Unit - 4 Satellite Links

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o Introduction :-

- A satellite link consists of an uplink (transmit earth station to satellite) and a downlink (satellite earth station).
- signal quality over the uplink depends on how strong the signal is when it leaves the source earth station and how the satellite receives it.
- Also, on the downlink side, the signal quality depends on how strongly the satellite can retransmit the signal and how the receiving earth station receives the signal.
- satellite link design involves a mathematical approach to the selection of link subsystem variables in such way that the overall system performance criteria are met.

The Earth station design consists of :-

- The transmission Link design or Link Budget.
- The transmission system design.
- The link Budget ~~est~~ establishes the resources needed for a given service to achieve the performance objectives.

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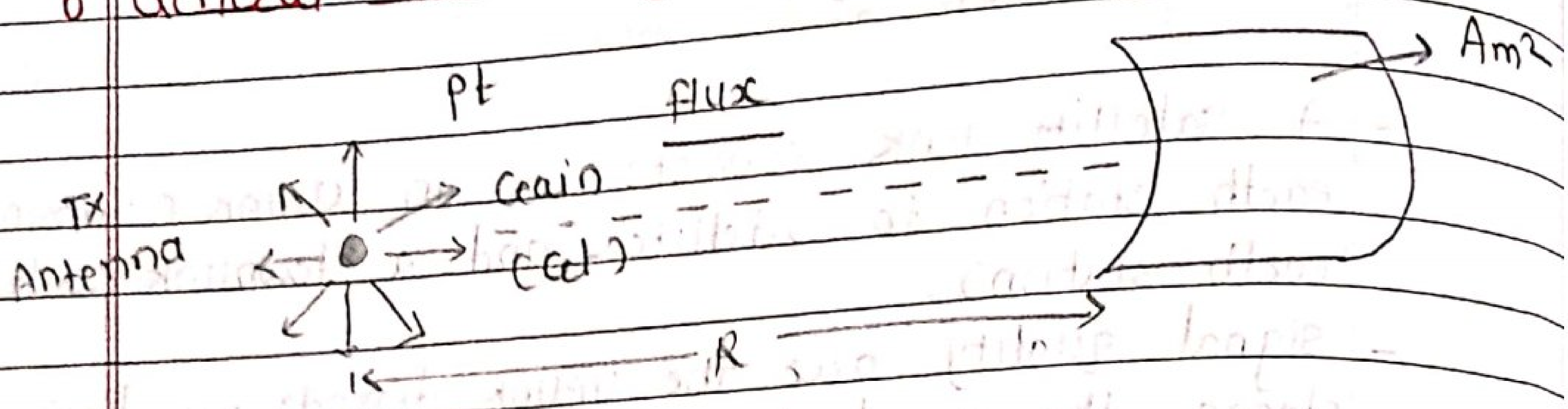
General Link design equation :-



Isotropic antenna (omnidirectional antenna)

- Let us assume that we are having source antenna which is spherical in shape & which radiates the energy in all directions, called as "Isotropic antenna (omnidirectional antenna)
- Let us assume that we are having receiver antenna which is having particular shape & area is A m^2. The distance from transmitter antenna to receiver antenna is R.
- The transmitter antenna transmit the amount of power pt. & which can be transmitted towards the receiver antenna.
- The amount of flux that can be radiated from source antenna towards the receiver antenna.

$$\boxed{F = \frac{pt}{4\pi R^2} \ W/m^2} \quad \text{———} (1)$$

Where F – Flux generated
pt – Amount of power transmitted/radiated
$4\pi R^2$ – ~~speet~~ spherical in shape.

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EIRP :- Equivalent Isotropic Radiated Power

$$EIRP = P_t \times G_t$$

Where P_t - The amount of power transmitted

G_t - The gain of transmitter antenna.

$$[EIRP]dB = [P_t] + [G_t] \quad \text{—— (2)}$$

$$\boxed{F = \frac{EIRP}{4\pi R^2} \; W/m^2} \quad \text{—— (3)}$$

P_r :- Received Power

$$P_r = F \times A_r$$

Where F - Flux radiate

A_r - Area of receiver antenna.

A phy - physical area of an antenna.

A_e - Effective aperture area of an antenna.

$$A_e = A_{phy} \times \eta$$

Where η - Efficiency of an antenna.

$$G_r = \boxed{Gain = \frac{4\pi A_e}{\lambda^2}}$$

Wher λ - wavelength of antenna

$$P_r = \frac{P_t G_t}{4\pi R^2} \times A_r \quad (\because A_r = A_e)$$

$$\boxed{P_r = \frac{P_t G_t}{4\pi R^2} \times A_e} \quad \text{—— (4)}$$

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

Value of A_e put in eq^n (4)

$$P_r = \frac{P_t G_t}{4\pi R^2} \times \frac{G_r \cdot \lambda^2}{4\pi}$$

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

$$\text{Path loss} = L_P = \left(\frac{4\pi R}{\lambda}\right)^2$$

$S/N \uparrow$

$$\boxed{P_r = \frac{P_t G_t \cdot G_r}{L_P}}$$

i> L_a – Losses due to attenuation in atmosphere.
ii> L_{ta} – Losses due to transmitting antenna.
iii> L_{ra} – Losses due to received antenna.
iv> L_{pol} – Losses due to Polarization mismatch.
v> L_{other} – losses due to other factor.

$$[P_r] = [P_t] + [G_t] + [G_r] - [L_P]$$

$$\boxed{L_P = [\text{Losses}] = [FSL] + [RFL] + [AML] + [PL] + [AA]}$$

Where FSL – Free space loss
RFL – Receiver feeder loss
AML – Antenna Misalignment Loss
PL – Polarization Loss
AA – Atomospheric Absorption Loss.

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Ex. A satellite at a distance of 40,000 km from a point on the earth's surface radiates a power of 10 W from an antenna with a gain of 17 dB in the direction of the observer. Find the flux density at the receiving point, and the power received by an antenna at this point with an effective area of $10 m^2$.

Ans :- Given :- $R = 40,000$ km

$P_t = 10$ W

$G_t = 17$ dB

$F = ?$

$P_r = ?$

$$F = \frac{P_t \cdot G_t}{(4\pi R^2)}$$

$$= \frac{10 \times 50}{(4\pi \times (4 \times 10^7)^2)}$$

$$= 2.49 \times 10^{-14} \ W/m^2$$

The power received with an effective collecting area of $10 m^2$ is therefore

$$P_r = F \times A$$
$$= 2.49 \times 10^{-13} \ W$$

The calculation is more easily handled using decibels. Nothing that

$$10 \log_{10} 4\pi = 11.0 \ dB$$

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F in dB units $= 10\log_{10}(P_t G_t) - 20\log_{10}(R) - 11.0$

$= 27.0 - 152.0 - 11.0$

$= -136.0$ dB (W/m²)

Then $P_r = -136.0 + 10.0$

$= -126$ dB W

Here we have put the antenna effective area into decibels greater than 1 m² (10m² = 10 dB greater than 1 m²).

Ex. The satellite operates at a frequency of 11 GHz. The receiving antenna has a gain of 52.3 dB. Find the receiver power?

Ans :- P_r = EIRP + G_r − Path loss (dBW)

EIRP = 27.0 dBW

G_r = 52.3 dB

Path loss $= (4\pi R/\lambda)^2 = 20\log_{10}(4\pi R/\lambda)$ dB

$= 20\log_{10}[(4\pi \times 4 \times 10^7)/(2.727 \times 10^{-2})]$ dB

$= -205.3$ dB

$P_r = 27.0 + 52.3 - 205.3 = -126.0$ dBW

We have the same answer because the figure of 52.3 dB is gain of a 10m² aperture at freq^n of 11 GHz.

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System Noise Temperature :-

Noise Temperature :

- Noise Temperature is a useful concept in commⁿ receivers.
- It determines generations of thermal noise by active and passive devices in the receiver system.
- At microwave frequencies a black body with a physical temperature 'TP' degree kelvin generates electrical noise over a wide bandwidth.
- The noise power is given by

$$P_n = K T_p B_n \quad \text{—— (1)}$$

Where KT_p - Noise Power spectral density (W/Hz)

K - Boltzmann's constant

$= 1.39 \times 10^{-23}$ J/K $= -228.6$ dB W/K/Hz

T_p - physical temperature of source in kelvin degrees

B_n - Noise bandwidth in which the noise power is measured in hertz

P_n - Available Noise Power in Watts

- Available noise power will be delivered only to a load Impedence is matched to the noise source.
- Unit of noise temperature is kelvins.
- In satellite communication system working with weak signal
- The noise level as low as possible to meet the C/N ratio requirements.

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- Noise Temperature from 30K to 200K can be achieved without physical cooling if GaAs FET (Gallium Arsenide Field Effect Transistor) amplifiers are employed.

- Noise Temperature of 30K at 4 GHz

- Noise Temperature of 100K at 11 GHz

- Noise Temperature increases with frequency.

Total Thermal Noise Power : To determine the performance of a receiving system.

- The noise power at the demodulator input is

$$P_{no} = K T_s B_n G_{rx} \text{ Watts} \quad \text{—— (2)}$$

Where G_{rx} : Gain of the receiver from RF input to demodulator input.

B_n : Narrowest Bandwidth.

- The power referred to the input of the receiver is P_n

$$P_n = K T_s B_n \text{ Watts} \quad \text{—— (3)}$$

- Carrier to noise ratio at the demodulator is given by

$$\frac{C}{N} = \frac{P_r G_{rx}}{K T_s B_n G_{rx}} = \frac{P_r}{K T_s B_n} \quad \text{—— (4)}$$

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from eq^n ④ we can calculate C/N ratios for receiving terminals at the antenna output port.

Calculation of System Noise Temperature :-

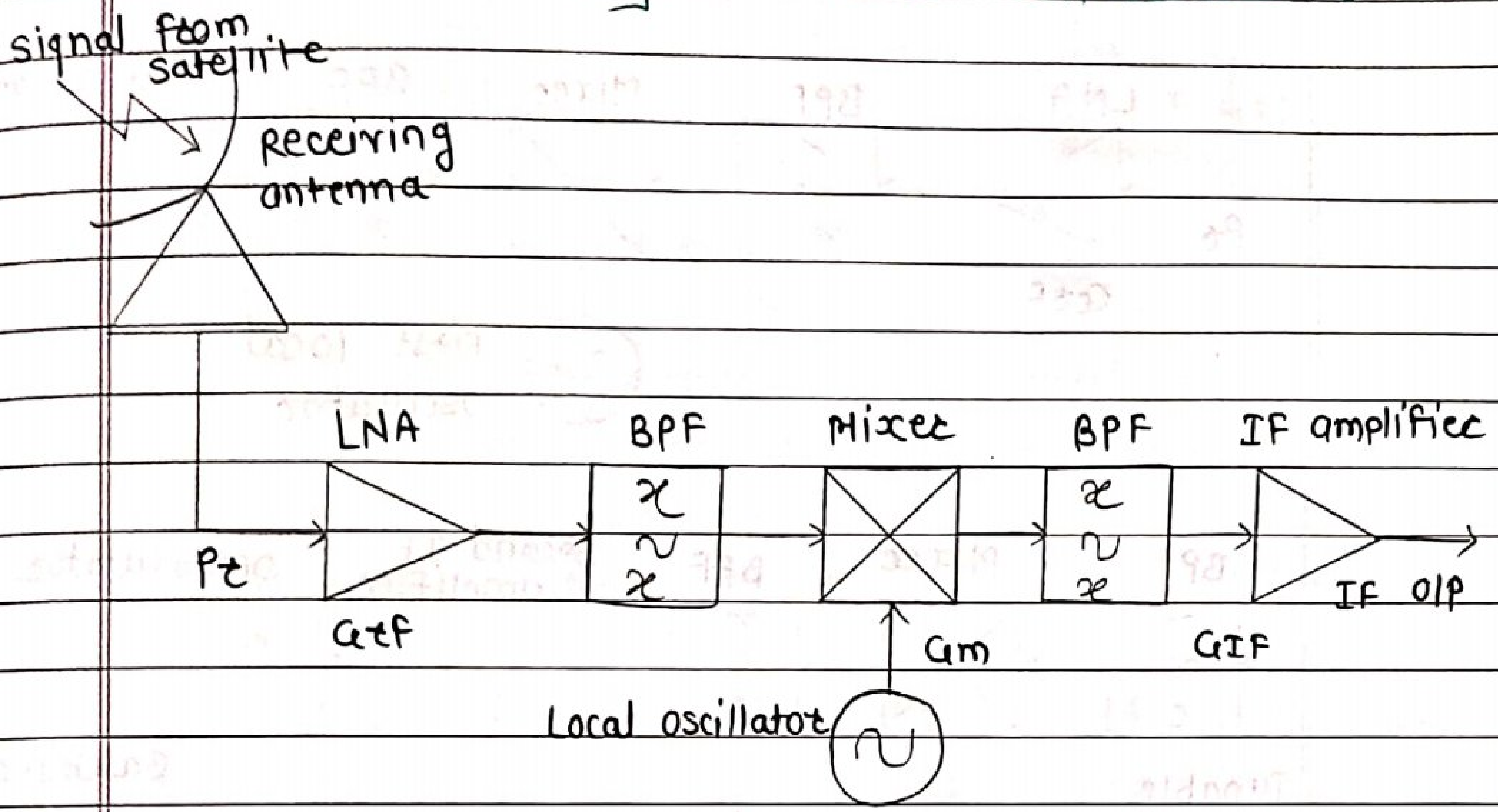

fig :- simplified earth station receiver.

- Above figure shows a simplified communications receiver with an RF amplifier and single freq^n conversion from its RF input to the IF output.
- This is the form used for all radio receivers with few exceptions, known as superhet.
- The superhet receiver has three main subsystems :- a front end (RF amplifier, mixer, and local oscillator) an IF amplifier (IF amplifier & filters) and a demodulator & baseband section.
- The RF amplifier generate as little noise called as low noise amplifier or LNA. The mixer & local oscillator form freq^n conversion RF signal to a fixed IF signal, where the signal can be amplified & filtered accurately

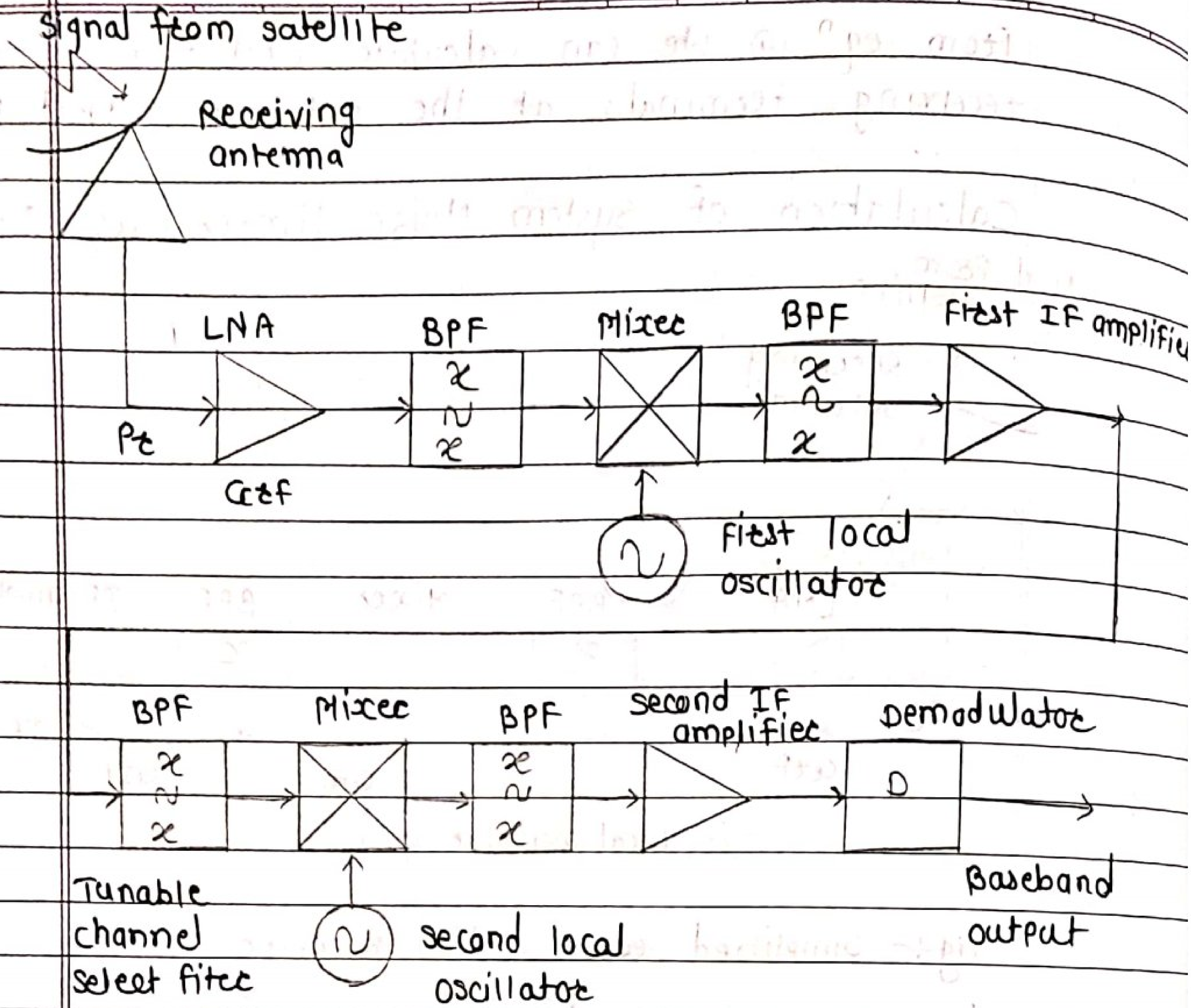

fig :- Double conversion earth station receiver. The first downconversion shifts signals in a 500 MHz band to the first IF range 900 - 1400 MHz. The second downconverter has a tunable local oscillator and channel selection filter to the select the wanted transponder signal in the second IF centered at 70 MHz

- In first stage LNA (low noise Amplifier) is given to the BPF & again it give to Local oscillator, convert RF freq^n to IF freq^n.
- In second stage : IF freq^n it will given to the receiver side with the help of co-axial cable & again with the help of Mixer & local oscillator convert RF freq^n into second IF amplifier & given to demodulator.

Noise Model of Receiver :-

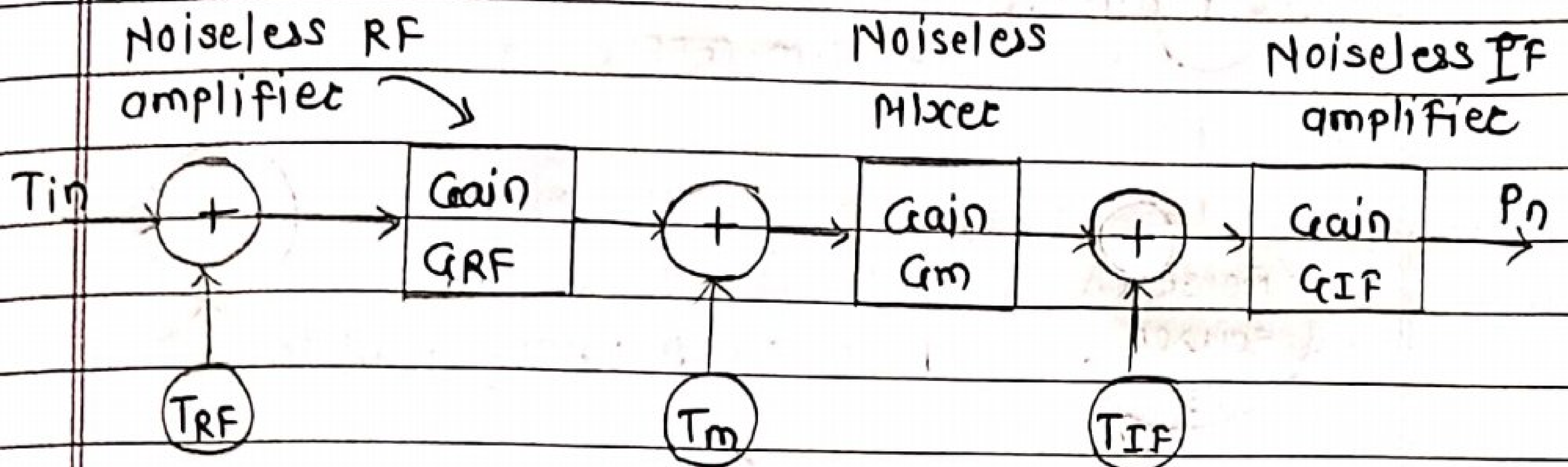

fig :- Equivalent Noise model of receiver.

The noisy amplifiers & downconverter have been replaced by noiseless units, with equivalent noise generators at their inputs.

- The total noise power at the output of the IF amplifier of the receiver is given by

$$P_n = G_{IF} K T_{IF} B_n + G_{IF} G_m K T_m B_n + G_{IF} G_m G_{RF} K B_n (T_{RF} + T_{in}) \quad \text{—— (5)}$$

Where, G_{IF}, G_m & G_{RF} are the gains of the IF amplifier, mixer & RF amplifier.
T_{IF}, T_m & T_{RF} are their equivalent noise temperature.

Equation (5) can be rewritten as

$$P_n = G_{IF} G_m G_{RF} [(K T_{IF} B_n)/(G_{RF} G_m) + (K T_m B_n)/G_{RF} + (T_{RF} + T_{in})]$$

$$P_n = G_{IF} G_m G_{RF} K B_n [T_{RF} + T_{in} + T_m/G_{RF} + T_{IF}/(G_{RF} G_m)] \quad \text{—— (6)}$$

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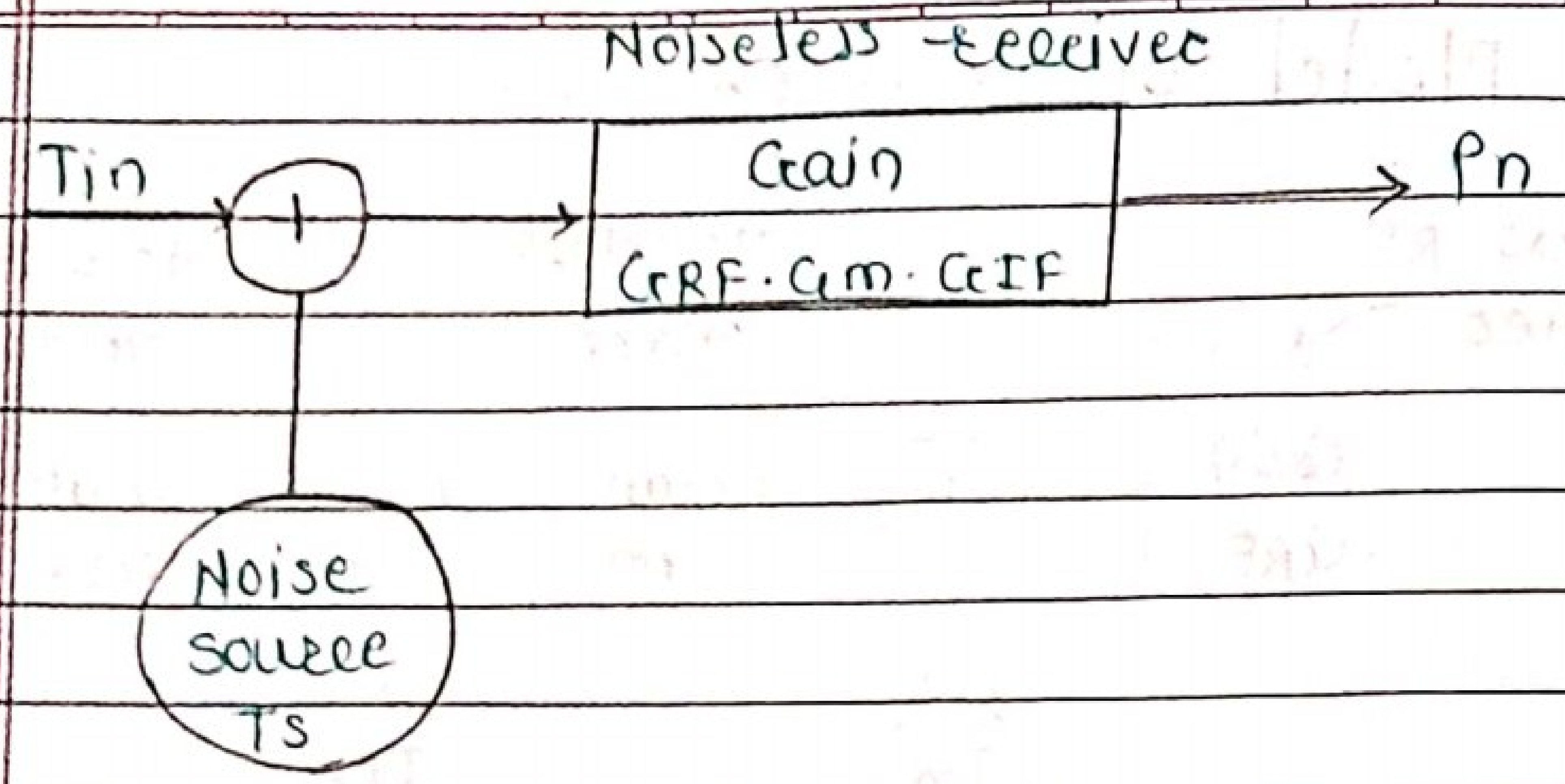

Fig 4:- Noise model of receiver. The All noisy units have been replaced by one noiseless amplifier with a single noise source Ts as its input.

- The single source of noise shown in fig. with noise temperature Ts generates the same noise power Pn at its output if

$$P_n = G_{IF}\, G_m\, G_{RF}\, K T_s B_n \quad \text{——} \quad (7)$$

- If we compare equation (6) & (7) we get system noise temperature as follows.

$$T_s = [T_{RF} + T_{in} + T_m / G_{RF} + T_{IF} / (G_m G_{RF})] \quad \text{——} \quad (8)$$

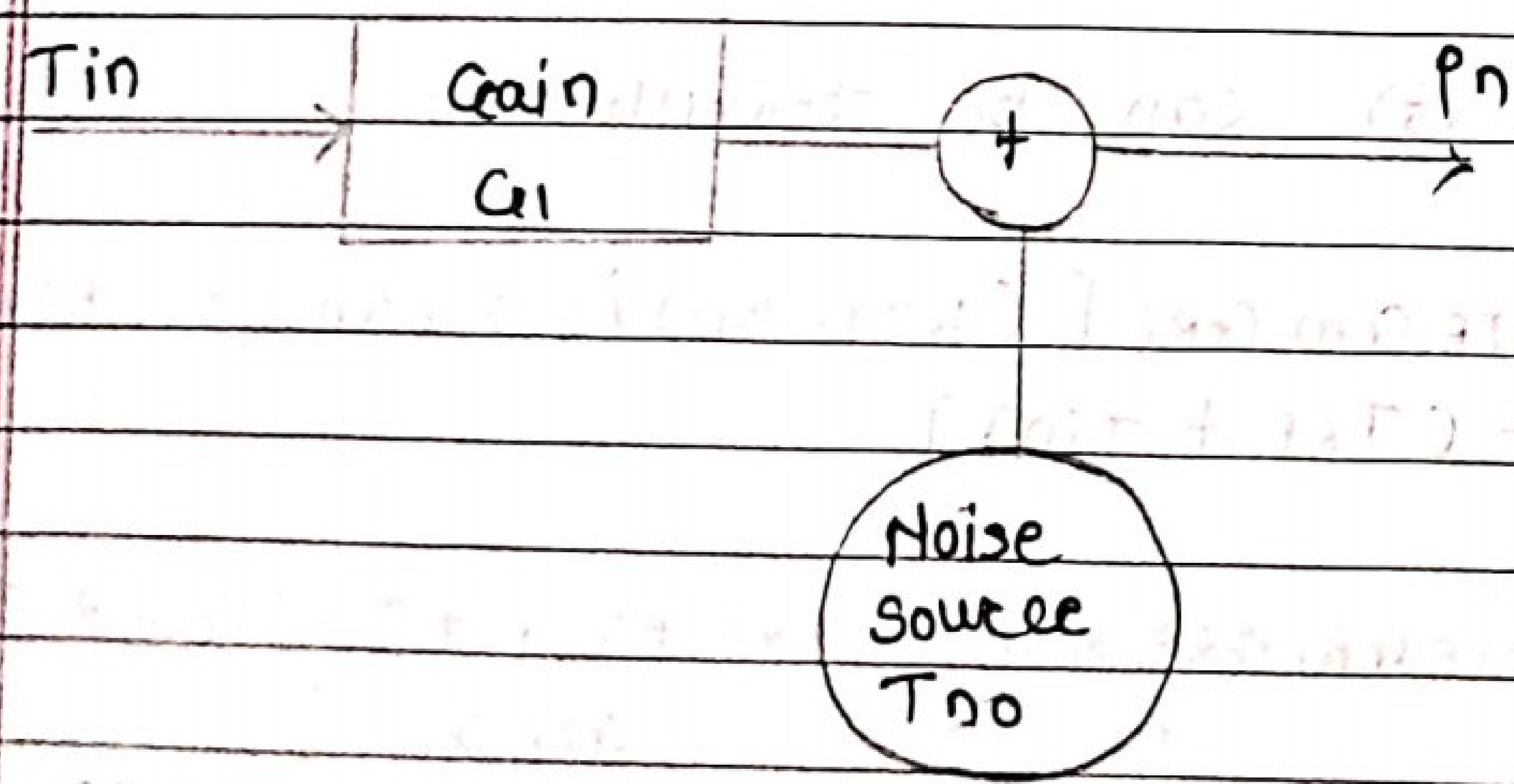

fig 5 :- Noise Model for a lossy device

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The lossy device has been replaced by a lossless device, with a single noise source T_{no} at its output source.

- The noise model for an equivalent output noise source as shown in fig (5) & producess a noise temperature T_{no} given by

$$T_{no} = T_p (1 - G_1) \quad \text{——— (9)}$$

Where G_1 - is the linear gain (less than unity, not in decibels).

T_p - Physical temperature in degree kelvin.

For an attenuation of A dB, the value of G is given

$$G_1 = 10^{A/10}$$

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Ex. Suppose we have a 4-GHz receiver with the following gains and noise temperatures:

$T_{in} = 25\,K$ $\quad G_{RF} = 23$ dB

$T_{RF} = 50\,K$ $\quad G_{IF} = 30$ dB

$T_{IF} = 1000\,K$

$T_m = 500\,K$

Calculate the system noise temperature assuming that the mixer has a gain $G_m = 0$ dB. Recalculate the system noise temperature when the mixer has a 10-dB loss. How can the noise temperature of the receiver be minimized when the mixer has a loss of 10 dB?

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Ans :- Given :-

$T_{in} = 25\ K$ $G_{RF} = 23\ dB$

$T_{RF} = 50\ K$ $G_{IF} = 30\ dB$

$T_{IF} = 1000 K$

$T_{in} = 500\ K$

The system noise temperature is given by

$T_s = [T_{in} + T_{RF} + T_m / G_{RF} + T_{IF} / (G_m G_{RF})]$

$T_s = [25 + 50 + (500/200) + (1000/200)]$

$= 87.5 K$

If the mixer has a loss, as it usually the case, the effect of the IF amplifier would be greater. For $G_m = -10\ dB$, the linear value is $G_m = 0.1$ as a ratio. then

$T_s = [25 + 50 + (500/200) + (1000/20)]$

$= 137.5\ K$

The lowest system noise temperatures are obtained by using a high gain LNA. Suppose we increase the LNA gain in this example to $G_{RF} = 50\ dB$, giving ratio $G_{RF} = 10^5$.

$T_s = [25 + 50 + (500/10^5) + (1000/10^4)] = 75.1 K$

The high gain of RF LNA ampr has made the system noise temperature almost low as

$T_s = T_{in} + T_{RF} = 75\ K$

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Uplink Design :-

- The uplink design is easier than the downlink in many cases, since

① Accurately specified carrier power must be presented at the satellite transponder.

② Feasible to use much higher power transmitters at earth stations.

VSAT system uses
① Earth station with small antennas.

② Transmitter power below 5W. giving low uplink EIRP.

- Satellite Telephone Handset are restricted to

Transmitting powers = Below 1 W. Low risk of EM radiation Hazard.

- The cost of transmitter tends to be high compared with the cost of receiving equipment in satellite communication system.

- The Major growth in satellite communication.

- Point to multipoint Transmission (Direct Broadcast satellite Television)

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- Earth station transmitter power is set by the power level required at the input to the transponder.

- Two ways :-

① specific flux density is required at the satellite.

② specific power level is required at the input to the transponder.

- At C band,

Uplink Earth station = 100 W

Height = 9 meters

flux density = 100 W/m²

$\boxed{\text{Analysis of the uplink requires}}$

↓

Calculation of the power level at the input to the transponder

↓

$\boxed{\text{Uplink C/N ratio}}$

- The Noise power referred to the transponder input

$$N_{xp} = k + T_{xp} + B_n \quad dBW \quad \text{——— ①}$$

Where T_{xp} - System Noise Temperature of the transponder in dBK

B_n - Noise bandwidth in dBHz

k - Boltzman const.

- The power received at the input to the transponder is

$$P_{rxp} = P_t + G_t + G_t - L_p - L_{up} \quad dBW \quad \text{——— ②}$$

Where $P_t G_t$ = Uplink Earth station EIRP in dBW
G_r = satellite antenna gain in dB in the direction of the uplink earth station.
L_p = path loss in dB
L_{up} = for all uplink losses other than path losses.

The value of $(C/N)_{up}$ at the LNA input of the satellite receiver is given by

$$C/N = 10 \log_{10}[P_r/(kT_s B_n)] = P_{rxp} - N_{xp} \text{ dB} \quad \text{——— (3)}$$

The received power P_r at the transponder input is also given by

$$P_{rxp} = N + C/N \text{ dBW} \quad \text{——— (4)}$$

In general

$$P_{rxp} = P_{sat} - BO_o - G_{xp} \text{ dBW} \quad \text{——— (5)}$$

Where P_{sat} = Saturated Power output of the transponder in dBW
BO_o = output backoff in dB
G_{xp} = Gain of the transponder in dB

Design for specified C/N combining C/N & C/I values in satellite links :-

$$S/N \text{ Ratio} = \left[\frac{\text{Carrier Power}}{\text{Noise power in the IF amp}^r}\right]$$

i/p to demodulator

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Noise Present in the IF Amplifier :-
- Receiver Thermal noise
- Noise radiated by atmospheric gases.
- Rain in the slant path.

The overall $(C/N)_o$ is measured in the earth station at the output of the IF amplifier

$$(C/N)_o = 1/[1/(C/N)_1 + 1/(C/N)_2 + 1/(C/N)_3 + \cdots] \quad (6)$$

Equation (6) is referred as the reciprocal C/N formula.

$$(C/N)_o = 1/[N_1/C + N_2/C + N_3/C + \cdots]$$
$$= C/(N_1 + N_2 + N_3 + \cdots) \quad (7)$$

In decibel units :
$$(C/N)_o = C\,dBW - 10\log_{10}(N_1 + N_2 + N_3 + \cdots W)\,dB \quad (8)$$

To calculate the performance of a satellite link Determine
1. The uplink $(C/N)_{up}$ in the transponder.
2. The downlink $(C/N)_{dn}$ in the earth station receiver.

Some useful rule of thumb for estimating $(C/N)_o$ from two C/N values.
1. If $(C/N)_1 = (C/N)_2$ then $(C/N)_o$ is 3 dB lower than either value.
2. If $(C/N)_1 - (C/N)_2 = 10$ dB then $(C/N)_2 - (C/N)_o = 0.4$ dB
3. If $(C/N)_1 - (C/N)_2 = 20$ dB the $(C/N)_o = (C/N)_2$

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- Overall $(C/N)_o$ with uplink & downlink Attenuation:

- The effect of a change in the uplink C/N ratio has a different impact on overall $(C/N)_o$ depending on ① Operating mode of the transponder
② Gain of the transponder.

There are three different transponder types or operating modes.

1> Linear Transponder :-

$$P_{out} = P_{in} + G_{xp} \quad dBW$$

2> Nonlinear Transponder :-

$$P_{out} = P_{in} + G_{xp} - \Delta G \quad dBW$$

3> Regenerative Transponder :-

$$P_{out} = \text{constant} \quad dBW$$

Where

P_{in} :- Power delivered by the satellite receiving antenna to the input of the transponder.

P_{out} :- Power delivered by the transponder to the input of the satellites transmitting antenna.

G_{xp} :- Gain of transponder

ΔG :- Loss of Gain

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Ex Thermal noise in an earth station receiver result in a $(C/N)_{dn}$ ratio of 20.0 dB. A signal is received from a bent pipe transponder with a carrier to noise ratio $(C/N)_{up} = 20.0$ dB. What is the value of overall $(C/N)_o$ at the earth station? If the transponder introduces intermodulation products with (C/I) ratio = 24 dB What is the overall $(C/N)_o$ ratio at receiving earth station?

Ans :- Given :- $(C/N) - 20.0$ dB corresponds to a (C/N) ratio of 100

$$(C/N)_o = \left[\frac{1}{1/(C/N)_{up} + 1/(C/N)_{dn}}\right]$$

$$= \left[\frac{1}{0.01 + 0.01}\right]$$

$$= 50 \text{ or } 17.0 \text{ dB}$$

The intermodulation (C/I) value of 24.0 dB corresponds to a ratio of 0.004. The overall $(C/N)_o$ value is then

$$(C/N)_o = \left[\frac{1}{0.01 + 0.01 + 0.004}\right]$$

$$= 41.7 \text{ or } 16.2 \text{ dB}$$

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o Downlink Design :-

- The design of any satellite communication is based on two objectives :

- Meeting a minimum C/N ratio for a specified percentage of time.

- Carrying the max^m revenue earning traffic at min^m cost.

- Any satellite link can be designed with very large antennas to achieve high C/N ratio under all conditions, but the cost will be high.

- The art of good system design, is to reach the best compromise of system parameters that meets the specification at the lowest cost.

- All satellite communication links are affected by rain attenuation.

  6/4 GHz ------ small
  14/11 GHz (Ku Band) ---- More
  30/20 GHz (Ka Band) ---- Even more

- C links can be designed (for specific Time period)
  Achievement : 99.99 %
  Rain attenuation : 1 or 2 dB
  Time : 0.01 % of year = 52 Minutes
  Rain Attenuation statistics - Not stable.

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- Ka Links can be designed
Achievement : Not Achieve 99.99 %
Rain attenuation : 10 or 20 dB
Time : 0.01 % of year = 52 Minutes.

- Telephone Traffic needs
Real time channels that are maintained for the duration of a call, so C or Ku band are used.
~~Internet~~
- Internet Transmission
Less affected by short outage
Ka band suited for internet access.

○ Link Budgets :-

- C/N ratio calculation is simplified by the use of link budgets.

- A link budget is a tabular method for evaluating the received Power and noise power in a radio link.

- Link Budgets invariably use decibel units for all quantities so that signal and noise power can be calculated by addition & substraction.

- The link budget calculated at an individual transponder.

- Repeated for each of the individual links. In a two way satellite communication link there will be four seperate links each requiring a calculation of C/N ratio.

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- When a bent pipe transponder is used the uplink and downlink C/N ratio must be combined to give an overall C/N.

- The calculation of C/N in a satellite link is based on the two equation.
  1. Received signal power
  2. Received Noise Power.

- The Received carrier power in dB Watts as

$$P_r = EIRP + G_r - L_p - L_a - L_{ta} - L_{ra} \text{ dBW} \quad \text{--- (4)}$$

Where

$EIRP = 10 \log_{10} [P_t G_t]$ dBW

$G_r = 10 \log_{10} (4\pi A_e / \lambda^2)$ dB

path loss $L_p = 10 \log_{10} [(4\pi R/\lambda)^2]$

L_a = attenuation in atmosphere

L_{ta} = losses assosiated with transmitting antenna.

L_{ra} = Losses associated with receiving antenna.

- A Noise power P_n referred to the output terminals of the antenna where

$$P_n = K T_s B_n \text{ Watts} \quad \text{--- (5)}$$

Where

T_s - A receiving terminal with a system noise temperature in K.

B_n - A noise bandwidth in Hz.

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- The Receiving system noise power is usually written in decibel units as

$$N = k + T_s + B_n \ \text{dBW} \quad \text{—— (6)}$$

Where

k - Boltzmann's constant

T_s - The system noise temp in dBK

B_n - The noise bandwidth in dBHz.

Ex An earth station antenna has a diameter of 30m has an overall efficiency 68% & is used to receive a signal at 4150 MHz. At this freqⁿ, the system noise temp is 79 K when the antenna points at the satellite at an elevation angle of 28°. What is the earth station G/T ratio under these condition?

Ans: At 4150 MHz, $\lambda = 0.0723$ m then:

$$G = \eta_A (\pi D/\lambda)^2$$

$$= 0.68 \times (\pi 30 / 0.0723)^2$$

$$= 1.16 \times 10^6 \text{ or } 60.6 \text{ dB}$$

converting T_s into dBK

$$T_s = 10 \log 79 = 19 \text{ dBK}$$

$$\frac{G}{T} = 60.6 - 19.0$$

$$= 41.6 \text{ dB/K}$$

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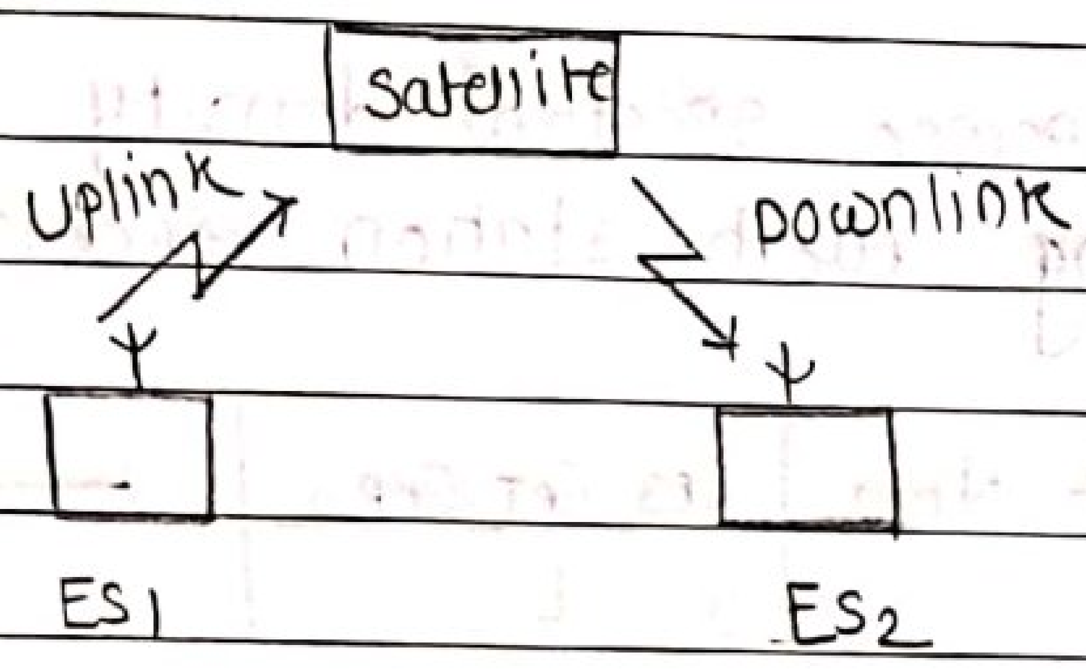
Complete Link Design :-

- A complete link consist of two earth stations and a satellite, therefore complete link is made up of uplink and downlink.



- Therefore the quality of information received on earth station depends on the uplink, the satellite transponder and downlik.

- The uplink is characterized by $(C/N_0)_U$ at the transponder input

$$N_0 = N/B$$

- The downlink is characterized by $(C/N_0)_D$

- The carrier to noise power spectral density ratio is $(C/N_0)_T$ at the receiving earth station by considering uplink and downlink.

- The useful carrier (signal) at the receiving earth station received input is :

$$C = \frac{C_U \, G_S \, G_T \, G_R}{L} \quad \text{——(1)}$$

$$\boxed{P_R = P_T \, G_T \, G_R \left[\frac{\lambda}{4\pi R}\right]^2}$$

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Where C_U – is the signal power at satellite transponder Input.

G_S, G_T, G_R – Satellite transponder gain, transmitting antenna gain, receiving antenna gain.

L – Loss on downlink.

- The noise power spectral density at the input to the receiving earth station receiver is written as:

$$N_0 = N_{OD} + N_{OU}\left[\frac{G_S G_T G_R}{L}\right] \quad \text{—— (2)}$$

Where

N_{OU} – is the noise power density at transponder input

N_{OD} – is the noise power density at the input to receiving earth station receiver.

- Therefore carrier to noise power spectral density is:

$$\left(\frac{C}{N_0}\right)_T = \frac{C}{N_0} = \frac{C_U G_S G_T G_R / L}{[N_{OD} + N_{OU}(G_S G_T G_R / L)]}$$

$$\frac{C}{N_0} = \frac{C_U G_S G_T G_R}{[N_{OD} \cdot L + N_{OU} G_S G_T G_R]}$$

$$\Rightarrow \boxed{\frac{C}{N_0} = \frac{C_U}{N_{OU} + \frac{N_{OD} \cdot L}{G_S G_T G_R}}}$$

If transponder bandwidth B & radiates power P_T & it gain G_S

$$G_S = \frac{P_T}{C_U + N_{OU} \times B} \quad \text{—— (3)}$$

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- For downlink signal power C_D is :-

$$C_D = \frac{P_T G_T G_R}{L}$$

Therefore

$$\frac{C}{N_0} = \frac{C_U}{N_{0U} + \frac{N_{0D}\, L\,[C_{0U} + N_{0U} \times B]}{P_T G_T G_R}}$$

$$\frac{C}{N_0} = \frac{C_U}{N_{0U} + \frac{N_{0D}\,(C_U + N_{0U} \times B)}{C_D}}$$

$$\frac{C}{N_0} = \frac{C_U C_D}{N_{0U} \cdot C_D + N_{0D} \cdot C_U + B\,(N_{0D} \cdot N_{0U})}$$

$$\boxed{\left(\frac{C}{N_0}\right)_T = \frac{(C/N_0)_U \; (C/N_0)_D}{(C/N_0)_U + (C/N_0)_D + B}} \quad \text{—— (4)}$$

- In most of cases, B is much smaller than the $(C/N_0)_U$ and $(C/N_0)_D$

Therefore,

$$\left(\frac{C}{N_0}\right)_T^{-1} = \left(\frac{C}{N_0}\right)_U^{-1} + \left(\frac{C}{N_0}\right)_D^{-1} \quad \text{—— (5)}$$

- Normally $(C/N_0)_U$ is much greater then $(C/N_0)_D$

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

Therefore,

$$\boxed{\left(\frac{C}{N_0}\right)_T \cong \left(\frac{C}{N_0}\right)_D}$$

Complete link design depends on the quality of downlink & on $(C/N_0)_D$.

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- If we include the effect of interfering signal also represents the noise power involved with interfering signal, then

$$\left(\frac{C}{N}\right)_{\text{Net Uplink}} = \left[\left(\frac{C}{N}\right)_U^{-1} + \left(\frac{C}{I}\right)_U\right]^{-1} \quad \text{—— (5)}$$

- Similarly for downlink we can write :-

$$\left(\frac{C}{N}\right)_{\text{Net downlink}} = \left[\left(\frac{C}{N}\right)_D^{-1} + \left(\frac{C}{I}\right)_D\right]^{-1} \quad \text{—— (6)}$$

- Therefor the net carrier to noise ratio is :

$$\left(\frac{C}{N}\right)_{\text{Net}} = \left[\left(\frac{C}{N}\right)^{-1}_{\text{Net Uplink}} + \left(\frac{C}{N}\right)^{-1}_{\text{Net downlink}}\right]^{-1}$$

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

$$\left(\frac{C}{N}\right)_{\text{Net}} = \left[\left(\frac{C}{N}\right)^{-1} + \left(\frac{C}{I}\right)^{-1}\right]^{-1}$$

where $\left(\frac{C}{Z}\right)^{-1} = \left(\frac{C}{I}\right)_U^{-1} + \left(\frac{C}{I}\right)_D^{-1}$

Case I :- $\left(\frac{C}{I}\right) > \left(\frac{C}{N}\right)$ (Noise dominant)

Case II :- $\left(\frac{C}{I}\right) < \left(\frac{C}{N}\right)$ (Interference dominant)

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o Effect of Rain :-

- Till now all the calculations have been done for clear sky conditions.

- In the c band, especially in ku band, rainfall is the most significant cause of signal fading.

- Rainfall results in attenuation of radio waves by scattering & by absorption of energy from the wave.

- Rain attenuation increases with increasing frequency and is worse in the ku band in comparision to the c band.

- Rainfall impacts both the link i.e.
  - o Uplink
  - o Downlink

- To understand the attenuation for
  - 99 % of the times the attenuation will be ≤ 0.2 dB
  - 99.5 % of the times ≤ 0.3 dB
  - 99.9 % of the times ≤ 1.3 dB

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Effect of Rain on Uplink :-

- Rainfall results in attenuation of the signal and an increase in noise temperature, therefore (C/N_0) decreases in two ways.

  - Uplink is not much effected due to rain because satellite antenna is pointed towards hot earth, there is no considerable increase in noise ~~th~~ temp.

  - The uplink carrier power is to be kept within close limits to overcome the rain fades.

- Rain attenuation on uplink path reduces the power at satellite receiver input, therefore $(C/N)_u$ reduces.

- If transponder operate in linear mode then output power will also be reduced by same amount i.e $(C/N)_0$ decreases by equal amount to attenuation on uplink.

- If both are reduced by factor 'A' value of (C/N_0) is also reduced by A dB.

For linear transponder

$$\left(\frac{C}{N_0}\right)_{U\,rain} = \left(\frac{C}{N_0}\right) - A \text{ dB} \quad \text{———} (1)$$

Where A → rain attenuation

C/N_0 → carrier to noise ratio of clear sky.

- If the transponder is non-linear, reduction in input power caused by uplink attenuation of A dB. results in small reduction in the output power.

- Let this reduction is denoted as ΔG

- for non-linear transponder :

$$\left(\frac{C}{N_0}\right)_D = \left(\frac{C}{N_0}\right) - A + \Delta G \text{ dB}$$

This eq^n is true only if received signal is above threshold bit error rate of recovered signal satellite transponder is small.

o Effect of Rain on Downlink :-

- In downlink, rainfall introduces attenuation by various factor : o Absorption , o Scattering of signal energy

- Let [A] dB represents the rain attenuation.

Power loss ratio : $A = 10^{[A]/10}$ —— ①

- The effective noise temperature due to rain is expressed as:

$$T_{rain} = T_a \left[1 - \frac{1}{A}\right] \quad \text{—— ②}$$

- The total sky noise temperature is written as :

$$T_{sky} = T_s + T_{rain} \quad \text{—— ③}$$

- The relationship bet^n downlink (C/N_0) power ratio & clear sky is written as :

$$\left(\frac{N_0}{C}\right)_{rain} = \left(\frac{N_0}{C}\right)\left[A + (A-1)\frac{T_a}{T_s}\right]$$

Assignment No. 4

Q.1 Explain general link design equation.

Q.2 A satellite at a distance of 40,000 km from a point on the earth's surface radiate a power of 10 W from an antenna with a gain of 17 dB in the direction of observer. Find the flux density at the receiving point, and the power received by an antenna at this point with an effective area of $10 m^2$.

Q.3 Explain design of downlink.

Q.4 Explain carrier to noise ratio.

Q.5 Write a short note on parameter to calculate link budget.

Q.6 Explain C-band downlink budget in rain.

Q.7 Design uplink for satellite communication.

Q.8 Design uplink for specified C/N.