

EE4036 Assignment 2 – Satellite Communications, Solution Guideline ~ this solution serves as a guideline only, students please verify the accuracy of numerical computation on your own !!

1. Determine the total noise power for a receiver with an input bandwidth of 40MHz and an equivalent noise temperature of 800K.

Solution

$$Total\ Noise\ Power = N = kTB$$

Within the above equation; k = Boltzmann's Constant = 1.38×10^{-23}

T = equivalent noise temperature

B = Bandwidth

Therefore;

$$\begin{aligned} N &= kTB \\ &= (1.38 \times 10^{-23}) \times 800 \times (40 \times 10^6) \\ &= 4.416 \times 10^{-13} \text{ Watts} \\ &= -123.55 \text{ dBW} \end{aligned}$$

2. Which one of the following systems has the best projected Bit Error Rate (BER)?

- QPSK $\frac{C}{N} = 16\text{dB}$ B = 2fn fb = 40Mbps
- 8-PSK $\frac{C}{N} = 18\text{dB}$ B = fn fb = 60Mbps

Solution

$$\frac{C}{N} \text{ dB} = \left(\frac{Eb}{No} \right) \text{ dB} - \left(\frac{B}{fb} \right) \text{ dB}$$

For QPSK system

$$\begin{aligned} \left(\frac{Eb}{No} \right) \text{ dB} &= \left(\frac{C}{N} \right) \text{ dB} + \left(\frac{B}{fb} \right) \text{ dB} \\ &= 16 + 10 \log \left(\frac{2 \times (40 \times 10^6 / 2)}{40 \times 10^6} \right) \\ &= 16 \text{ dB} \end{aligned}$$

For 8-PSK system

$$\begin{aligned} \left(\frac{Eb}{No} \right) \text{ dB} &= \left(\frac{C}{N} \right) \text{ dB} + \left(\frac{B}{fb} \right) \text{ dB} \\ &= 18 + 10 \log \left(\frac{60 \times 10^6 / 3}{60 \times 10^6} \right) \\ &= 13.23 \text{ dB} \end{aligned}$$

QPSK system has better projected Bit Error Rate (BER).

3. An earth station satellite transmitter has an HPA with a rated saturated output power of 12,000 W. The back-off ratio is 4 dB, the branching loss is 1.5 dB, the feeder loss is 5 dB, and the antenna gain is 38 dB. Determine the actual radiated power and the EIRP.

Solution

$$P_T = 10 \log_{10}(12000) \\ = 40.79 \text{ dBW}$$

$$\text{Actual Radiated Power} = P_T - L_{bo} - L_{bf} \\ = 40.79 - 4 - (1.5 + 5) \\ = 30.29 \text{ dBW}$$

$$\text{EIRP} = 30.29 + 38 \\ = 68.29 \text{ dBW}$$

4. A satellite system operates a 6-GHz uplink and 4-GHz downlink and has a projected $P(e)$ of one bit error in every 100,000 bits transmitted. The modulation scheme is 4-PSK, and the system will carry 80 Mbps. The equivalent receiver noise temperature is 120 K, and the receiver noise bandwidth is equal to the minimum Nyquist frequency. Determine the following:
- The C/N ratio that would be measured at a point in the receiver prior to the BPF where the bandwidth is equal to two times the minimum Nyquist frequency.
 - The C/N ratio that would be measured at a point in the receiver prior to the BPF where the bandwidth is equal to three times the minimum Nyquist frequency.

Solution

For 4-PSK modulation scheme with $P(e) = 10^{-5}$, the minimum C/N is 12.8 dB

$$\frac{E_b}{N_o} = \frac{C}{N} + \frac{B}{f_b} \\ = 12.8 + 10 \log\left(\frac{40}{80}\right) \\ = 9.79 \text{ dB}$$

- (a) For the bandwidth is equal to two times the minimum Nyquist frequency,

$$\frac{C}{N} = \frac{E_b}{N_o} - \frac{B}{f_b} \\ = 9.79 - 10 \log\left(\frac{80}{80}\right) \\ = 9.79 \text{ dB}$$

- (b) For the bandwidth is equal to three times the minimum Nyquist frequency,

$$\frac{C}{N} = \frac{E_b}{N_o} - \frac{B}{f_b} \\ = 9.79 - 10 \log\left(\frac{120}{80}\right) \\ = 8.03 \text{ dB}$$

Q4) Calculate the overall E_b/N_0 ratio for a satellite system with the following parameters. Use the antenna gain table in Figure 2-27 and the free space path loss & angle elevation correction in Figure 2-28.

Uplink

1. Earth station transmitter output power at saturation, 2000 W 33 dBW
2. Earth station back-off loss 3 dB
3. Earth station branching and feeder losses 4 dB
4. Earth station transmit antenna gain (from Figure 14-27, 15 m at 14 GHz) 64 dB
5. Additional uplink atmospheric losses 0.6 dB
6. Free-space path loss (from Figure 2-28, at 14 GHz) 206.5 dB
7. Satellite receiver G/T_e ratio -5.3 dBK₁
8. Satellite branching and feeder losses 0 dB
9. Bit rate 120 Mbps
10. Modulation scheme 8-PSK

Downlink

1. Satellite transmitter output power at saturation, 10 W 10 dBW
2. Satellite back-off loss 0.1 dB
3. Satellite branching and feeder losses 0.5 dB
4. Satellite transmit antenna gain (from Figure 2-27, 0.37 m at 12 GHz) 30.8 dB
5. Additional downlink atmospheric losses 0.4 dB
6. Free-space path loss (from Figure 2-28, at 12 GHz) 205.6 dB
7. Earth station receive antenna gain (15 m, 12 GHz) 62 dB
8. Earth station branching and feeder losses 0 dB
9. Earth station equivalent noise temperature 270 K
10. Earth station G/T_e ratio 37.7 dBK₁
11. Bit rate 120 Mbps
12. Modulation scheme 8 -PSK

Downlink

1. Satellite transmitter output power at saturation, 10 W	10 dBW
2. Satellite back-off loss	0.1 dB
3. Satellite branching and feeder losses	0.5 dB
4. Satellite transmit antenna gain (from Figure 2-27, 0.37 m at 12 GHz)	30.8 dB
5. Additional downlink atmospheric losses	0.4 dB
6. Free-space path loss (from Figure 2-28, at 12 GHz)	205.6 dB
7. Earth station receive antenna gain (15 m, 12 GHz)	62 dB
8. Earth station branching and feeder losses	0 dB
9. Earth station equivalent noise temperature	270 K
10. Earth station G/T_e ratio	37.7 dBK^{-1}
11. Bit rate	120 Mbps
12. Modulation scheme	8 -PSK

Solution *Uplink budget:* Expressed as a log,

$$\begin{aligned} \text{EIRP (earth station)} &= P_t + A_t - L_{\text{bo}} - L_{\text{bf}} \\ &= 33 \text{ dBW} + 64 \text{ dB} - 3 \text{ dB} - 4 \text{ dB} = 90 \text{ dBW} \end{aligned}$$

Carrier power density at the satellite antenna:

$$\begin{aligned} C' &= \text{EIRP (earth station)} - L_p - L_u \\ &= 90 \text{ dBW} - 206.5 \text{ dB} - 0.6 \text{ dB} = -117.1 \text{ dBW} \end{aligned}$$

C/N_0 at the satellite:

$$\frac{C}{N_0} = \frac{C}{KT_e} = \frac{C}{T_e} \times \frac{1}{K} \quad \text{where } \frac{C}{T_e} = C' \times \frac{G}{T_e}$$

Thus,
$$\frac{C}{N_0} = C' \times \frac{G}{T_e} \times \frac{1}{K}$$

Expressed as a log,

$$\begin{aligned}\frac{C}{N_0} &= C' + \frac{G}{T_e} - 10 \log(1.38 \times 10^{-23}) \\ &= -117.1 \text{ dBW} + (-5.3 \text{ dBK}^{-1}) - (-228.6 \text{ dBWK}) = 106.2 \text{ dB}\end{aligned}$$

Thus,

$$\begin{aligned}\frac{E_b}{N_0} &= \frac{C/f_b}{N_0} = \frac{C}{N_0} - 10 \log f_b \\ &= 106.2 \text{ dB} - 10 (\log 120 \times 10^6) = 25.4 \text{ dB}\end{aligned}$$

and for a minimum bandwidth system,

$$\frac{C}{N} = \frac{E_b}{N_0} - \frac{B}{f_b} = 25.4 - 10 \log \frac{40 \times 10^6}{120 \times 10^6} = 30.2 \text{ dB}$$

Downlink budget: Expressed as a log,

$$\begin{aligned}\text{EIRP (satellite transponder)} &= P_t + A_t - L_{\text{bo}} - L_{\text{bf}} \\ &= 10 \text{ dBW} + 30.8 \text{ dB} - 0.1 \text{ dB} - 0.5 \text{ dB} \\ &= 40.2 \text{ dBW}\end{aligned}$$

Carrier power density at earth station antenna:

$$\begin{aligned}C' &= \text{EIRP} - L_p - L_d \\ &= 40.2 \text{ dBW} - 205.6 \text{ dB} - 0.4 \text{ dB} = -165.8 \text{ dBW}\end{aligned}$$

C/N_0 at the earth station receiver:

$$\frac{C}{N_0} = \frac{C}{KT_e} = \frac{C}{T_e} \times \frac{1}{K} \quad \text{where} \quad \frac{C}{T_e} = C' \times \frac{G}{T_e}$$

Thus,

$$\frac{C}{N_0} = C' \times \frac{G}{T_e} \times \frac{1}{K}$$

Expressed as a log,

$$\begin{aligned} \frac{C}{N_0} &= C' + \frac{G}{T_e} - 10 \log(1.38 \times 10^{-23}) \\ &= -165.8 \text{ dBW} + (37.7 \text{ dBK}^{-1}) - (-228.6 \text{ dBWK}) = 100.5 \text{ dB} \end{aligned}$$

An alternative method of solving for C/N_0 is

$$\begin{aligned} \frac{C}{N_0} &= C' + A_r - T_e - K \\ &= -165.8 \text{ dBW} + 62 \text{ dB} - 10 \log 270 - (-228.6 \text{ dBWK}) \\ &= -165.8 \text{ dBW} + 62 \text{ dB} - 24.3 \text{ dBK}^{-1} + 228.6 \text{ dBWK} = 100.5 \text{ dB} \end{aligned}$$

$$\begin{aligned} \frac{E_b}{N_0} &= \frac{C}{N_0} - 10 \log f_b \\ &= 100.5 \text{ dB} - 10 \log(120 \times 10^6) \\ &= 100.5 \text{ dB} - 80.8 \text{ dB} = 19.7 \text{ dB} \end{aligned}$$

and for a minimum bandwidth system,

$$\frac{C}{N} = \frac{E_b}{N_0} - \frac{B}{f_b} = 19.7 - 10 \log \frac{40 \times 10^6}{120 \times 10^6} = 24.5 \text{ dB}$$

With careful analysis and a little algebra, it can be shown that the overall energy of bit-to-noise density ratio (E_b/N_0) , which includes the combined effects of the uplink ratio $(E_b/N_0)_u$ and the

downlink ratio $(E_b/N_0)_d$, is a standard product over the sum relationship and is expressed mathematically as

$$\frac{E_b}{N_0}(\text{overall}) = \frac{(E_b/N_0)_u (E_b/N_0)_d}{(E_b/N_0)_u + (E_b/N_0)_d} \quad (2-28)$$

where all E_b/N_0 ratios are in absolute values. For Example 2-25, the overall E_b/N_0 ratio is

$$\begin{aligned} \frac{E_b}{N_0}(\text{overall}) &= \frac{(346.7)(93.3)}{346.7 + 93.3} = 73.5 \\ &= 10 \log 73.5 = 18.7 \text{ dB} \end{aligned}$$

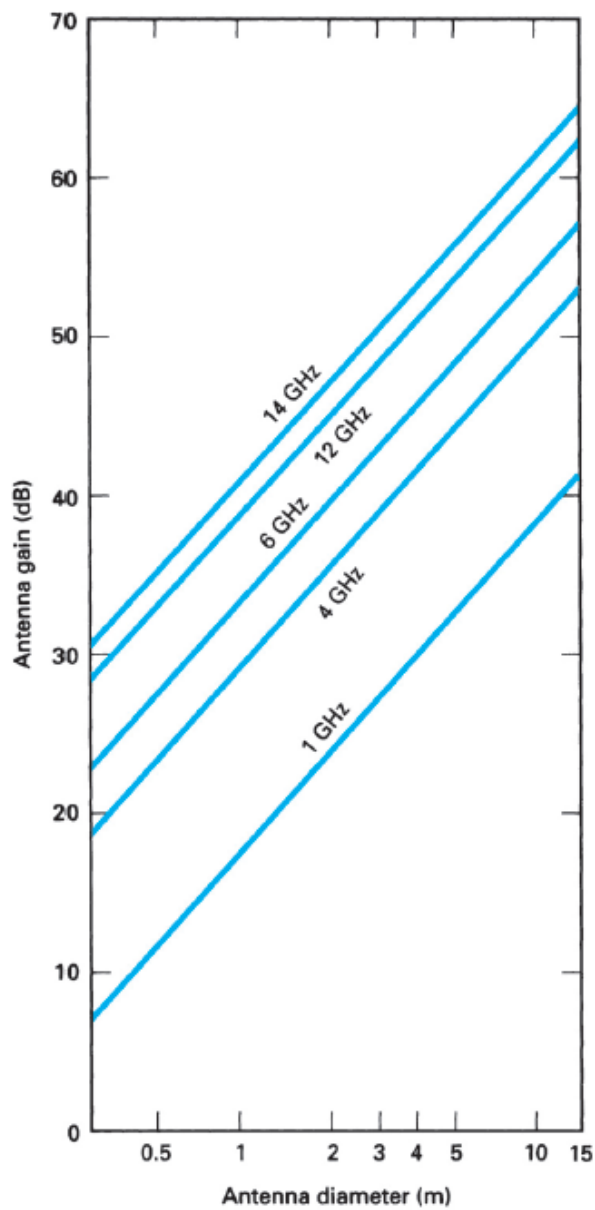


FIGURE 2-27 Antenna gain based on the gain equation for a parabolic antenna:

$$A [\text{db}] = 10 \log \eta [\pi D/\lambda]^2$$

where D is the antenna diameter, λ = the wavelength, and η = the antenna efficiency. Here $\eta = 0.55$. To correct for a 100% efficient antenna, add 2.66 dB to the value.

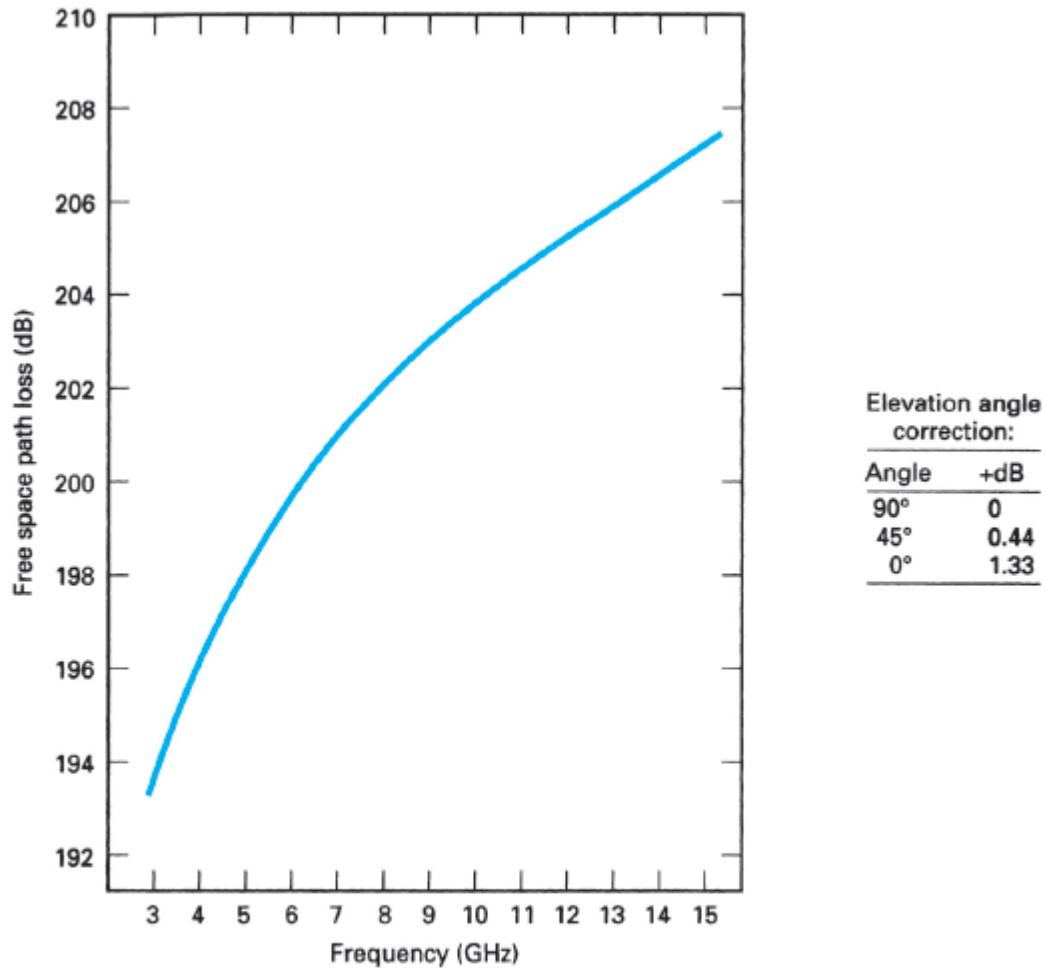


FIGURE 2-28 Free-space path loss [L_p] determined from $L_p = 183.5 + 20 \log f$ [GHz], elevation angle = 90°, and distance = 35,930 km