

Telometry:-

Task ①

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.

① FS PL formula. Derivation $P_r = P_t + G_t + G_r - L_{fs} - L_{misc}$ (units dB)

observing from transmitter side

The power density of transmitted signals given by.

$$PD = \frac{P_t}{4\pi D^2} \quad \text{① it's for isotropic antenna}$$

Antenna. In our formula we have Gain $\therefore D \rightarrow$ distance b/w antenna

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

observing from Receiver side

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

Relation b/w A_e and G

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

then

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

where G_r, G_t are gains

Applying log

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

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

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

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

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

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

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

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

$L_{fs} \rightarrow$ loss of signal strength occurs as electromagnetic waves spread 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 decibel (dB) (1-5) dB

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

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

$$10 \log_{10}(x^2) \text{ (dB)} = 20 \log_{10}(x) \text{ (dB)}$$

Antenna pattern ~~in loss~~

→ They describe directional radiation characteristics of an antenna. ideally we 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 transmitter and receiver polarization cause power loss.
 $K_{pol} = 20 \log_{10} |\cos \psi|$, ψ is angle b/w polarization, the loss can vary for linear or circular, horizontal fields. losses up to 3 dB
→ we can use same polarization type for antenna to reduce losses

pointing losses:-

→ arise from inaccurate in aiming the antenna beam towards transmitter/receiver
the results in reduction of effective gain up to 1-5 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.
• troposphere losses:- at lower atmosphere (0-10 km), absorption by gasses. the loss increases with frequency (significantly)
• ionosphere 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 Allocation:-

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 losses mentioned earlier.

Fade statistics:-

→ its description of probability and duration signal loss.

its specially for high frequency bands, rainfall data of ground station is used to determine the fade level exceedition.

we also have other fading like multipath fading, Rain fade, Ray fade.

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 error without retransmission

FEC improves link by providing coding gain; reduces P_{req} given by BER (Bit Error Rate)

→ convolution coding is chosen when link margin is low / low BER Required.

VHF, S-band & X-band downlinks for different mission type

→ There are frequency bands.

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

→ primarily for Telemetry Tracking and commanding, have low data^{rate}

→ low L_f (loss_{in} free space) at low frequencies / high tolerance to pointing losses

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

→ cons:- low Data Rates: limited bandwidth / large antenna size
lead 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 downlinking

con:- insufficient for large volume data (HD images)

③ X-Band Downlinks. 8-12 GHz

Highly stable

→ High Data Rate

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

cons:- complexity increased and power consumption (↑)

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