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A new concept of space solar power satellite

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ABSTRACT

Space solar power satellite (SSPS) is a tremendous energy system that collects and converts solar power to electric power in space, and then transmits the electric power to earth wirelessly. In this paper, a novel SSPS concept based on ε-near-zero (ENZ) metamaterial is proposed. A spherical condenser made of ENZ metamaterial is developed, by using the refractive property of the ENZ metamaterial sunlight can be captured and redirected to its center. To make the geometric concentration ratio of the PV array reasonable, a hemispherical one located at the center is used to collect and convert the normal-incidence sunlight to DC power, then through a phased array transmitting antenna the DC power is beamed down to the rectenna on the ground. Detailed design of the proposed concept is presented.

1. Introduction

Space solar power satellite (SSPS) is a tremendous energy system that collects and converts solar power to electric power in space, and then transmits the electric power to earth wirelessly [1]. Since it was proposed by Dr. Peter Glaser in 1968 [2], it started to attract attention worldwide, and various concepts were proposed in the United States, Japan, Europe, and China [3]. From the wireless power transmission (WPT) perspective, these concepts can be divided into two kinds, i.e., the microwave-based SSPS and the laser-based SSPS. Most of the concepts proposed so far were based on microwave power transmission (MPT), since the power efficiencies at both the transmitter and the receiver are generally higher and attenuation through the atmosphere is lower for MPT. Some typical microwave-based SSPS concepts are listed in Table 1.

From Table 1, it can be summarized that the microwave-based SSPSs can be classified into two types on the basis of the usage of sunlight-concentrating mirrors. The NASA's reference model [4] shown in Fig. 1 was proposed in 1979. It is a non-concentrating concept that composed of a huge sun-pointing PV array, a large earth-pointing MPT antenna, and a high-voltage rotary joint that connects them together. Though configuration of the reference model is simple, it needs a large rotary mechanism for the PV array to track the sun, which is technically complex. Another famous non-concentrating concept illustrated in Fig. 2 is the Tethered-SSPS [5]. It is a modular, gravity gradient stabilized system that comprises a large power generation/transmission panel, and a bus system that connected by multi-wires. The concept is simple and technically feasible. However, large power fluctuation exists due to its non-rotary structure. The Sun-Tower [6] SSPS shown in Fig. 3 is one of the sunlight concentrating models, it looks like a large sunflower, the face of which is the transmitting antenna, whereas the leaves are thin-film Fresnel solar concentrators. To efficiently collect the incident sunlight, attitude of hundreds of solar concentrators should be adjusted, which is hard to control. In addition, to overcome self-shadowing of the 'leaves', electric cable as long as 15 km is needed, which is higher weight.

Inspired by the Sun-Tower concept, and making use of the deployable sail-like structure, a variation called Sail-Tower [7] SSPS was proposed by ESA, it was a non-concentrating concept as illustrated in Fig. 4. Due to its thin-film PV array structure, the concept is light weight. However, the same drawbacks as the Sun-Tower concept still exist. The integrated symmetrical concentrator (ISC) [8] model illustrated in Fig. 5 is a typical sunlight-concentrating SSPS. It is consisted of two symmetrical parabolic reflectors that are used to collect and direct the incoming sunlight to a pair of PV arrays, a transmitting antenna mounted below the PV arrays is used to beam the microwave down. In this concept, the rotary joint mechanism and the long transmission line were deleted. However, to track the sun, technologies for attitude control and stabilization of the large concentrators should be investigated. In 2012, a highly-modular SSPS concept named ALPHA SSPS [9] was proposed by John Mankins. It looks like a cocktail glass as shown in Fig. 6, the main-body of which is worked as a sunlight concentrator, whereas the bottom is a sandwich transmitter. Though the main-body is a non-moving structure, thousands of individual thin-film reflectors that mounted should be adjusted to redirect the incident sunlight to the bottom sandwich structure. The

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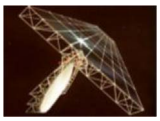
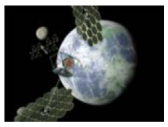
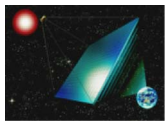
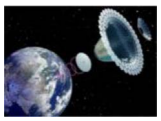
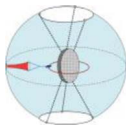
Table 1
Concepts of typical microwave-based SSPS.

	Reference model [4]	Sun-tower [6]	Sail-tower [7]	ISC [8]	Tethered [5]	ALPHA [9]	OMEGA [12]
Concept illustration							
Year	1979	1995	1999	1998	2001	2012	2015
Organization	NASA/DOE	NASA	ESA	NASA	USEF	AIMS	Xidian Univ.
Frequency	2.45 GHz	5.8 GHz	2.45 GHz	5.8 GHz	5.8 GHz	2.45 GHz	5.8 GHz
Power	5 GW	100–300 MW	450 MW	1.2 GW	0.75 GW	2 GW	2 GW
Orbit	GEO	LEO/MEO	GEO	GEO	GEO	GEO	GEO
Amplitude distribution	10 dB Gaussian	10 dB Gaussian	10 dB Gaussian	10 dB Gaussian	Flat distribution	10 dB Gaussian	10 dB Gaussian
Mass (MT)	30,000–50,000	2000–7000	2100	22,463	20,000	25,260	22,953
Rotary joint	Yes	Yes	Yes	No	No	No	Yes
Bus power	Yes	Yes	Yes	Yes	No	No	Yes
Modularity	No	Yes	Yes	Yes	Yes	Yes	Yes
Concentration	No	Yes	No	Yes	No	Yes	Yes

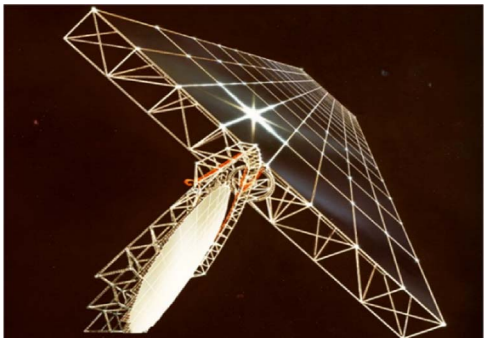


Fig. 1. 1979 Reference SSPS.

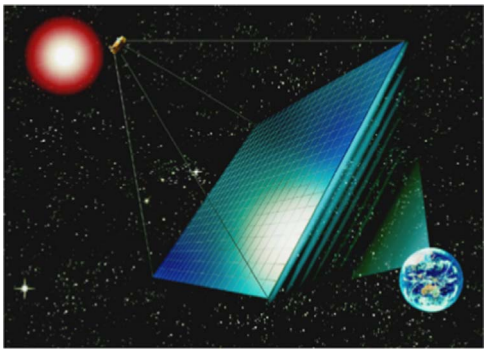


Fig. 2. Tethered SSPS.

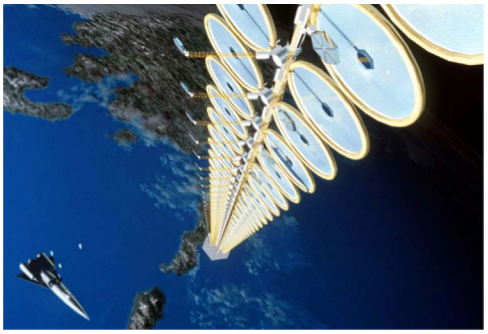


Fig. 3. Sun-tower SSPS.

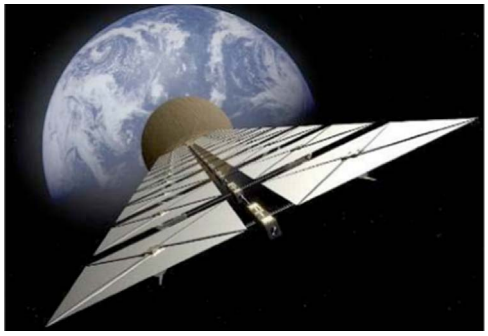


Fig. 4. Sail-tower SSPS.

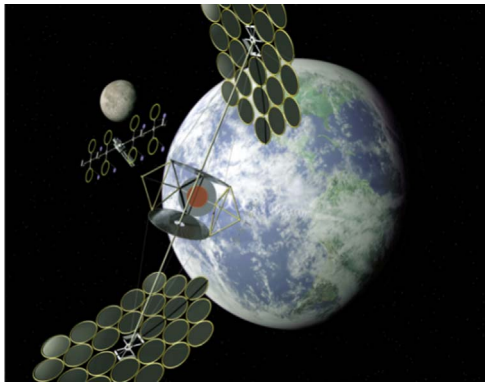


Fig. 5. ISC SSPS.

adjustment strategy is quite complex. Additionally, heat dissipation problem is extremely severe for sandwich structures [10,11]. Very recently, a new SSPS concept called OMEGA-SSPS [12] was proposed by our research group. It is composed of a large spherical condenser, a hyperboloidal PV array and a transmitting antenna. Through opening thousands of individual thin-film reflectors that face to the sun, sunlight can be captured and reflected to the PV array. One of the key advantages of this concept is its constant solar power collection ability. However, similar to the ALPHA concept, the attitude control of thousands of individual reflectors is complicated.

It can be concluded that most of the microwave-based SSPS concepts proposed so far are based on solar concentrators. By employing solar concentration, the required launch mass and as a result the