Journal of Physics Special Topics
An undergraduate physics journal

P1_1 Laser Power

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November 21, 2021

Abstract
The possibility of using a laser to provide power to a distant spacecraft via solar panels is examined. The power and divergence combinations of a laser required to outperform the Sun is determined at the distance of Pluto, a possible combination identified is a divergence of 3.5×10^{-6} rad, and a power of 260 TW. The results show that it would be possible however not recommended due to substantial inefficiency.

Introduction

All spacecraft including satellites require a source of power to operate during their mission time; most close enough will use an array of photo-voltaic panels to harness the sun's power, however at a distance the intensity falls below a usable limit. A satellite in orbit around Pluto will not have sufficient sunlight to operate [1], to counter this a high power and low divergence laser is proposed to shine on the panels and provide a source of energy.

Theory

Appropriate assumptions are made such as any atmospheric effects are ignored and interactions with other planets or bodies are ignored and the Sun, Earth and satellite are in the same plane in a straight line. These are all acceptable assumptions as the paper is examining the hypothetical best case scenario.

Divergence occurs on laser beams meaning that over distance, the total photon flux incident upon the spacecraft will decrease, see Figure 1. Over a distance d, the laser beam will diverge whilst maintaining the same overall power,

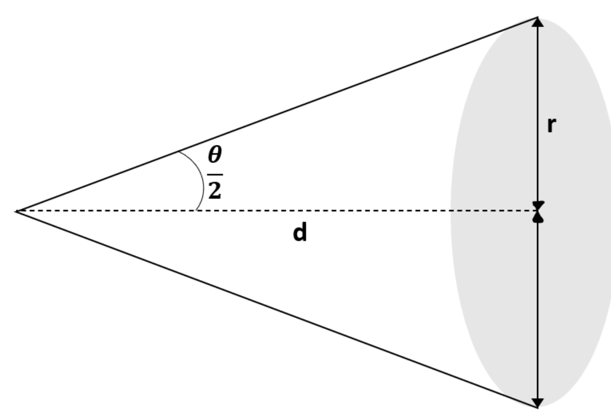

Figure 1: The beam cross section, shown as the shaded region, expands as a function of distance, d. The area can be calculated using the divergence of the laser θ.

meaning an increase in beam cross section, A, and a decrease in intensity, I; the two are inversely proportional. Radius, r, is defined as,

$$r = d \tan\left(\frac{\theta}{2}\right). \quad (1)$$

The cross sectional area as a function of distance, $A(d)$, from the laser can therefore be derived using Eq. (1) as,

$$A(d) = \pi d^2 \tan^2\left(\frac{\theta}{2}\right). \tag{2}$$

Eq. (2) is an approximation, as $A(d)$ will never equal zero even when $d = 0$, however for the distances used in the calculations, the approximation is suitable as the starting beam cross section becomes negligible.

Using the laser power, P_{Laser}, the intensity of the laser beam can then be given as,

$$I_{Laser} = \frac{P_{Laser}}{A(d)} = \frac{P_{Laser}}{\pi d^2 \tan^2\left(\frac{\theta}{2}\right)} \tag{3}$$

To simplify the problem, the positive x-direction is defined as the line from the Sun to the satellite with the laser on earth. For this reason the term d in Eq. (3) will become $(x - d_e)$ where d_e is the distance from the sun to the earth, equal to roughly 1 AU,

$$I_{Laser} = \frac{P_{Laser}}{\pi (x - d_e)^2 \tan^2\left(\frac{\theta}{2}\right)}. \tag{4}$$

Using the equations similar to above, the intensity of sunlight can also be found as,

$$I_{sun} = \frac{P_{sun}}{4\pi x^2}, \tag{5}$$

where x is the distance from the sun and P_{sun} is the power of the Sun.

Summary

The power of the sun is 3.9×10^{26} W [2]; and the distance of Pluto, approximately 40 AU [3], the intensity of sunlight is 0.82 W m^{-2}, calculated using Eq. (5). The power and divergence of a laser required to achieve an equal or better result can be found by plotting Eq. (4), the result of this is plotted in Figure 2.

The divergence of a laser is given by,

$$\theta = \frac{\lambda}{\pi w}, \tag{6}$$

where λ is the wavelength and w is the aperture. Using $\lambda = 550$ nm and $w = 5$ cm, the divergence

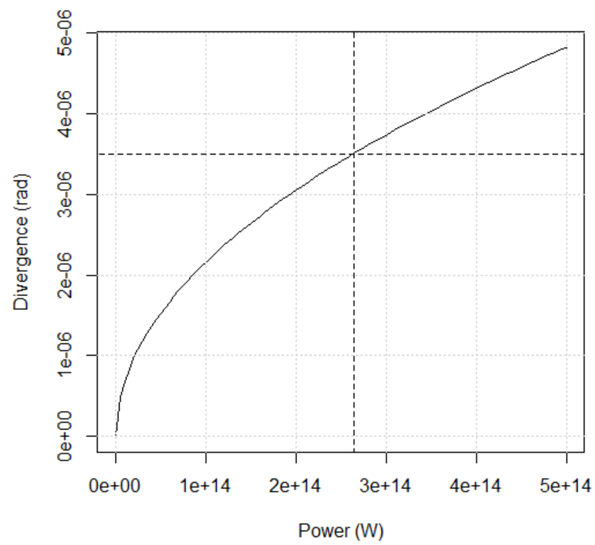

Figure 2: By plotting Eq. (4), the divergence and power combinations of a laser that will provide an equal intensity as the sun at Pluto can be determined.

$\theta = 3.5 \times 10^{-6}$ rad. Figure 2 shows that for this specification of laser, a power of around 260 TW would be required. While the calculations show that it would be theoretically possible to power a satellite in orbit around Pluto using a laser on earth, there are numerous reasons it has never been done including the low efficiency of photovoltaic panels and the monochromatic nature of laser light not being suitable compared to the Sun's near black body radiation.

References

[1] `https://web.archive.org/web/20080518124056/http://www2.jpl.nasa.gov/basics/bsf11-3.html` [Accessed 8 October 2021]

[2] `https://www.pveducation.org/pvcdrom/properties-of-sunlight/the-sun` [Accessed 8 October 2021]

[3] `https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-pluto-58.html` [Accessed 8 October 2021]