed / moving)
(a few 100 m to several km)



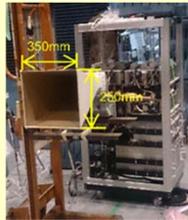
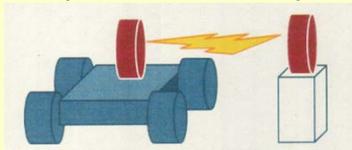
- Orbiter Type (Moving)
(more than 100 km)



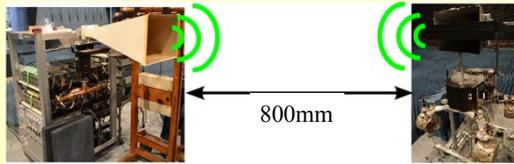


The WiCoPT to a Rover

- Hot-Spot Type (**Fixed**)
 (a few 10 cm to 10 m)



The 1 kW GaN SSPA
 (200W x 8 Unit combined)



Rover Battery Charging



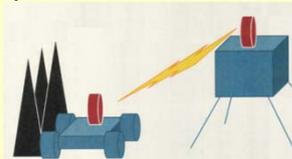
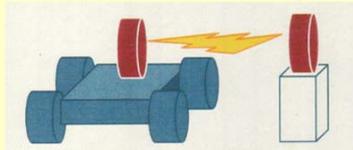
The hot-spot microwave power supply to a rover



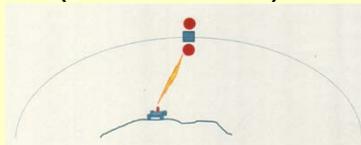


The WiCoPT to a Rover

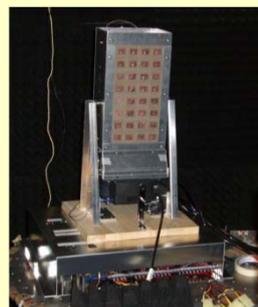
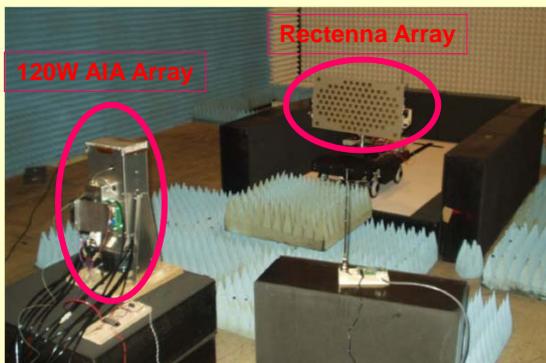
- Hot-Spot Type (Fixed)
(a few 10 cm to 10 m)
- Lander Supply Type (Fixed / **Moving**)
(a few 100 m to several km)



- Orbiter Type (Moving)
(more than 100 km)



The 32-element 120W-output compact high power AIA array



(The maximum requested power of the rover : 10W)

120W-output air-duct type
 32-element AIA Array
 (11cm thick / 4.0 kg w/o fan)

The Rover Control Test



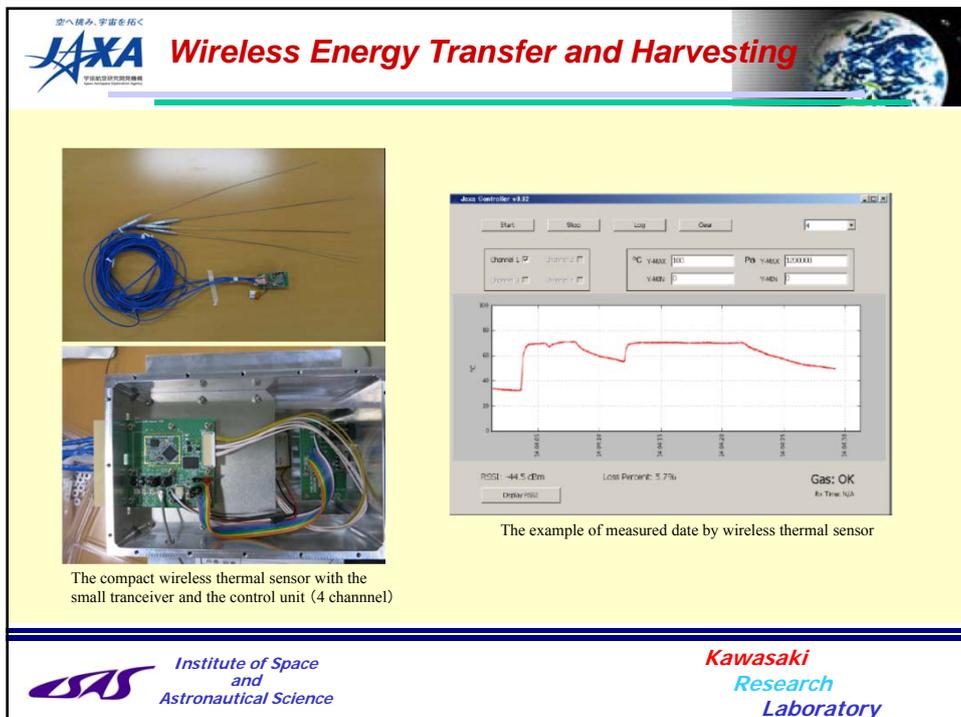
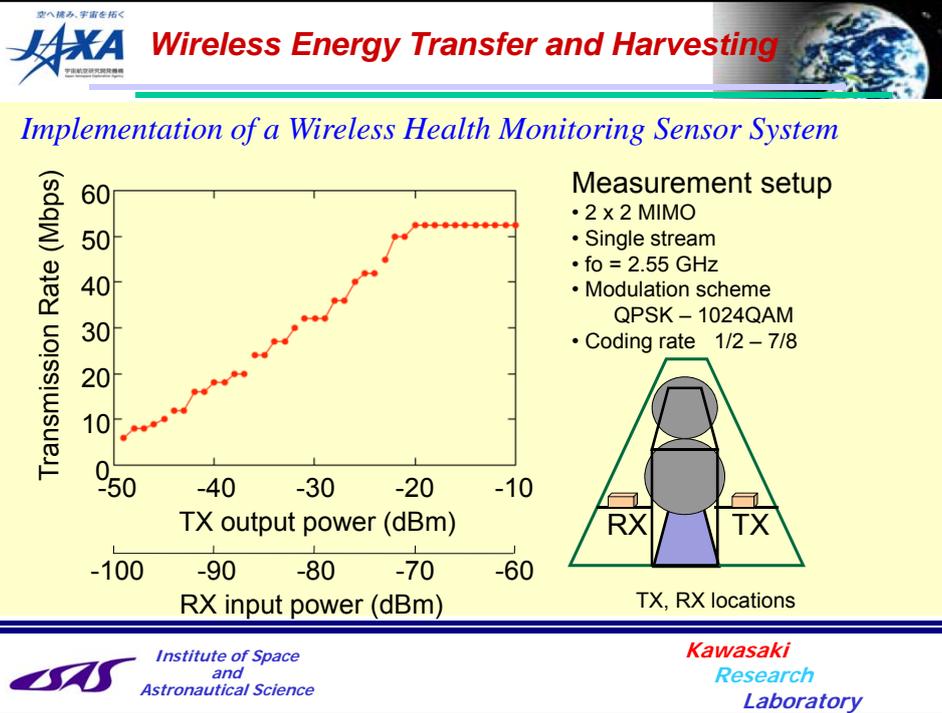
The high power AIPAA for wireless power transmission

Rover Control Test (Circular motion)



Implementation of a Wireless Health Monitoring Sensor System

- » Concept
 - > Use of microwaves for communication (command/ sensor data transmission) as well as for power supply (wireless power transfer: WPT)
- » Benefits
 - > Drastically removal of wire harness
 - > Equipment of sufficient numbers of sensor tags inside a spacecraft
 - > Compatibility with communication system inside of a spacecraft and that for up/down link



Conclusions



- *The Wireless Green-Eco Technologies by microwave technology and the category of WPT & EH were introduced.*
- *The components and high power transmitter AIA array for the microwave WPT and the AIPAA and the rectenna array were fabricated.*
- *The compatibility of MPT with communication and sensors were demonstrated for space use.*
- *Many applications of MPT in a wireless sensor network are expected to be realized.*



Thank you very much



ISAS/JAXA



Sagamihara Campus

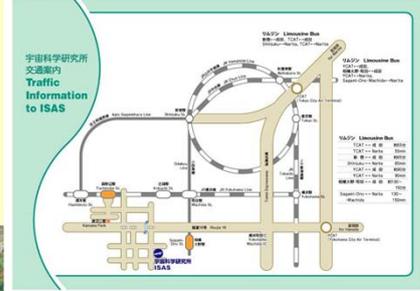


Tsukuba Space Center

Noshiro Testing Center
(Space Transportation Mission Directorate
Kubiki Space Center)

Usuda Deep Space Center
(Space Transportation Mission Directorate)

Uchinoura Space Center
(Space Transportation Mission Directorate
Kashihara Space Center)



Access to ISAS/JAXA

ISAS/JAXA Sagami-hara Campus



ISAS/JAXA



Sagamihara Campus and Kawasaki Laboratory

The Class 1 clean room
(more than 100m²)
and 24 Dust removal
hepa filters



Design and Discussion



SEM



RIE



Measurement

