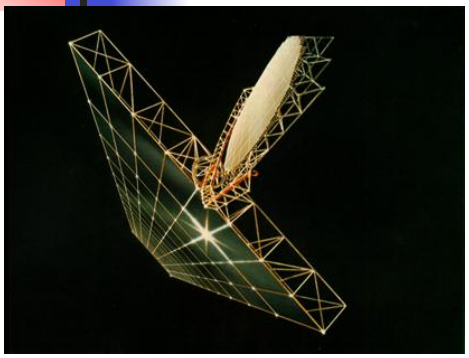
Engineering Research for New Tethered Solar Power Satellite

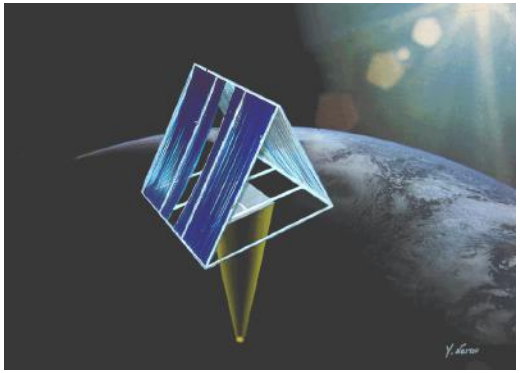
- New Concept of Tethered-SPS
- Engineering Aspects
  1. Attitude Stabilization
  2. Modularization
  3. Thermal Characteristics
  4. Construction and Maintenance
  5. Evolutionary Development
  6. Easy Investment
  7. Coexistence with Other Geostationary Satellites

ISTS Kanazawa, June 2006

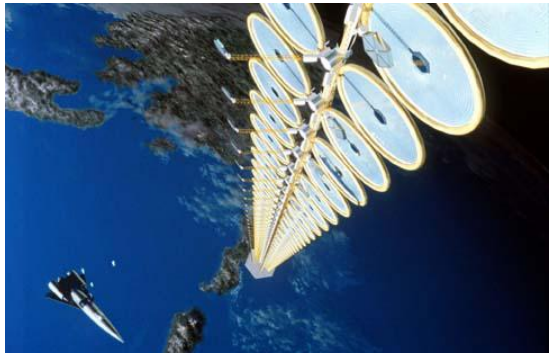
Typical Examples of SPS



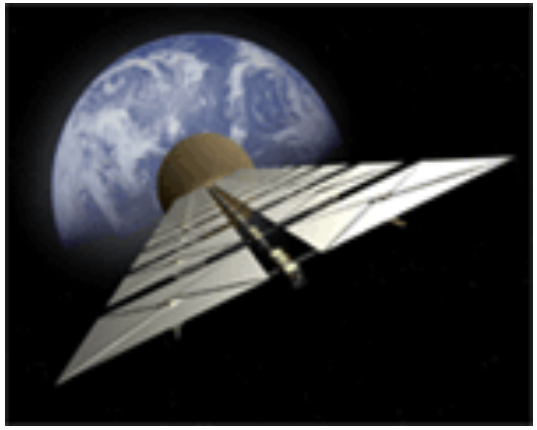
NASA Reference System



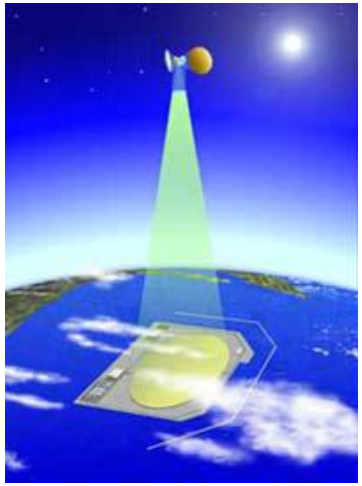
ISAS SPS 2000



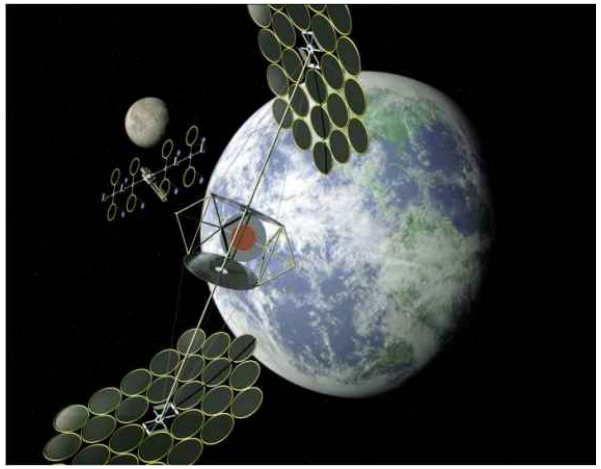
NASA Sun Tower



European Solar Sail Tower



NASDA (JAXA) SSPS Model

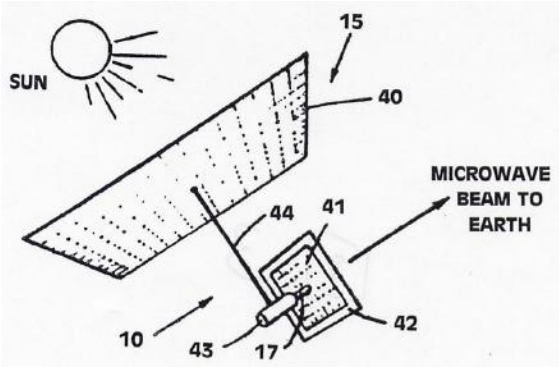


NASA Integrated Symmetrical Concentrator

Technical difficulties/feasibility problems in the past models

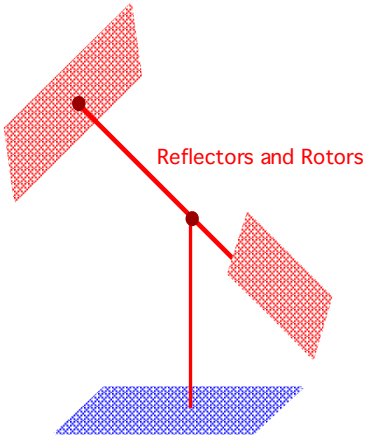
Most difficult point: to direct large solar panel to the sun while transmitting antenna be pointed to rectenna on ground

⇨ movable mechanism, rotary joint or rotating mechanism for mirrors, are required.



Glaser's original idea

However,
Rotary joint: no practical technologies without serious power loss
Rotating mirror: very difficult technologies for attitude control and stabilization of the large-thin film structure
Movable mechanism: one-point failure problem



Sun Pointing System

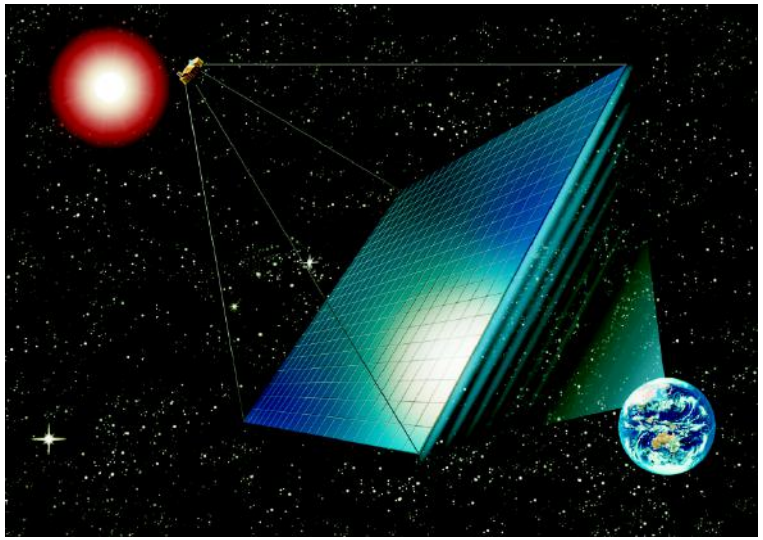
Why Tethered-SPS ?

⇨ cost analysis is not possible if technical feasibility is not assured

⇨ need to alter our perspective on the SPS system configuration: simple and feasible configuration

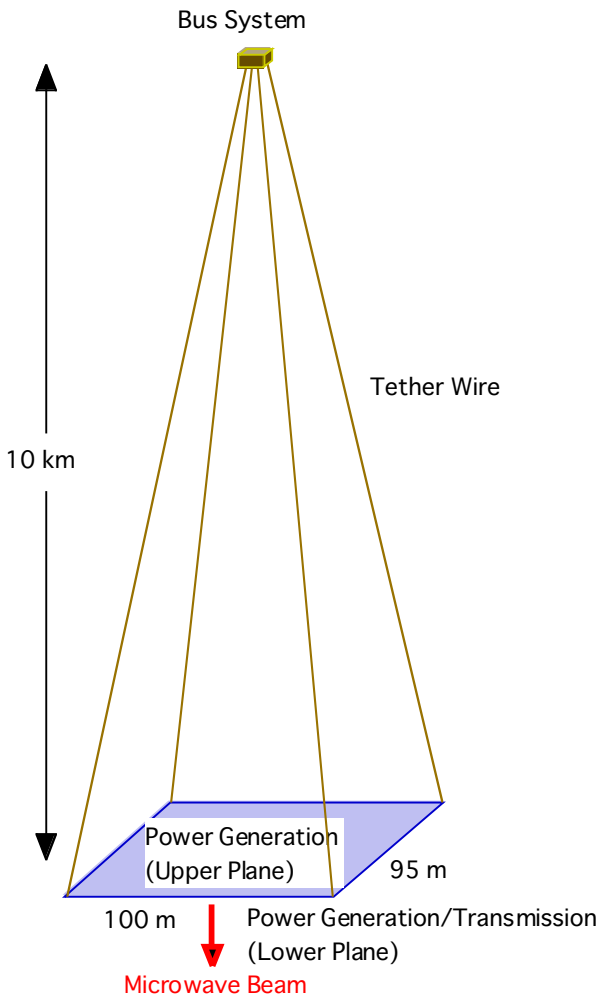
⇨ Tethered-SPS

Automatically stabilized by gravity gradient force.
No sun-pointing mechanism.
Less power efficiency but robust and costless.

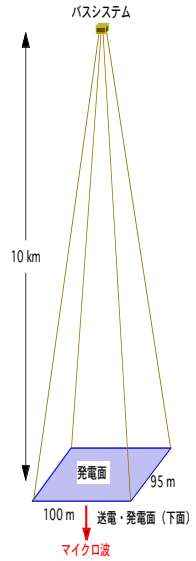


Unit of Tethered-SPS

Total Weight : 42.5 MT
Tether Length : 2-10 km
Output Power: 2.2 MW

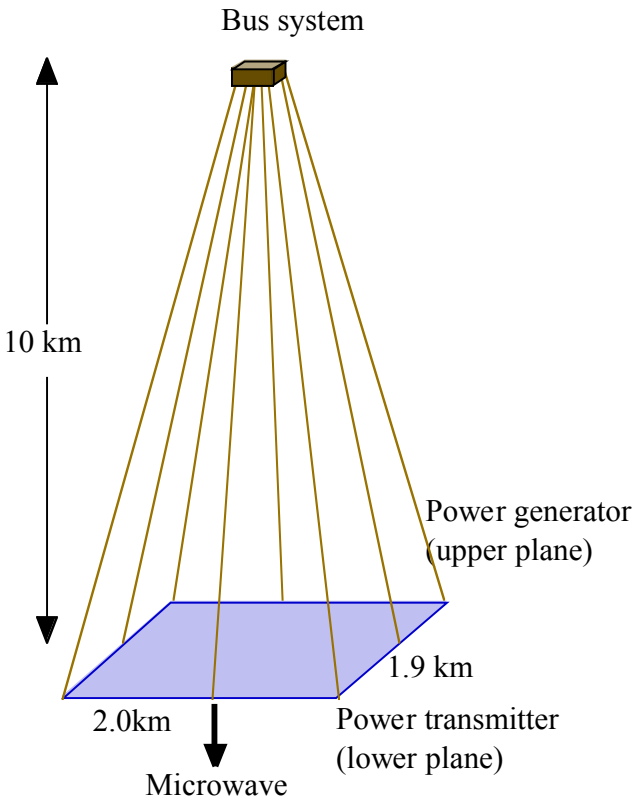


Concept of Tethered-SPS (Former Type)

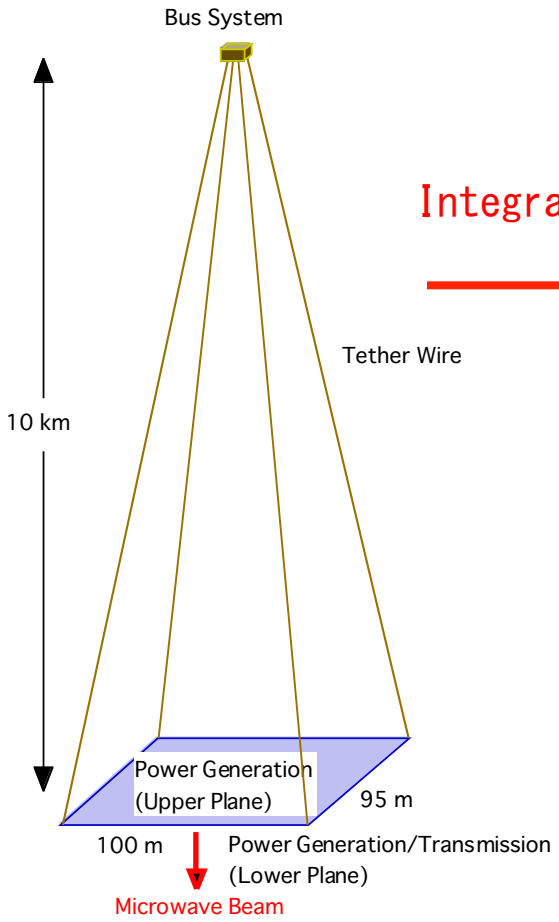


Unit of Tethered-SPS

Integration

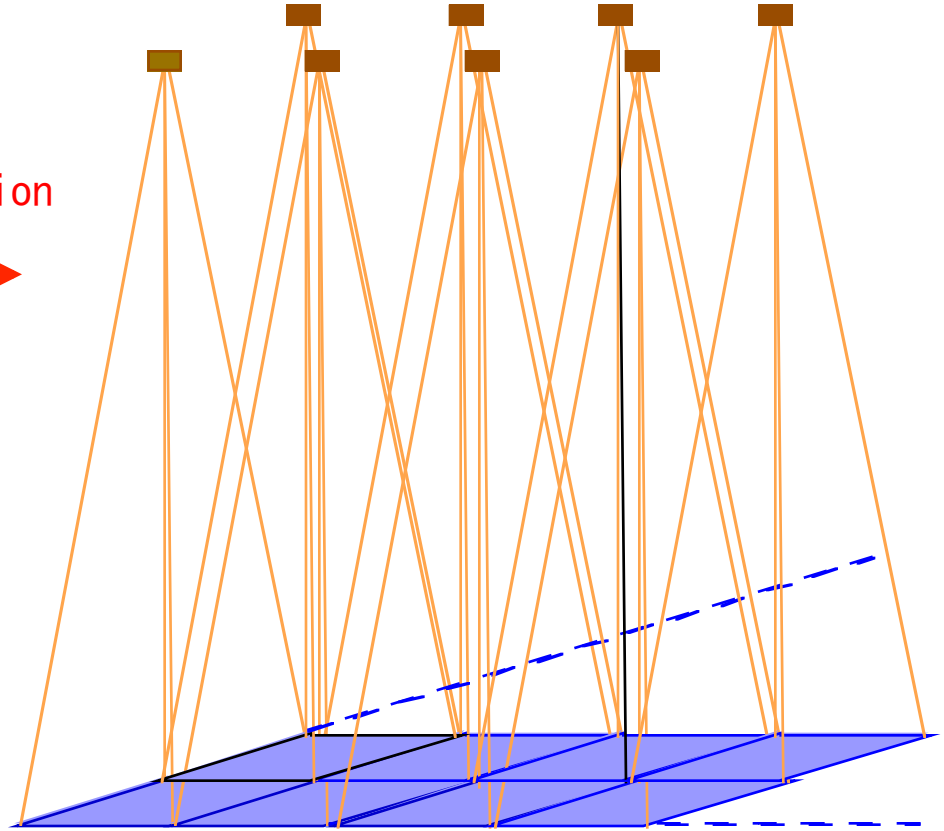


Concept of Tethered-SPS (New Type)



Integration

Total Weight : 26,500 MT Output Power : 1 GW(constant)

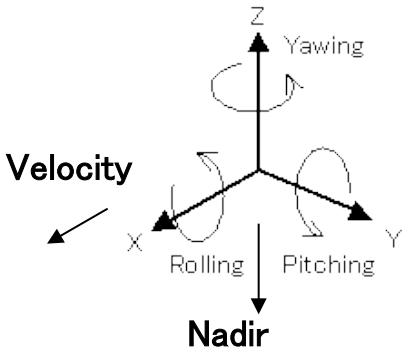


Enhanced flexibility, expansibility, and maintenance performance

System Characteristics of Tethered SPS (Constant Power)

	Item	Performance	Note
Tethered SPS	Weight	26,562 MT	25,234MT（Panel）、1,328MT（Bus）
	Size	2.5 km x 2.375 km x 10 km	250 Tethered SPS modules
	Output Power	1.36 GW	Microwave frequency 5.8 GHz
Tethered SPS Module	Weight	42.5 MT	40,375 kg（Panel）、2,125 kg（Bus）
	Tether Length	2-10 km	Width 1cm, Para-aramid fiber （Kevlar/DuPont), UV protection coating
	Panel Size	100m x 95 m	100x 95 Power generation/ Transmission modules
	Output Power	2.2 MW	Microwave frequency 2.45 GHz
Power Generation/ Transmission Module	Weight	4.25 kg	Microwave circuit 2.3kg(10g/W) Solar cell 0.45kg(0.5g/W) Batteriies 1.0kg(2000Wh/kg) Structure 0.5kg(0.025g/cc)
	Size	1 m x 1m x 2 cm	
	Output Power	230 W	Microwave frequency 2.45 GHz

(1) Attitude Stability of Tethered-SPS



Amplitude of attitude fluctuation induced by solar radiation pressure when deviation between the center of gravity and the center of shape is 1 %.

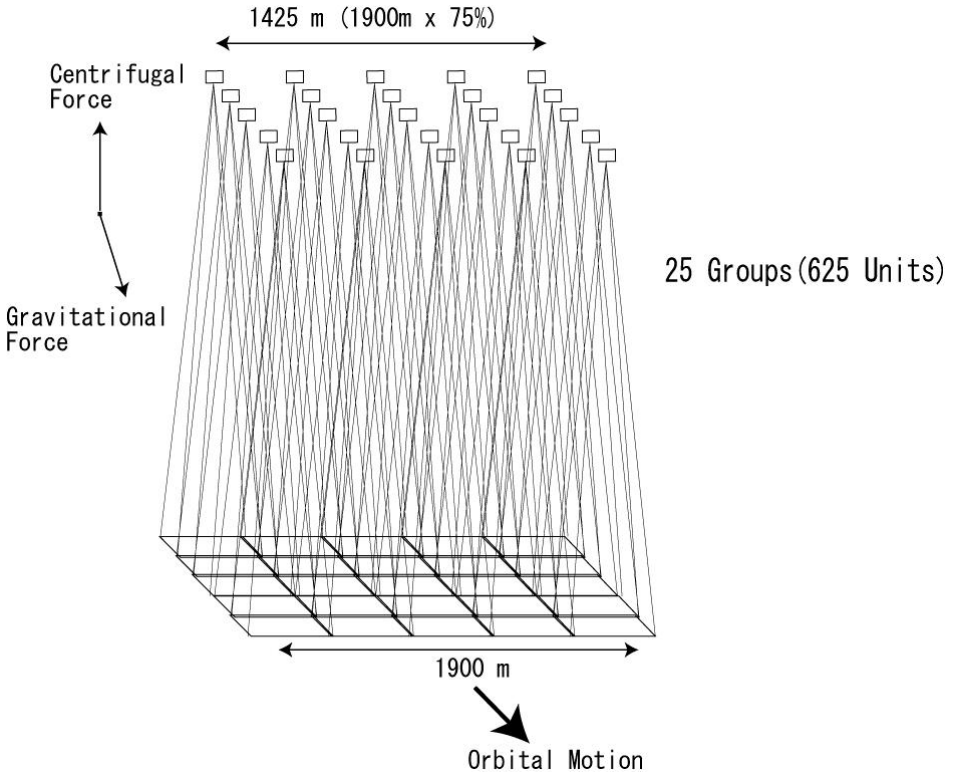
Direction of Fluctuation	Amplitude [rad]
Pitch angle by disturbance along pitch axis	2.8×10^{-3} (0.16 degrees)
Roll angle by disturbance along roll axis	1.3×10^{-4}
Yaw angle by disturbance along roll axis	1.2×10^{-4}
Roll angle by disturbance along yaw axis	5.8×10^{-5}
Yaw angle by disturbance along yaw axis	2.4×10^{-3}

Ishimura (Hokkaido Univ.) 2005

Balancing position of distributed bus systems

Balancing of gravity gradient force and centrifugal force

Panel size: P m (475 m)
Distance of bus: 0.75P m (356 m)
Allowable tether fluctuation:
0.75P/L (8.2°)
( ) : calculation for 5 x 5 unit grouping

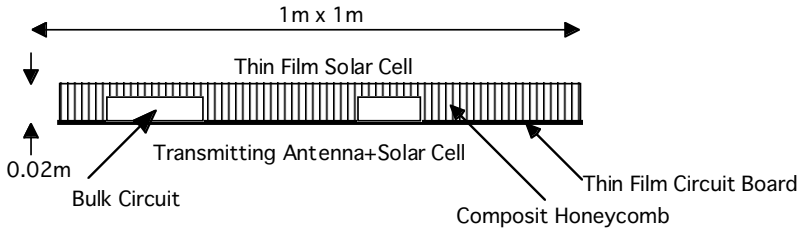


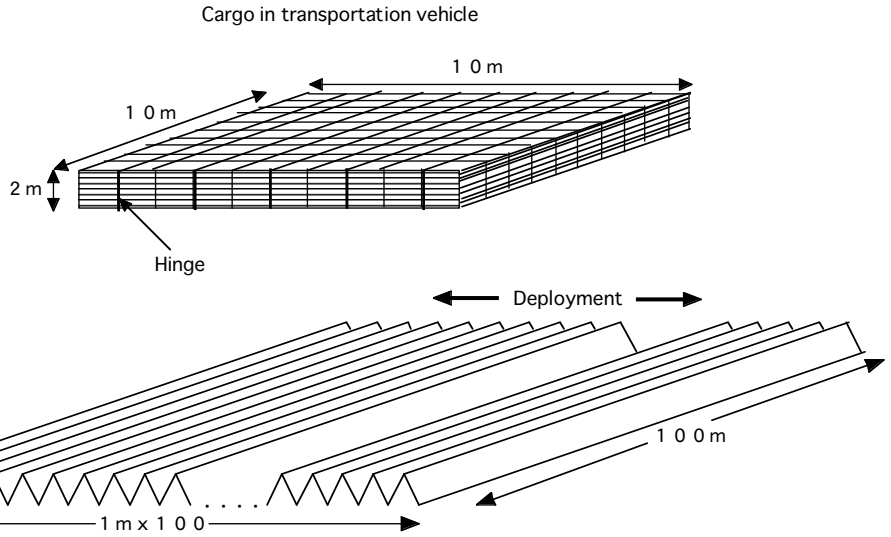
(2) Modularization

- Power generation and transmission panel is composed of perfectly equivalent modules.
- Power generated by the solar cell is converted into microwave power in a module.
- All modules are controlled by wireless LAN.

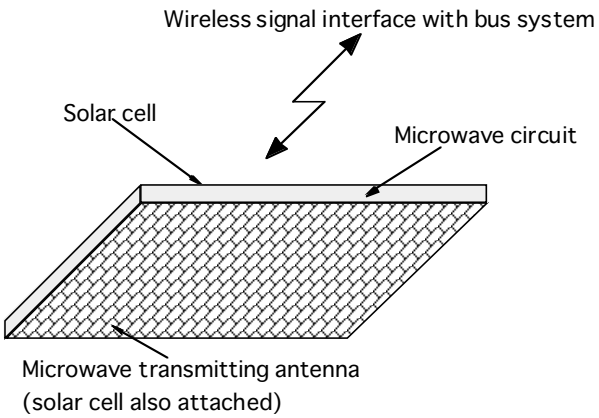
⇨No power/signal cabling between the modules.

⇨ Robust and low cost (mass production, easy quality control)

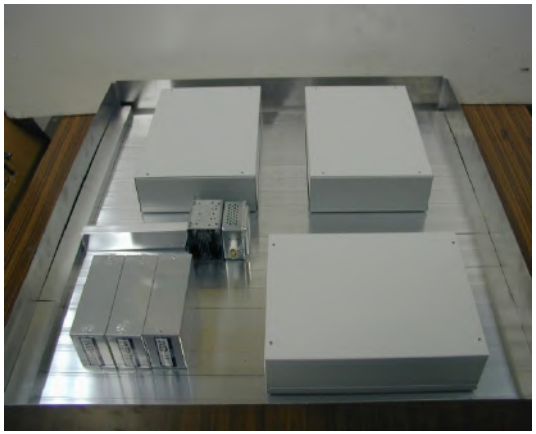




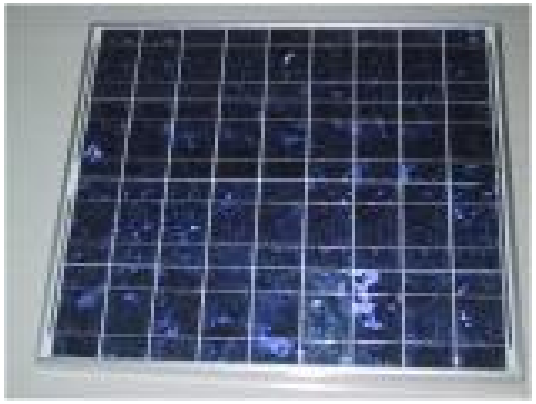
Power Generation/Transmission Module



Power generation/transmission module



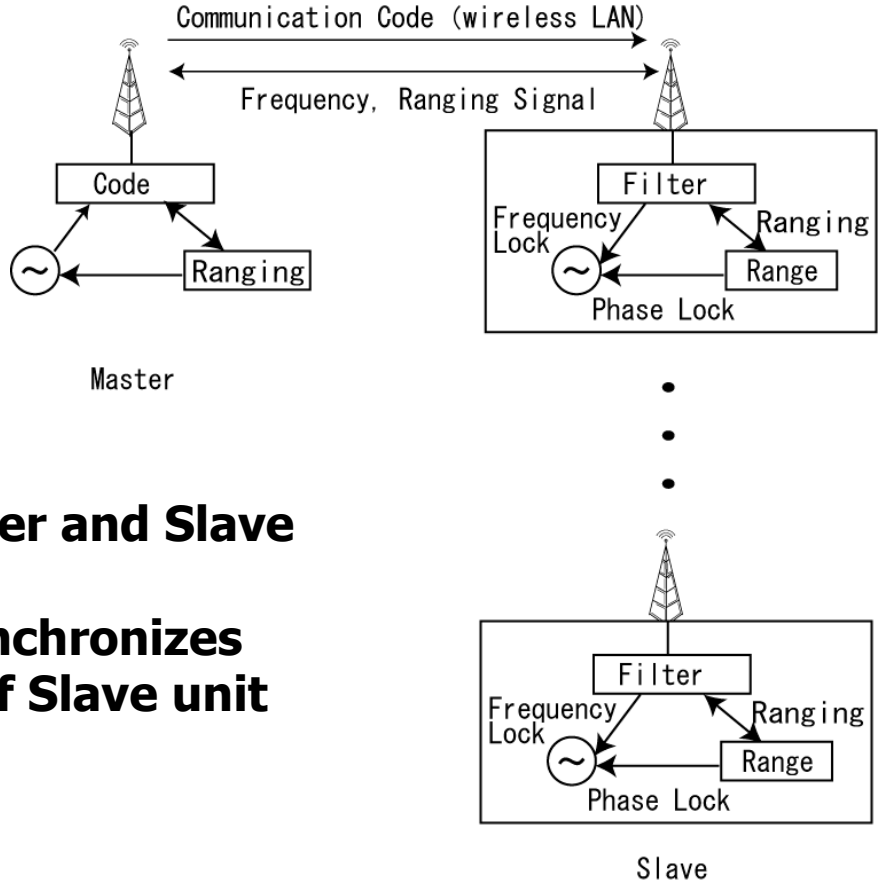
Mock-up of module



Functional model of module
(solar cell side)

Functional model of module
(microwave antenna side)

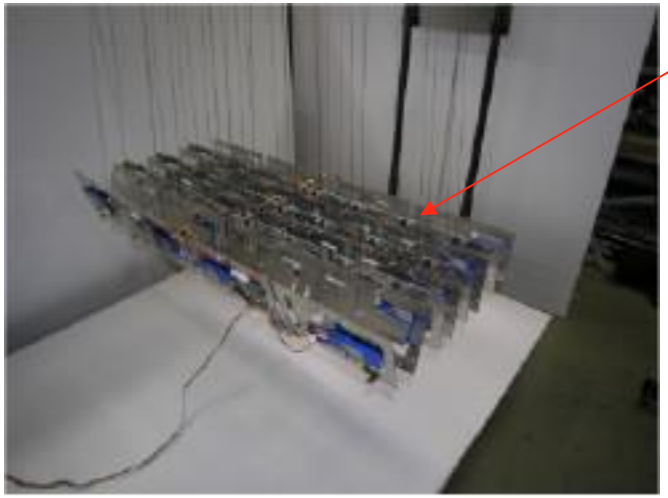
Synchronization of frequency and phase between separated bus units



Equivalent Circuit for Master and Slave units.
Mater unit sequentially synchronizes the frequency and phase of Slave unit with those of Master unit.

Concept of Simple Deployment Mechanism using SMA (Shape Memory Alloy) Actuators

Testing using miniature panel model



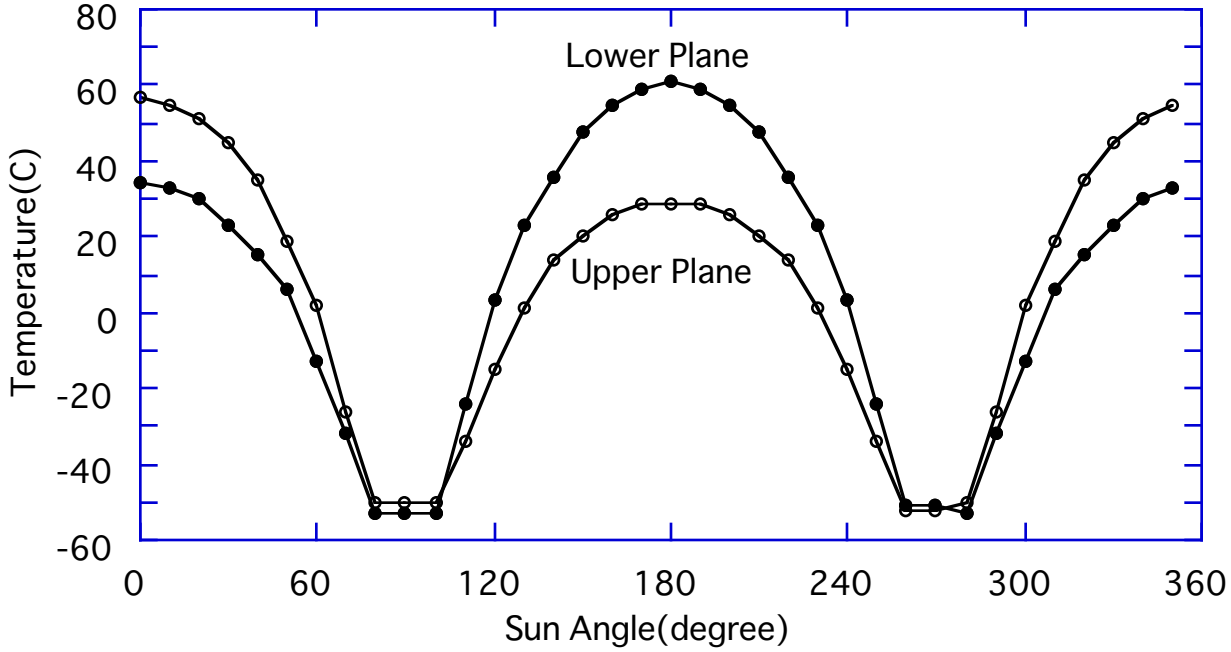
32 panels

Cancellation mechanism for gravity field

32 panels after deployment

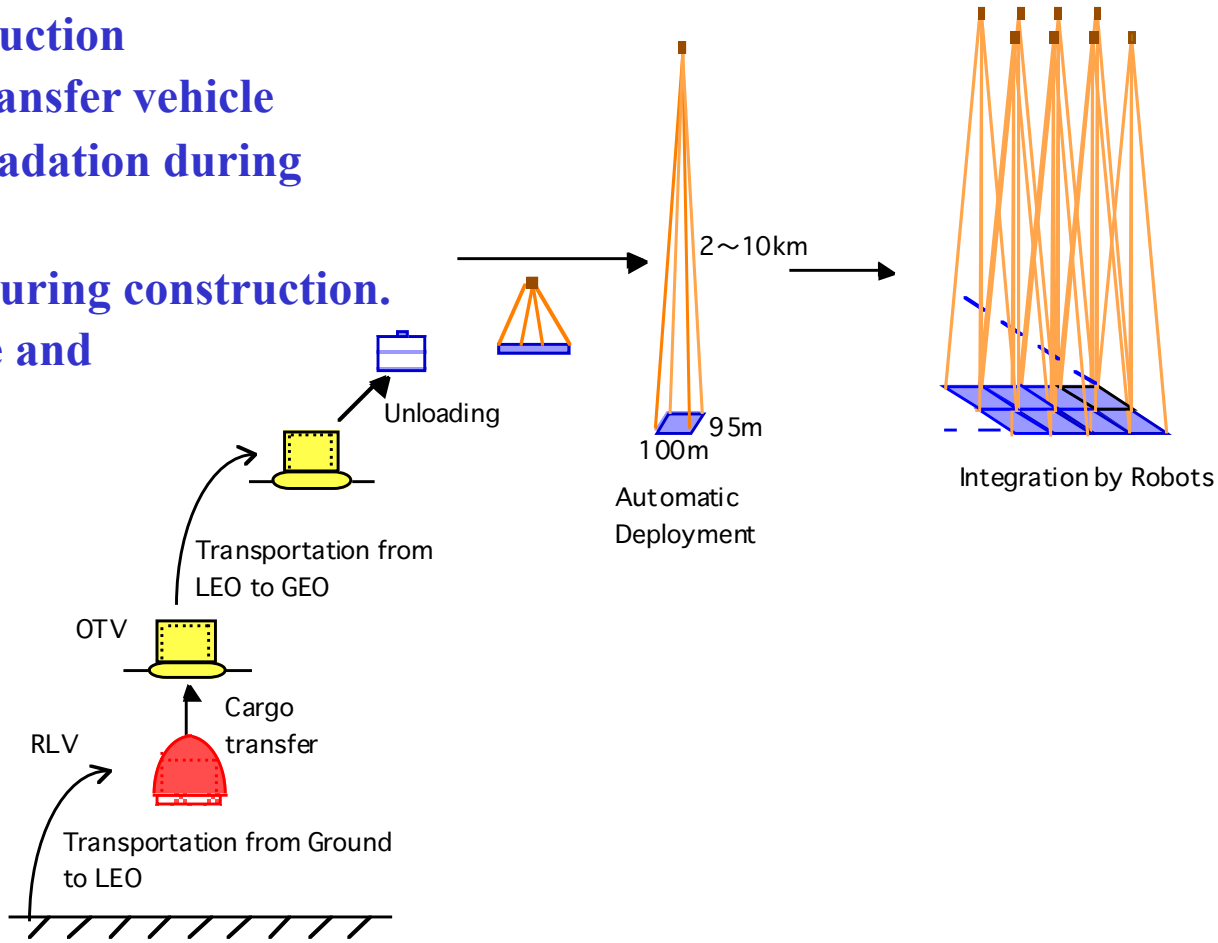
32 panels (23cmx11cm each) during deployment

(3) Temperature variation of the upper and lower planes

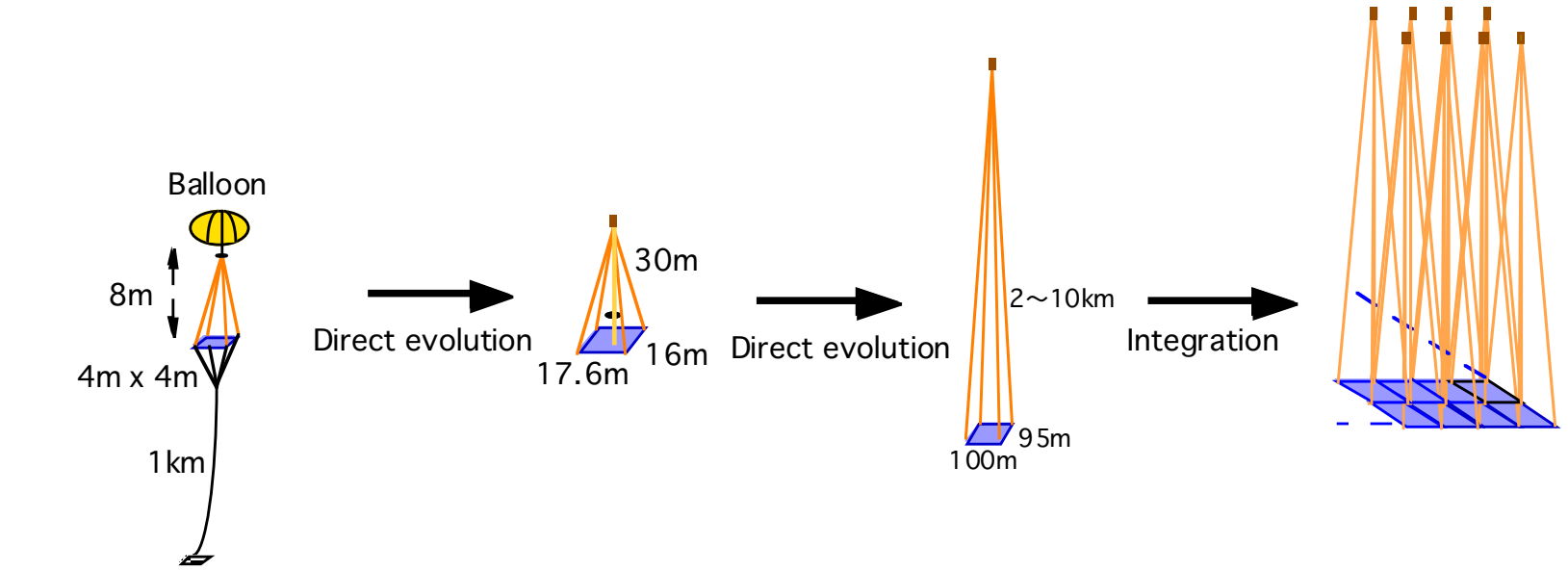


(4) Construction and Maintenance

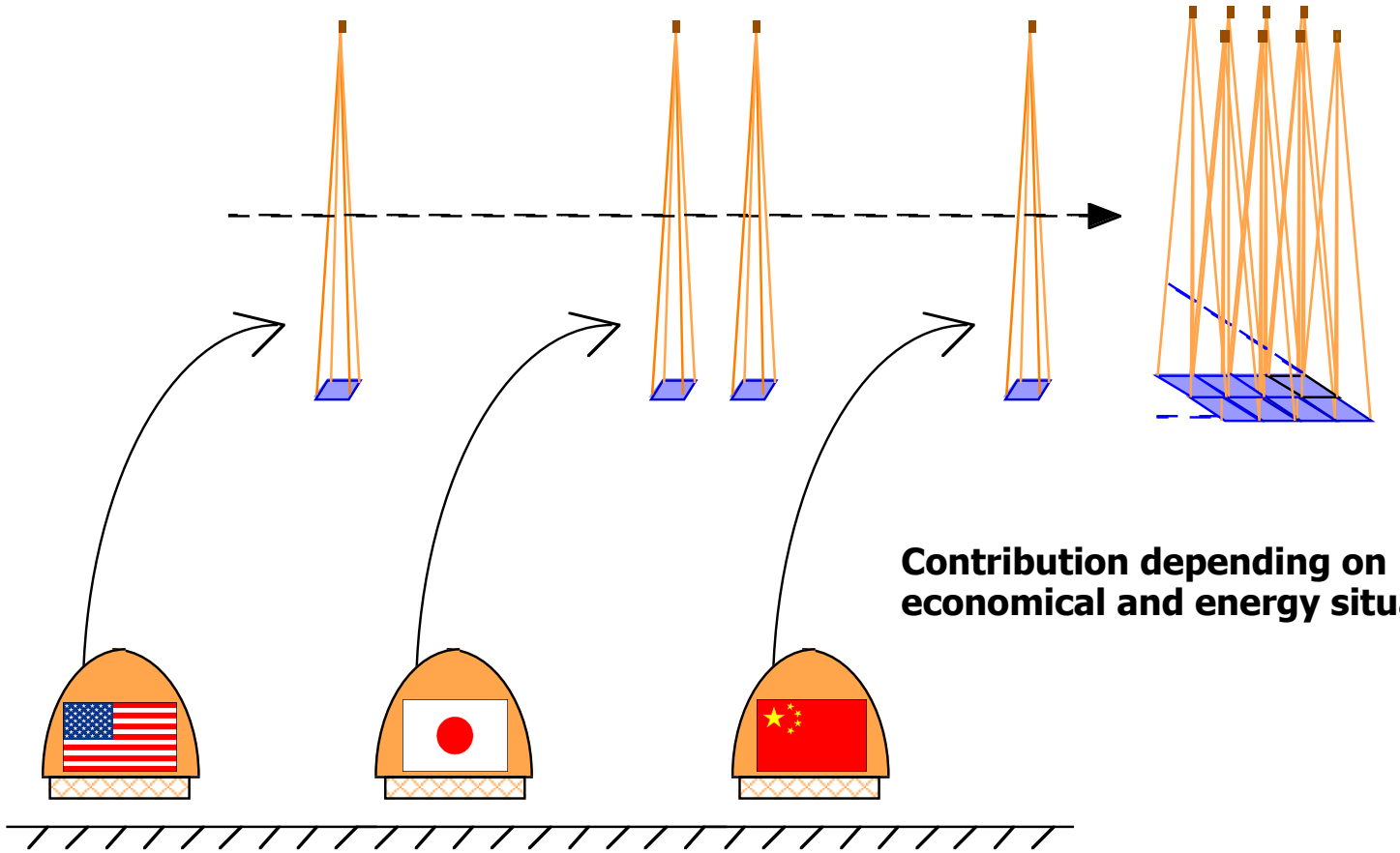
1. Unmanned construction
2. Moderate orbit transfer vehicle
3. No radiation degradation during transportation
4. Full verification during construction.
5. Easy maintenance and scale-up



(5) Evolutionary Development from Demonstration Model to Commercial Model

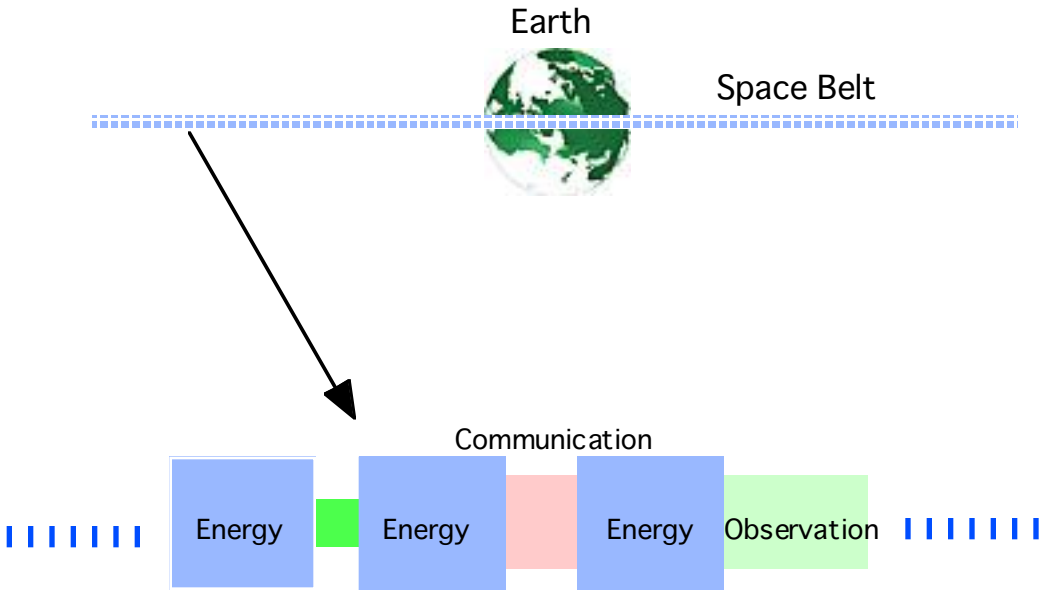


(6) Easy Investment with Clear Work Interface



Contribution depending on economical and energy situation.

(7) Coexistence with Other Geo-stationary Satellites



Complex of facilities for Energy, Communication, Earth Observation, Space Telescope, Space Experiment, and Maintenance in Geosynchronous orbit.

World primary energy(13,000 GW) can be supplied from space belt with the length of 32,500 km (14 % of total space belt).

Technologies required for Tethered-SPS

Solar cell	Power efficiency 35 %, 2 kW/kg, 0.5 kW/m^2, ¥50/W
Microwave transmission	DC/RF conversion efficiency 85 %, 10 g/W, ¥100/W, Beam control technologies for targeting at 3.5 km-diameter rectenna more than 90 % power efficiency
Power storage	1.5 kWh/kg, ¥10/Wh, Charge/discharge efficiency 90 %, DOD 50 %, Life 30,000 charge/discharge
Microwave reception	RF/DC conversion efficiency 85 %, ¥50/W
Transportation	¥15,000/kg（ground to LEO, LEO to GEO）

Summary and Conclusion

- New model Tethered-SPS is a highly practical SPS concept, with a number of advantages in the production, integration, construction, operation, and maintenance, as compared with the past SPS models.

- Since the technologies employed in the Tethered-SPS are essentially achievable, this model can be used as a realistic reference model to evaluate the cost and CO_2 load as a future energy system.

- Further investigations are required to confirm the technical feasibilities, especially for microwave control, integration of the units using robotics, and orbit maintenance of the large structure.