A C-band Earth station has an antenna with a gain of 54 dB. The transmitter output power is set to 100 W at the frequency of 6.15 GHz. The signal is received at the satellite at a distance \( d = 37500 \text{ km} \). The satellite has an antenna with a gain of 20 dB. The signal is then routed to the transponder with a gain of 85 dB and gain of 110 dB.

b) Calculate PL at 6.15 GHz

c) Calculate power at the output of satellite antenna

d) Calculate the noise power at the transponder input in dBW in 36 MHz at BW

e) Calculate C power at the output of transponder

\[
\begin{align*}
\text{ERP [dBW]} &= 10 \log (100) + 54 = 20 \text{dBW} + 54 \text{ dB} = 74 \text{ dBW} \\
\text{Pr [dBW]} &= 74 \text{ dBW} - 199.62 \text{ dB} + 26 \text{ dB} = -99.62 \text{ dBW} \\
\text{N [dBW]} &= 10 \log (kT_0 B) = \\
&= 10 \log \left( \frac{1.38 \times 10^{-23} J}{k} \cdot 500k \cdot 36 \times 10^6 \text{Hz} \right) \\
&= -126.04 \text{ dBW}
\end{align*}
\]
The \( C/N \) at the input of the transponder:

\[
C/N \ [\text{dB}] = -99.62 \ \text{dBW} - (-126.04 \ \text{dBW}) = 26.42 \ \text{dB}
\]

d) \( P_{\text{exp}} = -99.62 \ \text{dBW} + 110 \ \text{dB} = 10.38 \ \text{dBW} \rightarrow 10.91 \ \text{W} \)

2. Satellite in problem 1 serves CONUS (48 states in continental US). The antenna on the satellite transmits on \( f = 3875 \ \text{MHz} \) to the Earth station at the distance of \( d = 31,000 \ \text{km} \). The antenna has E-W beamwidth of 6° and N-S beamwidth of 30°. The receiving Earth station has an antenna with gain of 58 dB and 75° look. And is at -3 dB contour for the satellite antenna. Assume that the transponder power is 10 W. Assume \( \eta_s = 0.6 \).

   a) Calculate the gain of the satellite antenna towards the Earth station.
   b) Calculate the power at the Rx at the Earth Station.
   c) Calculate the noise power at the Earth station in 36 MHz of bandwidth.
   d) Find the \( C/N \) at the Earth station.

   a) \( \Theta_{3\ DBW} = 75^\circ / D \)

\[
\mathcal{C} = C/f = \frac{3 \times 10^3 \ \text{W/s}}{3.875 \times 10^9 \ \text{Hz}} = 0.0774 \ \text{W}
\]

\[
D_{\text{BW}} = \frac{75\degree}{\Theta_{3\ DBW}} = \frac{75 \times 0.0774 \ \text{W}}{6^\circ} = 0.9677 \ \text{W}
\]

\[
D_{\text{NE}} = \frac{75\degree}{\Theta_{3\ DBW}} = \frac{75 \times 0.0774 \ \text{W}}{2^\circ} = 1.935 \ \text{W}
\]

Gain on axis:

\[
G = \frac{N_s \cdot 4\pi}{\lambda^2} \cdot D_{\text{BW}} \cdot D_{\text{NE}} = 0.6 \times \frac{4\pi}{(0.0774)^2} \cdot 0.9677 \times 1.935
\]

\[
G = 2.356.7 \rightarrow 33.72 \ \text{dB}
\]
The gain towards the Earth station:

\[ G_e = G_{\text{rx}} - 3\, \text{dB} = 33.72\, \text{dB} - 3\, \text{dB} = 30.72\, \text{dB} \]

1) \[ F_{\text{SPL}} = 92.44 + 20 \log (P_{[\text{GHz}^2]) + 20 \log (d_{[\text{m}]) = 92.44 + 20 \log (3.875) + 20 \log (29000) = 196\, \text{dB} \]

\[ E_{\text{IRP}} = 10\, \text{dBW} + 30.72\, \text{dB} = 40.72\, \text{dBW} \]

\[ P_{\text{ESB}} = E_{\text{IRP}} [\text{dBW}] - F_{\text{SPL}} + G_{\text{rx}} [\text{dBi}] = \]

\[ = 40.72\, \text{dBW} - 196\, \text{dB} + 53\, \text{dBi} = -102.28\, \text{dBW} = C \]

2) \[ N_{\text{C/NI}[\text{dBW}]} = 10 \log \left( \frac{N}{I_{50}} \right) = 10 \log \left( \frac{1.38 \times 10^{-23} \text{J}}{100\, \text{kHz} \times 36 \times 10^6 \text{Hz}} \right) \]

\[ = -133.04\, \text{dBW} \]

3) \[ C/N [\text{dBW}] = -102.28\, \text{dBW} - (-133.04\, \text{dBW}) = 30.78\, \text{dB} \]

3. A 14/11 GHz satellite communication link has a transponder with a bandwidth of 52 MHz, which is operated at output power level of 20 W. The transmit antenna gain at 11 GHz is 80 dB towards a particular Earth station. Path loss to the station is 206 dB, including clear atmosphere losses.

The transponder is used in FDMA mode to send 500 BPSK voice channels with 1/2 rate FEC coding. Each coded BPSK signal has a symbol rate of 50 kbps and requires a receiver with a noise bandwidth of 50 kHz per channel. The Earth station used to receive the voice signals has antennas with gains of 40 dB (1 meter diameter) and the receiver with \( T_s = 150K \) in clean air. The IF bandwidth is 50 kHz.
a) Calculate power transmitted in a single voice channel from the satellite.
b) Calculate S/N in clear air for an earth station receiving a single voice channel.
c) What is the margin over coded BPSK threshold of 6 dB?

500 channels in an FDMA mode.

$$P_{ch} = \frac{25W}{50W} = 0.05W/\text{channel} \rightarrow -14\,\text{dBW}$$

$$P_t = P_{tx}[\text{dBW}] + G_{tx}[\text{dB]} - PL[\text{dB}] + G_{rx}[\text{dB}]$$

$$= -14\,\text{dBW} + 30\,\text{dB} - 206\,\text{dB} + 40\,\text{dB} = -150\,\text{dBW}$$

$$N = 10\log(kT_0B) = 10\log \left[1.88 \times 10^{-23} \times \frac{y}{k} \times 180k \times 50 \times 10^2 \right] = -159.9\,\text{dBm}$$

$$C/N = -153\,\text{dBW} - (-159.4\,\text{dBW}) = 9.85\,\text{dB}$$

$$\Delta(C/N) = C/N - 6\,\text{dB} = 9.85\,\text{dB} - 6\,\text{dB} = 3.85\,\text{dB} \text{ of margin}$$

**Geostationary satellites use L, C, Ku and Ka bands.** The path length from an Earth station to the GEO satellite is approximately 28500 km. For this range, calculate the path loss in dB for the following frequencies:
a) \( f = 1.6 \text{ GHz} \)  
\[ \text{FSPL (dB)} = 92.44 + 20 \log (1.6) + 20 \log (38500) = 188.23 \text{ dB} \]
\( f = 1.5 \text{ GHz} \)  
\[ \text{FSPL (dB)} = 187.67 \text{ dB} \]

b) \( f = 6.2 \text{ GHz} \)  
\[ \text{FSPL (dB)} = 92.44 + 20 \log (6.2) + 20 \log (88500) = 199.99 \text{ dB} \]
\( f = 4 \text{ GHz} \)  
\[ \text{FSPL (dB)} = 196.19 \text{ dB} \]

\[ \Delta \text{FSPL (dB)} = 3.8 \text{ dB} \quad \text{— difference between link} \]

c) \( f = 14.2 \text{ GHz} \)  
\[ \text{FSPL (dB)} = 207.23 \text{ dB} \]
\( f = 12.00 \text{ GHz} \)  
\[ \text{FSPL (dB)} = 205.73 \text{ dB} \]

\[ \Delta \text{FSPL (dB)} = 1.5 \text{ dB} \]

d) \( f = 30 \text{ GHz} \)  
\[ \text{FSPL (dB)} = 213.69 \text{ dB} \]
\( f = 20 \text{ GHz} \)  
\[ \text{FSPL (dB)} = 210.17 \text{ dB} \]

\[ \Delta \text{FSPL (dB)} = 3.52 \text{ dB} \]

6. A geostationary satellite comes with a transponder with a 20W transmitter at 4GHz. The transmitter is operated with 3dB backoff and drives an antenna of 80dB.
An Earth station at the center of the satellite's coverage area at the distance 38500 km receives the signal.
Calculate

a) Flux density at the earth station in dBW/m²
b) The power received by an antenna with the gain of 39 dB
c) The EIRP of the transponder in dBW
d) \[ EIRP [\text{dBW}] = P_t [\text{dBW}] + G_t [\text{dB}] = \]
\[ = 10 \text{dBW} + 30 \text{dB} = 40 \text{dBW} \]
a) \( W = \frac{P_t G_t}{4\pi R^2} \) = power flux density

\[
W [\text{dBW/m}^2] = E_{IRP} [\text{dBW}] - 10 \log |\text{ATT}| - 20 \log (R)
\]

\[
W [\text{dBW/m}^2] = 40 \text{ dBW} - 11.0 - 20 \log (28500 \times 10^3)
\]

= -122.7 dBW/m²

b) \( P_{Rx} = E_{IRP} - FSPL + Gr [\text{dBm}] \)

\[
FSPL = 92.44 + 20 \log (4) + 20 \log (28500) = 196.19 \text{ dB}
\]

\[
P_{Rx} = 40 \text{ dBW} - 196.19 \text{ dB} + 39 \text{ dB} = -117.19 \text{ dBW}
\]

7. An LEO satellite has a multibeam antenna with a gain of 18 dB in each beam. A transponder with antenna power of 0.5 W at 2.5 GHz is connected to one antenna beam. An earth station is located at the edge of coverage zone of this beam where the received power is 3 dB below the center of the beam. The range is 2000 km. Find

a) Power received on the ground with antenna of 1 dB gain

b) The noise power of the earth station receive Rx. Ts = 260 K and Bn = 20 kHz

c) The C/N for the signal and the ground receiver.

a) \( E_{IRP} = P_t [\text{dBW}] + G_t [\text{dB}] - 10 [\text{dB}] \)

= +3 dBW + 18 dB - 3 dB = 12 dBW

\[
FSPL = 92.44 + 20 \log (2.5) + 20 \log (2000) = 166.42 \text{ dB}
\]

\[
P_{[\text{dBW}]} = E_{IRP} [\text{dBW}] - FSPL [\text{dB}] + Gr [\text{dB}]
\]

= 12 dBW - 166.42 dB + 1 dB = -153.42 dBW
b) $N_{[\text{dBW}]} = 10 \log \left( \frac{1.38 \times 10^{-23} \cdot 9}{K} \cdot 260K \cdot 20 \times 10^2 \text{Hz} \right) = -161.44 \text{ dBW}$

c) $C/N [\text{dB}] = C[\text{dBW}] - N_{[\text{dBW}]} =$

$$= -153.42 \text{ dBW} - (-161.44 \text{ dBW}) = 8.02 \text{ dB}$$

8. A satellite in GEO orbit is at $d = 39,000 \text{ km}$ from an earth station. The required flux density at the satellite to saturate the transponder is $-90 \text{ dBW/m}^2$. The earth station's TX antenna has a gain of $50 \text{ dB}$. Operating frequency is $f = 14.3 \text{ GHz}$. Find:

a) The EIRP of the earth station when transmitter is at saturation

b) the transmit power of the ground transmitter

a) $F = 10 \log \left( \frac{P_t G_t}{4\pi R^2} \right) = \text{EIRP [dBW]} - 10 \log (4\pi) - 20 \log (R \text{[m]})$

$\text{EIRP [dBW]} = F \left[ \text{dBW/m}^2 \right] + 10 \log (4\pi) + 20 \log (39,000 \times 10^3)$

$= -90 \text{ dBW/m}^2 + 10 \log (4\pi) + 20 \log (39,000 \times 10^3)$

$= 72.8 \text{ dBW}$

b) $P_t \text{ [dBW]} = \text{EIRP [dBW]} - G_t \text{ [dB]} =$

$$= 72.8 \text{ dBW} - 52 \text{ dB} = 20.8 \text{ dBW} \Rightarrow 120.6 \text{ W}$$

9. A 12 GHz earth station system has an antenna with noise temperature of $50K$, an LNA with noise temperature of $100K$ and a gain of $40 \text{ dB}$ and a mixer with a noise temperature of $1000K$. Find the system noise temperature.
10. A geosynchronous satellite carries a C-band transponder which transmits 20 W into antenna with on-axis gain of 80 dB. An earth station is at the center of the beam at a distance 38000 km. The operating frequency is 4 GHz.

a) Calculate the incident flux density at the Earth station in W/m² and dBW/m².

b) The Earth station has an antenna with circular aperture = 2 m in diameter and η_a = 0.66%. Calculate the received power level in W and in dBW at the antenna output port.

c) Calculate on-axis gain of the antenna in dB.

---

a) $F_{dBW} = 10 \log (20W) + 30 \text{dB} = 13 \text{dBW} + 30 \text{dB} = 43 \text{dBW}$

$$ F = \frac{P + G_L}{4 \pi d^2} = \frac{20W \cdot 10^2}{4 \pi (38000 \times 1000)^2 \text{m}^2} = 1.102 \times 10^{-12} \text{W/m}^2 $$

$$ F [\text{dBW/m}^2] = -119.58 \text{ dBW/m}^2 $$

b) $A = \frac{D^2}{4 \pi} = \frac{2^2}{4 \pi} \approx 3.141 \text{ m}^2$

$$ A_e = \eta_a \cdot A = 0.66 \times 3.141 = 2.042 \text{ m}^2 $$

$$ G_i = \frac{4 \pi}{k^2} \cdot A_e = \frac{4 \pi \cdot (4 \times 10^9)^2}{(2 \times 10^8)^2} \times 2.042 = 4561 \rightarrow 36.6 \text{ dB} $$
c) \[ \text{FSPL} = 92.44 + 20 \log(4) + 20 \log(38,000) = 196.1 \text{ dB} \]

\[ \text{Pr [dBW]} = \text{EiPR [dBW]} - \text{FSPL [dB]} + \text{Gr [dB]} \]

\[ = 43 \text{dBW} - 196.1 \text{ dB} + 36.6 \text{ dB} = -116.5 \text{ dBW} \]

12. Design of a communication link through a geostationary satellite to meet C/N and link margin specifications. Path to satellite d = 38,500 km

**Satellite**
- GEO → 73°W longitude (location of the satellite)
- 24 C-band transponders
- 24 Ku-band transponders
- 32 kW RF power output
- Antenna gains TX & RX (C & Ku band) = 31 dB
- RX system noise temperature = 500 K
- Transponder saturated output power: 40 W - C band
- Transponder BW = 36 MHz - C band
- Transponder saturated output power: 80 W - Ku band
- Transponder BW = 54 MHz - Ku band

**Signals**
1. FM-AM analog signal with BW = 27 MHz
2. Multiplexed digital TV signals modulated with QPSK. Symbol rate 27 Mbps using 1/2 FEC with coding gain of 5.5 dB

\[ \text{Minimum C/N} = 9.5 \text{ dB} \]

1.1. Design a transceiving Earth station to provide a clear air C/N of 26 dB through a C-band transponder at a frequency of 6.285 GHz. Use an uplink antenna with a diameter of 24 m and an aperture efficiency of 68%. Find the uplink transmit power to achieve the required C/N. The uplink station is located on the 2 dB contour of the satellite footprint. Allow 0.5 dB for clear air atmospheric attenuation and other losses.
\[ G_e = \eta_b \frac{D^2}{4} \cdot \frac{4\pi}{\lambda^2} = \eta_A \cdot \frac{D^2}{4} \cdot \frac{4\pi F^2}{C^2} \]

\[ G_e = 0.68 \frac{(4\pi)^2}{4} \cdot \frac{4\pi^2 (6.285 \times 10^6)^2}{(3 \times 10^8 \text{w/5})^2} = 238.595 \Rightarrow 53.8 \text{ dB} \]

**UL budget**

\[ N = 10 \log \left| \frac{kT_s B_n}{\text{dBm}} \right| = 10 \log \left( \frac{1.38 \times 10^{-23} \cdot 4}{500 \cdot 27 \times 10^6} \right) = -127.3 \text{ dBm} \]

\[ C/N = 26 \text{ dB} \Rightarrow C = N [\text{dBW}] + C/N [\text{dB}] = -127.3 \text{ dBW} + 26 \text{ dB} = -101.3 \text{ dBW} \]

\[ P_t \left[ \text{dBW} \right] + G_e \left[ \text{dB} \right] - \text{FSPL} - AL + (G_r \left[ \text{dB} \right] - LG_r) = -C \left[ \text{dBW} \right] \]

\[ \text{FSPL} = 19.44 + 20 \log (6.285) + 20 \log (3500) = 200.1 \text{ dB} \]

\[ P_t \left[ \text{dBW} \right] = C \left[ \text{dBW} \right] - G_e \left[ \text{dB} \right] + \text{FSPL} + AL - (G_r \left[ \text{dB} \right] - LG_r) \]

\[ = -101.3 \text{ dBW} - 58.8 \text{ dB} + 200.1 \text{ dB} + 0.5 \text{ dB} - (31 \text{ dB} - 2 \text{ dB}) \]

\[ = 16.5 \text{ dBW} \Rightarrow P_t = 44.7 \text{ W} \]

---

12.2. Design a C-band receiving earth station to provide a signal \((C/N)_0 = 13 \text{ dB}\) in 27 MHz IF noise bandwidth. The DL frequency is 4.06 GHz. The antenna noise temperature is 20K and the LNA noise temperature is 55K. The gain of the LNA is very high (ignore the noise temperature of all other elements in the RX chain). The satellite transmission is operated at 1dB output backoff.
Clear air attenuation and due losses is 0.5 dB. Determine the diameter of the 
RX antenna assuming an aperture efficiency of η = 0.65. The receiving 
terminal is at the -3 dB contour of the satellite footprint.

\[
\frac{(C/N)_{Oln}}{(C/N)_{Upk} + (C/N)_{Dow}} = 1
\]

\[
(C/N)_{Upk} = 26 \text{ dB} \rightarrow 398.1 \quad \Rightarrow \quad q_0 = \frac{1}{398.1 + (C/N)_{Dow}} = 21.06
\]

\[
(C/N)_{Oln} = 13 \text{ dB} \rightarrow 20
\]

Therefore \( (C/N)_{DL} = 10 \log(21.06) = 13.23 \text{ dB} \)

\[
FSPL = 92.44 + 20 \log\left(\frac{d}{4.06}\right) + 20 \log\left(\frac{\lambda}{38.7 \text{ km}}\right) = 196.32 \text{ dB}
\]

\[
N = 10 \log\left(k T_s \cdot B_n\right) \rightarrow \text{noise}
\]

\[
T_S = T_A + T_{LWA} = 20K + 55K = 75K
\]

\[
N = 10 \log\left(1.38 \times 10^{-23} \frac{F}{K} \cdot 75K \cdot 27 \times 10^6 \text{ Hz}\right) = -135.54 \text{ dBW}
\]

\[
C_{rx} = N + (C/N)_{Oln} = -135.54 \text{ dBW} + 13.23 \text{ dB} = -122.31 \text{ dBW}
\]

Transponder output

\[
P_{sat} [\text{dBW}] = 10 \log\left(40W\right) = 16.02 \text{ dBW}
\]

\[
P_t [\text{dBW}] = P_{sat} - B_0 [\text{dB}] = 16.02 \text{ dBW} - 1 \text{ dB} = 15.02 \text{ dBW}
\]

\[
EIRP [\text{dBW}] = 15.02 \text{ dBW} + 31 \text{ dB} = 46.02 \text{ dBW}
\]

Link budget

\[
EIRP [\text{dBW}] - FSPL [\text{dB}] - L_{od} + (G_{dx} - L_e)
\]
\[ G_{xy} = 19.68 \text{ dB} + 0.5 \text{ dB} - 46.02 \text{ dBW} - 122.81 \text{ dBW} + 3 \text{ dB} = 31.49 \text{ dB} \]

\[ G_{xy} = 31.49 \text{ dB} \rightarrow 1409.3 \]

\[ G_{xy} = \eta_A \frac{\pi D^2}{4} \frac{4 \pi^2}{\lambda^2} = \eta_A \left( \frac{D}{\lambda} \right)^2 \]

\[ G_{xy} = \eta_A \left( \frac{D}{\lambda} \right)^2 \Rightarrow D = \frac{C}{\eta_A} \sqrt{\frac{G_{xy}}{\eta_A}} \]

\[ D = \frac{3 \times 10^8 \text{ W/s}}{\eta_1 \times 4.06 \times 10^9 \text{ W/s}} \sqrt{1409.3/0.65} = 1.095 \text{ m} \]