Title: Building a long-distance power transmission system that uses magnetic resonance with nano-satellite

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1. Need

Realization of external supplying power to satellite moving on its orbit can lead to weight reduction and miniaturization of power system. It can also reduce difficulties in launching satellite like launching cost. Standardization of wireless power transmission module has the effects of being on market faster and improvement of usability's effects. Thus, building of the Flexibility Power Supply Network which uses wireless power transmission technology expands potential of nano-satellites in space.

2. Mission Objectives

- Building a long-distance power transmission system that uses magnetic resonance with nano-satellite constellation.
- Deployment of wireless power transmission coil by arranging and connecting adjacently 16 nano-satellites on 100m x 100m square.
- Investigating the power distribution by using 18 nano-satellites to measure receiving power.
- Measuring the wireless power transmission gain characteristics at distance of 1000 [m].
- Standardization and practical realization of wireless power transmitting and receiving interface.

3. Concept of Operation

3.1 Concept

The development of bus equipment in each satellite mission causes the accelerated obstruction of the utilization of satellites because it has disadvantages like an increase of design period and cost. To solve this problem, we could develop the Standard Bus Systems. However, the development of bus system, especially the power supply system has the possibility of restricting the satellite mission because power supply system designed to match the peak power or lifetime is too heavy. To solve these problems, we can build the Flexible Power Supply Network. In this case, we probably not consider the restriction in the operation because of the electric power securing. By using this network, we are also able to provide the electric power for other nano-satellites. Therefore, with the new measure there is a possibility improve the ability of completing nano-satellites' missions. As the result, it is expected that nano-satellites can get higher achievement.

At present, experiments using the magnetic resonance coil in the wireless power transmission field are already conducted. It has a transmitting efficiency of about 10% in 5 times distance against diameter of the coil. In the future, with the improvement, further transmitting efficiency can be expected.

However, the long-distance wireless power transmission experiments had not been carried out because of restriction of Radio Law and gravity. In microgravity environment, we can build large-scale coil and do experiments of wireless power transmission. So, this mission here attempts to deploy the large-scale wireless power transmission coil with many nano-satellites and to get data of wireless power transmission characteristic. The advantages to use the nano-satellite could be as following:

- Shortening the design period by combining the airframe of the same design.
- Scattering risks like a breakdown by experimenting.
- Getting many data easily.
- Reducing development cost compared with the large satellites.

And, considering possibility in the future, we deploy the large-scale coil using the nano-satellite to extend transmission distance in this mission. In addition, it is considered to exploit the strong point of the nano-satellite to build large-scale wireless power transmission network that can transmit large-scale power within short time. Moreover, if the wireless power transmission for satellites spreads, this system will be normalized. In that case, we can develop satellites which can transmit electric power easily. The operation plan for the concept achievement is shown as below.

3.2 Operation plan

Initial operation (Operational time is 3 months after the launch)

The satellites are turned on to planned trajectory after it separates from the rocket. Then we verify the amount of power generation in wireless power transmission satellites, operation of the camera for confirmation of the deployment of coil and so on. Next, the wireless power transmission satellites and the receiving satellites are separated. The power transmission satellites separate further by inflatable tubes respectively and deploy a large-scale coil. After that, both the wireless power transmission and the receiving satellites revolve around the Earth while the attitude of satellites becomes stable. In the end of the initial operation, we verify the amount of power generation in wireless power transmission satellites and the transmitting function of the wireless power transmission coil.

Regular operation

First, the receiving satellites deploy coils to receive power respectively and finish preparation for receiving. Next, the receiving satellites push in vertical direction against the plane of the transmission coil so that the receiving satellites separate from central part of a cluster of satellites. After that, the wireless power transmission satellites start transmitting power and the receiving satellites immediately send the power transmission satellites a value of amount of receiving power and self-localization data. When the wireless power transmission satellites receive those data from the receiving satellites, the wireless power transmission satellites send those data to the ground station and continue sending until the communication between satellites is broken off.

Operation in abnormal circumstances

・Failure of deployment the wireless power transmission coil.

The failure of deployment the wireless power transmission satellites cluster constructed by 16 satellites cause failure of the mission. If resonance points of resonance coils can be adjusted, the failure of stretching inflatable tubes only may cause shortening the wireless power transmission distance, but it is unquestionable for the operation execution.

・Oversupply

If either the wireless power transmission satellites or receiving satellites become anomalous condition, the receiving satellites will stop receiving power. In this system, both kinds of satellites always communicate each other. But the receiving satellites will stop receiving power if both are not able to communicate or communication signals are wrong.

Off-the-air operation

After finishing mission operation, the satellites continue revolving around the earth and waiting for receiving commands. Those satellites will be used for constructing wireless power transmission network.

4. Key Performance Parameters

- It was proved that on the earth we can transmit and receive electric power within about 2 [m] with two magnetic resonance coils whose diameter is about 60 [cm].
- The satellites make a coil on orbit with inflatable tubes that was used to form huge structures.
- Establishing the technology which is used to separate the group of nano-satellite on theirs orbit

- Communication between a satellite and ground station or another satellite can be ensured by using a two-way radio that is being used in space.
- We use a GPS module that is being used in space to measure the distance between the power transmitting satellites and the receiving satellites.
- When the satellites transmit energy, they use EDLCs(Electric Double-Layer Capacitor) to prevent from damage of the main battery.

It was proved that this technology can transmit electric power. But it’s necessary to develop technology of deployment huge coils on orbit. When the huge coil deploy, the satellites are in danger of destruction of the coil because the coil connected the satellites. So we have to know the properties of the coil we use. And the most important properties we should know are what materials the coil is made of and how strong it is. Development of way the satellites hold and separate is necessary because we need to protect the coil from destruction and we need same function and versatility for several satellites.

5. Space Segment Description

The satellites are as small as possible and combine each other to make a huge coil. We want the power generation system can operate efficiently by changing its generating power flexibly. About controlling attitude , we do not want anything more than stopping high speed rotation for all satellites. Table 1 shows the satellite specification.

Primary interface

- Coil excitation
- Resonance coil
- Radio communication with the ground (with experience in nano-satellites, such as facsimile transmission has been developed at universities, etc.)
- A camera to check deployment

Table 1 The satellite specification

Size	150 [mm] ×150 [mm] × 150 [mm]
Weight	Approx. 5~6 [kg]
Frequency	100 [kHz]
Maximum power	160 [W] (16 satellites total)
Coil Diameter	100 [m]

6. Orbit/Constellation Description

In the technical verification phase, A wireless power transmit coil will be made by 16 satellites. In term of considering future service development, the orbit where nano-satellites are cast into frequently is good. This system will be able to transmit about 500 [m], depending on diameter of the transmission coil. In addition, power receiving satellites have some types of coil for test of future’s satellites system. In the future, mission satellite will be launched with wireless power transmitting satellites. But, by unifying the standards of wireless power transmission, other satellites can receive power from launched wireless power transmission satellites.

7. Implementation Plan

"Wireless power transmission examination group" is a team consisting of the student volunteers of University of Electro-Communications and University of Tsukuba. "Wireless power transmission examination group" are able to cooperate in satellite development and in term of providing staff, but cannot almost cooperate in term of facilities. Table 2 shows the estimates development costs in this satellite development.

Table 2 Cost of this mission

Development	$3.4M (@$0.1M×34 satellites＝$3.4M)
Operation	$0.3M
Inactivation cost	$0.3M
Employment	$2.0M
Total	$6.0M

There are some risks in this mission.

・Fault of deployment mechanism

The mechanism is the most important component of this mission. This trouble can lead to fault of mission. By regulating resonance point electrically, we can avoid this trouble. But it will shorten transmission distance.

・Torsion of the coil

Because of influence of force acting between satellites, coil can be twisted, and its characteristic can change. However, we can solve this problem by regulating resonance point electrically.

・The separation failure of receiving satellites

We cannot perform the measurement of wireless power transmission efficiency for different distances. But it seems that power supply mission is not unaffected.

・The joint failure of the succeeding satellite

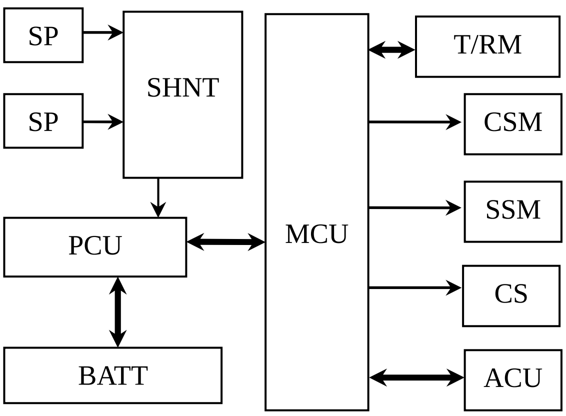
Because we cannot adjust orbit of a nano-satellite, it is hopeless.

・The feasibility of the coil

We cannot develop the large scale coil to use in this mission. And new problems may occur during development. Thus, we will determine the continuation of plan in EM phase. Table 3 shows the development schedule of this mission.

Reference

1) David Schneider,"Electrons Unplugged,Wireless power at a distance is still far away",IEEE SPECTRUW,2010.3,pp.34-39
2) Tetsuo Nozawa,"コイル間の効率は 98%以上 長野日本無線が無線給電装置を公開　1 対 N 型での高い伝送効率実現も視野に",NIKKEI ELECTRONICS,2009.10.5,pp.12-13
3) Satoshi Shimokawa,Hiroyasu Kawano,Kiyoto Matsui,Akiyoshi Uchida,Masakazu Taguchi,"A Study of the Effect of Capacitance Variation in Magnetic Resonant Coupling",IEICE Society Conference 2010,2010.9,B-1-7
4) Noriaki Oodachi,Hiroki Kudo,Kenichiro Ogawa,Shuichi Obayashi,Hiroki Shoki,Tasuku Morooka,"Measurement of transfer efficiency of wireless power transfer via magnetic resonances using the third coil",IEICE Society Conference 2010,2010.9,B-1-4
5) NASA Goddard Space Flight Centre, "Spartan 207/Inflatable Antenna Experiment Flown on STS-77", 1997



T/RM – Wireless power transmission and receiving module (coils, inflatable).

Figure 1 Schematic of the nano-satellite.

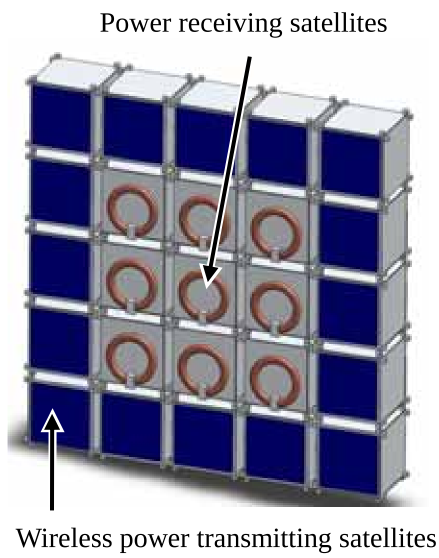


Figure 2 System’s conformation before deploying.

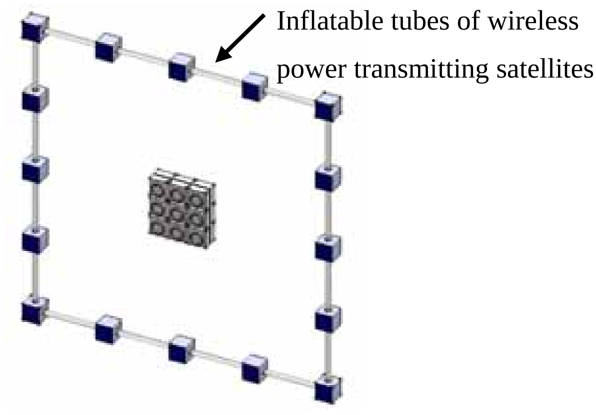


Figure 3 System's conformation after deploying.

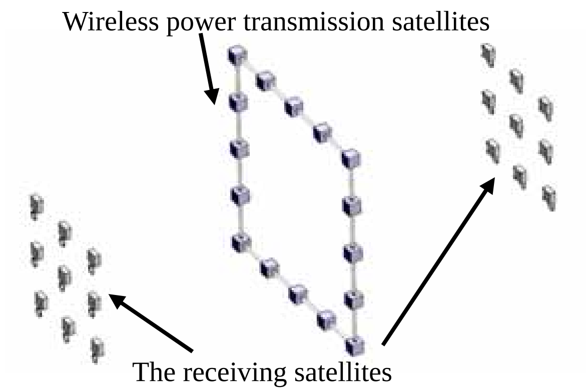


Figure 4 System's conformation after deploying (in regular operation state).

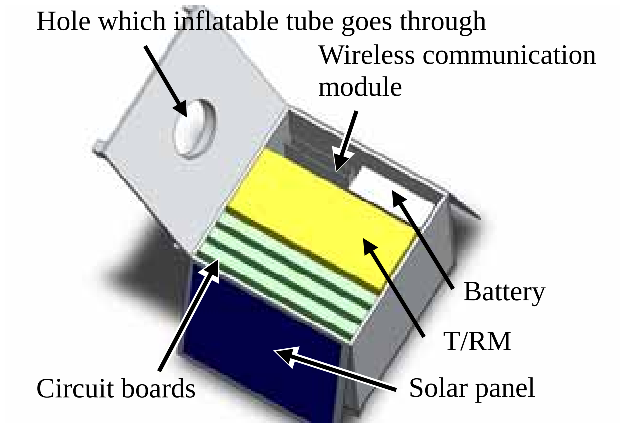


Figure 5 Inner structure of power transmitting satellite.

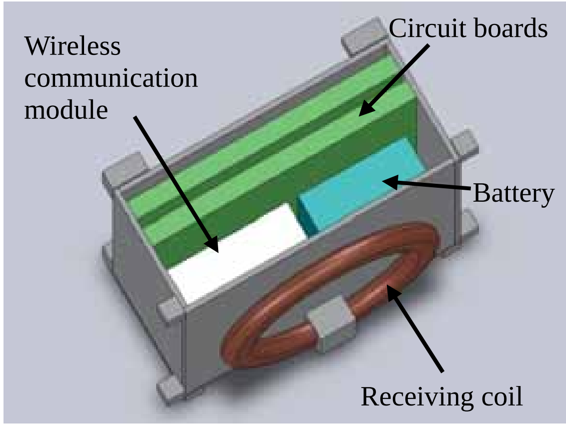


Figure 6 Inner structure of receiving satellite.

Table 3 Gantt chart

Task \ Schedule			The first year												The second year											
			1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Project		concept	■	■	■																					
		system design				■	■	■																		
		development							■	■	■	■	■	■												
		integration													■	■	■	■	■	■						
		test																	■	■	■	■	■	■		
		launch																							■	■
Mechanism	EM	concept	■	■	■	■	■	■																		
		coil deployment mechanism				■	■	■	■	■																
		sattelite deployment mechanism							■	■																
		test								■	■	■														
		environmental test											■	■												
	FM	coil deployment mechanism													■	■										
		sattelite deployment mechanism													■	■										
		test														■	■	■								
		environmental test																	■	■						
Program		concept	■	■	■	■	■	■																		
		design					■	■	■	■	■	■														
		debug							■	■	■	■	■	■	■	■	■	■	■	■	■	■				
		test											■	■	■	■	■	■	■	■	■	■	■	■		
Electronic component		concept	■	■	■	■	■	■																		
		design					■	■	■	■																
		prototype							■	■	■	■	■	■												
		production											■	■	■	■	■	■	■	■						