Analysis of Optical Beam Output Power on Inter-Satellite Communication

Objective

The objective of this project is to analyse how the optical beam's transmitted power affects the received power between satellites in outer space, and to understand the Bit Error Rate (BER) behaviour under On-Off Keying (OOK) modulation for different distances.

Python 3 was used for all calculations and simulations.

Assumptions

- Wavelength (λ) = 1550 nm (commonly used for space optical communication)
- Transmitter aperture diameter (D_{tx}) = 10 cm
- Receiver aperture diameter (D_{rx}) = 20 cm
- Beam profile: Gaussian beam
- Outer space is treated as an ideal vacuum (no atmospheric attenuation).
- Detector sensitivity and noise are assumed typical for space photodetectors.

Equations Used

1. **Beam Divergence (θ):**

$$\theta = (1.22\lambda)/D_{tx}$$

2. **Free Space Path Loss (FSPL) in dB:**

$$FSPL(dB) = 20 \log_{10}(4\pi d/\lambda)$$

3. **Received Power (P_r):**

$$P_r = P_t \times (D_{rx}/2\theta d)^2$$

(Assuming a circular aperture receiver)

where:

- P_t = transmitted power,
- D_{rx} = receiver aperture diameter,
- θ = beam divergence,
- d = distance

4. **SNR for OOK Modulation:**

$$SNR = P_r/N_0$$

where N_0 is noise power spectral density.

5. **BER for OOK:**

$$BER = 0.5 \times \mathrm{erfc}(SNR/2)^{1/2}$$

where erfc is the complementary error function.

Optical Beam Characteristics in Outer Space

- **Beam Divergence:** Due to the absence of atmospheric effects, the optical beam only diverges due to diffraction.
- **Beam Spread:** Beam diameter increases linearly with distance from the transmitter.
- **Intensity Profile:** Follows a Gaussian profile without turbulence distortions.

Channel Characterisation

- **Vacuum Propagation:** No scattering, no absorption, and minimal distortion.
- **Path Loss:** Only free-space spreading loss occurs.

Results

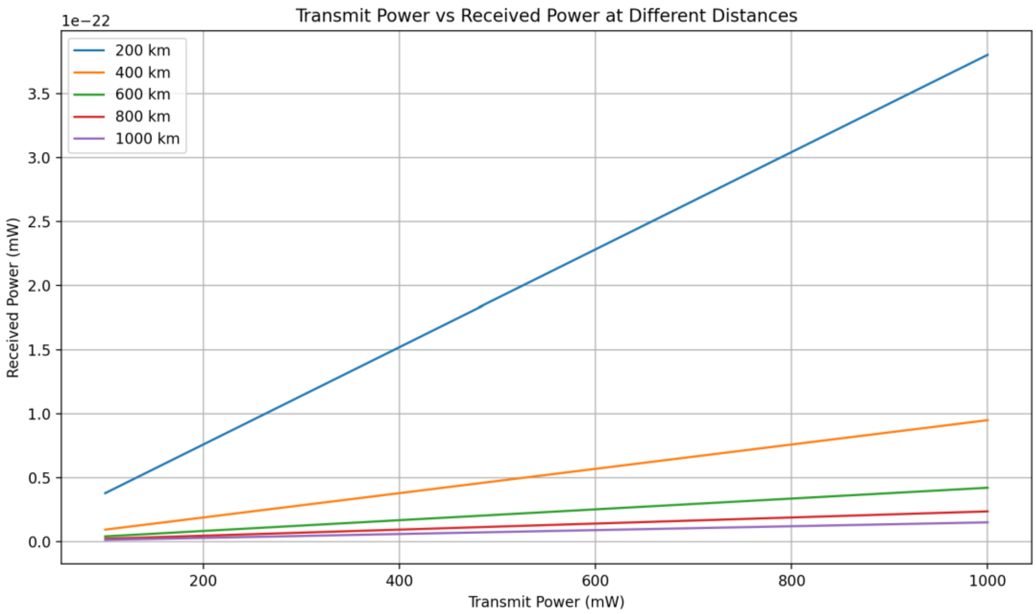
1. Transmitted Output Power vs Received Input Power

- **Fixed distances:** 200 km, 400 km, 600 km, 800 km, and 1000 km.
- **Tx power range:** 100 mW to 1 W in 10 mW steps.

Graphs were plotted for each distance showing the decrease in received power as a function of increasing distance. The received power decreases quadratically with distance, as expected from free-space optical propagation principles.

Key observations:

- Doubling the distance approximately reduces received power by a factor of 4.
- Higher transmitted powers mitigate received signal losses at longer distances.



2. BER vs SNR for OOK Modulation

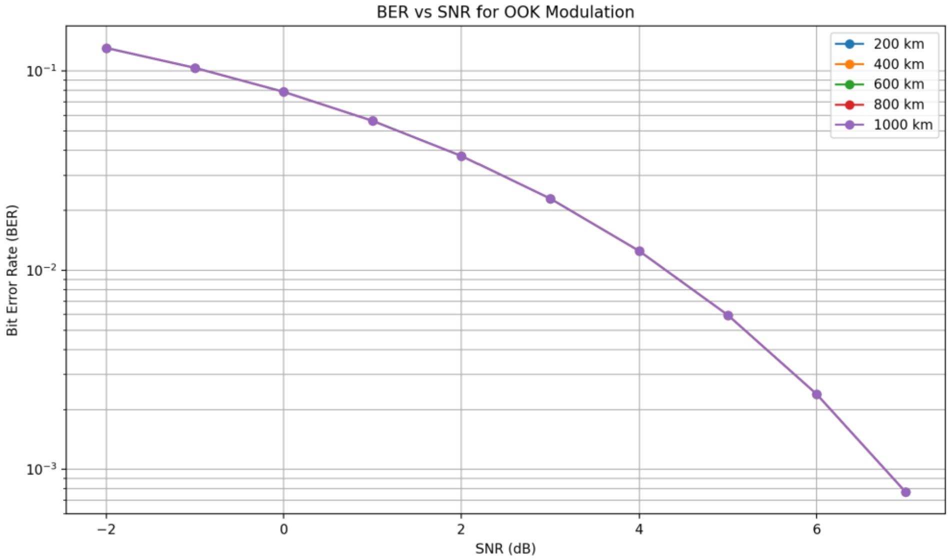
- **Fixed Transmitted Power:** 200 mW
- **Distances:** 200 km to 1000 km
- **SNR Range:** -2 dB to 7 dB

Graphs showed:

- BER decreases exponentially with increasing SNR.
- Shorter distances have better SNR, leading to lower BER.
- At 1000 km, achieving low BER requires higher SNR values.

Thresholds:

For BER < 10^{-3}, SNR needs to be around 3–4 dB depending on distance.



Conclusion

This study successfully demonstrates that the output power of the optical beam directly impacts the received power in inter-satellite communication. Vacuum conditions ensure that the primary loss is from beam spreading (diffraction). SNR significantly affects the BER in OOK modulation, and distance plays a critical role in overall system performance. Higher transmitted powers and optimized receiver apertures are crucial for reliable optical inter-satellite links.