Ground segment

→ Types of Earth station
→ Subsystems of ES
→ Antenna subsystems
→ measurement techniques of EIRP, G/T ratio

Earth station / Earth terminal

① mobile → Ground → Fixed
- meritime
- Aero
- Handheld → walking
- Railway
- Transportable } stop. point communicate
- Portable

② DTH → Fixed → Rx only
③ VSAT → Tx / Rx
④ Automatic weather station, Data collection point → Tx only

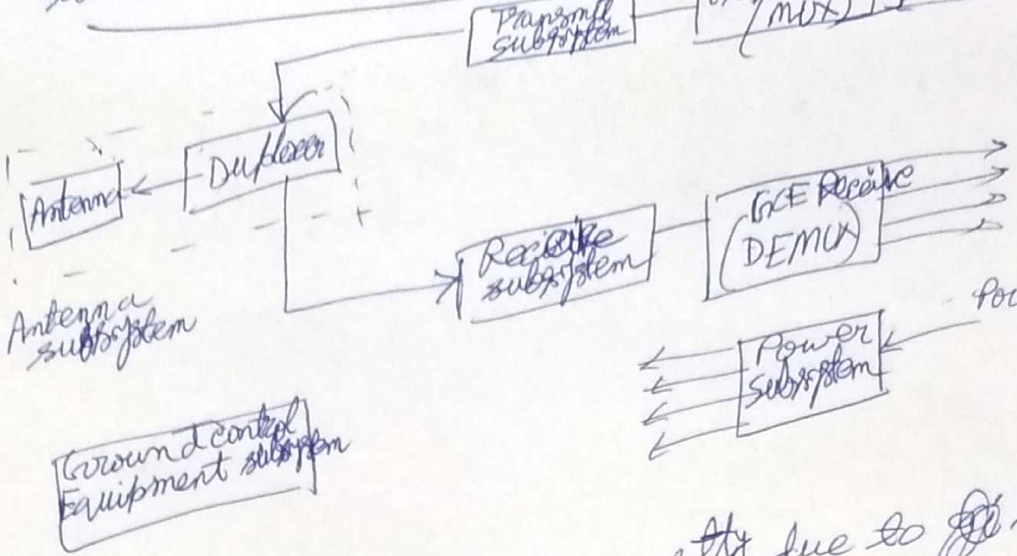
Earth station component

① Antenna, LNA, HPA, downconverter, upconverter & modem.
② HPA size ranges from 2-500 W
③ Antenna size - 1.8 - 4.8 m
④ Interfaces to customer's equipment directly or connects to terrestrial n/w via microwave, fiber or copper wire.

Earth station design objectives

① Reliability & availability
② Link budget consideration
③ customer driven objective
④ special consideration

Satellite Earth Station

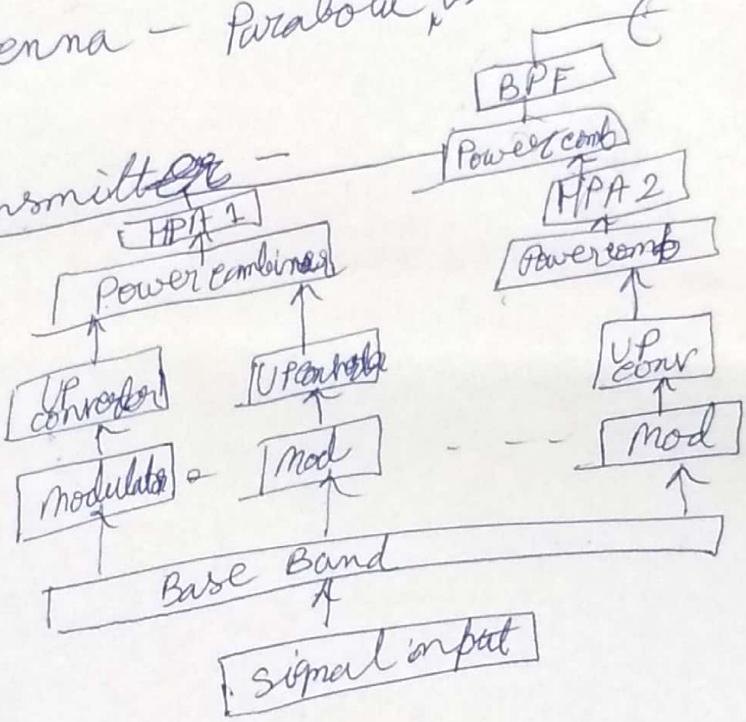


Antenna - Parabolic antenna, used mostly due to high gain

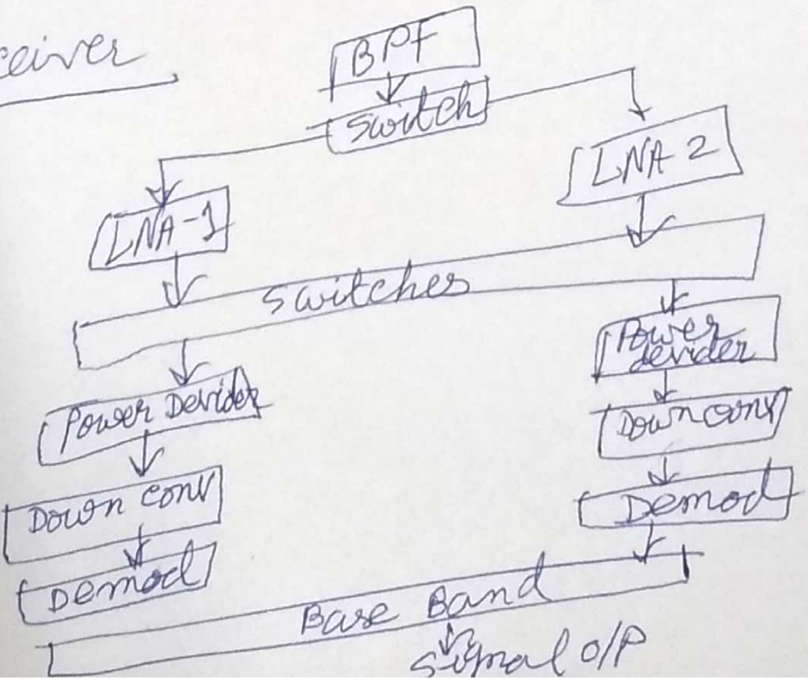
Tracking subsystem

1. Fixed-pointing only
2. occasional repointing
3. step tracking
4. Programmed
5. Fully automatic

Transmitter -



Receiver



Satellite link Design

Critical parameter - Weight, Dimension, freq band

Weight ↑ → cost ↑

1. Dimension — To fit spacecraft to launch vehicle
   - → Geo sat have deployable solar panels & anteena
   - → But anteena reflectors are not folded, so required space
   - → Hence anteenas are limiting factor for performance

2. Weight - Driven by 2 factors -
   - Number and Pout of transponders
   - Station-Keeping fuel (Half of total weight of sat to serve 15 years)

3. Choise of freq band
   → Rain and atmospheric attenuation minimum

at 6/4 GHz

→ It is worst with increase in freq

$$Att_{rain}(dB) \propto freq^2$$

→ GEO sat can be placed in every 2°

⇒ LEO, MEO → No of sat required is more

→ position of sat changed frequently — so omnidirectional anteena is used to receive signal

Satellite Design parameter

Bit error rate (BER) in digital link
Signal-to-noise ratio (S/N) in analog link
major term used → Carrier-to-noise ratio (C/N) at i/p of receiver demodulator (After receiving anteena)
overall C/N ratio → depends of both uplink & downlink C/N ratio
reciver is noiseless → No change in C/N ratio at receiver O/P

Design equation

Transmitter power → P_t in free space in all direction (isotropic source)
Distance → R meter
Flux dencity crossing surface of sphere with radius r → $F = \frac{P_t}{4\pi R^2}$ W/m²

Real anteena → directive
let Gain → $G(\theta) = \frac{P(\theta)}{P_0/4\pi}$
$P(\theta)$ → Power radiated per solid angle by antenna
P_0 → Total power radiated by anteena
θ → choose to be the direction in which max power radiated → boresight direction of anteena
So Flux dencity $F = \frac{P_t G_t}{4\pi R^2}$ W/m²
G_t → Gain of lossless anteena
$P_t G_t$ → Effective isotropically radiated power → EIRP

Receiving anteena power $P_r = F \times A$ watts

- $A \rightarrow$ Aperture area of receiving anteena

If $A_r \rightarrow$ Physical aperture area of anteena

$A_e \rightarrow$ Effective aperture area [after reflected back some incident energy and some energy absorbed by lossy components]

$\eta_A \rightarrow$ aperture efficiency of antenna (50 – 75%)
Horn antenna $\rightarrow$ 90%

so, $A_e = \eta_A A_r$

$$P_r = \frac{P_t G_t A_e}{4\pi R^2} \text{ watts}$$

Equation is freq independent as

G_t & $A_e \rightarrow$ constant within a given band

Relation between Gain & area of antenna $\rightarrow$

$$G \doteq 4\pi A_e/\lambda^2$$

$\lambda \rightarrow$ freq of operation wavelength (in meter)

$$\Rightarrow P_r = \frac{P_t G_t G_r}{(4\pi R/\lambda)^2} \text{ watts}$$

$$\text{Power received} = \frac{\text{EIRP} \times \text{Receiving antenna gain}}{\text{Path loss}} \text{ watts}$$

$$P_r = \text{EIRP} + G_r - L_p \text{ dBW}$$

$$P_r = \underbrace{10\log(P_t G_t)}_{\text{dBW}} + \underbrace{10\log(4\pi A_e/\lambda^2)}_{\text{dB}} - \underbrace{20\log(4\pi R/\lambda)}_{\text{dB}}$$

$$P_r = \text{EIRP} + G_r - L_p - L_a - L_{ta} - L_{ra} \text{ dBW}$$

$L_a \rightarrow$ Attenuation in atmosphere

$L_{ta} \rightarrow$ Losses associated with transm antenna

$L_{ra} \rightarrow$ Losses associated with receiv antenna

Satellite system noise temperature

Noise temperature → Thermal noise generated by active & passive devices in receiving system

Noise power general equation for a black body

$P_n = kT_pB_n$ ... Watts

k ⇒ Boltzmann's constant = 1.39×10^{-23} J/K

T_p → Physical temp of source in kelvin degrees

B_n → Noise Bandwidth (Hz)

kT_p → noise spectral dencity (W/Hz)

↳ constant for all radio freq upto 300 GHz

* If noise Bandwidth is unknown, use 3dB bandwidth of receiver → error introduced is less

Noise power at demodulator input of a noiseless receiver is -

$P_{no} = kT_sB_nG_{rx}$ W

T_s → system noise temperature at i/p of noiseless receiver

G_{rx} → Gain of receiver from RF i/p to demod i/p

carrier to noise ratio at demodulator is -

$$C/N = \frac{P_r G_{rx}}{kT_sB_nG_{rx}} = \frac{P_r}{kT_sB_n}$$

P_rG_{rx} → signal power delivered at demod i/p

Noise figure and Noise temperature

$$NF = \frac{(S/N)_{in}}{(S/N)_{out}}$$

conversion of NF to noise temperature

$$T = T_0(NF - 1)$$

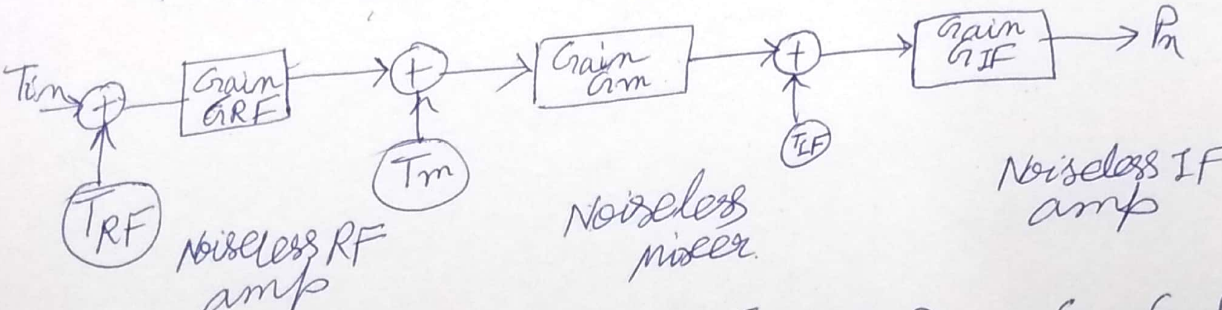
T_0 → ref temp to calculate standard NF → 290K

G/T ratio of earth station

$$\frac{C}{N} = \left[\frac{P_tG_tG_r}{kT_sB_n}\right]\left[\frac{\lambda}{4\pi R}\right]^2 = \left[\frac{P_tG_t}{kB_n}\right]\left[\frac{\lambda}{4\pi R}\right]^2\left[\frac{G_r}{T_s}\right] \Rightarrow \frac{C}{N} \propto \frac{G_r}{T_s}$$

calculation of system noise Temperature

Noise model of receiver -



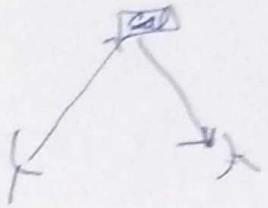
$$P_n = G_{IF} k T_{IF} B_n + G_{IF} G_m k T_m B_n + G_{IF} G_m G_{RF} k B_n (T_{RF} + T_{in})$$

$$P_n = G_{IF} G_m G_{RF} k B_n \left[T_{RF} + T_{in} + T_m / G_{RF} + T_{IF} / G_{RF} G_m \right]$$

$$P_n = G_{IF} G_m G_{RF} k B_n T_s$$

$$T_s = \left[T_{in} + T_{RF} + T_m / G_{RF} + T_{IF} / G_m G_{RF} \right]$$

Complete link design



Useful carrier power at receiving earth station $C = \frac{C_U G_S G_T G_R}{L}$

C_U → carrier power at sat transponder

L → loss present in down link

G_S, G_T, G_R → sat transponder, tras antenna & receive antenna gain

Noise power spectral density $N_0 = N_{0R} + N_{0U}\frac{G_S G_T G_R}{L}$

N_{0R} → noise power density at i/p of receiving antenna

N_{0U} → " " " " sat ~~transponder i/p~~ transmitting antenna

$$\left(\frac{C}{N_0}\right)_T = \frac{C_U G_S G_T G_R/L}{N_{0R} + N_{0U}(G_S G_T G_R/L)}$$

Total power radiates by sat transponder $P_T = G_S(C_U + N_{0U}B)$

Down link signal power $C_D = \frac{P_T G_T G_R}{L}$

$$\left(\frac{C}{N_0}\right)_T = \frac{C_U}{N_{0U} + N_{0R}\left[\frac{L}{G_S G_T G_R}\right]}$$

$$= \frac{C_U}{N_{0U} + N_{0R}\left[\frac{L(C_U + N_{0U}B)}{P_T G_T G_R}\right]}$$

$$= \frac{C_U}{N_{0U} + N_{0R}\left[(C_U + N_{0U}B)/C_D\right]} = \frac{C_U C_D}{N_{0U}C_D + N_{0R}C_U + N_{0R}N_{0U}B}$$

$$= \frac{\frac{C_U C_D}{N_{0U}N_{0R}}}{\frac{C_D}{N_{0R}} + \frac{C_U}{N_{0U}} + B}$$

$$= \frac{\left(\frac{C}{N_0}\right)_U \cdot \left(\frac{C}{N_0}\right)_D}{\left(\frac{C}{N_0}\right)_D + \left(\frac{C}{N_0}\right)_U + B}$$

$$\left(\frac{C}{N_0}\right)_T^{-1} = \left(\frac{C}{N_0}\right)_U^{-1} + \left(\frac{C}{N_0}\right)_D^{-1}$$

$$\left(\frac{C}{N_0}\right)_U \gg \left(\frac{C}{N_0}\right)_D$$

$$\left(\frac{C}{N_0}\right)_T^{-1} = \left(\frac{C}{N_0}\right)_D^{-1}$$

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Q) An earth station antenna has a dia of 30m & overall efficiency of 68%. It is used to receive a signal at 4150 MHz. At this freq system noise temp is 79K when antenna points at the sat at an elevation angle of 28°. What is earth station G/T ratio under these conditions. If heavy rain causes the sky temp to increase so that the system noise temp is 88k. What is the new G/T value?

Antenna gain $G_R = \frac{\eta_A 4\pi A_e}{\lambda^2} = \cancel{0.68 \times \pi}\ \eta_A\left(\frac{\pi D}{\lambda}\right)^2$

$= 1.16 \times 10^6 = 60.6\,dB$

$T_S = 10 \log 79 = 19\,dB$

$G/T = 60.6 - 19 = 41.6\,dB/K$

(G/T) at 88K $= 60.6 - 19.4 = 41.2\,dB/K$

Q) A transponder of ku-band sat has linear gain of 127 dB and a nominal o/p power at saturation is 5W. The sat's 14GHz receiving antenna has gain of 26 dB on axis. calculate power o/p of uplink transmitter that gives power o/p of 1W from sat transponder at f = 14.45 GHz. If ES antenna gain = 50 dB, waveguide loss of 1.5 dB between antenna & transmitter. ES antenna countour loss = 0.5 dB, Atmos loss = -2 dB. If rain in path attenuates 7 dB for 0.01% of year, what power rating is required for Tx to garantee 1W o/p from sat transponder for 99.99% of year?

Uplink budget $P_r = EIRP + G_r - L_p - L_{at} - L_{Ta} - L_{ra}$

$EIRP = P_t + G_T$

$P_t = P_r - G_T - G_r + L_p + L_{Ta} + L_{at} - L_p$

Q) In a sat comm link uplink carrier-to-noise ratio is 25 dB, whereas ~~for~~ downlink it is 20 dB. Find overall (C/N) ratio.

$25dB = 316.22$
$20dB = 100$

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

$$\left(\frac{C}{N}\right)_T = \left[\frac{1}{316.22} + \frac{1}{100}\right]^{-1}$$

Q) calculate the noise temperature of a 6GHz receiver system having following data

$T_{in} = 75\,K$, $T_{RF} = 75k$, $T_M = 400k$, $T_{IF} = 1000k$, $G_{RF} = 23dB$, $G_M = 0\,dB$, $G_{IF} = 35dB$

system noise temp $= T_S = \left[T_{RF} + T_{in} + \frac{T_M}{G_{RF}} + \frac{T_{IF}}{G_m G_{RF}}\right]$

Q) A sat at a dis of 36000 km from the surface of earth radiates power of 4W from an antenna of gain 15dB. Find flux density & power received by antenna with effective area $12m^2$. If the receiving antenna has a gain of 50dB, then calculate the received power.

Flux density of power received at antenna $F = \frac{P_t G_t}{4\pi r^2}\ W/m^2$
$= 7.77 \times 10^{-15}\ W/m^2$

Power received by receiving antenna $= P_R = F \times A_e$
$= 0.093 \times 10^{-12}\ W$

Power at o/p of receiving antenna $= P_R G_R = 0.093 \times 10^{-7}$

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