

Telometrics

Task①

Treatment of RF link budget for satellite (cubesat) downlink to ground station.

→ Free-space path loss used to predict the strength of a RF signal at a particular distance. RF link budget calculations of all gains and losses in a wireless communication link to estimate the received signal power. used to determine signal will be strong enough to be received successfully and includes factors like transmitter power, antenna gains, cable loss, path loss through air

$$@ \text{FSPL formula. Derivation } Pr = Pt + Gt + Gr - Lfs - Lmisc \left(\frac{\text{mW}}{\text{dB}} \right)$$

observing from transmitter side

The power density of transmitted signals given by.

$$PD = \cancel{P_t} \frac{P_t (\pi D^2)^{-1}}{4\pi D^2} = \frac{P_t}{4\pi D^2} \quad \text{--- (1)} \quad ; \text{ it for isotropic antenna}$$

Antenna. In our formula we have gains

$$PD = (P_t / 4\pi D^2) G_t \quad \text{--- (2)}$$

observing from Receiver side

$$Ar = \frac{Pr}{PD} = \frac{\text{Power received}}{\text{Power density}} \quad ; \quad Pr = \frac{P_t \cdot G_t}{4\pi D^2} Ar$$

Relation b/w Ar and G

$$Ar = \frac{\lambda^2}{4\pi} \cdot G_r$$

then

$$Pr = \frac{P_t \cdot G_t}{4\pi D^2} \cdot \frac{\lambda^2}{4\pi} G_r = P_t G_t \left(\frac{\lambda}{4\pi D} \right)^2 G_r \quad \text{--- (3)}$$

where Gt, Gr are gains

Applying log

$$\log(Pr) = \log \left(P_t \cdot G_t \cdot \left(\frac{\lambda}{4\pi D} \right)^2 G_r \right)$$

$$\log(Pr) = \log(P_t) + \log(G_t) + \log(G_r) + \log \left(\frac{\lambda}{4\pi D} \right)^2$$

\therefore we know that $10 \log_{10}(x) = x^m$ then

$$10 \log_{10}(P_r) = 10 \log_{10}(P_t) + 10 \log_{10} G_r + 10 \log_{10} G_t + 20 \log_{10} \left(\frac{\lambda}{4\pi D} \right)$$

$$P_r^{\text{dB}} = P_t^{\text{dB}} + G_r^{\text{dB}} + G_t^{\text{dB}} + 20(\log \lambda - \log(4\pi D))$$

By observing the equation also $\lambda \ll 4\pi D$ then

$\rightarrow \underline{\log(\lambda) - \log(4\pi D)}$ is < 0

$$L_{fs} = 20 \log_{10} \left(\frac{4\pi D}{\lambda} \right); \text{ free space path loss.}$$

$L_{fs} \rightarrow$ loss of signal strength occurs as electromagnetic waves spreads out in free space. even with no obstacles power density (\downarrow) with distance

$L_{misc} \rightarrow$ miscellaneous losses

\hookrightarrow group of all additional system losses account for real world imperfections. non ideal situation.

typically small decade (dB) (1-5) dB

$$\boxed{P_r^{\text{dB}} = P_t^{\text{dB}} + G_r^{\text{dB}} + G_t^{\text{dB}} - L_{fs} - L_{misc}} \quad | 10 \log(x^2)(\text{dB}) = 20 \log(x)(\text{dB})$$

$$P_r = P_t + G_r + G_t - L_{fs} - L_{misc}$$

Antenna pattern

- They describe directional radiation characteristics of an antenna. Ideally max gain direction is assumed as boresight, but in physical world the alignment also causes some small amount of losses in propagation of signals. For example parabolic dish antenna the perfect pattern have high gain but sidelobes can introduce Interference else they reduce gain, the pattern losses can add up to 3 dB

Polarization mismatch:

- ↳ orientation of electromagnetic waves "electric field"
- mismatch b/w transmitte and received polarization cause power loss.
- mismatch b/w transmitted and received polarization, the loss can $L_{pol} = 20 \log_{10} |\cos \varphi|$, φ is angle b/w polarization, the loss can vary for linear or circular, horizontal fields. Losses upto 3 dB
- we can use same polarization type for Antenna to reduce losses

Pointing losses:-

- arise from inaccurate in alining the antenna beam towards transmitter/receiver
- the results in reduction of effective gain upto -5 dB depending on inaccuracy. The natural causes like wind, thermal distortion, mechanical errors creates losses here

Atmospheric losses:-

- atmosphere effects attenuate signal through absorption, scattering and refraction, varying by frequency, weather / path.
 - Tropospheric losses:- at lower atmosphere (0-10 km), absorption by gasses. The loss increases with frequency (significantly)
 - Ionospheric losses:- random fluctuation due to irregularity in ionosphere, more at lower frequencies.

- Ground clutter:- signal blockage from obstacle near ground station or reflection that cause multi-path fading. Solution is to locate ground station in area where minimal nearby structures

Marginal Allocations

link margin is the extra power above minimum required.

$$M = P_{req} - P_{min}$$

Allocation strategy is process of deciding how much margin to add based on system uncertainty. Normally varies from 3 dB to 10 dB. Margin also covers all the zones mentioned earlier.

Fade statistics:-

- its description of probability and duration of signal loss.
- its specially for high frequency bands, rainfall data of ground station is used to determine the fade level exceedance rate and determination we also have other fading like multipath fading, Rain fade, Precipitafade.

Modulation and Coding Selection:-

- it depends directly on calc link margin and data rate
- modulation converts digital data stream into an analog waveform. High order modulations require higher SNR (Signal to noise ratio) but offer higher throughput. Coding adds multiple records of error at cost of rate.
- Coding (FEC → Forward Error correction)
 - it adds redundancy to data allow receiver to correct errors without retransmission.
 - FEC improves link by providing coding gain; reduces P_{req} given by BFR (Bit Error Rate)
 - convolution coding is chosen when link margin is low. Low BFR required.

UHF, S band & X-band downlinks for different mission types

→ There are frequency bands.

① UHF (Ultra High Frequency) → (400-500) MHz

→ primarily for Telemetry Tracking and Commanding, have low data rates

→ have less loss (losses in free space) at low frequencies / high tolerance to pointing losses

→ however cost, less sophisticated (ADCS) - machine is simple

→ cons:- low Data Rates : limited bandwidth / large antenna size leads low data rates.

② S-band (2-4 GHz)

→ stable performance and good penetration through atmospheric conditions

→ medium rate Data ; commanding and Telemetry

Pros:- Balanced performance

→ commonly used for both uplink and downlink

cons:- → insufficient for large volume data (HD images)

③ X - Band Downlinks. 8-12 GHz

Highly stabilized

→ High Data Rate

→ Smaller antennas → high gain smaller antennas on both cubesat and ground station

cons:- complexity increased and power consumption (\uparrow)

→ more susceptible for signal degradation due to atmospheric rain fade, tropospheric losses, required higher link margin