Chapter 2: SSPS concept and features

2.1. Introduction

2.1.1. Basic Concept

The idea of the satellite solar power station is consistent with the laws of physics [5, 59]. It is a large satellite constructed with electric power plant which is placed in suitable orbit and transmitting the power wirelessly using the microwave to a large receiving antenna on earth where it can be used as a conventional power resource [5-7], it is shown in Figure 2. 1. An SSPS primarily consists of three sections, 1st is the space power generation, where space solar energy is collected and transformed into DC (Direct current) power [5-7, 11]. The 2nd section is power transmission where DC power is converted into microwave and space antennas are utilized to transmit microwave power wirelessly [5-7, 13]. The 3rd section is the ground section where a large antenna on the earth is used to receive microwave power and integrated rectifiers convert it back into electrical power [5-7]. Space solar power is collected by using photovoltaic. The DC-to-microwave converter that is used in the SSPS can be either a microwave tube structure or a semiconductor structure, or their combination [13, 16]. The power generated from the SSPS system is significantly high in comparison with the terrestrial solar system due to unhindered solar power accessibility in the space [17]. Also, there is no absorption in earth atmosphere as an SSPS is placed in GEO and solar power is available 24 hours every day. It has been estimated that Atmospheric absorption significantly decreases solar power density by around 35 % [41] which is unavoidable in the terrestrial solar system.

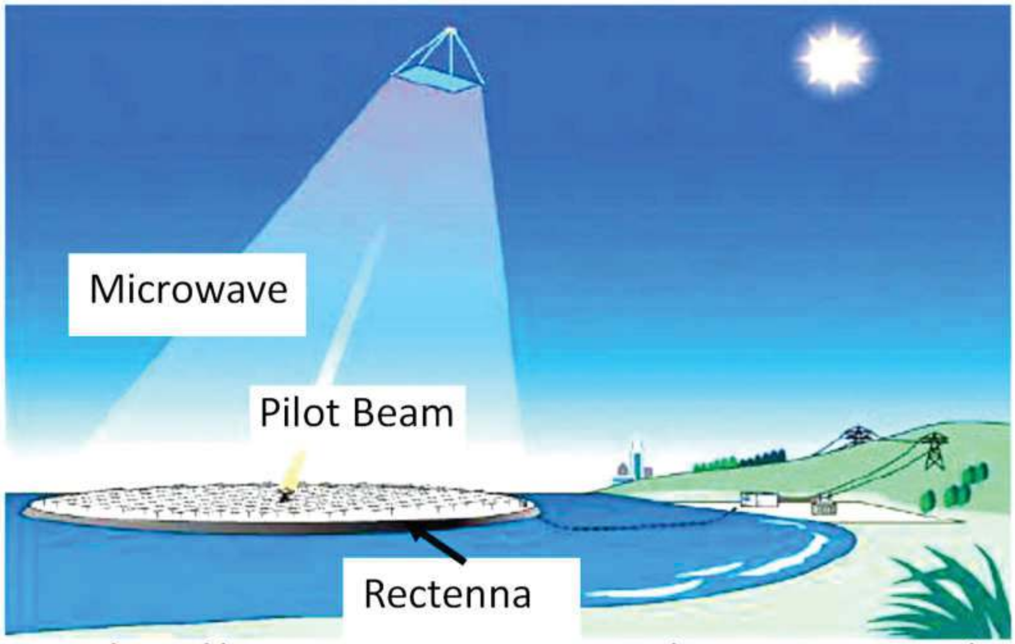

Figure 2. 1 Satellite solar power station [5]

2.1.2. Green energy source

Table 2. 1 Comparison of relative CO_2 emissions from different electricity generation systems (units: g CO_2 /kWh) [1-2, 67]

Generating system	Operations	Construction	Total
SSPS	0	20	20
COAL	1222	3	1225
OIL	844	3	847
Liquefied Natural Gas (LNG)	629	2	631
Nuclear power	19	3	22

For sustainable development, the need to come up with sources of green energy has emerged [5-7]. The electrical power generation from conventional sources like coal, oil & LPG produces carbon dioxide even nuclear power plant produces carbon dioxide for the production of nuclear fuel [1]. However in SSPS operation, significantly less carbon dioxide emission is expected, the estimated value is even less than a nuclear power plant. The comparison of relative carbon dioxide emission per kWh electrical energy from different sources is presented in Table 2. 1 [1-2, 67].

2.1.3. Comparison with terrestrial

The terrestrial solar plants having photovoltaic or solar thermal can generate power only for limited daytime [41, 53]. As solar irradiance fades away on cloudy and stormy days, it's output decreases drastically. The solar panels or solar thermal energy plants have the need of regular care and maintenance for their proper functioning; it is a critical issue in photovoltaic cells because pollution and dirt can degrade photovoltaic efficiency or electrical power production [1-3]. The 24 hours non-interrupted accessibility to solar power in SSPS system makes it the most promising substitute for the current non-conventional energy resources [6].

A direct comparison of electrical energy available from the terrestrial photovoltaic and SSPS as is presented below. Also, the comparative power flow diagram from the terrestrial photovoltaic and SSPS is shown in Figure 2. 2 [2]. The Solar power flux that is available in the space is assumed to be 1370 W/m2 [1, 6]. Commercial thin-film solar cells have an efficiency of 20% [1-2]. Also, DC power to microwave conversion efficiency is 70% [1-2]. In this case, it is assumed that the Microwave transmission beam efficiency is 87% and Microwave to DC power rectenna unit efficiency is 80% [1-2].

The average Energy available per day from SSPS is;

1370W/m2 ×0.2 ×0.7 ×0.87 ×0.80 ×24= 3.20 kWh/m2 /day

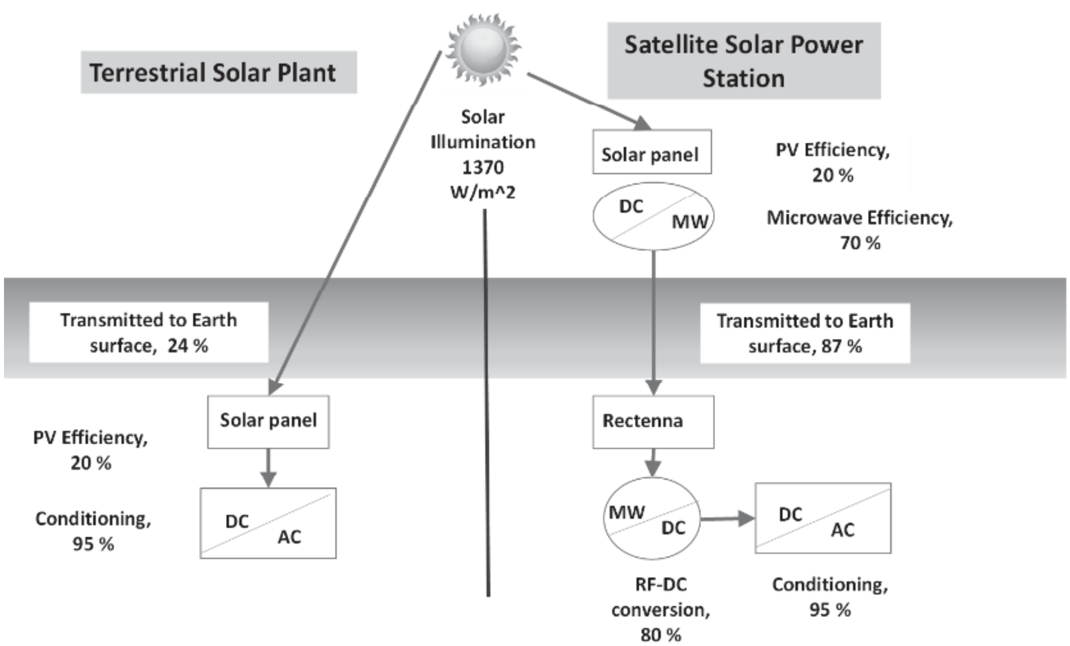

Figure 2. 2 Electrical energy available from the terrestrial photovoltaic and SSPS [2]

On the other hand, for the terrestrial solar power plant, the average solar power flux at a sunny place in New Delhi is 5.6kWh/m^2 [64]. Therefore, the average energy available per day for terrestrial solar power is;

5.6kWh/m2 /day (average) × 0.20 solar cell efficiency = 1.12 kWh/m2 /day

From the above-calculated data, it is found that the available energy output for SSPS is around three times higher than terrestrial units. Therefor SSPS has advantages over terrestrial solar power in many aspects; it is due to undiminished and continuous solar flux available in space [45, 54].

2.2. SSPS Key Technology

2.2.1. Space-based photovoltaic conversion

To develop a practical SSPS, technical issues of photovoltaic, i.e., low weight, low cost, and large-scale production need to be resolved [40, 53-58]. Different photovoltaic technologies are presently being exhausted, aimed at increasing its cell efficiency [53-58]. Summary of different solar cell's efficiencies are listed in Table 2. 2 [57-58]. Recent photovoltaic technology and next-generation photovoltaic will be discussed in this section. Triple junction photovoltaic has been developed with the reported highest efficiency of 30% [1].

Triple junction photovoltaic is currently leading in the space applications, because of their high efficiency per unit mass [58]. The next generation of triple junction photovoltaic with the expected increase in air mass 0 (AM0) efficiency of 2-3% is under development [1, 57-58]. Thin and highly flexible triple junction photovoltaic are desired in space application to provide a low mass photovoltaic array, and it is possible by the elimination of substrate.

Table 2. 2 Summary of Solar Cell Efficiencies [57-58]

Cell Type Demonstrated	Efficiency of Laboratory Devices	Efficiency of Production Devices
Triple junction concentrator cells (GaInP/GaInAs/Ge)	40.7% @ 240 suns	37%@1000 suns, 25 ° C, 1 cm2 aperture (Emcore)
Triple junction 1 sun (GaInP/InGaAs/Ge)	33.8%	28.6% AM0 (Emcore) 28% AM0 (Spectrolab)
Thin Film Crystalline TJ GaInP/InGaAs/InGaAs (IMM)	32% AM0	
Single Crystal GaAs	25.1%	
Single Crystal Si	24.7%	22%, 5” (Sunpower)
Single Crystal InP	21.9%	
Multicrystalline Si	20.3%	16%, 6” (Solarfun) 18.5% (Kyocera)
Thin Film CuInxGa1-xSe2 on glass	14.5% (Nanosolar, Daystar)	
Thin Film CuInxGa1-xSe2 on flex subst		10% (Global Solar Energy, Nanosolar)
Thin Film CdTe on glass	16.5%	10.5%, 2’ × 4’ (First Solar)
Amorphous Si, Nano crystalline Si, dye sensitized, organic polymer	<12%	Ovonics Solar

Triple junction with concentrated irradiance can result in increased efficiency of 40 %. Since air mass spectrum contains ultraviolet and infrared light which is less convertible, thus the photovoltaic efficiency is less in air mass 0 spectrum [1-2, 57-58]. Moreover, thin film and amorphous silicon have low efficiency, and these are still used in satellites because these are less likely to get damaged due to radiation and high temperature (<150 ° C) [1-2]. These are developed on a lightweight and flexible metal base and found suitable in space applications even it has lower specific power than triple junction [1-2].

Table 2. 3 RF source technology for SSPS [17-23]

RF Source	Power/ module (kW)	Efficiency (%)	Comments
Klystron	10-100	70 – 75	High voltage, bulky, moderately expensive
MBK	10-100	70 - 75	Moderately high voltage, expensive
TWT	0.1-0.3	65 - 75	Space qualified, relatively compact, moderately expensive
Magnetron	0.5-5	75 - 85	Inexpensive, compact, phase controllable
GaN SSPA	0.01 – 0.1	50 - 70	Compact, expensive, thermal issues
(MBK: multiple beam klystron, TWT: traveling wave tube, SSPA: solid-state power amplifier)			

2.2.2. DC- microwave

There are various technologies available as alternatives for the transformation of electrical energy into the microwave [10, 13-14]. There are important factors that influence the selection of the optimum DC to microwave converter, these are: a) conversion efficiency, b) operating voltage, c) mean time between failures (MTBF), d) form factor (size, weight, and power per module, and e) cost per watt [1, 10, 27, 33, 45, 65]. Table 2. 3 lists primary technologies at the RF frequencies of interest (2.4 to 6 GHz) and summarizes some of these factors [13, 43].

2.2.3. Launch and transportation

For providing baseload power supply, satellites in SSPS system have to be placed in GEO orbit [5-7]. This leads to many technological challenges, because of the large size of an SSPS system [11]. The expected operational lifetime of SSPS system is around 30 years only [5-7, 11]. Therefore the current transportation system cannot provide with an economic solution. It calls for a cost-effective measure to solve the transportation problem. Thus a reusable space vehicle is needed for this purpose [1, 32-33]. This reusable space vehicle is used to transport the segments of SSPS to a low earth orbit, where it's assembling is performed [32]. Another orbital dispatch vehicle is needed to transfer the SSPS assembly to higher geostationary earth orbit [1]. Thus, these two types of space vehicles can jointly perform this operation efficiently and economically. A novel and economic rocket propulsion technology is required to transfer the payload in this system [32-33]. Mostly the space transport framework at present is mainly focussed on the deployment of communication satellites, which is not applicable for SSPS [32]. Therefore, there is a requirement of 3rd generation reusable launch vehicle aimed for SSPS [1, 32-33].

2.3. Wireless power transfer via microwave

In the point to point wireless power transmission, a highly directive transmitting and receiving antenna is required [10-11, 13]. Nowadays, the phased array antenna beamforming technique is a mature technology [21, 23, 66]. It is used for the design of a high directive beam; Figure 2. 3 shows the propagation of a beam. Here it can be observed that the traveling wave behaves as planer wavefronts for the main lobe region, and after that, it starts propagating like spherical wavefronts [13]. The main lobe length (planar wavefronts) is called near-field region and beyond this (spherical wavefronts) is called far-field region [45, 54, 61, 65]. Since each propagating wavefronts is a packet of the same power, power density depends on the wavefronts own surface area, i.e., more surface area results in less power density [61, 65]. Therefore in wireless power transfer, a receiving antenna beyond the main lobe is undesirable. SSPS considers microwave power transmission for the large distance of 36000 Km, i.e., from GEO orbit to earth [7, 10, 64]. Therefore a propagation technique is required which can cover such large distances under main lobe region. Otherwise, power density received on the earth surface will be too low and rectenna size required to receive most of the power will be very large and impractical [20-23, 45, 54]. In general, Friis transform equation [63], which is used in the communication is given in equation (2.1); it is called far field condition friis transmission [63]. It is noted that equation (2.1) is not valid for SSPS power transfer because SSPS considers near field condition [63-65].

$$\frac{p_{recieved}}{p_{transmitted}} = G_t G_r \left(\frac{\lambda}{4\pi D}\right)^2 \qquad (2.1)$$

Where G_t and G_r are the antenna gains, λ is the wavelength

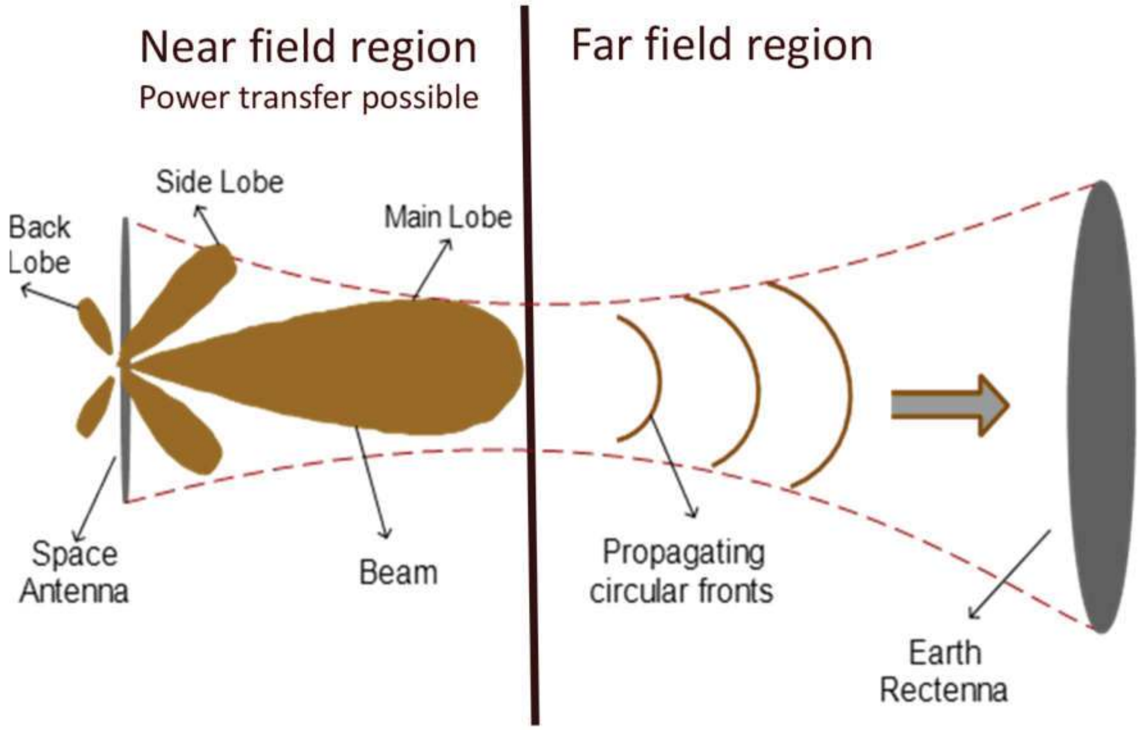

Figure 2. 3 Directive beam propagation [10]

2.3.1. High power transmission for large distance

As discussed earlier SSPS aims at sending high power wirelessly for the large distances, i.e., from geostationary equatorial orbit (GEO) orbit to earth [7]. To bring this large distance in the near-field region is a challenging task, but with technological advancement it is possible.

The most suitable way to do this is by using the Gaussian beamforming technique for the transmission [10, 13, 60-65]. A properly designed phase antenna array with amplitude tapering can be utilized for Gaussian beamforming as shown in Figure 2. 4 [65]. As Gaussian beam generates planar wavefronts for a large range of distance, so it is conceivable for SSPS implementation [1, 20-21]. For the Gaussian beam propagation, Rayleigh length is the boundary condition, where planar wavefront changes to spherical [61-65]. So the distance up to Rayleigh length is called near field condition and beyond that is called Far field condition. For the efficient point to point power transfer, the receiver antenna must be placed within near field. Considering equation (2.2) which gives expression of Rayleigh length. Here it is noticeable that Rayleigh length depends on the beam waist ω_0 at the transmission level [61,65]. Thus, a properly tapered phase antenna can be designed with large beam waist ω_0 such that it covers GEO distance within near field condition.

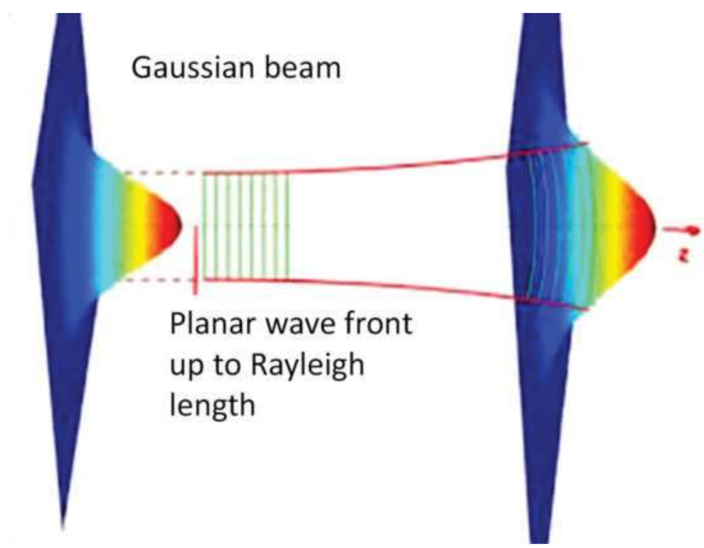

Figure 2. 4 A properly designed phase antenna array with amplitude tapering is utilized for Gaussian beamforming [65]

There are safety and security limits on microwave power density level on the ground, which needs critical consideration in SSPS design process [50]. Thus the power density received on the ground rectenna is a key issue. Considering SSPS in Rayleigh length or near field condition, the Gaussian beam reaches ground antenna has the average power density P_d which depends on Beam waist contour ω *(z)* and Radius of curvature *R (z)*, where *z* is the distance of transmission [62, 65]as shown in Figure 2. 5 [65]. Also, it has to be noticed that, the designed rectenna efficiency is sensitive to variation in P_d, and at a particular P_d value maximum efficiency is obtained. Therefore SSPS design depends on many interrelated parameters and an optimized design is required. Here parameters Z_0, ω *(z), R (Z)* are given as follows.

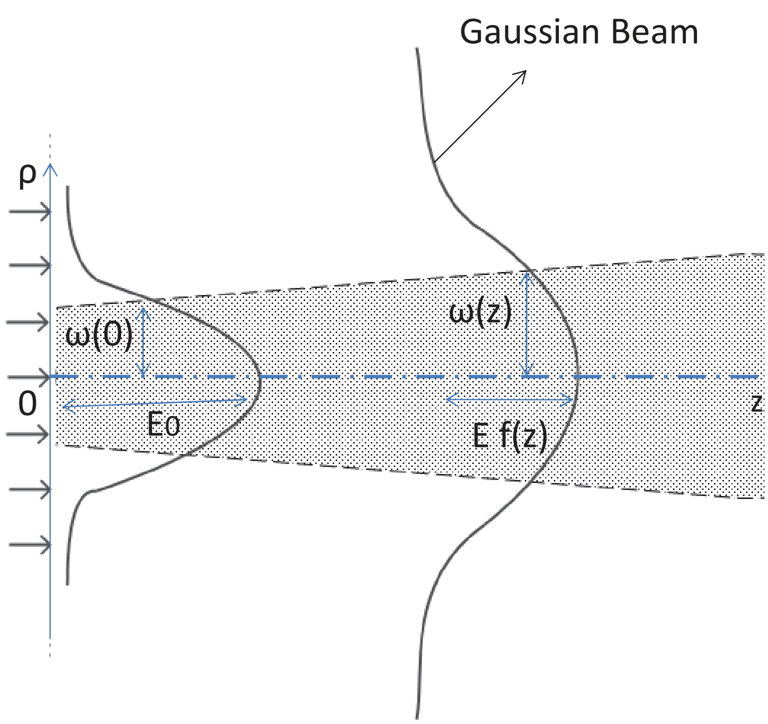

Figure 2. 5 Gaussian beam propagation [65]

$$Z_0 = \frac{\pi n \omega_0}{\lambda} \qquad (2.2)[63]$$

$$\omega^2(z) = \omega_0^2 \left[1 + \left(z / Z_0 \right)^2 \right] \qquad (2.3)[63]$$

$$R(z) = z \left[1 + \left(Z_0 / z \right)^2 \right] \qquad (2.4)[63]$$

Here, Z_0 is Rayleigh length; ω_0 is beam waste at transmission level; λ is wavelength; $\omega(z)$ is beam waste changes with Z ;
$R(z)$ is Radius of curvature;

$$\frac{p_r}{p_t} = \frac{\left| \int_A E_r \bullet E_t ds \right|^2}{\left\{ \mathrm{Re} \int_{A_r} |E_r|^2 ds \right\} \left\{ \mathrm{Re} \int_{A_t} |E_t|^2 ds \right\}} \qquad (2.5)$$

Here, *Pr, Er*, power and electric field at Receiving station respectively;
Pt, Et, power and electric field at transmitting station respectively
At, Transmitting antenna area
Ar, Receiving antenna area

For the fundamental Gaussian mode, these integrations in equation (2.5) result in equation (2.6)

$$\frac{p_r}{p_t} = \frac{A_t A_r}{\left(\frac{A_t + A_r}{2} + \lambda^2 D^2 \right)} \qquad (2.6)$$

λ, Operating wavelength
D, the distance between

Where for the large value of D equation (2.6) reduced to equation (2.7) that is the reformed Friis transmission expression.

$$\frac{p_r}{p_t} \simeq \frac{A_t A_r}{\left(\lambda^2 D^2\right)} = \tau^2 \qquad \tau^2 \text{ is power transmission efficiency} \qquad (2.7)$$

$$\eta_{beam} = 1 - e^{-\tau^2} \qquad \text{Beam efficiency} \qquad (2.8)$$

Thus considering near field condition transformed Friis transmission equation is given in equation (2.7) [62, 64]. Also, the expression for beam efficiency is provided in equation (2.8).

2.4. SSPS Microwave Power Transmission Effects on the Atmosphere and Space

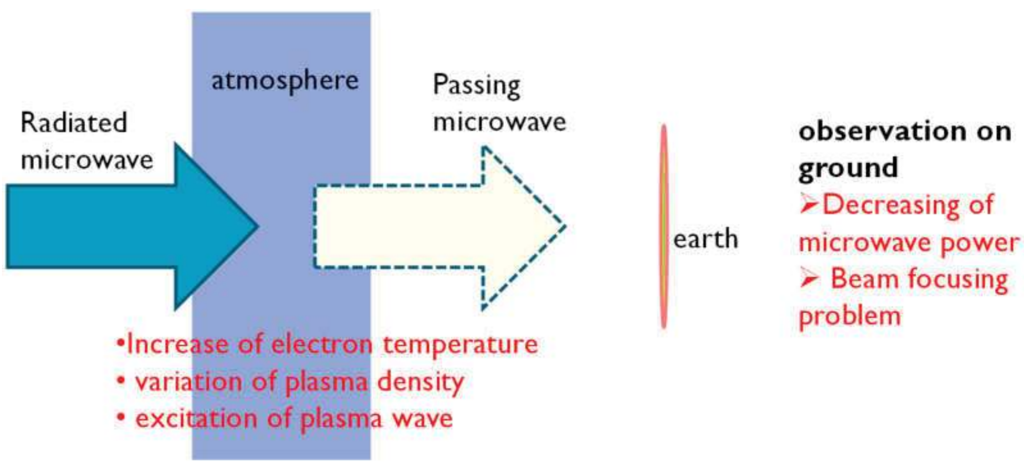

Figure 2. 6 Microwave power transmission in space [48]

In SSPS, the microwave transmission effects in the space and atmosphere cannot be ignored, and analytical study is required before implementation and testing [50-52]. SSPS microwave power transmission in space is shown in Figure 2. 6, and transmission through the atmospheric layers is shown in Figure 2. 7 [17]. In general, the transmission at lower frequencies has higher atmospheric attenuation. On the other hand for higher frequencies of transmission, ionosphere interaction is more effective [65]. Therefore frequencies, i.e., 2.45 and 5.8 are suitable for transmitting the power to the ground, which is within the microwave windows of the atmosphere [46-50, 65].

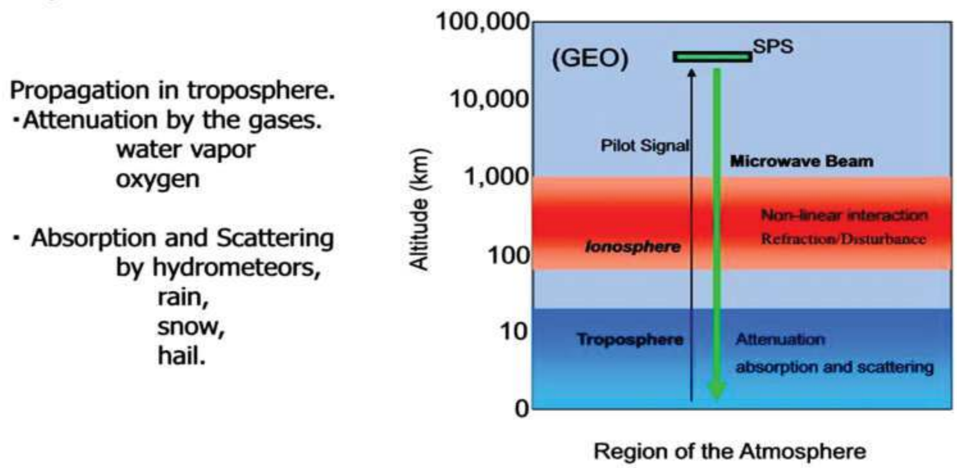

Figure 2. 7 A pilot control Microwave power transmission [17]

Microwave passing through ionosphere is affected due to absorption [14-15]. This phenomenon is called ohmic heating [46-48, 65]. In lower ionosphere higher electron density is present causing more ohmic heating. Unfortunately, electron heating measurement due to high power microwaves is not available in the literature, and only theoretical results are available [14-15, 62, 65]. Another effect of high power microwaves is the production of plasma waves through resonant interactions; it is due to parametric instabilities. It is noticed that this plasma instability can produce secondary electromagnetic (EM) waves, which have further electron heating effect and irregular electron density [1, 46-48, 65]. Also, it is expected that there will be a loss of microwave Power due to normal atmospheric absorption. However, it is assumed to be below 2% which is significantly low [1, 65]. Therefore if microwave exposure safety and security limit is applied to the received power density on the earth, it has negligible effect. The impact of microwave transmission, its mechanism and assessment are shown in Figure 2. 8.

	influence	mechanism	assessment
Ionosphere	Refraction effect	Refraction by plasma	Pilot beam control
	Faraday rotation	Rotation by the magnetic field	Transmission efficiency is not affected
	Non linear interaction	Parametric instability excitation, electron thermal runway	Small impact on transmission with high power density beam
Atmosphere	Atmospheric absorption	Attenuation by gases, water vapors	Effect on efficiency is 2%

Figure 2. 8 Microwave power transmission impacts and assessment on space [1]

2.5. SSPS cost minimization method

2.5.1. SSPS estimated economic modeling

In this section, SSPS economic model is presented. SSPS total system cost reduction is desirable, and therefore an economic model of the system is needed to be developed. The initial cost of the system is estimated using various interrelated parameters of the components. The components of Initial cost are as follows:

$$Initial\ cost = solar\ array\ cost + microwave\ circuit\ cost + transmission\ antenna\ cost + recieving\ antenna\ cost + power\ processing\ unit\ cost$$

In the space section, initial costs comprise of the solar array cost, microwave equipment cost, and microwave transmission cost [1-6]. The microwave power beam transmits the space energy to the earth. The ground rectenna then changes the received microwave power back to electrical energy. In the ground segment, the cost is expected as the cost of rectenna and power handling unit [1-2, 7]. The above expression terms could be expressed mathematically in the form of interrelated parameters as given below:

$$C = \frac{m_s P_t}{\eta_{sm}} + m_t P_t + a_t A_t + m_r P_r + a_r A_r \tag{2.9}$$

Here, C= Initial cost; P_t= Transmitted power; m_s= Cost of Photovoltaic power per kW; η_{sm}= Photovoltaic conversion efficiency; m_t= Cost of equipment to convert microwave power per kW; a_t= Cost of transmission antenna per unit area; A_t= Transmission antenna area; m_r= Cost of ground equipment to convert received power per kW; P_r= Power received on rectenna; a_r= Cost of ground rectenna per unit area; A_r= Rectenna area.

In the formation of equation (2.9), it is assumed that there is a comparable SSPS model is available, which has attained the standard cost level [10-13]. For the space segment, the solar array and the transmitting modules which contain both antenna and DC-microwave converter are considered. The solar array cost can be expressed in terms of microwave power *Pt* , and the solar to microwave power conversion efficiency η_{sm} [4]. Microwave transmission cost is dependent on the components size and their power rating. For the power transmission, the related cost is linearly dependent on antenna size [1, 60-65]. And the cost regarding the power ratings are also considered to be directly proportional to the transmitted value of power *(Pt*) [65]. In the same way, the derivation is done for the ground segment where rectenna and power modules costs are formulated. The proportionality constants m_s, m_t, m_r and a_t,a_r are used in the algebraic formulation of power and area related expression as given in equation (2.9). Now, *Pt* can be expressed in the form of *Pd* (the power density at the ground rectenna site) utilizing reformed Friss equation (2.7).

On putting equation (2.7) in the Equation (2.9), Equation (2.10) and (2.11) gives the expression in terms of *Pd*. The received power density *Pd* is known value because it has limitation due to microwave safety and security confines [50-52]. In equations (2.12)-(2.14), parameters are arranged to make expression simple.

$$C = m_s \frac{P_r \lambda^2 D^2}{\eta_{sm} A_t A_r} + m_t \frac{P_r \lambda^2 D^2}{A_t A_r} + a_t A_t + m_r A_r + a_r P_r \tag{2.10}$$

$$C = m_s \frac{P_d \lambda^2 D^2}{\eta_{sm} A_t} + m_t \frac{P_d \lambda^2 D^2}{A_t} + a_t A_t + m_r A_r + a_r P_r \tag{2.11}$$

$$C = \left(\frac{m_s}{\eta_{sm}} + m_t\right) \frac{P_d \lambda^2 D^2}{A_t} + a_t A_t + m_r A_r + a_r P_r \tag{2.12}$$

$$C = \left(\frac{m_s}{\eta_{sm}} + m_t\right) \frac{P_d \lambda^2 D^2}{A_t} + a_t A_t + (m_r + a_r P_d) A_r \tag{2.13}$$

$$C = (m_{st})\frac{P_d\lambda^2D^2}{A_t} + a_tA_t + (m_{rd})A_r \qquad (2.14)$$

Here, $m_{st} = \frac{m_s}{\eta_{sm}} + m_t$; And $m_{rd} = m_r + a_rP_d$;

2.5.2. Derivation for cost minimization

Up to this point, the equation (2.14) has both A_t and A_r terms. Now the beam efficiency [10, 13] as given in equation (2.8) is used to interrelate both terms. On putting equation (2.7) in equation (2.8), A_r is expressed in term of A_t parameter as in equation (2.15).

$$A_r = \frac{\lambda^2D^2\{-ln(1-\eta_{beam})\}}{A_t} \qquad (2.15)$$

On Putting the value of the expression (2.15) in the equation (2.14), the formulated cost is expressed now in terms of A_t, power density P_d, wavelength λ, the separation D and the proportionality constants as in equation (2.16). Now expression (2.16) can be used to find the size of transmitting antenna at which it will give the least cost. The derivative condition is applied as in equation (2.17) to determine the minimum cost value. For minimum cost case, At_{min} as in expression (2.18) gives the value of the required antenna dimension. On putting equation (2.18) in the expression (17), the minimum cost expression is derived in equation (2.19) and simplified in expression (21).

$$C = (m_{st})\frac{P_d\lambda^2D^2}{A_t} + a_tA_t + (m_{rd})\frac{\lambda^2D^2\{-ln(1-\eta_{beam})\}}{A_t} \qquad (2.16)$$

$$\frac{d(C)}{dA_t} = (m_{rd})\frac{\lambda^2D^2\{ln(1-\eta_{beam})\}}{{A_t}^2} - (m_{st})\frac{P_d\lambda^2D^2}{{A_t}^2} + a_t \qquad (2.17)$$

$$A_{t_{min}} = \lambda D \sqrt{\frac{(m_{st})P_d - (m_{rd})\{ln(1 - \eta_{beam})\}}{a_t}} \quad (2.18)$$

$$C_{min} = a_t A_{t_{min}} + (m_{st}) \frac{P_d \lambda^2 D^2}{A_{t_{min}}} + (m_{rd}) \frac{\lambda^2 D^2 \{-ln(1 - \eta_{beam})\}}{A_{t_{min}}} \quad (2.19)$$

$$C_{min} = 2\lambda D \sqrt{a_t} \sqrt{(m_{st})P_d - (m_{rd})\{ln(1 - \eta_{beam})\}} \quad (2.20)$$

2.5.3. SSPS prototype estimated cost

Table 2. 4 SSPS prototype parameters [1]

Parameters	Value
D(km)	36000 (Geo separation)
Frequency(GHz)	2.45 & 5.8
m_s($)	1000
η_{sm}(%)	70
m_t($)	1000
m_r($)	200
a_t($)	4(aluminium)
a_r($)	100
P_d(w/m^2)	100(microwave exposure safety limits)
η_{beam}(%)	90

SSPS prototype parameters are given in Table 2. 4. On putting parameters values in the expression (20) and calculated results are shown in Figure 2. 9, it is noted that minimum cost value is sensitive to the operation frequency and the distance D.

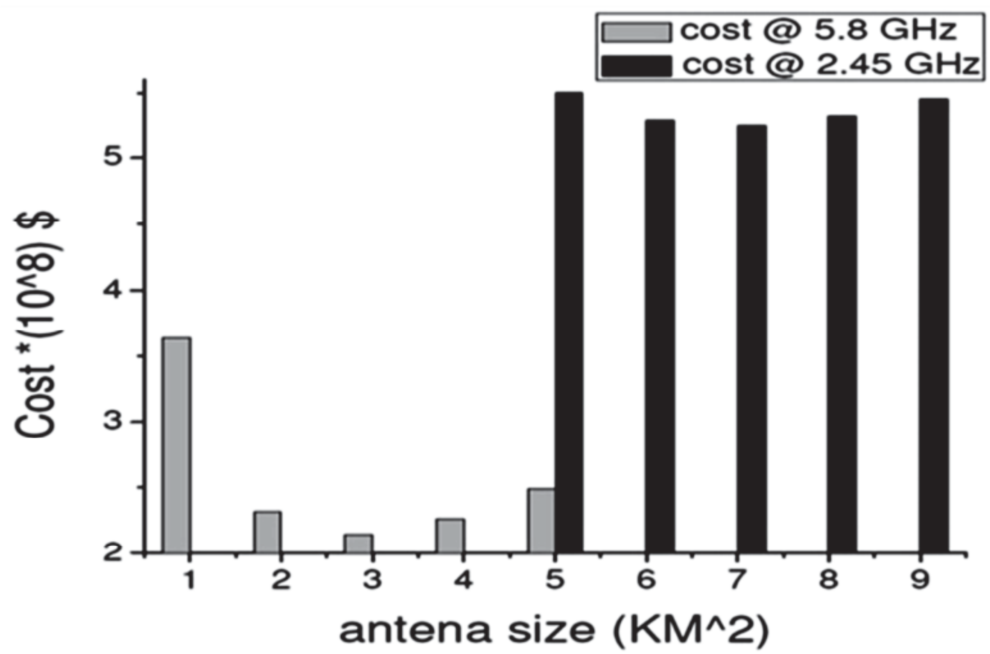

Figure 2. 9 Cost variation with antenna size

2.5.4. Levelized cost of Energy (LCOE) estimation

SSPS life cycle of 30 years is considered here to calculate the LCOE. Life cycle cost includes SSPS launch, space segment, and the ground segment costs. Here SSPS launch cost can be assumed 1000$/kg in the financial year 2030 [1-6]. For the weight to power conversion efficiency 20%, space launch cost becomes 5000$/ kW [1-2, 65]. LCOE for operating frequency of 2.45 GHz & 5.8 GHz is shown in Figure 2. 10, and Figure 2. 11 respectively. It has been illustrated here that at higher power ratings the LCOE of SSPS system tends to saturate.

$$LCOE = \frac{Life\ cycle\ cost}{Total\ energy}$$

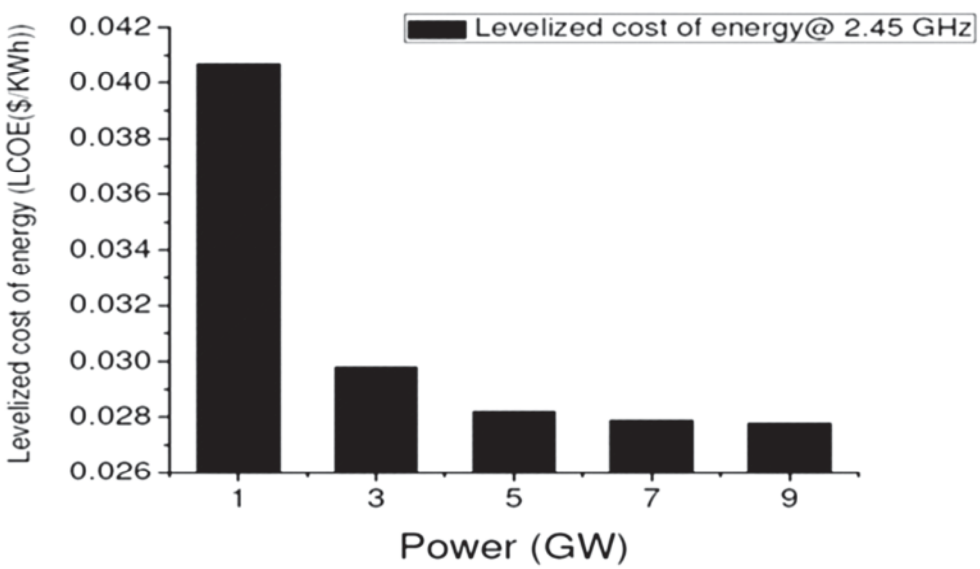

Figure 2. 10 LCOE for different GW power at 2.45 GHz

2.5.5. Least cost per kW derivation

By using At_{min}, the corresponding transmitted power, received power and minimum cost per kW has been found in equation (2.21), (2.22) and (2.23) respectively. Here it is noted that minimum cost per kW is independent of frequency and transmission distance, although it depends on the parameters P_d and η_{beam}.

$$P_{t_{min}} = \frac{P_d \lambda^2 D^2}{A_{t_{min}}} \tag{2.21}$$

$$P_{r_{min}} = \frac{P_d \lambda^2 D^2 \{-ln(1 - \eta_{beam})\}}{A_{t_{min}}} \quad (2.22)$$

$$C_{min}/_{per\ KW} = 2a_r + \frac{2m_r}{P_d} + \frac{2m_{st}}{\{-ln(1 - \eta_{beam})\}} \quad (2.23)$$

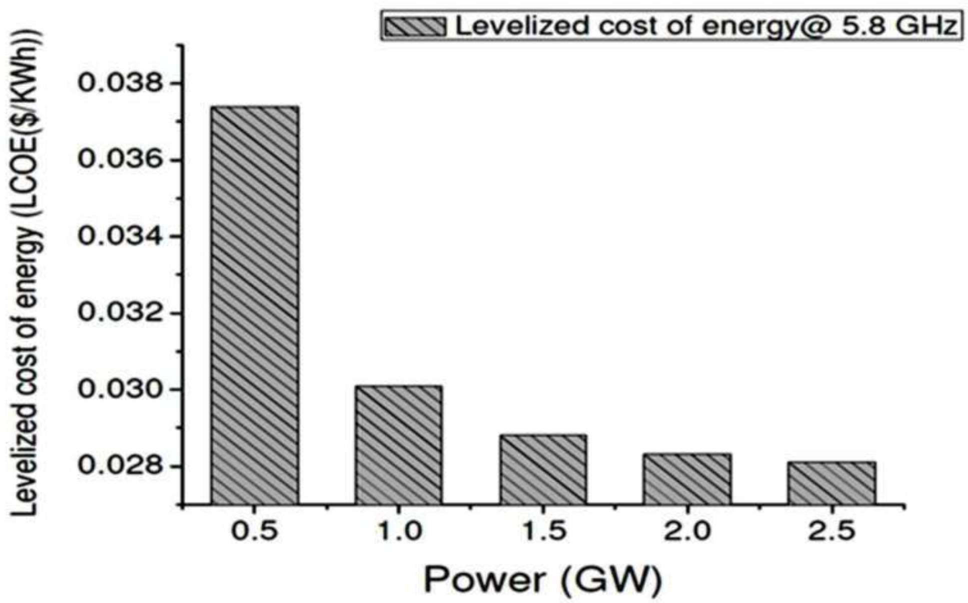

Figure 2. 11 LCOE for different GW power at 5.8 GHz

2.6. Summary

Various key issues pertaining to SSPS are discussed in this chapter. Furthermore, large distance high power transfer via microwave is explored, and Gaussian beamforming is found suitable at 2.45 GHz and 5.8 GHz frequency. Moreover, the cost minimization method for SSPS is proposed. In Space section, transmitting antenna size reduction is possible utilizing optimized interrelated parameters of the system components. For the given parameters of SSPS prototype, the minimum cost is derived for transmitting microwave power with power density (100 W/m^2) at the receiving antenna. The minimum cost is found at 5.28 $\times 10^8$ \$ at 2.45 GHz and 2.3 $\times 10^8$ \$ at 5.8 GHz. In the cost vs. frequency analysis, it is found to be inversely proportional. Also, it is found that the least cost /kW value is not depending on frequency and distance. The initial cost/kW with addition space launch cost/kW is determined for LCOE evaluation; the LCOE value decreases initially then saturates with power variation. At 5.8 GHz and 2.45 GHz, it saturates after 3 GW and 10 GW respectively. Therefore one can conclude, SSPS with higher capacity is economically beneficial.