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A2_9 Beaming energy

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Abstract

If a solar shade was placed in space between the Earth and the Sun, it could be converted to gather the solar energy it is designed to block. This paper examines the amount of useful power that such a collector array could yield when beamed to a satellite orbiting the Earth. It is found that using a collector array of area 7.45x10^{12} m^2 and a doped insulator laser, a power of 1.81 W is achievable.

Introduction

The L_1 point is about 1.5 x10^9 m from the Earth [1]. It is the point between the Earth and the Sun where the combined gravitational force of the two bodies equals the centripetal force required for an object to orbit the Sun with the same period as the Earth. If a solar shield were employed at the L_1 point to block a portion of sunlight from reaching the Earth, then its Sun-facing surface could be covered in solar panels in order to utilise the energy that the shade is blocking. To make use of this energy it would have to be transported back to Earth. This could be done by a craft docking with the shade and physically ferrying the energy back or by beaming the energy back using a laser. Beaming the energy back would represent a lower maintenance option as the deployment of the equipment would be a one time event, requiring replacement and maintenance only after a number of years.

Calculations

The power produced by a solar panel is given by

$$P_s = P_I \epsilon_{p,} \qquad (1)$$

where P_I is the power incident upon the panel and ϵ_p is the efficiency of the panel. The power produced by a laser, with the solar panel's power used to fuel the pumping mechanism, is

$$P_L = P_s \epsilon_L, \qquad (2)$$

where ϵ_L is the efficiency of the laser. The emission from the laser will be subject to diffraction, which is dependant on the solid angle subtended at the aperture of the laser. The area covered by the beam at Earth is

$$A_B = \Omega r^2, \qquad (3)$$

where Ω is the solid angle and r is the distance from L_1 to the Earth. The flux of the beam is then

$$F_L = \frac{P_L}{A_B}, \qquad (4)$$

and the power absorbed by a receiver of area, A_R, is

$$P_R = F_L A_R. \qquad (5)$$

The useful power claimed from this receiver would be

$$P_U = P_R \epsilon_R, \qquad (6)$$

where ϵ_R is the efficiency of the receiver. Hence, combining equations (1) to (6), the useful power is

$$P_U = \frac{P_I A_R}{\Omega r^2} \epsilon_P \epsilon_L \epsilon_R. \quad (7)$$

If we redefine the initial incident power, P_I, as the solar flux at the L_1 point, F_s, multiplied by the size of the solar array, A_D, then we get

$$P_U = \frac{F_S A_D A_R}{r^2} \frac{\epsilon_P \epsilon_L \epsilon_R}{\Omega}. \quad (8)$$

If the same panels are used for both the collector array and the receiving array then ϵ_P=ϵ_R=0.25 [2], which represent a lower end estimate of operating efficiency. If the size of the collector array was 7.45x10^{12} m^2, as proposed by *Wilson et al 2009*[3], and receiver array had an active area of 1000 m^2, we can see that the useful power obtained is only dependant on the efficiency and solid angle of the laser as shown in (9).

The solar flux was found by dividing the bolometric power output of the Sun (3.9x10^{26} W) by the surface area of a sphere with radius equal to the distance between the Sun and the L_1 point. This value is 1407 Wm^{-2}.

$$P_U = 0.29 \frac{\epsilon_L}{\Omega}. \quad (9)$$

The type of laser used would therefore, ideally, have a high efficiency and low beam divergence. Some other factors may need to be taken into account. The laser should require minimum maintenance. Gas or liquid dye lasers may be subject to leaks, diminishing their effectiveness or ceasing operation altogether. Lasers that require another laser to provide the pumping mechanism should also be avoided as this adds another level of loss due to efficiency. A solid state laser such as a semiconductor or doped insulator laser may be preferable. A semiconductor laser contains only solid components and its pumping mechanism is a potential applied across the semiconductor junction. However the nature of production of a semiconductor laser beam usually results in a widely diverging beam. A doped insulator laser uses short light pulses as a pumping mechanism and contains a solid mass of active medium. If a typical doped insulator were used (with an example efficiency of 0.1 [4] and a beam with a solid angle of 0.016 steradians [5]), then a power of 1.81 W is achievable. This translates to a yearly output of about 57 MJ of energy.

Conclusion

Increasing the size of either the collector array or the receiving array would increase the amount of useful energy obtained, although this may have undesirable side effects such as an unwanted level of global cooling for the Earth. This model assumes the total flux of the Sun could be converted by solar cells, whereas in reality wavelengths outside the optical spectrum cannot be utilised. However much of the Sun's emission is in the optical wavelength so a significant proportion of the solar flux would be useable by solar cells.

The power incident upon the collector array is of the order 10^{16} W, which illustrates the massive power losses incurred by this system, in the drop to 1.81W of useable power. This system does not appear to present a sensible option for power generation but such a system becomes more economical with time. A further study of the energy gain/deficit could be carried out to investigate whether it would be economically feasible to implement and maintain this concept

References

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