Satellite Signal Strength

- power lvl. of electromagnetic signal received at ground station.

- Primary metric of strength: received power
- Unit: watts OR decibels milliwatt (dBm)

→ Free-space path loss (FSPL)

- Reduction in signal power as it travels through space
  ↓
  due to spreading

Assumption: Unobstructed line-of-sight path b/w receiver & transmitter

$$FSPL = \left(\frac{4\pi d f}{c}\right)^2 \quad OR \quad FSPL_{dB} = 20\log_{10} d + 20\log_{10} f + 20\log_{10}\left(\frac{4\pi}{c}\right)$$

$d \rightarrow$ distance b/w satellite and receiver
$f \rightarrow$ freq. of signal
$c \rightarrow$ speed of light (3×10^8 m/sec)

Eg Geostationary satellite at distance 36,000km and a signal frequency of 12 GHz.. FSPL?

Soln

$$FSPL_{dB} = 20\log_{10}(3.6\times10^7 m) + 20\log_{10}(12\times10^9 Hz) + 20\log_{10}\left(\frac{4\pi}{3\times10^8}\right)$$

$$= \boxed{165.3\,dB}$$

Link Budget

- all gains & losses in communication link, to find received signal power.

$$\left[P_r = P_t + G_t + G_r - FSPL - L_{atm} - L_{other}\right]$$

L_{other} → other losses

P_r → received power

P_t → transmitted power

G_t → transmitter antenna gain

G_r → receiver Antenna gain

L_{atm} → atmospheric loss

Antenna Gain (G)

- How well antenna focuses energy in particular direction
- For parabolic dish antenna

Antenna gain → $$G = \left(\frac{\pi D f}{c}\right)^2 \eta$$

OR

$$G_{dB} = 20\log(\eta) + 20\log(D) + 20\log(f) + 20\log\left(\frac{\pi}{c}\right)$$

η → Antenna Efficiency (0.55 – 0.7 typically.)

D → Antenna Diameter.

Carrier-to-noise Ratio (C/N)

- Signal quality wrt background noise

$$\frac{C}{N} = P_r - N$$

$$N = 10\log_{10}(KTB)$$

N → Noise Power (dBm or dBW)

K → Boltzmann's constant (1.38×10^{-23} J/K)

T → System noise Temperature (K)

B → receiver Bandwidth (Hz).

High C/N ratio, Better signal quality

Factors affecting Signal Strength

① Atmospheric Attenuation:

- Rain absorbs & scatters signals, especially at higher frequencies.
  Attenuation depends on rain rate (mm/hr)

Ku-band	Ka-band
12-18 GHz	26-40 GHz

- Gaseous absorption (O_2 & water vapour) absorbs signal at frequency of 22 GHz.

② Interference: From other satellites/terrestrial sources reduces signal quality.

$$\left[\text{carrier-to-interference ratio} = P_r - P_i\right]$$ } P_i = power of interfering signal.

③ Antenna misalignment: loss due to pointing error (θ)

$$L_{pointing} = 2\left(\frac{\theta}{\theta_{3dB}}\right)^2$$ } $\theta_{3dB} \rightarrow$ antenna's 3dB Bandwidth.

④ Polarization: satellite uses linear or circular polarization mismatch b/w transmitter or receiver can cause loss of 3dB (for linear-circular mismatch) or upto 20dB (for orthogonal polarization)

⑤ Distance : GEO Satellites → higher path loss but stable position.
LEO Satellites → lower path loss but needs tracking.

→ Mathematical modeling of Signal strength.

① Friss Transmission Eqn.

$$\left[P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \right] \Big\} \lambda = \frac{c}{f}$$

OR

$$\left[P_{r_{dBm}} = P_{t_{dBm}} + G_{t_{dBm}} + G_{r_{dBm}} - FSPL_{dB} \right]$$

② Noise Figure & System temperature

↓ quantifies degradation of signal-to-noise ratio by receiver

$$F_{dB} = 10\log_{10}(F)$$

↓ $T_{sys} = T_{antenna} + T_{receiver}$

③ Bit Error Rate (BER)

↓ Energy per bit to noise power spectral density Ratio

$$\frac{E_b}{N_0} = \frac{C/N}{R_b/B} \Big\} R_b \rightarrow \text{bit Rate}$$

→ Frequency Bands

f Bands

- **L Band** — 1-2 GHz, Low attenuation
- **C Band** — 4-8 GHz, moderate attenuation
- **Ku Band** — 12-18 GHz, High data rates but suceptible to rain fade
- **Ka Band** — 26-40 GHz, very high data rates (significant atmospheric loss)

→ Receiver Sensitivity

- minimum detectible signal (MDS)

~~MDS = -174 + log~~

$$MDS = -174 + 10\log_{10}(B) + NF$$ NF → noise figure