Development of New Sandwich SPS concept

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Abstract

We have proposed the new concept of the Solar Power Satellite (SPS), which consists of a power generator / transmitter of a sandwich structure and large reflectors. The concept has many good points: (1) Heavy long power transmission lines on the solar paddles and a rotary joint for the connection between the solar paddles and the microwave transmitter are unnecessary for the new concept, because the solar cells are directly connected to high power amplifiers. (2) The size of the solar paddles can be reduced to that of the microwave transmitter. (3) The very light inflatable collectors can effectively concentrate the solar energy on the solar paddles. Thus, the SPS of the new concept can be very light enough to be realized.

We have already reported the preliminary result of our development of a new high power microwave transmitter in the sandwich structure for our new concept of the SPS(1). We are further improving the transmitter and the main improvements are as follows;

1. A frequency of 5.8 GHz is used for the power transmission, which can reduce the size of the microwave transmitter and the cost of the SPS.
2. The half frequency (2.9 GHz) is used as a pilot signal of the retrodirective antenna to make RF circuit very simple and accurate.
3. A phase detector for the pilot signal, which is separated from the power transmitter, can output received phases of the pilot signal as digital data. The control system of the power beam is very accurate and flexible with computer control.
4. A grand plane slot antenna is suitable for the transmitting antenna of the sandwich type, because the grand plan can be used as the heat radiator.
5. The transmitting antenna is directly connected to the amplifiers to reduce the loss of cables and the weight of the antenna.

Thermal reduction is a very important issue for the sandwich SPS concept to realize high concentration of the solar energy on the solar cells. I will describe the results of our improvements in this paper.

1. Introduction

The Solar Power Satellite (SPS) proposed by Dr. P. Glaser generates an electric power of the order of several hundreds to thousands of mega-watts by solar cells and transmits the generated power via microwave power beam to the ground. The SPS is one of the unique and hopeful electric power stations to satisfy ever-increasing energy demand on the ground without destroying the environment of our mother planet Earth. DOE and NASA investigated its concept in detail to design the SPS of 5 GW as a Reference system in 1978.

The Reference system consists of a very large solar paddle and a transmitting antenna at a diameter of 1 km, which are connected by a big rotary joint. The Reference system has many difficult issues to need further investigations, though those were examined in detail by the DOE/NASA team. The most critical issue is that the Reference system is too expensive for the realization because of high launch costs. The SPS must be improved to decrease the weight in order to reduce the cost.

In the Reference system, the generated electric power is transformed to high voltage with very heavy DC-DC converters and supplied through very heavy power transmission lines and the rotary joint to the transmitting antenna. The power lines must be so thick enough to reduce an energy loss by the resistance of the power lines that they are very heavy. The rotary joint rotates one turn every day. Because the solar paddle always faces to the sun, while the transmitting antenna faces to the earth. The SPS can be much lighter and simpler if the DC-DC converters, the power lines and the rotary joint are removed from the SPS.

2. Concept of the new SPS

The new SPS consists of the generator/transmitter of the sandwich structure and a pair of the large reflectors. The sunlight reflected by a flat reflector is again reflected by another reflector. The second reflector concentrates the solar energy ten times into the solar paddle on the sandwich module in the figure. The inflatable mirror used as the reflector is very light due to a structure of a balloon.

The reflectors are connected to the sandwich module with a long tether. The SPS can stably stay in space by force of the gravity gradient between the reflectors and the sandwich module. Thus, the sandwich module always faces to the ground, while the reflectors are pulled at the opposite direction from the Earth. A drive mechanism to rotate the Reflector is necessary to concentrate the solar ray on the solar paddle all day long.

Each block of the solar cells is directly connected to F-class amplifiers of high power with no voltage converters and no heavy power transmission lines in the sandwich structure. The F-class amplifiers can convert the generated electric power into microwave power with a very high efficiency and reject higher harmonics radiations with a tank circuit. The microwave is radiated from a printed slot antenna, which is directly connected to the amplifier. The printed slot antenna has a very simple and light structure, which is composed only of a stripline as a radiator and a very small slot. The board where the amplifiers are attached to, works as a heat radiator, though there are many small halls as the slots for the transmitting antenna.

The frequency of the microwave for the wireless power transmission toward the Earth is 5.8 GHz, which is allocated as one of the ISM bands. Because higher frequencies can reduce the size of the transmitting antenna, though the attenuation of the microwave increases by rain. However, the attenuation of the microwave of 5.8 GHz by raindrops is so little that the frequency of 5.8 GHz is useful for the wireless power transmission from space to the ground. The diameter of the transmitting antenna at 5.8 GHz is reduced to be half shorter than at 2.45 GHz, while the area is a quarter smaller. However, an effective cooling system is necessary, because the reduction of the size makes the heat from the antenna four times higher.

There is another critical issue on the control of the microwave beam. The microwave transmitted from the SPS must be exactly radiated on the rectenna. The retrodirective antenna is expected as the most practical system for the control of the microwave beam. In the retrodirective antenna system, phases of the transmitting microwave are determined by the pilot signal transmitted from the rectenna. However, the frequency of the pilot signal can never be the same as that of the microwave for the power transmission, because the pilot signal cannot be distinguished from the high power microwave. We proposed and verified an asymmetry two-tone pilot system, which has no phase ambiguity. Also, a new retrodirective antenna is proposed here using a pilot signal at the half frequency of the transmitting microwave. It has no phase ambiguity and needs only a very simple circuit. However, space experiments are necessary to investigate the propagation characteristics through the ionosphere, because there is a possibility that the path of the high power microwave is different from that of the pilot signal due to the ionospheric plasma.

3. Heat Dissipation

The heat dissipation is one of the most important and difficult issues in the sandwich SPS concept, because the solar energy should be concentrated several times onto the solar cells. The solar cells can convert the solar energy to the electric power only at very low efficiency of 15 %. Thus, the most of the concentrated solar energy is consumed only to heat the sandwich structure. On the other hand, the sandwich structure must be very large, if the solar energy is not concentrated.

We assume that the concentration ratio of the solar energy is 10 times and the efficiencies of the solar cells and the FET amplifiers are 15 % and 80 %, respectively. The concentrated solar energy of 12 kW/m^2 heats the sandwich structure, while only solar energy of 2 kW/m^2 can be converted to electric power. The FET amplifiers generate microwave power of 1.6 kW/m^2 with heat of 0.4 kW/m^2 at the efficiency of 80 %. The heat of 0.6 kW/m^2 is radiated from one side of the sandwich structure at the temperature of 60 degree C. Thus, the remained heat of 11.2 kW/m^2 is estimated to increases the temperature of the sandwich structure to 334 degree C.

A passive cooling system should be developed for the heat dissipation of 11.2 kW/m^2, though the active cooling system can easily reduce it. The following items are examined here.

1. Optimum temperature
2. Efficiency of the solar cells
3. Filtering in the solar spectrum

Concerning the temperature, we assume that the temperature is 120 degree C, which can radiate heat energy of 2.2 kW//m^2. We must look for solar cells at as a high efficiency as possible. The rainbow cells are one of the most promising candidates, which has an efficiency of 50 %. GaAs solar cells have a peak efficiency of 60 % at 0.8 μm. It indicates the GaAs solar cells can achieve the average efficiency of 50 % in the spectrum from 0.5 to 0.9. This filtering can easily be realized by the Solar Optical Reflector Coating. The surface of the reflectors should be coated to reflect only solar ray convertible to electric power by the solar cells and to absorb the unnecessary solar energy, which only heats the sandwich structure. If this idea can be realized, the heat energy from the sandwich structure is estimated 2.4 kW/m^2 at the concentration ratio of 10 times shown in Fig. 1. The concentration ratio is concluded to be nine times, where the heat can be dissipated at the temperature of 120 degree C.

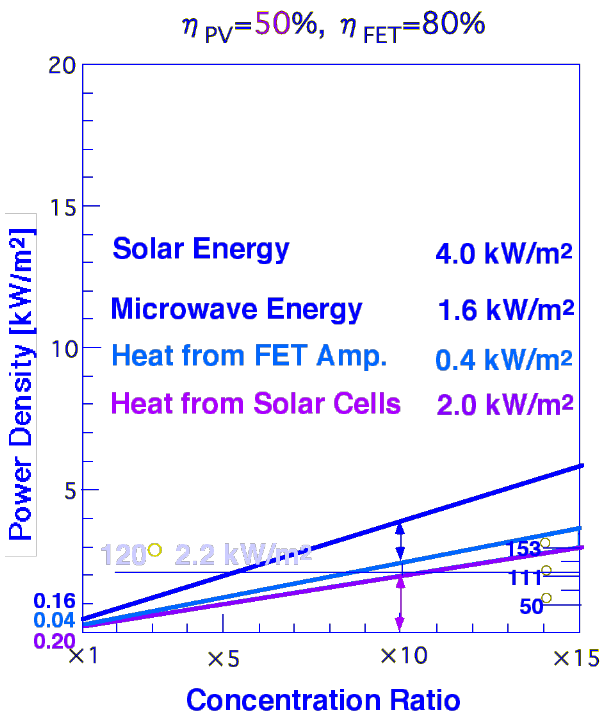

Fig. 1 Estimations of superfluous heat versus concentration ratios

4. Conclusions

The thermal problem in the new concept of the SPS was examined in this paper. The following methods are concluded to reject the superfluous heat from the Sun.

1.Design the sandwich structure to bear as high temperature as possible.

2.Develop as a high efficiency of the solar cells as possible.
Reject the superfluous solar energy by filtering in the solar spectrum with the reflectors.

Reference

1. N.Kaya, A new concept of SPS with a power generator/transmitter of a sandwich structure and a large solar collector, Space Energy and Transportation, 1, 3, 205-213, 1996.