ECE 3300 Link Budgets

Define:

- **Signal to Noise Ratio** (Energy per bit / Noise per bit= Eb/No)
  This depends on the detection method.
  Examples:

Modulation	**Eb/No**
BPSK	9.6
FSK	13.3
QPSK	9.6
8-FSK	9.2

- **Bit Error Rate (BER)** (1 error per million bits gives BER = 10^{-6})
- **Bandwidth:** F1 = Lowest frequency used, F2 = highest frequency used, BW = F2-F1
- **Link Budget:** Analysis of power transmitted, received, lost, etc. within the system in order to ensure that the signal to noise ratio is sufficiently high.
- **Gain (of an antenna):** = Power received in the direction of maximum transmission / Power that would have been received from an isotropic radiator (radiator that radiates equally in all directions). This includes the effect of directional antenna and the efficiency.
  Examples:

Antenna	Gain
Isotropic Radiator	1.0
Half-wave Dipole	1.64

Signal power received P_{RX}:

$$\frac{P_{RX}}{P_{TX}} = G_{AT} G_{FS} G_{AR}$$

$$P_{RX} = power \quad received$$

$$P_{TX} = power \quad transmitted$$

$$G_{AT} = antenna \;\; gain \; (transmitting)$$

$$G_{AR} = antenna \;\; gain \; (receiving)$$

$$G_{FS} = \; free\; space\; "gain" \; (channel\; loss)$$

$$All \;\; gains\; are\; wrt.\; isotropic\; radiator$$

As an antenna radiates, the power "spreads" out over a circle, so the received power at a given distance (d):

$$P_{RX} = G_{AT} \left(\frac{P_{TX}}{4\pi d^2} \right) (A_e)_{RX}$$

$$(A_e)_{RX} = Effective \;\; Area\; of \;\; receiving\; antenna$$

$$G_A = \frac{4\pi A_e}{\lambda^2}$$

Friis Transmission Equation:

$$\frac{P_{RX}}{P_{TX}} = G_{AT} G_{FS} G_{AR} = G_{AT} \left(\frac{\lambda}{4\pi \, d} \right)^2 G_{AR}$$

Free Space "Gain" :

$$G_{FS} = \left(\frac{\lambda}{4\pi d}\right)^2 = \frac{1}{L_{FS}}$$

$$L_{FS} = Free\ space\ path\ loss$$

"Signal" = P_{RX} = (P_{TX} G_{TX}) G_{FS} G_{RX}= (P_{EIRP}) G_{FS} G_{RX}

P_{EIRP} = Effective Radiated Power

Noise

N = kT_{syst} BW (broadband or analog system)

BW = bandwidth (Hz)

K = Boltzman's constant = 1.38×10^{-23}

N = kT_{syst} R (digital)

R = bit rate (bits/second)

Signal to Noise Ratio (also called Carrier to Noise Ratio)

$$\frac{S}{N} = \frac{P_{EIRP} G_{FS} G_{AR}}{kT_{syst} B}$$

Where B is either BW or R, depending on the type of system

Use of dB:

When you have all of the values measured in dB, you can do the math simply:

S/N (dBm) = P_{EIRP} (dBm) - G_{FS} + G_{AR} - k(dB) - T_{syst} (dB) - B(dB)

Other Sources of Loss:

If the antennas are mismatched…(Γ_{RX}, Γ_{TX})
Or have a polarization loss factor (PLF):

$$\frac{S}{N} = \frac{P_{EIRP} G_{FS} G_{AR} (1 - |\Gamma_{RX}|^2)(1 - |\Gamma_{TX}|^2) PLF}{kT_{syst} B}$$

In dB:
S/N (dBm) = P_{EIRP} (dBm) - G_{FS} + G_{AR} - Receiver Mismatch loss (dB) - Transmitter Mismatch Loss (dB) - PLF (dB) - k(dB) - T_{syst} (dB) - B(dB)

There are several other sources of loss:

Loss due to the environment

(-30 dB for line of sight outdoor ground-to-ground communication, for instance)

indoor may include loss through walls, etc.

Atmospheric loss, etc.

Depolarization due to the environment

Mismatch at several points within the electronics and losses within the elements

Antenna pointing error

Etc. Etc. Etc.

Design Steps:

1. Identify all sources of loss in your system

2. Identify all sources of noise (the noise temperature T_{syst}) in your system
3. Identify the transmitted power available P_{TX}
4. Identify the BW or R (bit rate)
5. Identify the type of modulation and find the allowable S/N
6. Decide a "link margin" , how much extra power to allow for unexpected losses
7. Calculate the S/N and be sure it is greater than the required value from 5 plus the link margin from 6.