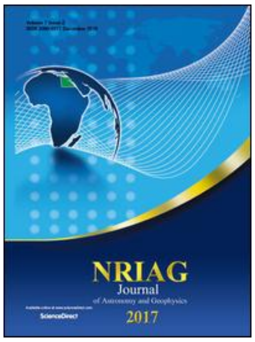


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# Space-based solar laser system simulation to transfer power onto the earth

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# Space-based solar laser system simulation to transfer power onto the earth

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**ABSTRACT**
A simulation model of a space-based solar laser system to transfer the power onto the earth is carried out. The system consists of a solar-pumped laser by a concentration system installed on a satellite. The resulted laser beam is re-directed onto the earth surface, where it can be used to generate power. The intensity and the divergence of the laser are calculated in order to obtain the suitable solar laser system as a payload on the satellite that matches and the terrestrial applications. According to our model, around 40 kW laser can be obtained by a frequency-doubled Nd:YAG laser rod which has a radius of 5 cm and a length of 10 cm, when we use the direct solar pumping via parabolic dish of a radius 100 m and a focal length 121 m accompanied with a 3D-CPC of an acceptance angle of 30°.

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**KEYWORDS**
Space power; solar laser; space solar energy; space-based solar laser

## 1. Introduction

The solar energy in space is very much greater than what we use today on the earth. The lifetime of the sun is estimated to be 4–5 billion years, making space solar power a recommended long-term energy alternative solution. Combined with already demonstrated wireless power transmission, this technology on a larger scale can supply nearly all the energy needs of the mankind on the earth. In parallel to this, there is also an exceeding need for using such a clean energy to sink the use of combusting fossil fuels for our transportation system. Hybrid systems of solar and fossil fuel engines will soon evolve into plug-in hybrids which can use electric energy from the grid. As solar energy components are developing with the time, the fuel engine role will get smaller in transportation if the needed high quantities of electrical energy can be generated. Therefore, the needed clean power for any electric transportation system in the future will be obtained from space solar power, which has a number of fundamental advantages over other energy sources.

The Space Solar Power (SPS) is clean and has no wastes which can pollute the environment. It is available all the time independently on the time of day and the weather. Also, it does not depend on oil to meet energy needs. Its transportation to any place in the world is much easier than the fossil energies. The development in this field is supposed to sink its prices.

The idea of transferring the solar energy from the space means actually collecting the solar energy in the outer space, converting it into a laser beam and sending it to the earth. The reason of using the laser beam here is to minimise the dispersion of the radiation during its transfer through the earth's atmosphere. This would make the energy reserved from getting wasted, which will maximise using it in the needed applications. This was one of the promising applications of the solar-pumped laser which was developed for the terrestrial applications for the first time by Young (1966). A sketch of the space-based solar laser is shown in Figure 1

The use of space for power generation is strongly recommended because it offers highest energy conversion efficiency sinking the heat as an energy dissipation makes best use of solar energy and lowers the prepaid costs (Lior (2001)). The applications of using such a space power in the space are many such as the space communication, satellite and space craft powering and asteroid deflection (Matsumoto and Hashimoto (2007) and Vasile and Maddock (2012)). Figure 2 shows a representation of some of these applications from which many benefits for the mankind could be obtained based on this technology.

Many applications can benefit from the idea of transferring the space power to the earth such as communications, telemetry, military (in air defence) and using this energy in the photovoltaics to generate the electricity. Figure 3 shows a photovoltaic plant that uses the laser beam generated in the space using solar energy to generate electricity more efficiently than the direct solar panel plant which is based on the global solar radiation received on the earth from the sun. The laser energy transmitted to the surface will be converted to electricity by photovoltaic panels. (Williams et al. (1993)).

A solar power satellite is a very large satellite carrying a solar laser system put in a definite orbit. This satellite

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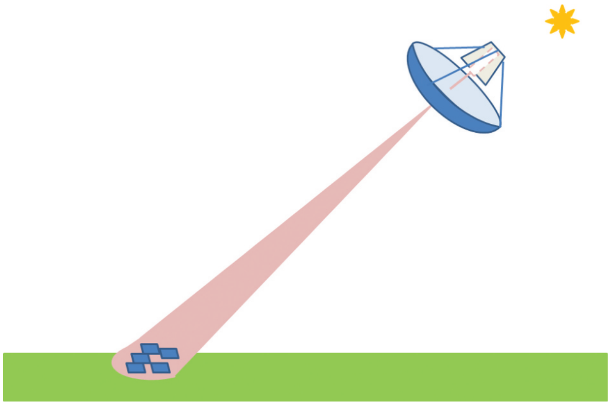

**Figure 1.** A sketch of the space-based solar laser.

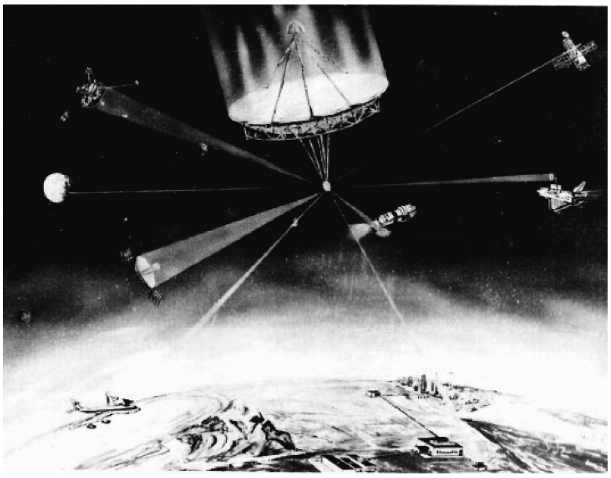

**Figure 2.** Applications of the space solar power in the space technology.

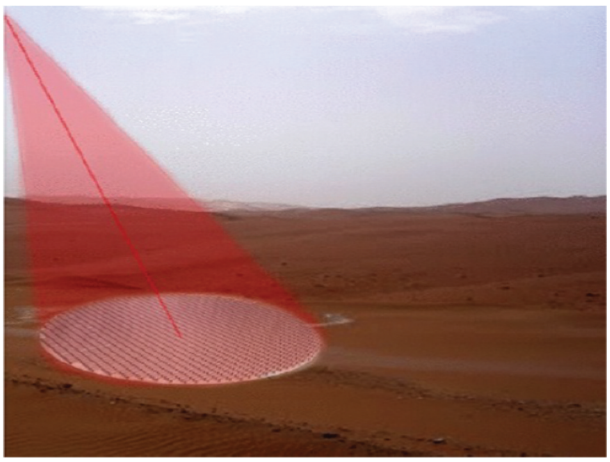

**Figure 3.** A photovoltaic plant that uses the laser beam generated in the space using solar energy.

would consist of three main parts: a solar energy concentration system; a laser system; and an emitter. The concentrated solar energy will pump the laser head converting the white multi-chromatic dispersed non directed solar radiation into monochromatic directed laser beam. A schematic graph of a solar laser system on

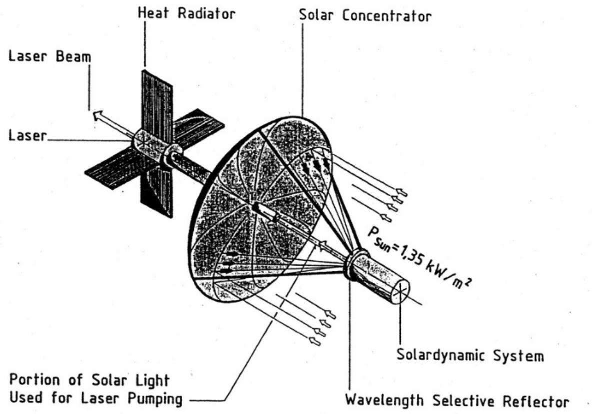


**Figure 4.** A schematic graph of a solar laser system in space.

this satellite in space is shown in Figure 4. This system was used by Brauch et al. (1991).

NASA claimed that the most appealing locations for solar space power plants are: (1) In the geosynchronous Earth orbit (GEO), it sits in a fixed position above the equator at a maximum distance of 35,785 km from which it can provide energy to huge population centres;(2) In Molniya-type orbits (a type of highly elliptical orbit with an inclination of 63.4 degrees, a perigee argument of −90 degrees and an orbital period of half a - sidereal day) over the Arctic regions (at maximum distances of 1820 to 40,165 km for 2–24 h Molniya, respectively) for supplying energy to those energy-deficient regions; (3) in Sun-synchronous orbits for providing a power peak in the 6–9 a.m. and 6–9 p.m. periods; (4) on the Moon, for base power demand anywhere on Earth, with potential for mining it to provide the material necessary for building the power stations (Claybaugh and Redmond (1994)). Also, space-to-space power beaming is useful in providing power from a main power generation station in space to other satellites. This would simplify the satellites and would thus extend their life significantly (De Young et al. (1987)).

Finally, Abdel-Hadi (2018) reported a simulation model of a space-based solar-pumped laser system sensitised by a luminescent nano-crystal to transfer the power onto the earth. The system consisted of a solar-pumped laser by a concentration system set on a satellite. The laser material is coupled with a nano-crystal luminescent, which acts as a sensitiser. The resulted laser beam is re-directed onto the earth surface, at which it can be used to generate power in several types. Adding the nano-material reduced the threshold pumping power of 3 times, increased the slope efficiency about 4.5 times and accordingly increased the laser output power about 4.5 to 5 times.

## 2. Space-based solar laser system model

A space-based solar laser system on a space station rotating in an orbit around the earth is modelled. The solar laser system consists of a three-dimensional parabolic concentrator (parabolic dish) of radius of 100 m, a compound parabolic concentrator of an acceptance angle of 30° and a Nd:YAG laser rod. A combined model of the work done by Abdel-Hadi (1996; 1997, 1998) is carried out in the present work in order to expose the entire laser rod to the concentrated solar radiation by joining the side- and end-pumping techniques together. There is only slight difference has been considered here, which is replacing the secondary concentrator (the conical concentrator) by the mentioned three-dimensional compound parabolic concentrator (CPC). The entire system is similar to that of Abdel-Hadi (2018) but without adding the nano-materials. We selected the frequency-doubled Nd:YAG laser, since it has a relatively shorter wavelength (532 nm), higher energy (2.34 eV) and higher transmission through the earth's Atmosphere (70%) (Luce and Michael (2002)). The three-dimensional parabolic concentrator has an optimum rim angle of 44.866° (which is the angle made at the focus of the concentrator between the outermost reflected beam from the concentrator and its focal axis as shown in Figure 5), at which the concentration is maximum (which is theoretically more than 2800 times depending on the reflectivity of the concentrator mirror). The concentration ratio of the three-dimensional parabolic concentrator against the rim angle is shown in Figure 6. The compound parabolic concentrator is a non-imaging secondary concentrator which is necessary to increase the level of the concentration and to distribute the concentrated radiation homogenously as well as possible on the laser rod.

The Nd:YAG laser rod is put inside the CPC at the focus of the primary concentrator in a resonator of an

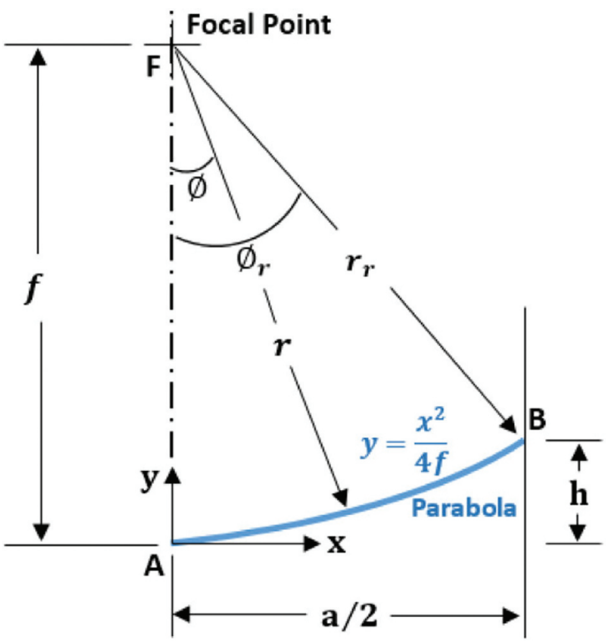


Figure 5. The geometry of the parabolic concentrator.

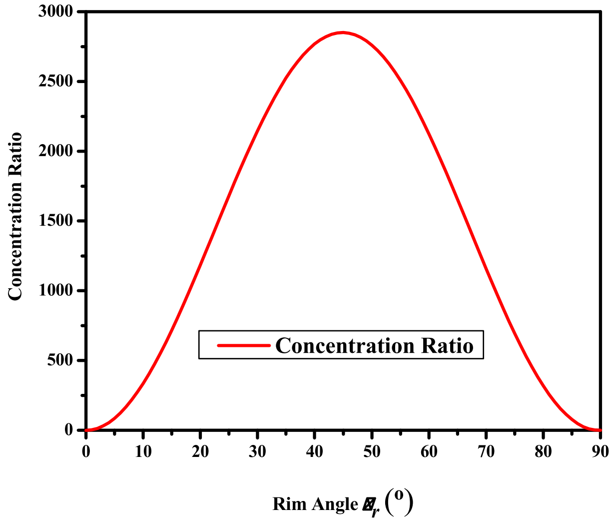


Figure 6. The concentration ratio of the three-dimensional parabolic concentrator against the rim angle.

output coupler which is a mirror of 90% reflectivity. The entire system is supposed to track the sun by a feedback sensor motor driven by a solar panel fixed on the space station itself. The primary concentrator (3D-Dish) redirects the concentrated solar radiation onto the laser rod inside the CPC. The solar radiation will be of the value of the solar constant (≈1370 W/m$^2$). This system is supposed to generate a laser beam of a wavelength of 1064 nm. Then, it will be frequency doubled to get its wavelength to be 532 nm using a non-linear crystal such as lithium niobate ($LiNbO_3$), potassium titanyl phosphate (KTP = $KTiOPO_4$), or lithium triborate (LBO = $LiB_3O_5$) (Paschotta R. et al.). Then it will be sent to the earth surface and atmosphere to be used for many applications. The frequency-doubled laser beam will suffer a distinction coefficient of the earth's atmosphere of around 30%. Accordingly, only 70% of its energy can reach the earth surface. During its path, it will be dispersed in a conical shape ended by a spot of a circle shape with a radius can be calculated by Equation (1) (La Pointe M. R. and Oleson S. R. (1994)).

$$r_{Spot} = \frac{0.61 d\lambda}{r_{Lens}} \qquad (1)$$

where $d$ is the target distance, $\lambda$ is the laser beam wavelength and $r_{Lens}$ is the radius of the emitting telescope which can be considered as the radius of the output coupling mirror or the adapting lens used to redirect the beam.

We chose three cases of orbits on which the space station can be put in order to study the power of the laser beam arriving to the earth's surface:

(1) A 300 km height over the earth's surface orbit.
(2) Low Earth Orbit LEO, which is an Earth-centred orbit with an altitude of 2,000 km (1200 miles) or less (approximately one-third of the radius of Earth), or with a total of

11.25 periods a day (128 minutes or less) and an eccentricity of less than 0.25.

(3) Geostationary Orbit GEO, which is a circular geosynchronous orbit 35,786 kilometres (22,236 miles) above Earth's equator and following the direction of Earth's rotation.

We studied the intensity reached to the earth surface from this system against the dimensions of the laser rod. Figure 7 shows a probability curve of the laser beam intensity against the length of the laser rod, while Figure 8 shows a probability curve of the laser beam intensity against the radius of the laser rod. The probability curve is a type of curves displaying the data ranging between very tiny and very large scales. It is used here because the values of the laser intensity are from such a type of data.

## 3. Results and discussion

The resulted data in Figures 7 and 8 show the laser output intensity against the dimensions of the laser rod. Due to its shortest radius (among the three cases), the intensity of the laser beam received on the earth's surface from a space solar laser on satellite on a 300 km distance has the highest values. Nevertheless, the cases of using the other higher orbits cannot be ignored if the terrestrial application needs lower intensity laser and has a larger area. In our model and from the dimensions of our system, it is easy to calculate that around 40 kW laser can be obtained by a frequency-doubled Nd:YAG laser of 5 cm radius and 10 cm long when we use the direct solar pumping via parabolic dish of 100 m radius and 121 m focal length accompanied with a 3D-CPC of an acceptance angle of 30°.

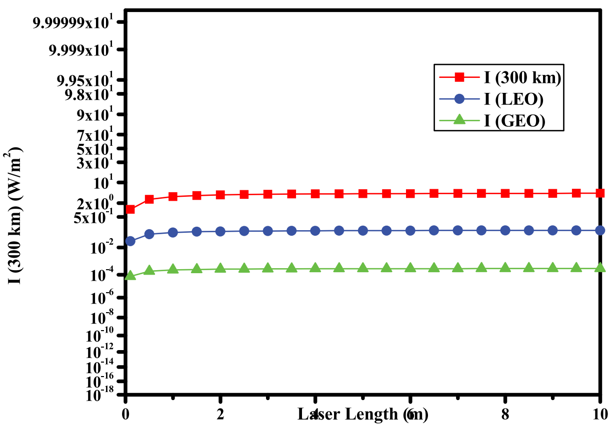


Figure 7. A probability curve of the laser beam intensity against the length of the laser rod.

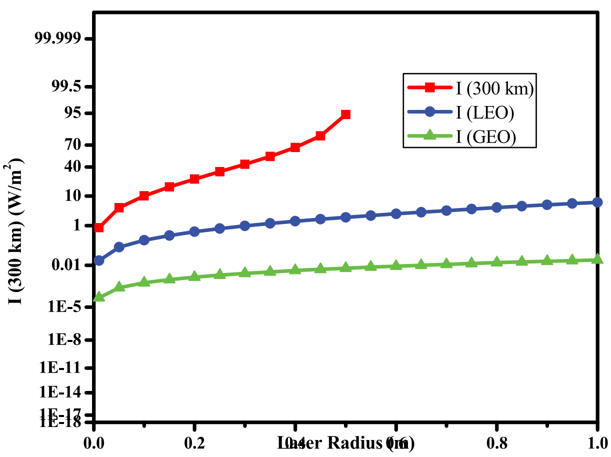


Figure 8. A probability curve of the laser beam intensity against the radius of the laser rod.

## 4. Conclusion

Transmitting the energy via space-based solar lasers (SBSS) is very promising manner for bringing more clean energy onto earth.

We selected the frequency-doubled Nd:YAG laser, since it has a relatively shorter wavelength (532 nm), higher energy (2.34 eV) and higher transmission through the earth's Atmosphere (70%).

According to our model, around 40 kW laser can be obtained by a frequency-doubled Nd:YAG laser of 5 cm radius and 10 cm long when we use the direct solar pumping via parabolic dish of 100 m radius and 121 m focal length accompanied with a 3D-CPC of an acceptance angle of 30°.

A comparison between three cases of orbits (300 km, LEO and GEO) is done. It shows that the lower orbits are better than the higher orbits to avoid the divergence of the laser beam and to minimise the energy loss.

## Disclosure statement

No potential conflict of interest was reported by the author.

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## References

Abdel-Hadi YA. 1996. Numerical simulation model for the optical behaviour of the compound parabolic and conical solar energy concentrators for laser beam generation [M. Sc. thesis]. Cairo (Egypt): Physics Department, Faculty of Science, Ain Shams University, Nov 21.

Abdel-Hadi YA. 2018. Space-based nano-material enhanced solar laser system simulation for transfering power onto the earth. J Exp Theor Nanotech Spec Res. 2(2):2–12.

Brauch, U. Opower, H. Wittwer, W. Muckenschnabel, J. 1991. Solar-pumped solid state lasers for space to space power transmission. Space Power Res Manufac Dev. 10 (3–4):285–294.

Claybaugh W, Redmond C. 1994. Commercial space transportation study. Final Report, NASA, Apr.

Deyoung, RJ, Walker, GH, Williams, MD, Schuster, GL & Conway, EJ. 1987. Preliminary design and cost of a

1-megawatt solar-pumped iodide laser space-to-space transmission station. NASA Technical Memorandum 4002, Sep.
La Pointe MR, Oleson SR. 1994. Low power ground-based laser illumination for electric propulsion applications. NASA Contractor Report 194444, IEPC 93 – 208. Brook Park (Ohio, USA): Sverdrup Technology Inc., Lewis Research Center Group, Jan.
Lior N. 2001. Power from space. Energy Convers Manage. 42 (15–17):1769–1805. doi:10.1016/S0196-8904(01)00040-1.
Luce R, Michael S. 2002. "Laser beaming experiment", a report presented to NASA SCTM TIM, Sep.
Matsumoto H, Hashimoto K. 2007. URSI White Paper on Solar Power Satellite (SPS) systems and report of the URSI inter-commission working group on SPS. Report of the URSI Inter-Commission Working Group on SPS, Jun.
Shaltout MM, Medhat M, Hadi YA. 1997. End pumping technique model for laser pumped by solar energy. In: Proc. of 4th IEEE International Conference on Electronics, Circuits, and Systems (ICECS'97), Vol. 2, Dec 15-18. Cairo, Egypt. p. 766–775.
Shaltout MM, Medhat M, Hadi YA. 1998. Side pumping technique model for laser pumped by solar energy. In: Proc. of 4th International Conference for Solar Energy Storage and Applied Photochemistry (SOLAR'97); January 1-6, 1997; Cairo, Egypt, Jun. Proc. Indian Academy of Science (Chemical Science), Vol. 110, No. 3, p. 335–349.
Vasile M, Maddock CA. 2012. Design of a formation of solar pumped lasers for asteroid deflection. Adv Space Res. 50 (7):891–905. doi:10.1016/j.asr.2012.06.001.
Williams MD, De Young RJ, Schuster GL, Choi SH, Dagle JE, Coomes EP, Antoniak ZI, Bamberger JA, Bates JM, Chiu MA, et al. 1993. Power transmission by laser beam from lunar-synchronous satellite. NASA Technical Memorandum 4496, Nov.
Young CG. 1966. A sun-pumped CW one-watt laser. Appl Opt. Jun 5(6):993–997. doi:10.1364/AO.5.000993