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**Semester: I**

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| **Seminar Title** | | | **Space Based Solar Power** | |
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**ABSTRACT:**

Space-based solar power (SBSP) is the concept of collecting solar power in space (using an "SPS", that is, a "solar-power satellite") for use on Earth.   In conventional solar power generation a considerable fraction of incoming solar energy (55–60%) is lost on its way through the Earth’s atmosphere by the effects of reflection and absorption. Space-based solar power systems convert sunlight into microwaves outside the atmosphere thus avoiding these losses.

**INTRODUCTION:**

Every hour more solar energy reaches the earth than humans use in a year. About 30% of this energy is reflected back into the space by the atmosphere. Space-based solar power (SBSP) is the concept of collecting solar power in space (using an "SPS", that is, a "solar-power satellite") for use on Earth. It has been in research since the early 1970s. SBSP would differ from current solar collection methods in that the means used to collect energy would reside on an orbiting satellite instead of on Earth's surface. Some projected benefits of such a system are a higher collection rate and a longer collection period due to the lack of a diffusing atmosphere and night time in space. Part of the solar energy (55-60%) is lost on its way through the atmosphere by the effects of reflection and absorption. Space-based solar power systems convert sunlight to microwaves outside the atmosphere, avoiding these losses, and the downtime due to the Earth's rotation.[1][2]

**HISTORY AND DEVELOPMENTS:**

(1973)

 The SBSP concept, originally known as satellite solar-power system (SSPS), was first described in November 1968. In 1973 Peter Glaser was granted U.S. patent number 3,781,647 for his method of transmitting power over long distances (eg. from an SPS to Earth's surface) using microwaves from a very large antenna (up to one square kilometer) on the satellite to a much larger one, now known as a rectenna, on the ground.

**Satellite Power System Concept Development and Evaluation Program (1978-1986)**

Between 1978 and 1986, the Congress authorized the Department of energy (DoE) and NASA to jointly investigated the concept. They organized the Satellite Power System Concept Development and Evaluation Program. Several reports were published investigating the engineering feasibility of such an engineering project. They include:

* Resource Requirements (Critical Materials, Energy, and Land)
* Financial/Management Scenarios
* Public Acceptance
* State and Local Regulations as Applied to Satellite Power System Microwave Receiving Antenna Facilities
* Student Participation
* Potential of Laser for SBSP Power Transmission
* International Agreements
* Centralization/Decentralization
* Mapping of Exclusion Areas for Rectenna Sites
* Economic and Demographic Issues Related to Deployment
* Some Questions and Answers
* Meteorological Effects on Laser Beam Propagation and Direct Solar Pumped Lasers
* Public Outreach Experiment
* Power Transmission and Reception Technical Summary and Assessment
* Space Transportation

The project was not continued with the change in administrations after the 1980 US Federal elections.  The Office of Technology and Assessment concluded that "Too little is currently known about the technical, economic, and environmental aspects of SPS to make a sound decision whether to proceed with its development and deployment.[1]

**NASA’s "Fresh Look” Study: (1997)**

In 1997, NASA conducted its "Fresh Look" study to examine the modern state of SBSP feasibility. The study examined 5 different markets and about 30 different SPS concepts, ranging from the 1979 SPS Reference Concept defined by the US Department of Energy and NASA to very advanced concepts.[1]

### Space Solar Power Exploratory Research and Technology program(1999)

In 1999, NASA's Space Solar Power Exploratory Research and Technology program (SERT) was initiated. SERT went about developing a solar power satellite (SPS) concept for a future gigawatt space power system, to provide electrical power by converting the Sun's energy and beaming it to Earth's surface, and provided a conceptual development path that would utilize current technologies.

Some of SERT's conclusions:

* The increasing global energy demand is likely to continue for many decades resulting in new power plants of all sizes being built.
* The environmental impact of those plants and their impact on world energy supplies and geopolitical relationships can be problematic.
* Renewable energy is a compelling approach, both philosophically and in engineering terms.
* Many renewable energy sources are limited in their ability to affordably provide the base load power required for global industrial development and prosperity, because of inherent land and water requirements.
* Based on their Concept Definition Study, space solar power concepts may be ready to re-enter the discussion.
* Solar power satellites should no longer be envisioned as requiring unimaginably large initial investments in fixed infrastructure before the emplacement of productive power plants can begin.
* Space solar power systems appear to possess many significant environmental advantages when compared to alternative approaches.
* The economic viability of space solar power systems depends on many factors and the successful development of various new technologies (not least of which is the availability of much lower cost access to space than has been available); however, the same can be said of many other advanced power technologies options.
* Space solar power may well emerge as a serious candidate among the options for meeting the energy demands of the 21st century.
* Launch costs in the range of $100–$200 per kilogram of payload from low earth orbit to Geosynchronous are needed if SPS is to be economically viable.[1]

**The IAA Study of Space Solar Power: (2011)**

The International Academy of Astronautics (IAA) has conducted the first broadly based international study of the concept of space solar power. The goals of the study were to determine what role space solar power (SSP) might play in meeting the rapidly growing need for abundant and sustainable energy during this century, to assess the technological readiness and risks associated with the SSP concept, and (if appropriate) to frame a notional international roadmap that might lead to the realization of this visionary concept. [3]

Some of the findings of IAA were:

1: Solar Power Satellites appear to be technically feasible as soon as the coming 10-20 years using technologies existing now in the laboratory (at low- to moderate- TRL) that could be developed / demonstrated (depending on the systems concept details).

2: There are several important technical challenges that must be resolved for each of the three SPS systems types examined by the IAA study. S

3 : Low-cost Earth-to-orbit transportation is an enabling capability to the economic viability of space solar power for commercial baseload power markets. [[][[[[[[[[[energy reaches

### Japan Aerospace Exploration Agency (2015):

The May 2014 IEEE Spectrum magazine carried a lengthy article by Susumu Sasaki. The article stated, space-based solar power could at last become a reality—and within 25 years, according to a proposal from researchers at the Tokyo -based Japan Aerospace Exploration Agency (JAXA)."

JAXA announced on 12 March 2015 that they wirelessly beamed 1.8 kilowatts 50 meters to a small receiver by converting electricity to microwaves and then back to electricity. This is the standard plan for this type of power.[[37]](https://en.wikipedia.org/wiki/Space-based_solar_power#cite_note-ATarantola-37)[[38]](https://en.wikipedia.org/wiki/Space-based_solar_power#cite_note-PKT-38) On 12 March 2015 Mitsubishi Heavy Industries demonstrated transmission of 10 kilowatts (kW) of power to a receiver unit located at a distance of 500 meters (m) away.[4]

ofays onto smaller solar collectors. This radiation is then wirelessly beamed to Earth in a safe and controlled way as either a microwave or lase

**DESIGN AND WORKING:**

Space-based solar power essentially consists of three elements:

1. Collecting solar energy in space with reflectors or inflatable mirrors onto solar cells or heaters for thermal systems.
2. Wireless power transmission to Earth via microwave or laser.
3. Receiving power on Earth via a rectenna, a microwave antenna

**1.Collecting of Solar Energy:**

Self-assembling satellites are launched into space, along with reflectors and a microwave or laser power transmitter. Reflectors or inflatable mirrors spread over a vast swath of space, directing solar radiation onto solar panels. These panels convert solar power into either a microwave or a laser, and beam uninterrupted power down to Earth. On Earth, power-receiving stations collect the beam and add it to the electric grid.

The two most commonly discussed designs for SBSP are a large, deeper space microwave transmitting satellite and a smaller, nearer laser transmitting satellite.[1][2][3]

**2.Wireless power transmission to Earth via microwave or laser:**

**a.Microwave Transmitting Satellites**

Microwave transmitting satellites orbit Earth in geostationary orbit (GEO), about 35,000 km above Earth’s surface. Designs for microwave transmitting satellites are massive, with solar reflectors spanning up to 3 km and weighing over 80,000 metric tons. They would be capable of generating multiple gigawatts of power, enough to power a major U.S. city.

Microwaves are a form of electromagnetic waves in a wavelength range often used for communications, 0.1 mm to 10 cm (frequencies between 0.1 and 100 GHz). Antenna arrays composed of numerous antenna elements can be used to transmit electric power from space to the ground in microwave form. By controlling and synchronizing the phases and amplitudes of the microwaves sent from each antenna element of the array, a desired beam shape can be produced and a precisely focused beam can be directed (transmitted) in any direction. Using these unique properties, the microwave-based SSPS (M-SSPS) is a space system that converts sunlight energy into beamed microwave energy, transmits the microwave energy to power receiving site on Earth, and converts them back into direct current electricity.

### b. Laser transmitting satellites

### Laser power beaming was envisioned by some at NASA as a stepping stone to further industrialization of space. In the 1980s, researchers at NASA worked on the potential use of lasers for space-to-space power beaming, focusing primarily on the development of a solar-powered laser. In 1989, it was suggested that power could also be usefully beamed by laser from Earth to space. In 1991, the SELENE project (Space Laser Energy) had begun, which included the study of Laser power beaming for supplying power to a lunar base.

In 1988, the use of an Earth-based laser to power an electric thruster for space propulsion was proposed by Grant Logan, with technical details worked out in 1989. He proposed using diamond solar cells operating at 600 degrees to convert ultraviolet laser light.[1][2][5]

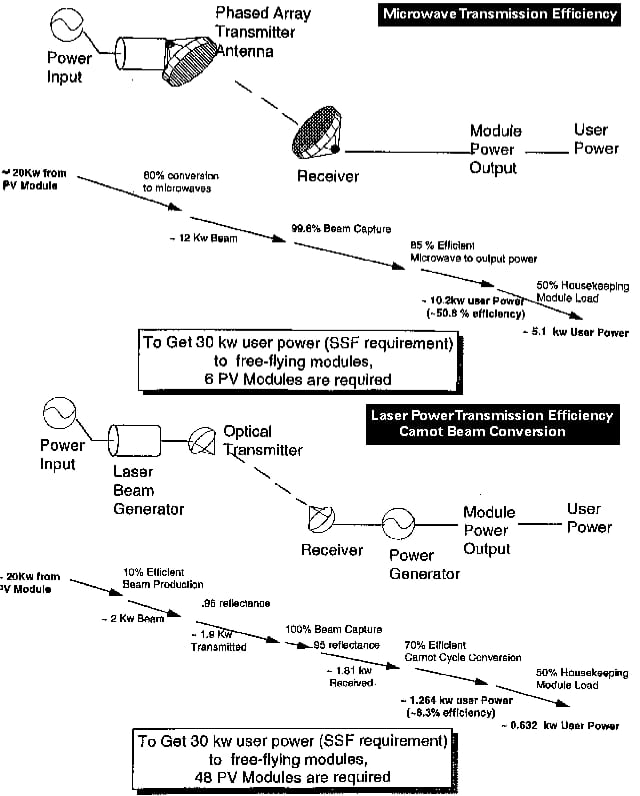


Figure 1: Working of microwave transmission and laser transmission

### Comparison between Laser Solar Satellite and Microwave Solar Satellite:

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| Laser Solar Satellite | Microwave Solar Satellite: |
| Relatively low startup costs in the $500 million to $1 billion range. | Steady, uninterrupted transmission of power through rain, clouds, and other atmospheric conditions. |
| The single launch per laser transmitting satellite would be self assembling, lowering costs and risks substantially. | Safely transmit power through air at intensities no greater than midday sun. |
| The small diameter of the laser beam would make it simpler and cheaper to implement on the ground. | Provide upwards of 1 GW of energy to terrestrial receiver, enough to power a large city. |
| Comparatively low power of each individual satellite, in the area of 1 to 10 MW per satellite, would require several satellite to make a substantial impact. | Production cost in the tens of billions of dollars range, requiring as many as 100 launches into space, with space based assembly required. |
| There are several safety concerns with lasers in space, such as blinding and weaponization. | The terrestrial receiver would be several kilometers in diameter. |
| Laser transmitting satellites would have trouble beaming power through heavy clouds and rain | The long distance of the satellite from Earth would make it nearly impossible to repair. |

### [2]

**3.Receiving power on Earth via a rectenna, a microwave antenna:**

The Earth-based rectenna would likely consist of many short dipole anetnnas connected via diodes. Microwave broadcasts from the satellite would be received in the dipoles with about 85% efficiency. With a conventional microwave antenna, the reception efficiency is better, but its cost and complexity are also considerably greater. Rectennas would likely be several kilometers across.[1]

**PROS AND CONS OF SBSP:**

PROS:

The SBSP concept is attractive because space has several major advantages over the Earth's surface for the collection of solar power:

1.It is always solar noon in space and full sun.

2.Collecting surfaces could receive much more intense sunlight, owing to the lack of obstructions such as atmospheric glasses, clouds, dust and other weather events. Consequently, the intensity in orbit is approximately 144% of the maximum attainable intensity on Earth's surface.

3.A satellite could be illuminated over 99% of the time, and be in Earth's shadow a maximum of only 72 minutes per night at the spring and fall equinoxes at local midnight. Orbiting satellites can be exposed to a consistently high degree of solar radiation, generally for 24 hours per day, whereas earth surface solar panels currently collect power for an average of 29% of the day.

4.Power could be relatively quickly redirected directly to areas that need it most. A collecting satellite could possibly direct power on demand to different surface locations based on geographical baseload or peak load power needs.

5.Reduced plant and wildlife interference.[1][2]

CONS:

The SBSP concept also has a number of problems:

1. The large cost of launching a satellite into space. For 6.5 kg/kW, the cost to place a power satellite in GEO cannot exceed $200/kg if the power cost is to be competitive.
2. Microwave optic requires GW scale due to airy disk beam spreading. Typically, a 1 km transmitting disk at 2.45 GHz spreads out to 10 km at Earth distance.
3. Inability to constrain power transmission inside tiny beam angles. For example, a beam of 0.002 degrees (7.2 arc seconds) is required to stay within a one kilometer receiving antenna target from geostationary altitude. The most advanced directional wireless power transfer systems as of 2019 spread their half power beam width across at least 0.9 arc degrees.
4. Inaccessibility: Maintenance of an earth-based solar panel is relatively simple, but construction and maintenance on a solar panel in space would typically be done telerobotically. In addition to cost, astronauts working in GEO (geosynchronous Earth orbit) are exposed to unacceptably high radiation dangers and risk and cost about one thousand times more than the same task done telerobotically.
5. The space environment is hostile; PV panels (if used) suffer about 8 times the degradation they would on Earth (except at orbits that are protected by the magnetosphere).
6. Space debris is a major hazard to large objects in space, particularly for large structures such as SBSP systems in transit through the debris below 2000 km. Collision risk is much reduced in GEO since all the satellites are moving in the same direction at very close to the same speed.
7. The broadcast frequency of the microwave downlink (if used) would require isolating the SBSP systems away from other satellites. GEO space is already well used and it is considered unlikely the ITU would allow an SPS to be launched.
8. The large size and corresponding cost of the receiving station on the ground. The cost has been estimated at a billion dollars for 5 GW by SBSP researcher Keith Henson.
9. Energy losses during several phases of conversion from photons to electrons to photons back to electrons.
10. Waste heat disposal in space power systems is difficult to begin with, but becomes intractable when the entire spacecraft is designed to absorb as much solar radiation as possible. Traditional spacecraft thermal control systems such as radiative vanes may interfere with solar panel occlusion or power transmitters.[1][2]

**FUTURE OF SBSP:**

The future is indeed very bright for Space-based Solar Power. With rapid increase in space technology in the last decade and development of different launch system and reusable rockets will soon drastically reduce the cost of launching a satellite in space, one of the biggest hurdle for SBSP. SBSP’s ability to provide clean, reliable power for the planet 24/7 at a cheaper cost than any other energy source is real. It will take decades of investment, building, testing, and successful implementation before the system can begin to recoup its initial costs. With various nations actively pursuing SBSP, it might not be too far away when entire cities are powered by energy transmitted from space. But for this to happen the super-powers of the world will need to work together to overcome the technological and logistical hurdles and ensure for a greener and brighter future for humanity.

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