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A New Innovative Optical Approach for Long-Range RF Transmission Systems to Minimize the Aperture Area of Receiver

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Abstract

In Wire-less Power Transmission (WPT) reducing the aperture size of receiving station, increasing the concentration ratios and decreasing the effect of side-lobe levels much of the concern has been related with Antenna pattern Optimization problems. Here, in this paper we have introduced a novel optical approach that could be used to curb these problems. In our approach, the generated radiated Radio Frequency beam is made to travel through a unique and specially designed Ultra-large Fresnel Array (UFA) that focuses the radiated RF beam from the RF transmitter to the receiver/Rectenna. The aperture size of the receiver/Rectenna remains the function of Focal length (f) & aperture size (AT) of the UFA, and the distance (L) between UFA and Rectenna. In general, the basic design considerations of the UFA and its cost-effective impact to the space-based power systems in future is described here. The case of 1979 Reference concept from NASA/DOE studies is also used here to demonstrate how the aperture size of receiving station would get reduced with the help of this UFA. The approach has the potential to be used in areas of space applications including SSPS and earth observation radiometry.

Keyword

Space Solar Power, Wireless Power Transmission, Fresnel Lens, Rectenna, Microwave Power

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1. Introduction

The concept of long-range Wireless Power Transmission (WPT) is not new. It goes back to 1941 when Isac Asimov first predicted thcandye possibility of wireless transmission from the space station to various planets in his science fiction story “Reason”. However, in 1968 (Glaser, 1968) Dr Peter Glaser renovated the concept and later after 1973, the concept got worldwide attention when his concept was granted U.S. patent. Currently, the Wireless Power Transmission concept is gathering a considerable interest for its envisaged applications, for example, for unmanned aerial vehicles (UAVs) & High-Altitude Platforms (HAPs) (Gavan & Tapunch, 2010; Oda et al., 2011), feeding pervasive sensors and actuators (Shams & Ali, 2007), fuelling electrical vehicles & transmitting energy to inaccessible regions (Oida et al., 2007; Oman, 2002), etc. Many successful experiments have been carried out to show the feasibility of WPT like the fuel-free airplane experiment called as MILAX (MIcrowave Lifted Airplane eXperiment) (Matsumoto et al., 1993), ISY-METS rocket experiment (Kaya et al., 1993), Microwave Ionosphere Nonlinear Interaction eXperiment (MINIX) (Nagatomo et al., 1986), etc.

There are two fundamental Radio Frequency approaches for WPT: laser power transmission (LPT) and microwave power transmission (MPT). However, MPT is getting greater interest in further development due to its greater efficiency component than laser power transmission and its mature technology enabling it to apply in Space-based Solar Power Systems (SSPS) as confirmed by several experiments (Ishikawa et al., 2013; Mankins, 2014; Brown & Eves, 1992). As far as the working projects of the systems are concerned particularly of SSPS, the size of the transmitting antenna and Rectenna are key point among many constraints about its establishment, which determine the system scale and cost. More specifically, the Rectenna has to maximize the ratio between the incident and collected RF power (Shinohara & Matsumoto, 1998; Strassner & Chang, 2003; Ren & Chang, 2006a; Ren & Chang, 2006b) while Transmitting antenna must coherently focus the transmitted power in a narrow angular sector to the rectennae by possibly minimizing the side lobes (Baki et al., 2006; Baki et al., 2008; Jamnejad & Hoorfar, 2008) to get the maximum Beam Collection Efficiency (BCE). One of the general ways to minimize the aperture area of the antenna on given BCE is the use of shorter wavelength, in other words, a higher frequency for MPT. However, a limited range of microwave frequencies particularly frequencies at 2.45 GHz, 5.8 GHz and 35 GHz are suitable for MPT to the surface of the earth. Therefore, more challenging and significant theoretical and practical developmental techniques are sought to come over the above-mentioned problems.

A large number of design techniques for transmitting antennas have been introduced to solve the shaping problem of WPT beam. In (Takahashi et al., 2011) a remarkable beam steering accuracy (error below 0.1^{o}) despite its minimal complexity in terms of array design, Gaussian taper (Garmash et al., 1998), isosceles-trapezoidal distribution (ITD) (Baki et al., 2006), optimization approaches (Rocca et al., 2009; Rocca et al., 2011), combined stochastic algorithm (CSA) (Shishkov et al., 2006), and an evolutionary programming [EP] strategy as applied in (Jamnejard & Hoorfar, 2008) are some of the other promising techniques to reduce the sidelobe level up to -50 dB (Garmash et al., 1998) and enhance the transmission efficiency up to ~ 99.69% (Baki et al., 2008). However, none of the techniques has proved its viability to converge the Radiating beam to the limit such that the required aperture size of the Rectenna (A_R) can be minimized at least up to the aperture size of Radio Power Transmitter ‘RPT’ (A_T), neglecting the effect of side lobes and meanwhile increase the concentration level of the beam towards the particular point, to reduce the cost of the terrestrial segment and minimize therefore terrestrial environmental effects.

In the literature of Space-based Solar Power Systems, an additional technique using Fresnel optics have been introduced to meet the need of focusing the RF beam. For example, in a very recent published US patent entitling

'Systems for solar power beaming from space' (Rubenchik et al, 2010) a foldable Fresnel optical system developed at Lawrence Livermore National Laboratory (LLNL) was used to focus the laser light onto the ground receiver. The LLNL allows a very compact packaging for launch with an automatic unfolding mechanism and is originally experimented for space-based large telescopes with a diameter of 5 metres and focal length of 250 m (Hyde et al, 2002). Likewise, several large aperture diffractive lenses have been studied to perform astronomy observations. A very recent review study on such telescopes was carried by Haolin Zang et al (Zhang et al, 2019). In the literature, the use of Large aperture Fresnel lens has been also studied for other space exploration programs. Robert Forward in 1984 proposed a first conceptual idea about solar system-based lasers to push large LightSail spacecraft over interstellar distances using 1000-km-diameter lightweight Fresnel zone to focus the laser beam (Forward, 1984). Following the same fundamental concept, some other studies (Matloof, 1984; Meyer et al., 1985; Forward, 1987, Landis, 1999) were also carried out. After the thorough study on the use of Fresnel lens for the different space-based programme, the fact can be established that at smaller scales up to few metres in diameter of the Fresnel lens much technical and basic studies have been carried for the practical implication in the space. However, for other space-based programmes, particularly space travelling and space-based solar power programmes, only some conceptual studies have been presented, paying an open way to study more in detail about the use and construction of Fresnel structures for vast sized space programmes.

In the context of minimizing the required area for the receiver and accessing the freedom of choosing the area for construction of Rectenna for Space-based solar power systems, this paper aims to present a solution using an optical approach of Fresnel array system to focus the RF beam towards the ground station. The array of square-shaped optical elements, integrally consisting as a single and a very large Fresnel lens, is added to the transmitting antenna that converges and focuses the radiated beam towards the receiving station. It is investigated that the aperture size of the receiving station or Rectenna (A_R) depends on the factors like f-number (n) of the Ultra-large Fresnel array (UFA), and the distance (L) between the antennas, and thus the aperture size is controlled.

2. Proposed Optical Approach

In the literature of WPT to minimize the aperture of Receiving Antenna much concern has been given on pattern optimization problems and certain constraints of side-lobe levels of the antenna pattern. However, here in the paper, to reduce the aperture size of the receiving antenna, for the first time in the literature of space based solar power systems we are using an innovative optical technique that consist a specially designed array of optical elements that as a whole act as a single Ultra-large Fresnel lens which changes the optical direction of the integral pattern of the emerging beams from the RF power transmitter and directs the same to the receiver at ground. The ultra-large Fresnel Array (UFA) converge the emerging beam from the transmitter by focusing the beam to the particular point. In this approach, the emerging beam is considered as the parallel beam of the chromatic microwaves and the transmitting surface of the transmitting antenna is considered as a plane array in the configuration.

The UFA is located in the same orbit of the satellite the space part of the SSPS is located and is placed parallel to the array of transmitting antenna at the distance of few meters apart to keep open the path for the dissipation of the heat from the antenna. To visualize the concept of our system we have analyzed the basic conceptual design of the MPT and UFA and is illustrated in Figure 1.

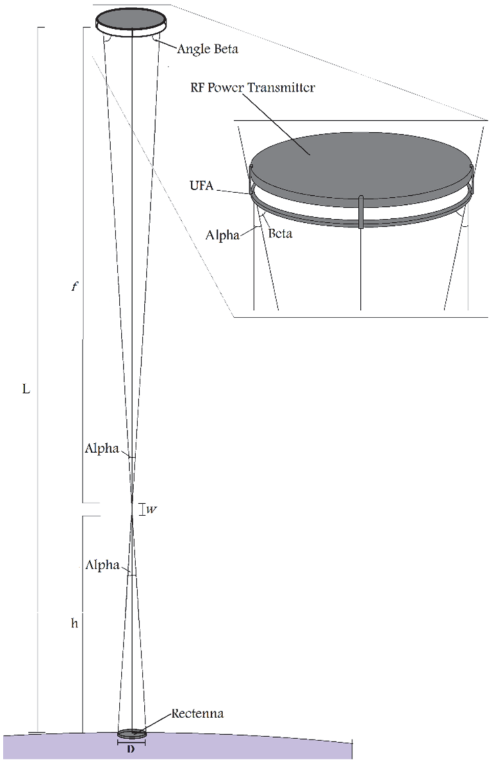

Figure 1 Basic conceptual illustration of MPT & UFA

2.1. Transmitting Array

The fundamental requirement of the transmitting array in our concept is its ability to uniformly excite transmitting elements, meanwhile, decrease the level of side lobes and emit a parallel beam of RF waves.

In literature, several Uniform Weighting and Spacing techniques (Takahashi et al., 2011; Nanokaichi et al., 2005; Hsieh et al., 2003; Kaya & Mankins, 2010) for transmitting antenna have been proposed to improve its performance in terms of maximizing the radiated RF power and at the same time control the sidelobe levels in the beam. As an example, in reference (Takahashi et al., 2011) a prototype has been able to achieve a remarkable beam steering accuracy (error below 0.1o). In (Hsieh et al., 2003) the transmitting array has been able to effectively deliver and steer a 40 W beam at 5.8 GHz by using only two power amplifiers and two-phase shifters. In one of the more recent examples on uniform feeding strategies, as in (Kaya & Mankins, 2010) the experimental validation is presented to deploy a large radiating structure capable of transmitting 20 W at about 150 Km.

2.2. Ultra-Large Fresnel Array (UFA) Plane Assembly & Integration

The aperture area of the required Fresnel lens for each UFA is equal to the aperture area of transmitting area, however, weighs much lesser than transmitting antenna due to ultra-thin and ultra-light nature of the material used in its manufacture. Because of the vast size of the aperture, it becomes impossible to construct UFA as a single aperture; therefore, the approach of sub-array modular design is required to construct the architecture. For this plane assembly of square-shaped symmetric sub-arrays measuring 20 m x 20 m is preferred, for the simple construction of UFA. Each sub-array itself is made from symmetric and square-shaped foldable modules measuring 10 m x 10 m from sides. UFA measuring to 1 km2 as a reference, may, therefore, consist of around 10,000 modules that equals to 40,000 symmetric square-shaped optical elements. The basic illustration of the design of UFA is shown in figure 2.

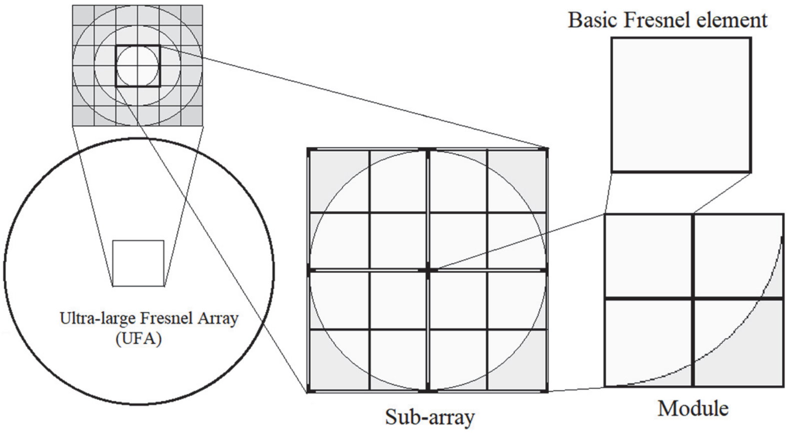

Figure 2 Configuration of Ultra-large Fresnel Array (UFA)

Material

Being the space part of the SSPS the material used in the construction of UFA must be an ultrathin, light weighted and promising material to accept space environmental challenges. A smart starting point for selecting a material is to look at materials used for similar applications. Many studies have been conducted demonstrating the use of Fresnel lens as optical concentrators. (Minano et al., 2013; Languy et al., 2011; Kusko et al., 2009; Jing et al., 2012) are the examples where Polymethylmethacrylate (PMMA) as a basic material is used in the construction of Fresnel lens for Optical concentrator. Furthermore, the Fresnel lens as refractive concentrator has been extensively studied by O'Neil for use in SSPS (O'Neill et al., 2005). In the reference (O'Neill et al., 2015) O'Neill gives the comparison of the different materials used in the construction of Fresnel lens with the lowest possible areal mass density achieved by FEP Film with silicone prisms of about 0.075 kg/m2. The transmittance of the Fresnel lens can be achieved up to 92% as mentioned in references (Piszczor et al., 2006).

In reference (Wong et al., 2000) Refractive concentrators were studied for ultra-high-temperature applications as secondary concentrators, where they bear more than 2000 K of temperature. The Shooting Star Project was initiated by the NASA Glenn Research Centre (GRC) with the collaboration of NASA Marshell Space Flight Centre to demonstrate the thermal propulsion flight experiment using the material Sapphire as refractive secondary concentrator (Wong et al., 2000; Zhu et al., 1999). To design and fabricate the secondary concentrator the tests were taken on, 4-inch x 4-inch x 11.7-inch sapphire bar, it was concluded the transmission efficiency of 96% can be achieved with the help of an anti-reflective coating (Wong et al., 2000). Thus, promising the transmittance efficiency of the Fresnel lens to go up to 96% in future.

The material used in the construction of UFA would be PMMA or the updated version of it with the areal mass density of about 0.075 kg/m^2 and the thickness of about 12.5 microns as is available for Fresnel lens made of FEP film with silicone prisms (O' Neill et al., 2015). The enhanced efficiency of UFA must reach at least 96% that is possible after some research in PMMA Fresnel films fabrication.

Structural Support System

To hold the alignment of optical elements in a plane and maintain the required stretch from deformation, if hit by micrometeorite, space debris or any solar activity, some structural support consisting assembly of frames and interconnects of some light-weighted material is required for UFA construction. For strengthening and restraining the structure from any untoward movement, the structure of UFA is attached in a parallel plane with the transmitting array through the help of some attaching system that may consist an arrangement of clamping elements with jaws on both sides for a firm grasp.

An equal amount of mass to the refractive material is allotted to the structural support. Some of the main parameters of UFA are summarized in Table 1.

Table 1 Design and Structural Parameters of UFA

Parameter	Value	Units
Specific Areal Mass density without Structural Support	0.075	kg/m^2
Average Specific Mass of Each Element with Structure Support	0.15	kg/m^2
Area per Module	100	m^2
Transmission Efficiency	96	%
Total Mass of UFA Taking the Diameter of Transmitting Antenna Equal to 1km as Reference	117,750	kg

Module Packaging

Our module consists of a plane assembly of four identical square-shaped Fresnel elements. Each element is firmly fitted to the separate frame and each frame is interconnected to the neighbouring frame with the help of some hinge system, that helps the module to compactly fold and easily fit in the spacecraft for launching purposes. At the deployment, the hinge system produces the automatic mechanism to flatten and stretch again the module. Because of the vast size of UFA, many space flights are required to transfer the construction material of UFA to the GEO, thus making the final assembly of sub-arrays difficult to form a single plan structure without the use of space robotic techniques, which may exceed therefore the cost of UFAs deployment. In brief, the folding mechanism of modules is illustrated in Fig. 3.

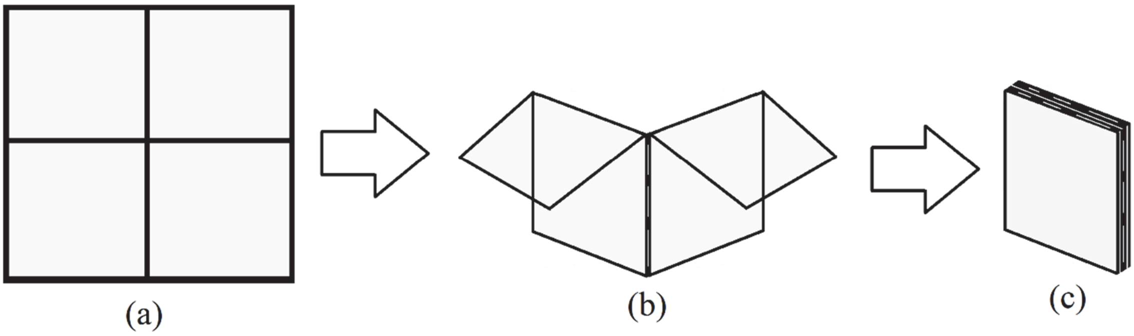

Figure 3 Illustration of the packaging concept of the module.

3. Potential Optical Characteristics of UFA

In general, in radio wave theory, the beam collection efficiency (BCE) between transmitting and receiving antennas based on methods outlined by Goubau and Schwering (Goubau & Schwering, 1968) is calculated by,

$$\tau = \frac{\sqrt{A_T A_R}}{\lambda L} \qquad (1)$$

$$\eta = \frac{P_R}{P_T} = 1 - e^{-\tau^2} \qquad (2)$$

Where AT, AR, L, η , λ and τ are aperture area of the MPT, aperture area of the Rectenna, the distance between these two antennas, the ratio between total power received at receiving station (PR) and total power transmitted by RPT (PT), wavelength of beam, and parameter that connects the system parameters to beam collection efficiency (BCE) respectively.

However, while inducing the UFA the optical characteristics of our system alternate from its original form and looks much similar to the traditional space-based illumination concepts as given in reference (baki and Allen, 1982). Where the size/diameter (D) is related to the altitude (L) of the space-based reflector and solar angle (α) as;

$$D = 2L\tan\alpha \qquad (3)$$

Using the same approach here, we have in figure (1) the value of 'β'- the angle at which microwave beam bends towards the focal point at the boundary of FLA, depends on the focal length 'f' and the radius 'l' of FLA, and are inter-related as;

$$\tan\beta = \tan(90^0 - \alpha) = f/l \qquad (4)$$

Where, α is the converging angle.

Neglecting waist size 'w', since $w \langle\langle L$, the spot size in the design depends on three factors 'α', 'f' and 'L', that is D = f (α, f and L), and are related as;

$$D = 2(L - f)\tan\alpha \qquad (\text{at } w \langle\langle L) \qquad (5)$$

According to the above description and the schematic diagram in figure 1, from the point of waist 'w', the microwave beam get transmitted towards the receiving array 'rectenna' without any side lobes and is predetermined based on the f of UFA to fall in any of the desired field regions of the receiving station by the modified version of relation [5] as;

$$R_r = (L - f)\tan\alpha \qquad (6)$$

Where Rr is the mean radii of Rectenna required.

In terms of f-number (n), where $f = 2nR_t$, equation [6] reads;

$$R_r = (L - f)\frac{1}{2n} \tag{7}$$

Or,

$$R_r = (L - f)\frac{R_t}{f} \tag{8}$$

For the GEO oriented spacecraft, taking the values of L and Rt constant the equation reduces to

$$R_r = \frac{c}{f} - b \tag{9}$$

Where, $c\left(= L \times R_t\right)$ and $b\left(= R_t\right)$ are constants.

For GEO based spacecraft while the AT equals 1 Km2, the dependence of Rectenna size (Rr) on f and in terms of n-factor are shown in figures 4 and 5.

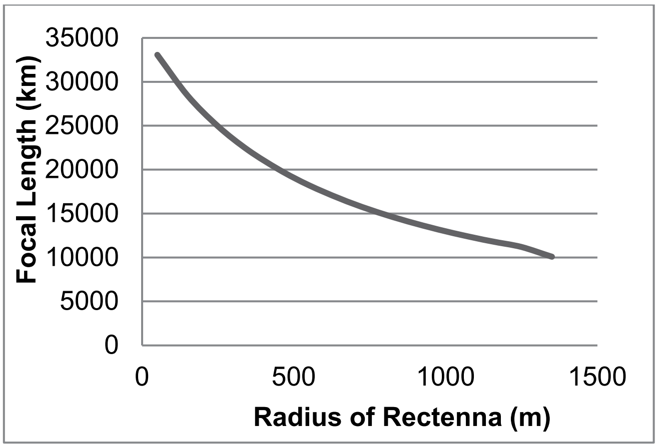

Figure 4 The relation between Rectenna size and focal length of UFA

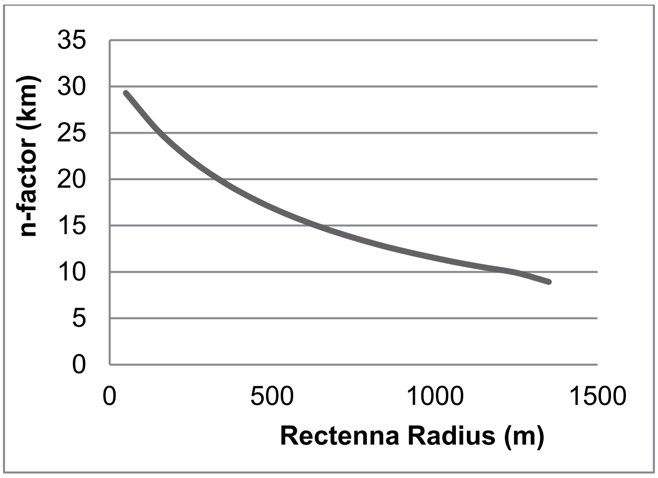

Figure 5 The relation between Rectenna size and n-factor of UFA

4. Case Study of 1979 Solar Power Satellite Reference Concept from the NASA/DOE Studies

To study the input on the terrestrial segment of SSPS using UFA, we take here a reference SSPS concept from the NASA/DOE studies. It is a 5 GW system with a large photo PV array of 50 km2 oriented in GEO. The array converts sunlight into electrical energy, which is then converted into microwaves and transmitted to Earth-based Rectenna with the help of Transmitting Antenna measuring 1 km in diameter. The rectifying antenna measuring 10 km in diameter converts the collected microwave energy back into electrical energy and then it is fed into the power grid for power distribution and management.

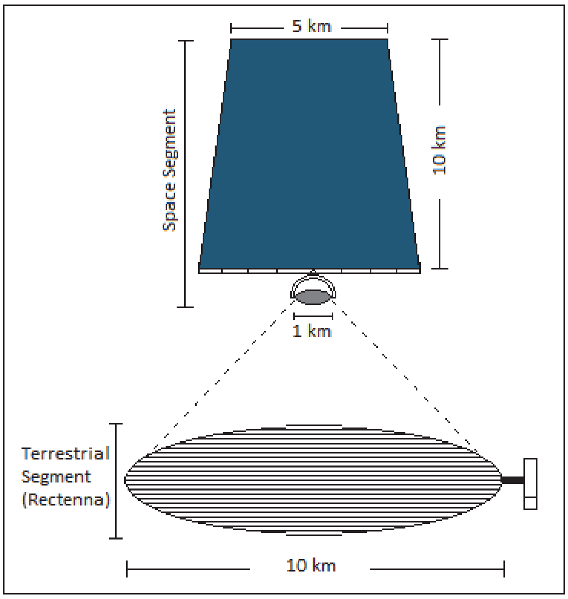

Figure 6 (a) Schematic 1979 Reference System Concept (5 GW)

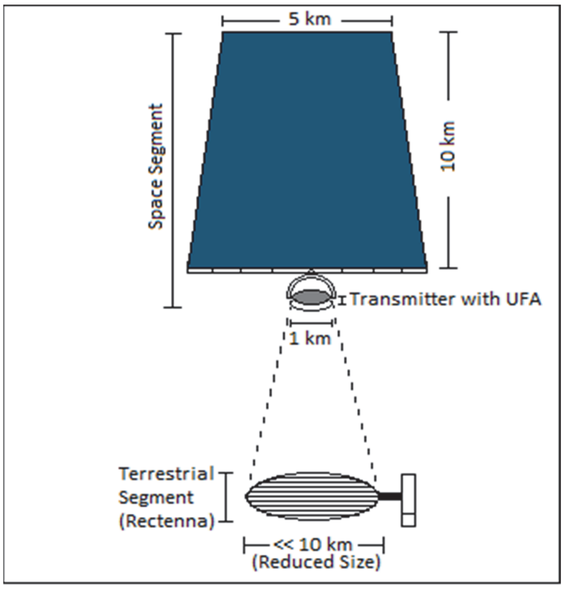

Figure 6 (b) Schematic 1979 Reference System Concept (5 GW) with UFA

The schematic illustration of SSPS reference concept with and without using UFA in the construction of the space segment is shown in Figure 6(a) & 6(b). As represented in reference (Smithermann, 2013) the end-to-end efficiency of SSPS reference concept is 14.79%. Adding the UFA to the transmitting antenna end-to-end efficiency of concept reduces to 14.19 % indicating a 4% drop in efficiency. The list of parameters that get changed after the inclusion of UFA in the concept is enlisted in Table 2 using the data from references (Smithermann, 2013; Office of Energy Research, 1979; Mankins, 1997; Zerta et al., 2004).

Table 2 Some Design and Economical Parameters of SSPS Reference Concept

Parameter	Value without UFA	Value with UFA	Units	Reference
Atmospheric Attenuation to Microwave Transmission	90	≥ 90	%	Smithermann, 2013
Total End-to-End Efficiency	14.79	14.19	%	Smithermann, 2013
Total Mass of Space Satellite	$35x10^6$ (PV)* $50x10^6$ (PV)**	$35.12x10^6$ (PV)* $50.12x10^6$ (PV)**	kg	Office of Energy Research.
Required Land Area for Rectenna *(Neglecting Angular Orientation Effects of Transmitter)*	10	2	km (in diameter)	Smithermann, 2013; Mankins, 1997
Transportation Cost of Space Segment Alone	157.5 (PV)* 225 (PV)**	158.04 (PV)* 225.54 (PV)**	USD (in billions)	Office of Energy Research; Jaffe et al, 2019
Land Cost of Rectenna (European based Rectanna)	847.8	~34	USD (in millions)	Zerta et al., 2004

* Gallium Aluminium Arsenide PV Cells
** Arsenide PV Cells

Due to the atmospheric effects on Microwaves, the transmission of Microwaves reduces to 90% as has been proposed for SSP systems. By attaching the UFA to the transmitter, the beam intensity of microwave increases multiple times. The increasing intensity exceeds the temperature and pressure of the beam enabling the beam to intrude the atmosphere with better efficiency than in normal transmission conditions of the microwave. Hence, in Table 2 transmission efficiency of microwave beam due to inclusion of UFA in reference concept is assumed more than 90%, although more analysis is required to calculate the actual value.

Although, the use of UFA will provide the freedom of choosing the size of the rectenna but the increasing intensity, particularly in the core, may lead to the exceed in environmental effects like ionospheric electron effects and impacts on telecommunications. If the system is used for other space explorations like space travel and civilizing mankind on other heavenly bodies besides planet Earth, the effects can be largely neglected. However, for earth-based receiving stations special concentration is required to be given on certain characteristics while choosing the location of Rectenna like latitude, altitude, local habitation and geography, to reduce the impacts of intense beam crossing the intensity level above the safety standards specified by Institute of Electrical and Electronics Engineers (IEEE) and the American National Standards Institute International (ANSI). One can worry about the dangers associated with the microwave power beam to people, birds or animals that may come accidentally in the radiation zone, however, it is pertinent to know that the biological hazard depends in general on the lag time of the accident the living creature would come. In this regard in1985, the effects of microwave power beam on birds at 2.45 GHz was examined with more than twice the IEEE standard and five times the ICNIRP standard for human exposure. It was found that there was no discernible difference between the control group and the exposed birds (Wasserman et al., 1985).

5. Cost-Effectiveness

To reduce the installation cost of SSPS, much of the concern is given to the space segment of the system. Generally, the job is doing by studying new techniques to increase the efficiency of the elements used in the construction of the space satellite which for specific power production at ground helps to reduce the required concentrator size in reflector based SSPS and collector size in PV based SSPS. However, the actual cost of any SSPS can be analysed by considering installation cost of both segments, i.e. Space segment which primarily includes material cost and its launching cost, and the Terrestrial segment that primarily includes the cost of material, cost of land and the cost required in fencing the station to prevent radiation outside the parameter.

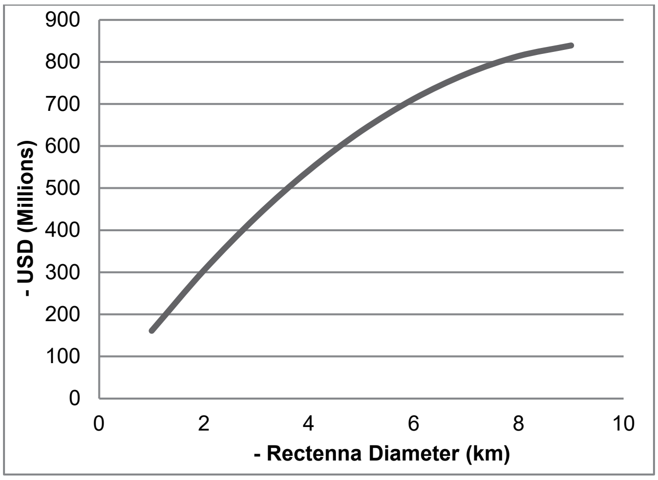

Figure 7 Reduction in cost of Terrestrial segment of Reference concept in terms of change in size of the required land.

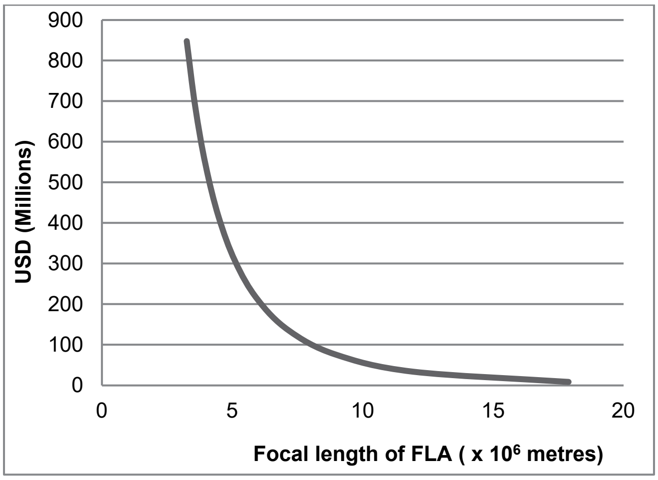

Figure 8 Variation in cost of Terrestrial segment of Reference concept with respect to the change in focal length '*f*' of UFA.

Using a Falcon 9 or a Falcon Heavy in “standard payment plan” configuration with a notional 30% discount on current pricing the cost of placing hardware in GEO is ~ $ 4,500/kg (Jaffe et al., 2019). For our referenced case using the parameters given in Table 1, the total extra mass of UFA required to add in the space segment is 117,750 kg. Since its orientation is GEO the total transportation cost of the space segment will exceed by ~ $ 529.9 million (while the cost of material is excluded here). In the meantime, due to the addition of UFA, the Rectenna size gets reduced that scraps down the total cost of material, land and fencing at Terrestrial station. For European based Rectenna where the cost of land is assumed as 10 EUR/m2 (i.e., ~ 10.8 USD/m2) (Zerta et al., 2004) the cost of land required for installation of Rectenna sized 10 km in diameter (equals to 78.5 km2) account USD 847.8 million. After using specific optical considerations in the manufacture of UFA to change the f of UFA, the cost of Terrestrial segment (Rectenna) based on the cost of the total required land gets varied as indicated in Figure 7and Figure 8. Further, the installation cost reduction of Rectenna in terms of reduction in material cost and fencing cost due to the addition of UFA is not assumed here.

In Figure 7 minus sign (-) indicates the reduction in Rectenna diameter of the Reference concept from its original proposed 10 km diameter value and the associated reduction in total land cost in the Terrestrial segment.

Being the population growth as the main factor the cost of land is consecutively increasing and after a few decades it will touch the skies. Since the successful installation of SSPS is also possible after few decades, it can be therefore assumed that in future Terrestrial segment will be an important concern than Space segment and the trails would be made in reducing the Rectenna sizes as possible. The further growth in technology related to manufacturing and transportation will also reduce the concern of space segment and increase the values of Terrestrial Ground segment of SSPS.

6. Further Research Considerations before Practical Implications of Our System

The approach considering the addition of UFA to the transmitter of Space part of SSPS is a tremendous and promising idea in reducing the aperture size of the Rectenna and thus neglecting the environmental effects at the terrestrial station. However, before its practical adaptation in the SSPS systems, a lot of research is remained to accomplish before. Some of the most prominent areas that need further research before the practical implication are;

1) As already mentioned, active and experimental research is being conducted on the development of Fresnel lens extending in size up to the few metres. However, constructing a UFA of the size of around 1 km^2 with concentric Fresnel zones starting from the centric elements of the array possessing an ability to focus the beam to a single point and having a transmission efficiency of more than 95% is a most challenging task in the approach. Much research is still required to be done on the development of Fresnel zones, simulation and experimental validation of the proposed module concept.
2) Fresnel zones and their corresponding levels led to some non- uniformity in converging beam, this part also needs some consideration to study to neglect the effects.
3) Many design techniques and considerations for transmitting antennas (Massa and Viani, 2013) like closed-form design techniques, synthesis optimization approaches and theoretically Optimal design techniques prove efficiency gains more than uniform weighting technique, challenging, therefore, antenna design of our concept to improve more for enhancing its efficiency.
4) In the approach, a phased array antenna with the least level of sidelobes of RF waves is considered. However, there will be still some effect of diverged sidelobes to the produced beam that would require some additional mathematical and practical study.

7. Conclusions

For the very first time a novel optical approach was introduced in the paper in order to converge the RF wave beam in SSPS before transmitting it towards the receiving station using an Ultra-large Fresnel Array (UFA). The potential optical considerations, the layout of the Fresnel array and the future research considerations before the practical implication of using this novel UFA approach were discussed here also. Furthermore, using the case study of 1979 Solar Power Satellite Reference Concept, the cost-effectiveness of the proposed concept was analyzed based on the land-use area factor for the construction of Rectenna. Finally, it was concluded that the UFA concept offers the potential to reduce the Rectenna size at the receiving station and if used in the future it will curb the total budget of receiving stations in billions of US dollars. As expected, this concept will be of interest also in earth observation radiometry and other space applications other than SSPS area.

Data Availability

The data used to support the findings of this study are included in the article and have been cited with reference where ever it is required.

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수신 스테이션의 개구 면적을 최소화하는 장거리 RF 전송 시스템을 위한 새롭고 혁신적인 광학적 접근 방식

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초록

WPT(무선 전력 전송)에서 수신 스테이션의 개구 면적을 줄이고 집중 비율을 높이고 사이드 로브 레벨의 영향을 줄이는 문제는 안테나 패턴 최적화 문제와 관련이 있다. 연구자는 이러한 문제를 억제하는데 사용할 수 있는 새로운 광학적 접근 방법을 소개하고자 한다. 이 접근방법에서 방사 무선 주파수 빔은 RF 송신기에서 수신기/렉테나(Rectenna)로 방사된 RF 빔을 집중시키는 독특하고 특별히 설계된 UFA(Ultra-large Fresnel Array)를 통해 이동한다. 수신기/렉테나(Rectenna)의 구경 크기는 UFA 의 초점 거리(f) 및 구경 크기(AT)와 UFA 와 렉테나(Rectenna) 사이 거리(L)의 함수로 유지된다. 연구자는 UFA 의 기본 설계시 고려 사항과 향후 공간 기반 전력 시스템에 대한 UFA 의 비용상 효율적 영향을 설명하였다. UFA 의 도움으로 수신 스테이션의 개구 크기가 어떻게 축소하였는지 보여주기 위해 1979 년 NASA/DOE 의 연구 사례도 사용되었다. 본 연구에서 제시되는 접근 방식은 향후 SSPS 및 지구 관측 방사 측정을 포함한 우주 응용 분야에서 사용될 가능성이 있다.

키워드

우주 태양광 발전, 무선 전력 전송, 프레넬 렌즈, 렉테나, 마이크로파 전력