Astronautics (SESA2024)

Section 9: Space Telecommunications – Exercises.

1. Describe the physical constraints imposed by the atmosphere that define the atmospheric window for space-based communication systems, using frequencies from about 1 GHz to 30 GHz. What are the advantages and disadvantages of using the higher end of this frequency range.

2. The fundamental relationship between the frequency f and wavelength λ of electromagnetic radiation is given by $c = f\lambda$, where $c = 3 \times 10^8$ m/s is the speed of light. Calculate the wavelength of microwave radiation at L-Band (1.5 GHz), C-Band (4 GHz), X-Band (8 GHz), and Ku-Band (14 GHz).

3. Find the gain and 3 dB beamwidth of a parabolic antenna that has a diameter of 3 m, operating at the same frequencies as given in the previous question (assume an antenna efficiency of 0.5).

4. Describe three types of digital modulation. Which is the most commonly used?

5. Work through the derivation of the link budget equation,

$$10\log_{10}\left(\frac{C}{N_0}\right) = 10\log_{10}(P_T G_T) + 10\log_{10}\left(\frac{G_R}{T_R}\right) - 20\log_{10}\left(\frac{4\pi\rho}{\lambda}\right)$$
$$-10\log_{10} L_A - 10\log_{10} k.$$

Explain the physical significance of the Equivalent Isotropic Radiated Power, $EIRP = P_T G_T$, and the (G_R/T_R) ratio of the receiver.

6. Give two advantages, and two disadvantages of a large comms antenna on a spacecraft. Explain what is meant by the ‘power-gain trade-off’, for a satellite communication system.

7. A spacecraft in geostationary Earth orbit has an antenna which has a 3 dB beamwidth giving global coverage. If the comms link operates at 1.5 GHz, estimate the required antenna size. Calculate the gain of this antenna in dB if its efficiency is $\eta = 0.5$ (Use $R_{GEO} = 6.611\ R_E$).

8. The bit error rate (BER) is a measure of link quality for a digital communication system. Explain what it is, and how it is related to the signal to noise ratio C/N_0 appearing in the link budget equation above.

9. A spacecraft autonomously records and stores 2 Gigabits (2×10^9 bits) of image and other payload data, during a fly-by of the Pluto/Charon system. After the encounter, while at an Earth-Pluto distance of 40 AU, the

spacecraft downlinks the data using an X-Band transmitter with a frequency of 8.44 GHz. The spacecraft has an EIRP of 65 dBW, and the data stream is received by a Deep Space Network antenna, which is a parabolic dish of 70 m diameter with an effective system noise temperature of 28 K. If the required E_b / N_0 ratio at the receiver is 10 dB, estimate the time taken to downlink the payload data. Assume no additional losses, and an antenna efficiency η of 0.5.

The spacecraft's transmitting antenna is a parabolic dish of diameter *D*. Use the specified EIRP to show that the dish diameter *D* (m) and the spacecraft transmitted power P_T (W) are related by

$$D^2 P_T \approx 810.$$

Plot a graph of *D* against P_T , and considering the power-gain trade-off discussed in Q6, suggest an approximate, appropriate dish size for the spacecraft.

Data: Boltzmann constant, $k = 1.38 \times 10^{-23}$ J/K
1 AU = 1.5×10^8 km