UNIVERSITY OF
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Link Budgets

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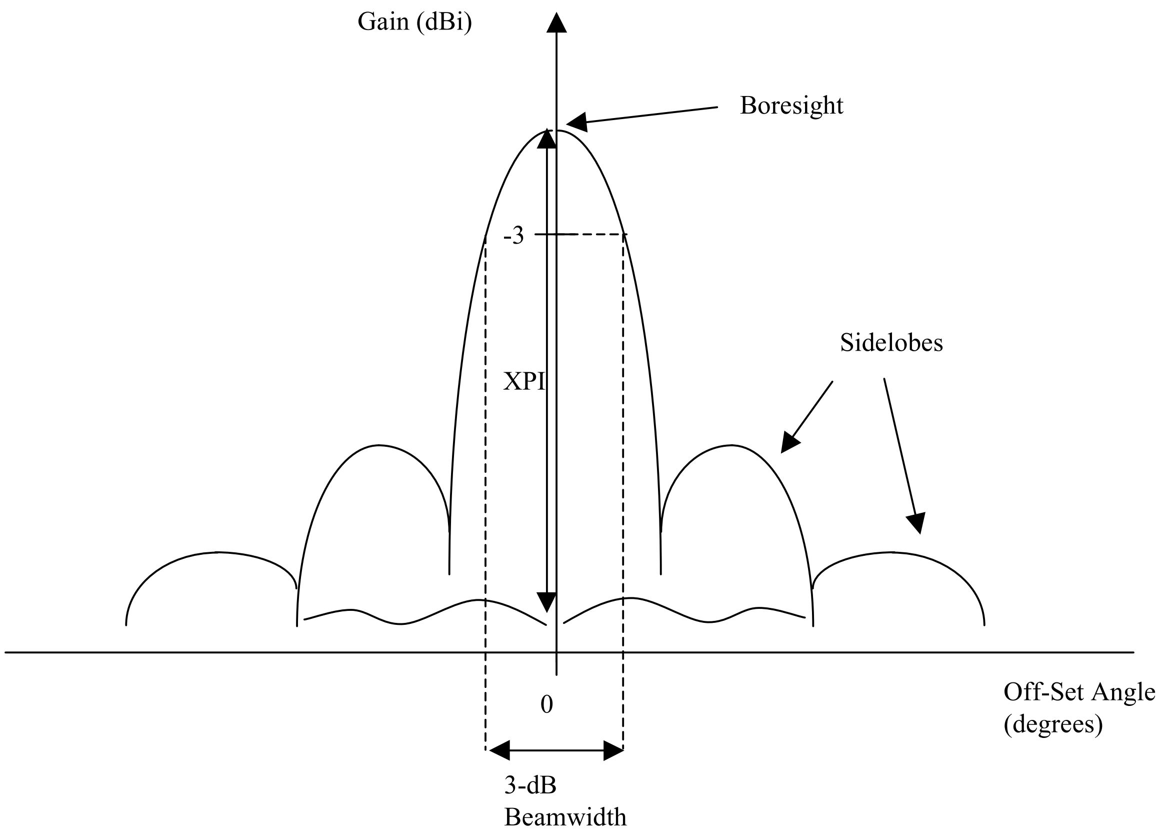
Contents

- Antenna Gain Characteristics
- Link Parameters
- Noise
- Noise Figure

Antenna Radiation Pattern



Definition of Gain

- An *IDEAL* isotropic antenna radiates power of uniform strength in all directions from a point source
- In practice, antennas with directional gain are used to *focus* the transmitted power towards a *wanted direction*

Gain Equation

$$G(\vartheta,\varphi)=\frac{P(\vartheta,\varphi)}{\frac{P_T}{4\pi}}$$

P_T = Total power radiated per unit solid angle from an isotropic source

$P(\theta, \varphi)$ = Power radiated per unit solid angle in the direction (θ, φ)

Antenna Definitions

- Boresight
  - Direction in which the maximum power is received
- Half-Power Beamwidth
  - Angular separation between half-power signal points
- Non-symmetrical antennas have half-power beamwidth for co- and cross-planes

Half-Power Beamwidth

- This is approximated by:

$$\gamma_{hp} = \frac{70\lambda}{D} \qquad \text{Degrees}$$

- where
  - D = antenna diameter, m
  - λ= wavelength, m

Antenna Gain

- The gain of an antenna is given by:

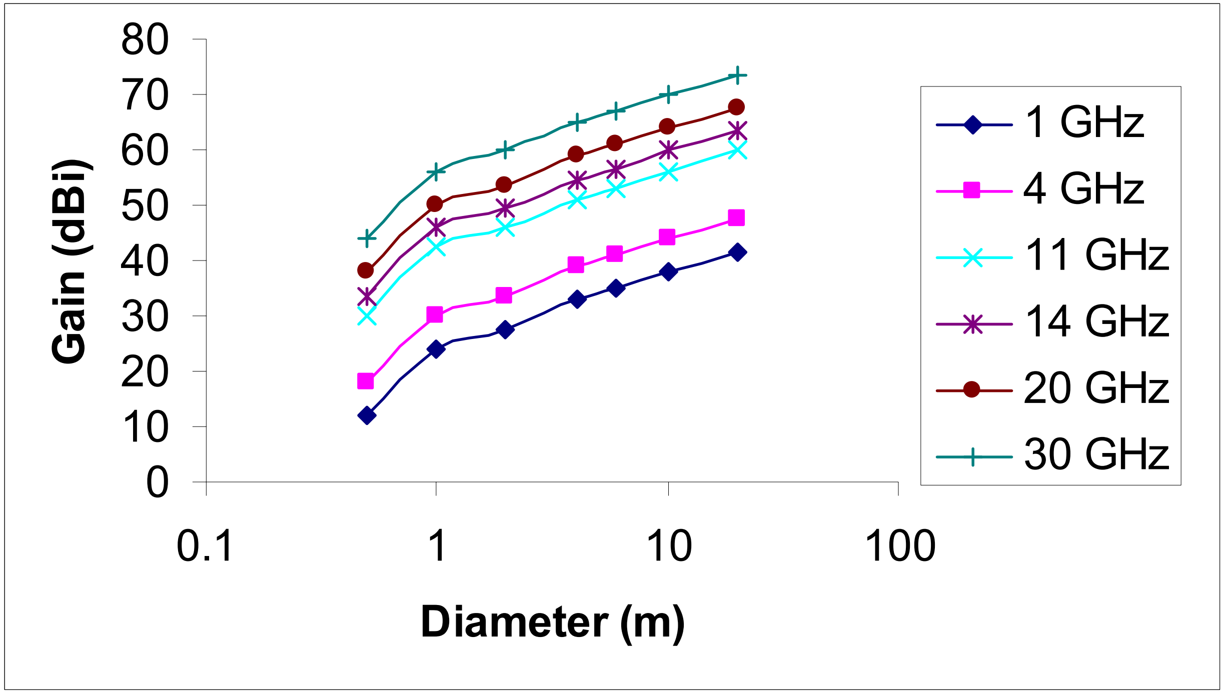
$$G = \frac{4\pi A_{eff}}{\lambda^2}$$

- λ= wavelength, m
- A_{eff} = Effective area of antenna, m^2

Effective Area

- Used to take into account non ideal performance of antenna
  - $A_{eff} = \mu A$
- μ = antenna efficiency
  - typically in the region of 0.5 - 0.7
  - 1/(root 2) is commonly used

Gain Variation



Sidelobe Characteristics

- The antenna's sidelobe gain is limited in order to protect other services/users from interference
- ITU specifies limits for various types of antenna characteristics
- For a parabolic antenna, the sidelobe envelope is given by:

Sidelobe Envelope

$G = 32 - 25 \log \Phi$ dBi $\quad \Phi_{min} <= \Phi <= 48°$

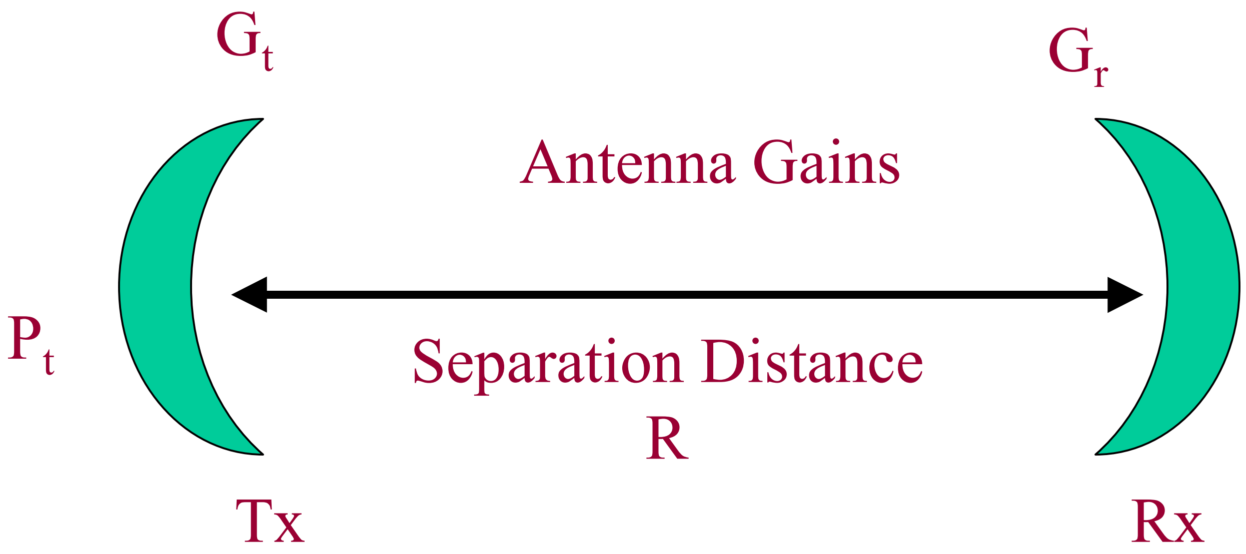
$= -10$ dBi for $48° <= \Phi <= 180°$

where:

Φ_{min} is 1° or $\dfrac{100\lambda}{D}$, whichever is the greater

Two Antennas Separated by R

- Transmitter provides a signal of power P_t



Power Flux Density

- PFD is measured in Wm^{-2}
- Assuming a point source radiating isotropic power, i.e. of equal spectral strength in all directions

$$PFD = \frac{P_{tx}}{4\pi R^2} \quad Wm^{-2}$$

- Power flux density is defined as the ratio of the Tx power to the surface area of sphere of radius equal to the distance from the point source

Effective Isotropic Radiated Power

- In practice, antennas are used to focus and direct transmit power into a particular direction
- The EIRP is a combination of power and antenna gain
- It has units of W (or dBW)
  - $EIRP = P_t G_t$ W
  - $EIRP = 10\log P_t + 10 \log G_t$ dBW

Received Power

- The received power at a distance *R* is given by:
  - Power flux Density x Receiver Area
  - Wm^{-2} x m^2 (= W)
  - Recall from Antenna Gain:

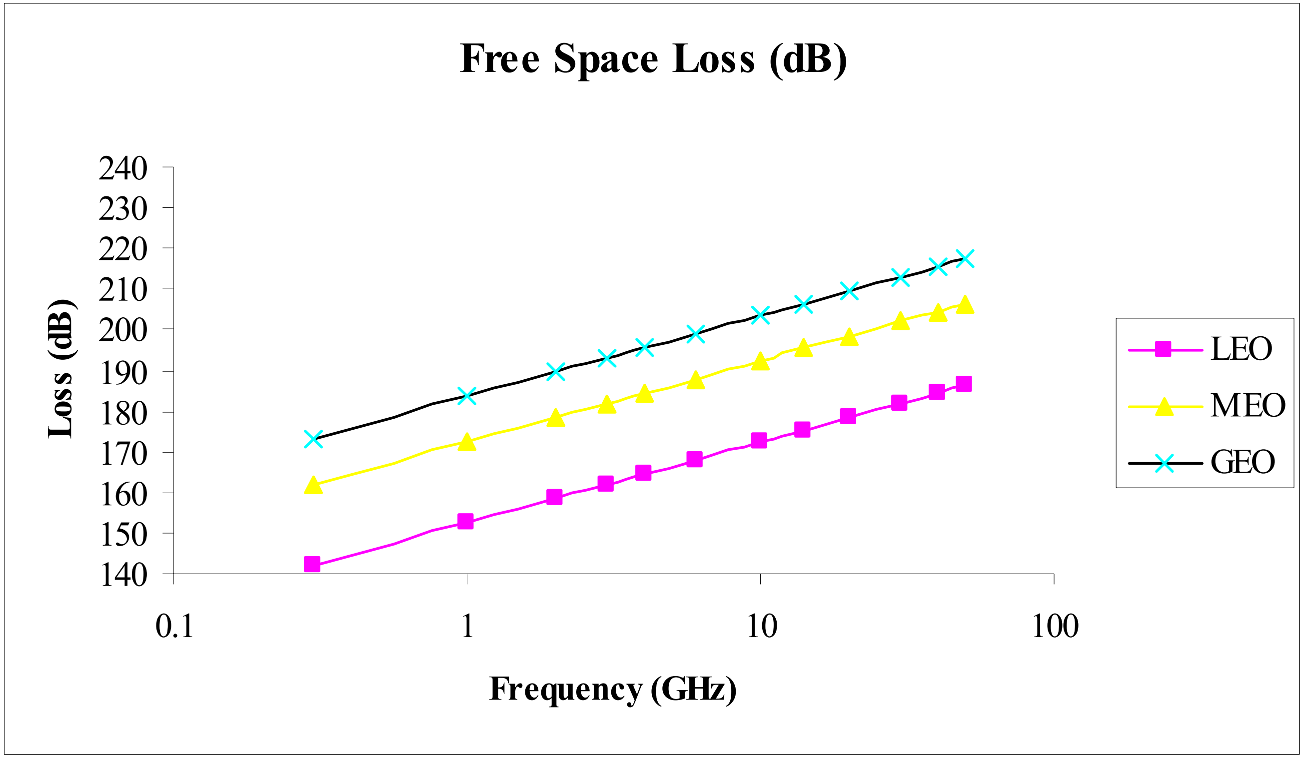
$$A_{eff} = \frac{G\lambda^2}{4\pi}$$

Free Space Loss

- Free Space Loss has no units
- It is frequency dependent
- It is given by:

$$FSL = \left(\frac{\lambda}{4\pi R} \right)^2$$

Free Space Loss Variation



Available Thermal Noise

- Definition: Noise due to random fluctuations of electric currents

$$\overline{e_n^2} = 4kTBR$$

- where
  - e_n = noise voltage
  - K = Boltzmann's constant
  - R = Resistance
  - B = Noise bandwidth, Hz
  - T = Absolute temperature, K

Noise Power in a Matched Load

- P_n is independent of frequency
- Termed 'White Noise'

$$P_n = \frac{\overline{e_n^2}}{4R} = kTB \quad \text{Watts}$$

Higher Frequency Noise

- At higher mm wavelengths and infra-red, the exact quantum formula for noise density must be used

$$N_Q = \frac{hf}{e^{\frac{hf}{kT}} - 1} + hf \qquad \text{WHz}^{-1}$$

- h = Planck's constant (6.62608 X 10-34 Js]
- Presently not required for operating frequencies under consideration

Carrier to Noise Ratio

- Recall thermal noise:

$$N = KT_S B \qquad W$$

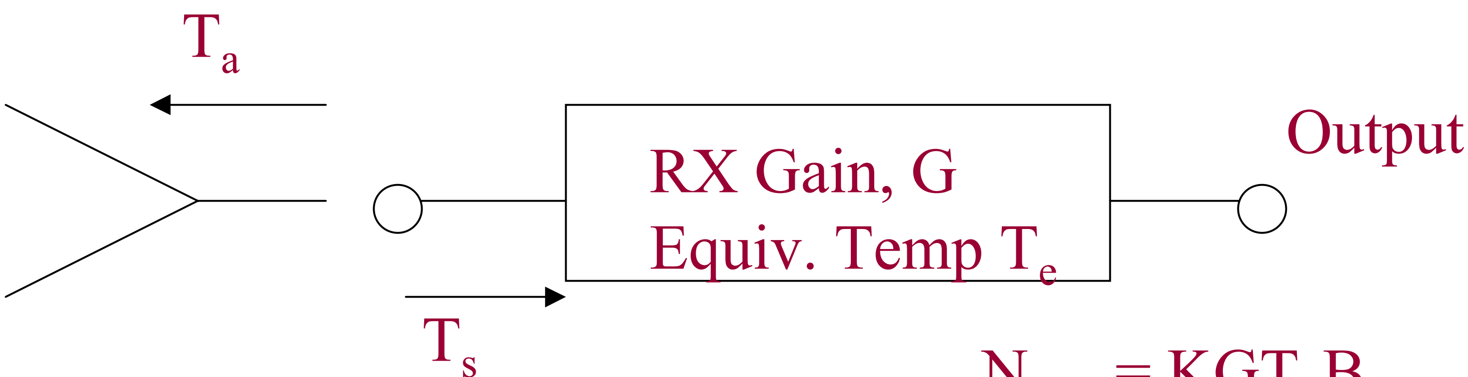
  - T_S = Receiver System Temperature {K}
  - B = Bandwidth determined by modulation method and bit rate

Equivalent Noise Temperature

- Comprises:
  - Link thermal noise
  - Random noise from the atmosphere
  - Device noise

Equivalent Noise Temperature Representation

T_a = antenna temperature



$$N_{out} = KGT_SB$$

N_{out} = Output Noise Power

$$T_s = T_a + T_e$$

- T_S is used to represent the noise of the entire receiver system

Antenna Noise Temperature

$$T_{ant} = T_{sky} + T_{ground} \quad K$$

- T_{sky} is due to atmospheric absorption gases and rain
- T_{ground} is due to reception of unwanted signals via sidelobes

Effect of Rain on Antenna Noise

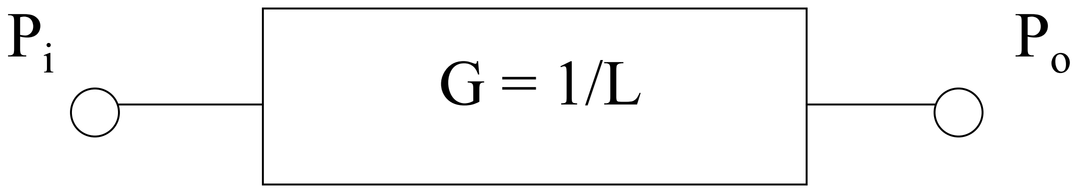
- Rain can be viewed as a lossy feed (see later)

$$T_{ant} = \frac{T_{sky}}{A_{rain}} + T_0\left(1 - \frac{1}{A_{rain}}\right) + T_{ground} \qquad \text{K}$$

- Antenna noise increases (N), while wanted signal decreases (C)
  - C/N doubly affected

Noise Temperature of Lossy Network

- T_0 = Ambient Temperature (290 K)

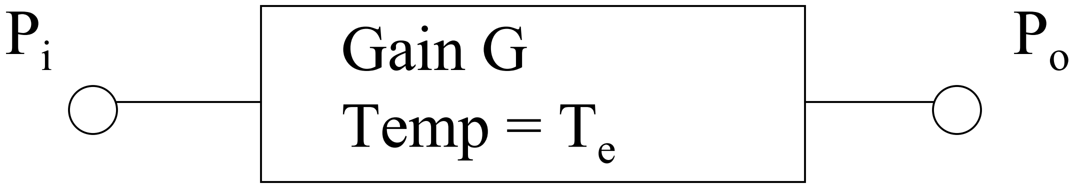


$$T_e = T_0\left(1 - \frac{1}{L}\right)$$

$$L = \frac{P_i}{P_o}$$

Noise Figure Definition

- F is defined as the ratio of Signal to Noise Ratio (SNR) at the input to the output



$$F = \frac{P_i / N_i}{P_o / N_o}$$

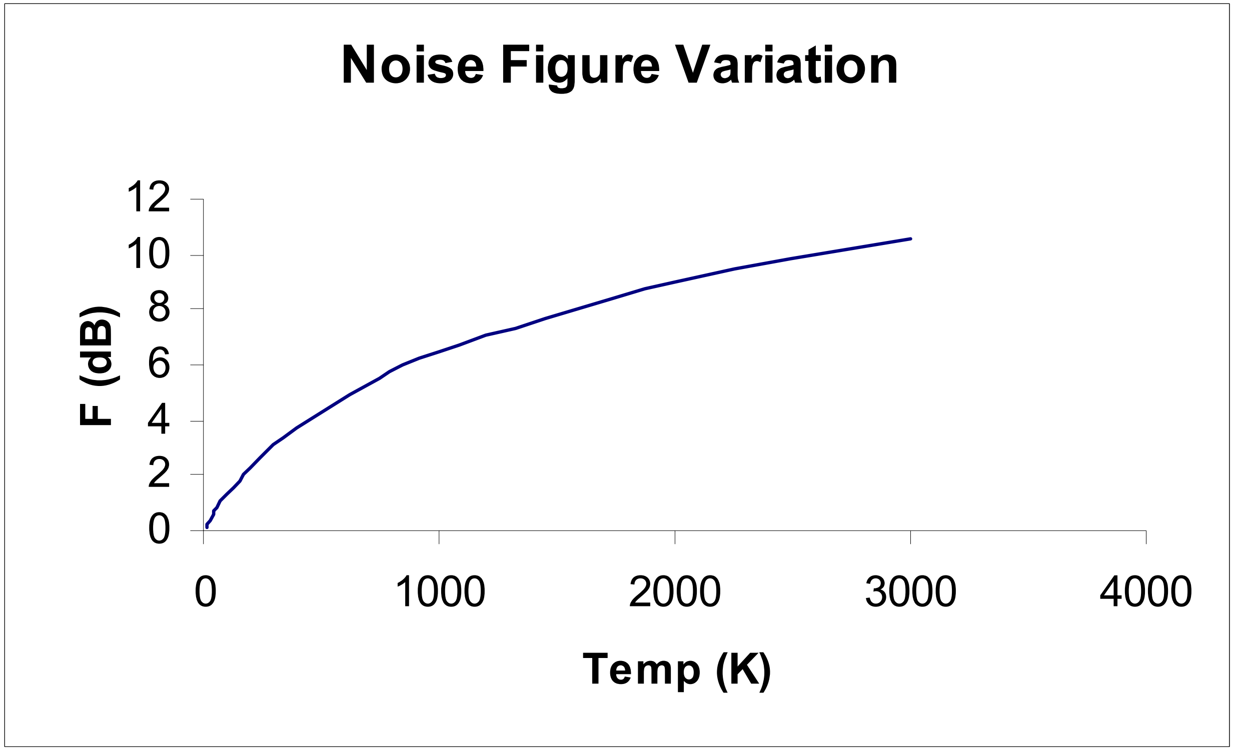
Noise Figure in Terms of T_e

- It can be shown that:

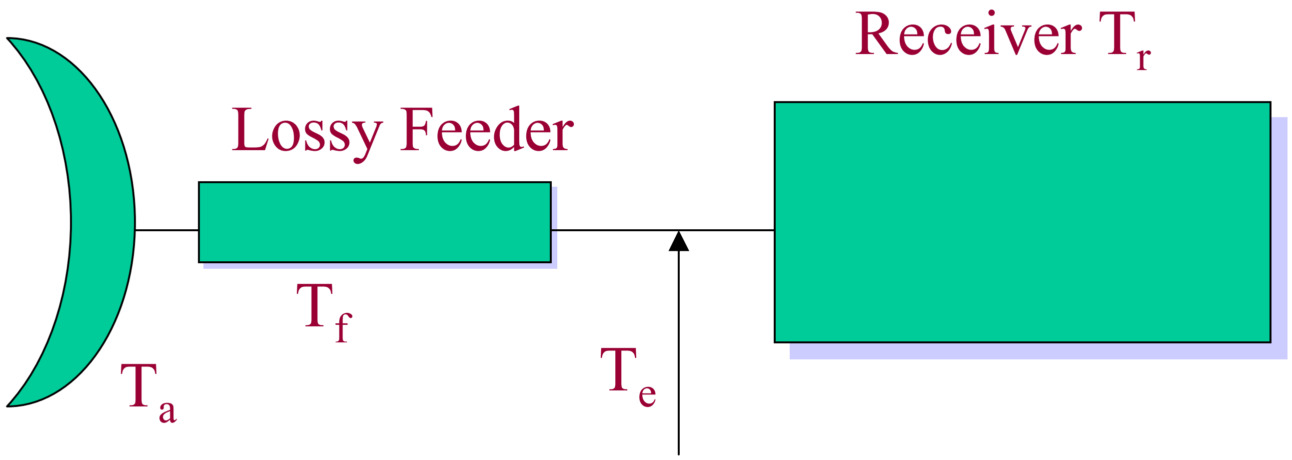
$$F = 10\log\left(1+\frac{T_e}{T_o}\right) \qquad \text{dB}$$

- T_0 = Ambient Temperature (290 K)

Noise Figure Variation



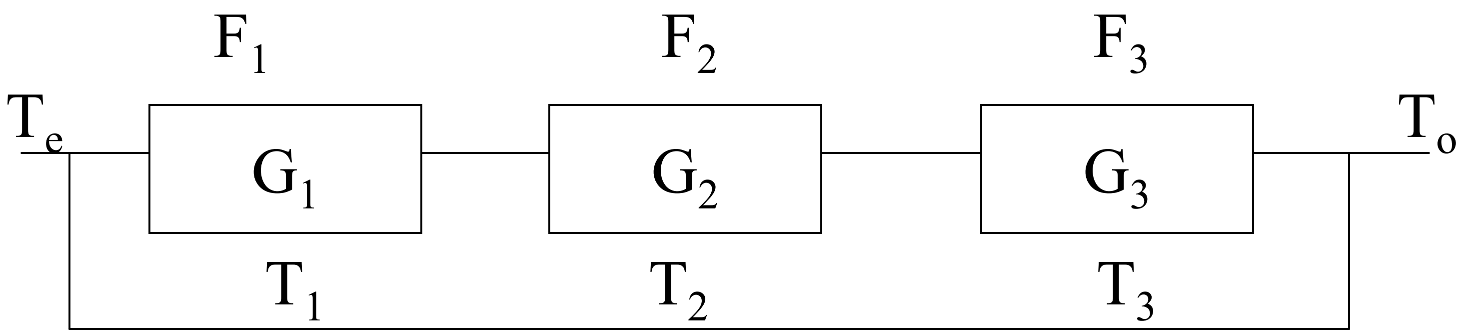
Receiver Input Noise Temperature



- T_a = Antenna Noise Temp.
- T_e = Effective Input Noise Temp.
- T_f = Feeder Temperature
- L = Power loss of Feeder

$$T_e = \frac{T_a}{L} + T_f\left(1 - \frac{1}{L}\right) + T_r$$

Amplifiers in Cascade



$$T_o = G_1 G_2 G_3 T_1 + G_2 G_3 T_2 + G_3 T_3 \qquad \text{K}$$

$$T_e = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} \qquad \text{K}$$

General Rule

- For n amplifiers in cascade
- Overall noise figure

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \ldots \frac{F_n - 1}{G_1 G_2 \ldots G_{n-1}}$$

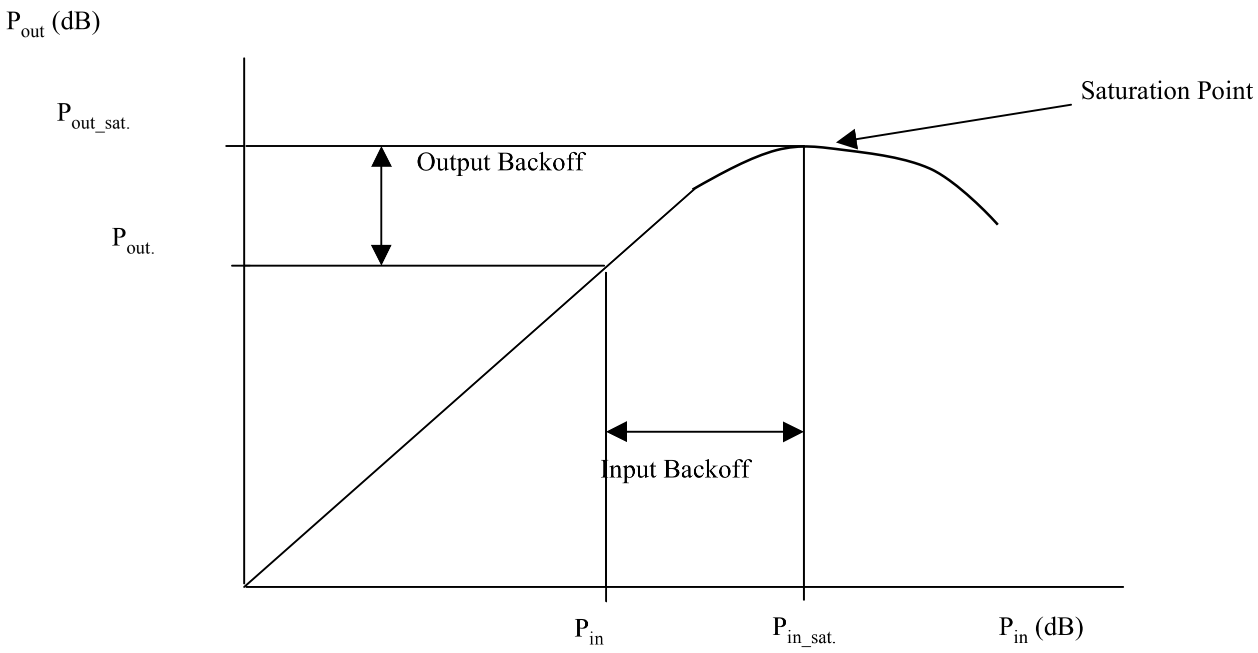
- System noise temperature

$$T_e = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} + \ldots \frac{T_n}{G_1 G_2 \ldots G_{n-1}} \qquad \text{K}$$

Some Important Remarks

- The first amplifier in the chain is the most critical in the design
- The gain of the first amplifier should be as large as possible
- Noise Figure of the first amplifier should be as low as possible

Satellite Transponder



Downlink Backoff

- Let $EIRP_{sat}$ = Downlink Saturation Power
- Output Backoff = BO_d dB
- Downlink
  - $EIRP_d = EIRP_{sat} - BO_d$ dBW

Uplink Backoff

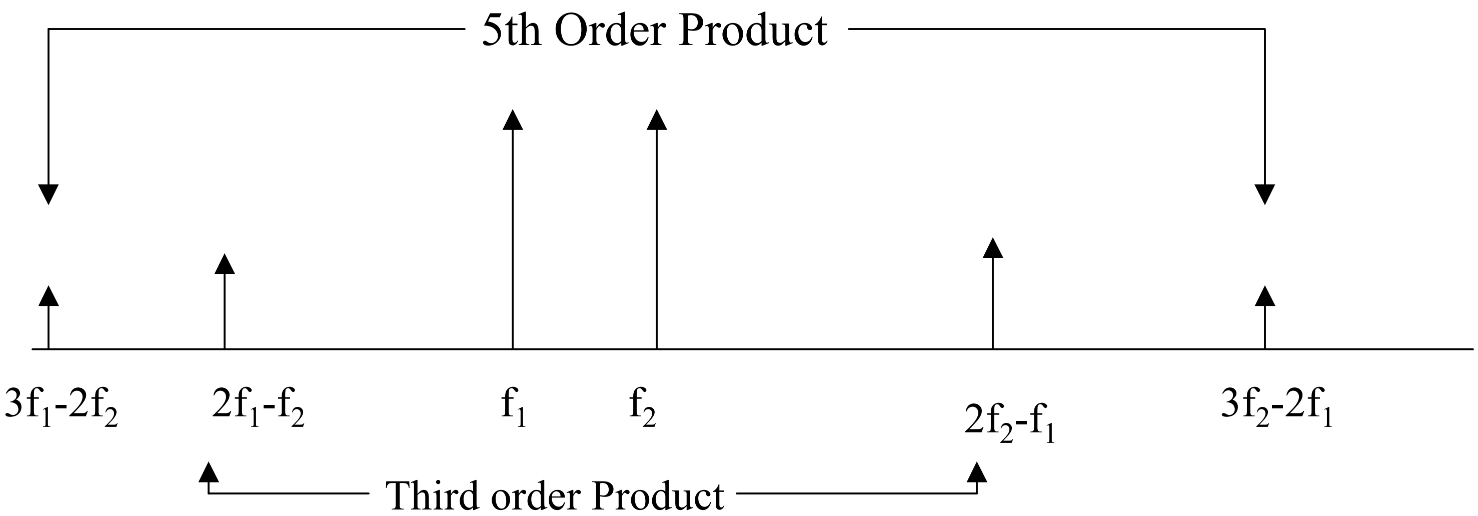
- Let
  - $EIRP_U$ = Uplink Power to Saturate Transponder
  - Input Backoff to achieve Output Backoff = BO_U
- Uplink Transmit EIRP
  - = $EIRP_U$ - BO_U dBW

Multicarrier Operation

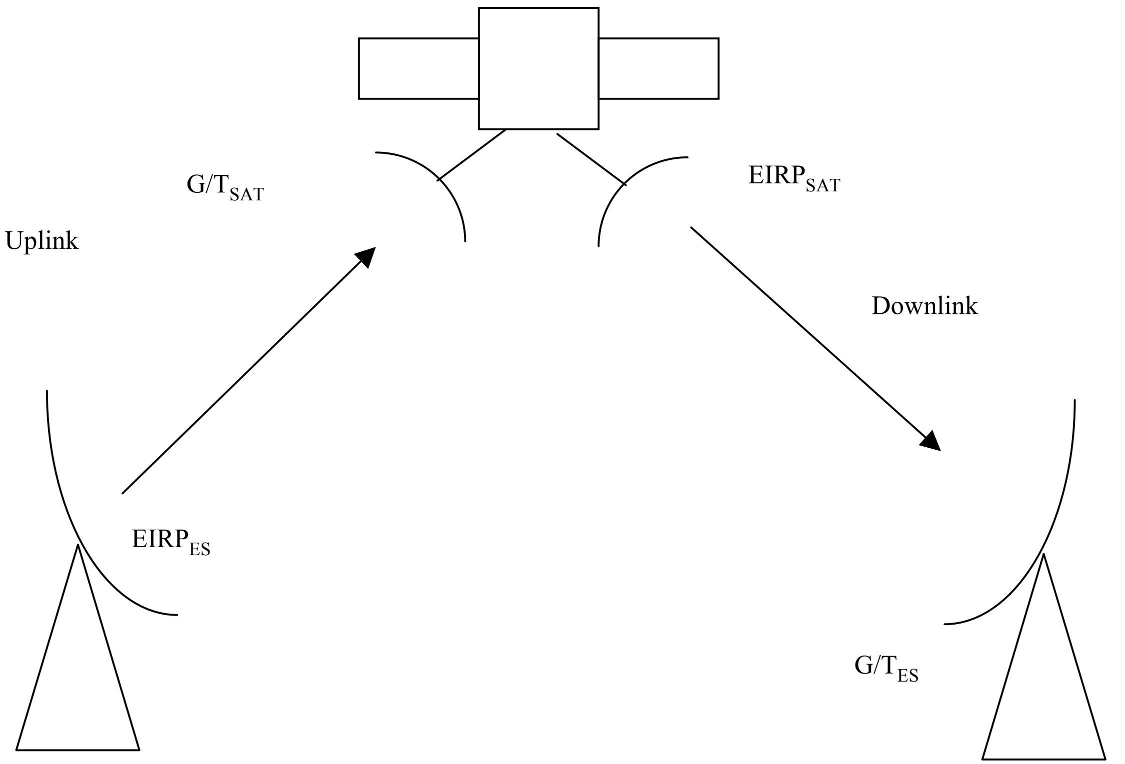
- $PFD_{up} = PFD_{sat} - 10 \log n - Bu_u$ $dBWm^{-2}$
- $EIRP_d = EIRP_{sat} - 10\log n - Bo_d$ dBW
- Assumes n carriers all with same power

Intermodulation

- Non-linear effects of the amplifier generate intermodulation (IM) products
- IM occurs during multi-carrier operation
- Can be considered as adding, on a power basis, thermal noise



Composite Link Budget



Total Noise Power

- Total Noise Power
  - $N_T = N_u + N_d + N_I + N_j$
- Where:
  - N_u = Uplink Noise
  - N_d = Downlink Noise
  - N_I = Intermodulation Noise
  - N_j = Interference Noise

Total Carrier to Noise Ratio

$$\frac{C}{N_T} = \frac{C}{N_U + N_D + N_I + N_i}$$

$$= \left[\frac{1}{\left(C/N\right)_U} + \frac{1}{\left(C/N\right)_D} + \frac{1}{\left(C/N\right)_I} + \frac{1}{\left(C/N\right)_i} \right]^{-1}$$

E_b/N_0

- Energy per transmitted information bit to noise density ratio

$$\frac{C}{N_0} = \frac{E_b R}{N_0}$$

- R = rate of transmission

Directed Reading

- Chapter 5, Mobile Satellite Communication Networks, Sheriff & Hu
- Blackboard multiple choice revision questions