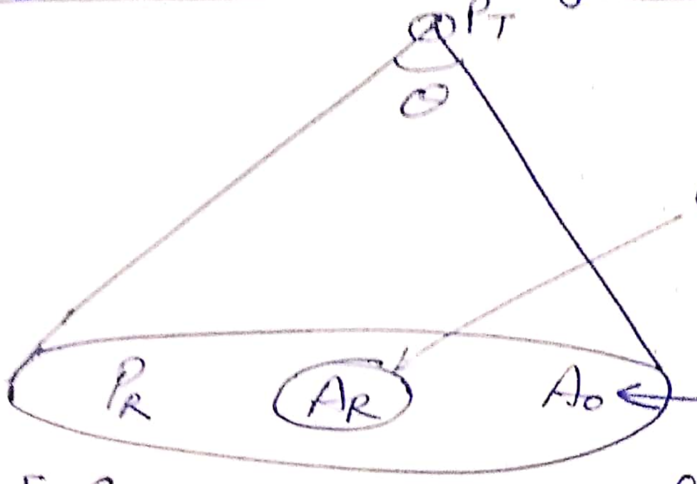
UNIT → 06

* General Link Design Equation :→

→ Flux density and Received Signal Power equation



$$\text{Flux density} = \frac{P_T}{4\pi R^2}$$

[Geometry of a radio link]

The Power received by the receiving antenna of either the Satellite receiver or the receiver of the Earth Station.

Consider that the transmitting antenna is a Point Source. illuminating an area A_0. (Place where a light comes from) the Power density over this area is P_T/A_0. If A_R be the effective area of the receiving antenna.

then Power incident upon is –

$$P_R = \frac{P_T A_R}{A_0} \quad — (1)$$

Now, the directivity G_T of the transmitting antenna can be defined as the ratio of the area illuminated by an isotropic antenna to that illuminated by the antenna under consideration.

$$G_T = \frac{4\pi d^2}{A_0} \quad — (2)$$

$$A_0 = \frac{4\pi d^2}{G_T}$$

Put A_0 value in Eqn no (1)

$$P_R = \frac{P_T G_T A_R}{4\pi d^2} \quad — (3)$$

Now the gain of the receiving antenna G_R in relation to effective area A_R is given by the relation.

$$G_R = \frac{4\pi A_R}{\lambda^2} \quad — (4)$$

$$A_R = \frac{G_R \lambda^2}{4\pi}$$

Put the value of A_R in Eqn (3),

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2 \quad — (5)$$

Eqn (5) is Known as the transmission eqn.

$$\frac{P_T}{P_R} = \frac{(4\pi)^2 d^2}{G_T G_R \lambda^2}$$

The Power attenuation in decibel. (7)

$$\alpha_{dB} = 10\log_{10}\left(\frac{P_T}{P_R}\right) = 22 + 20\log_{10}\left(\frac{d}{\lambda}\right) - G_T - G_R = L_P - G_T - G_R \quad -(6)$$

Where G_T and G_R are the gains of the transmitting and Receiving antennas in decibels.

L_P = Path loss or free space loss $= 22 + 20\log_{10}\left(\frac{d}{\lambda}\right)$ dB. —(7)

from Eqn (7). it is clear that Path loss increases with freqn ~~bu~~ but can be compensated by increasing antenna gain.

As uplink freqn is higher (6 GHz), the Path loss is 199 dB, which is more than the downlink (4 GHz) Path loss of 196 dB (approx.).

Apart from the above Path loss. there are additional losses (L_A) also present and thus the total loss $L = L_P \times L_A$.

$L_P \to$ Path loss
$L_A \to$ Additional loss

thus the Eqn (7) becomes.

$$P_R = \frac{P_T G_T G_R}{L} \rightarrow (8)$$

the Product $P_T G_T$ is called effective isotropic radiated Power (EIRP). which is also the figure of merit of the transmitting antenna.

Now the additional loss Components are,

$$L_A = L_{TX} A_{AI} A_{PC} L_{POL} L_{dp} L_{RX} \quad —(9)$$

Where L_{TX} = losses b/w the transmitter o/p and Transmitting antenna.

A_{AI} = attenuation due to atmosphere and ionosphere.

A_{PC} = attenuation due to precipitation and cloud. Rapidly

L_{POL} = losses due to Polarization mismatch b/w transmitting and Receiving antenna

(8)

L_{dp} = losses due to de-pointing of antenna

L_{Rx} = losses b/w the receiving antenna and the receiver input.

then Eqn (8) can be rewritten as:-

Power Received $P_R = EIRP + G_R - L_{Tx} - A_{AL} - A_{PC} - L_{POL} - L_{dp} - L_{Rx}$ —(10)

* System Noise Temperature, C/N (Carrier/Noise) and G/T (Gain/Tempr.) Ratios:-

Noise tempr. is another important parameter that affect the performance of a receiver and thus the Design of satellite link also depends on noise tempr.

Noise power due to thermal noise in a receiver is given by:-

$$P_n = K T_s B \quad \text{—(1)}$$

Where K = Boltzmann Constant

T_s = System Noise Temperature

B = Bandwidth of the system.

If G is the overall gain of these cascaded amplifier, then the noise power at the demodulator input is

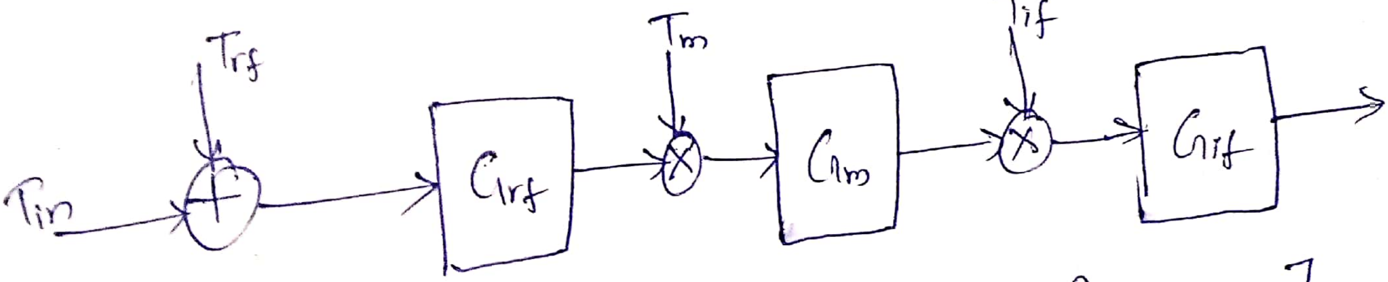
$$P_n = G K T_s B \quad \text{—(2)}$$

If P_r is the power reaching at the input of the receiver. then the signal power reaching at the input of the demodulator is $P_r G$.

Thus the Carrier to noise ratio at the demodulator input is :-

$$\left(\frac{C}{N}\right) = \frac{P_r G}{G K T_s B} = \frac{P_r}{K T_s B} \quad \text{— (3)}$$

A Satellite receiver Comprises an RF amplifier a down Converter (mixer), and an IF amplifier with their respective equivalent noise Tempr. and their Respective gain be T_{rf}, T_m, T_{if}. and G_{rf}, G_m, and G_{if}.



[Noise model of an RF Receiver]

thus the total noise power at the output of the IF amplifier is :-

Total noise Power → $P_n = KB\, G_{if} G_{rf} G_m \left[T_{rf} + T_m + \left(\frac{T_m}{G_{rf}}\right) + \left(\frac{T_{if}}{G_m G_{rf}}\right)\right]$ — (4)

T_s be the noise tempr. of the total Receiver.

$$T_s = T_{rf} + T_m + \left(\frac{T_m}{G_{rf}}\right) + \left(\frac{T_{if}}{G_m G_{rf}}\right) \quad \text{— (5)}$$

Prob-1 Calculate the noise tempr. of a 6 GHz receiver System having the following gain and noise tempr.

$T_{rm} = 75K$, $T_{rf} = 75K$, $T_m = 400K$, $T_{if} = 1000K$

$G_{rf} = 23dB$, $G_m = 0dB$, $G_{if} = 35dB$

Soln:- the System noise tempr. is:-

$$T_s = \left[75 + 75 + \left(\frac{400}{200}\right) + \left(\frac{1000}{200}\right)\right].$$

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$T_s = \cancel{175}\ K$

Problem 2. A Satellite at a distance of 36,000 km. from the Surface of the earth radiates a Power of 4 Watts from an antenna of gain 15dB. find the flux density and Power received by an antenna of effective area $12 m^2$, if the receiving antenna has a gain of 50dB then also Calculate the received Power.

Soln:- $G_T = 15dB = \text{Antilog}(15/10) = 31.62$

flux density at a Point d from the antenna is

$$F = \frac{P_R}{A_R} = \frac{P_T G_T}{4\pi d^2} = \frac{4 \times 31.62}{4 \times 3.14 \times (36 \times 10^6)^2} = 7.77 \times 10^{-15}\ w/m^2$$

Power Received by the receiving antenna

$P_R = F \times A_R = 7.77 \times 10^{-15} \times 12 = 0.093 \times 10^{-12}$ Watt.

therefore Power at the o/p of the receiving antenna

$= G_R \times P_R = \text{Antilog}\left(\frac{50}{10}\right) \times 0.093 \times 10^{-12}$

$= 0.093 \times 10^{-7}$ Watt.

* Noise figure and Noise Temperature :→

Noise figure is used to specify the noise generated within a device. The operational noise figure is defined as the ratio of input signal to noise power to the output signal to noise power.

It is given by:-

$$\text{Noise figure (NF)} = \frac{(S/N)_{in}}{(S/N)_{out}} \quad \text{—} (1)$$

The relationship b/w a noise tempr. and noise figure is given by:-

$$\boxed{T_e = T_0 (NF-1)} \quad \text{—} (2)$$

$T_0 = 290K$

where

T_0 = reference tempr. used to calculate the standard NF. Usually noise figure is given in decibles.

* Antenna Noise Temperature :→

The antenna noise is due to energy, which is fed to the antenna by unwanted radiation sources such as stars, galaxies and other communication signals. the atmosphere itself behaves as a resistive medium, which supplies noise power to the antenna.

The output noise power from the antenna

$$\boxed{N_A = K T_A B} \quad \text{—} (1)$$

K = Boltzmann's constant (1.38×10^{-23})

T_A = Antenna Tempr., B = Bandwidth

* **Uplink Design** :- In the uplink of a Satellite System, the earth Station is transmitting the Signal and the Satellite is receiving it. The Carrier Power to noise power Spectral density ratio for amplification Purpose to design the uplink.

$$\left(\frac{C}{N_o}\right)_{uplink} = 10\log P_T G_T - 20\log\left(\frac{4\pi d}{\lambda}\right) + 10\log\left(\frac{G_R}{T_S}\right) - 10\log L_A - 10\log K - (BO)_I \quad \text{— (1)}$$

where L_A = Additional losses.
G_R = gain of Receiving Antenna
P_T = Transmitting Power.
G_T = Tx Gain.
T_S = System Temp^r.

where $(BO)_I$ is the nonlinear effect at the Input and the loss due to that is 3 to 7 dB.
Input back off will be specified for multiple Carrier operation referred to the single Carrier saturation level. When a number of Carriers are Present Simultaneously in a TWTA, the operating Point must be backed off to a linear Portion of the transfer Characteristic to reduce the effects of inter-modulation distortion.

* **Downlink Design** :- In the downlink Part, the Satellite will transmit the Signal for the Earth Station. thus the uplink Eqn no-(1) (above). Can be u... the ...uation

(3)

of the earth station receiver feeder losses, the earth station receiver G/T, and also free space and other losses at the corresponding downlink freqn.

$$\left(\frac{C}{N_0}\right)_D = [EIRP] + \left(\frac{G}{T}\right)_D - [\text{losses}]_D - [K] - [BO]_i \quad \text{— (2)}$$

There are two major points that must be remember in the design of downlinks of any satellite commn system.

(1) it should carry maximum number of channels at a minimum launching cost and minimum maintenance cost.

(2) with a given (S/N) ratio, for a given percentage of time (99.9%). it gives guarantee continuity of the link.

C/N Ratio calculation in clear Air and rainy Conditions :-

* Downlink Rain Fade Margin :-

Rainfall introduces attenuation by absorption and scattering of signal energy.

Let [A] dB represents the rain attenuation caused by absorption the corresponding power loss ratio is

$$A = 10^{[A]/10} \quad \text{— (1)}$$

The effective noise temperature of the rain is -

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

The total sky noise tempr. is the clear sky temperature T_{cs} plus the rain tempr.

$$T_{sky} = T_{cs} + T_{rain} \quad \text{— (3)}$$

T_{cs} = Noise tempr. of Clear sky/Air

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The downlink $\left(\frac{C}{N_0}\right)$ Power ratio is related to the Clear Sky value by :-

$$\left(\frac{N_0}{C}\right)_{rain} = \left(\frac{N_0}{C}\right)_{CS} \left[A + (A-1)\left(\frac{T_a}{T_{S,CS}}\right)\right] \quad -(4)$$

Where $T_{S,CS}$ = System Noise temperature at clear Sky Condition.

- Complete Link Design :→ A Link Can be Considered as Complete when both uplink and downlink are Considered together. i.e. two earth Stations and a Satellite. A Carrier to noise spectral density ratio Characterizes the uplink, downlink and the transponder of the Satellite. The useful Carrier at the receiving earth Station is

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

Where, C_U = Signal Power at the Satellite transponder input.

G_S, G_T, G_R = Satellite transponder gain, Sat. transmitting antenna gain, Satellite receiving antenna gain.

The noise power spectral density at the input to the receiving earth Station receiver would be given by.

$$N_0 = N_{0D} + N_{0U} \frac{(G_S G_T G_R)}{L} \quad -(2)$$

Where :- N_{0U} = noise power density at transponder input.

N_{0D} = noise power density at the input to receiving earth Station receiver.

(2)

Thus

$$\left(\frac{C}{N_o}\right)_T = \frac{C}{N_o} = \frac{\frac{C_u G_s G_T G_R}{L}}{\frac{N_{oD} + N_{ou}(G_s G_T G_R)}{L}}$$

LCM

$$= \frac{C_u}{N_{ou} + \frac{N_{oD} \cdot L}{G_s G_T G_R}} \quad \text{--- (3)}$$

If the bandwidth of transponder is B and it radiates a constant power P_T, its Gain G_s will be expressed as:—

$$G_s = \frac{P_T}{C_u + N_{ou} \times B} \quad \text{--- (4)}$$

for downlink only the Signal Power C_D is

$$C_D = \frac{P_T G_T G_R}{L} \quad \text{--- (5)}$$

Substituting the value of G_s in Eqn (3)

$$\frac{C}{N_o} = \frac{C_u}{N_{ou} + \frac{N_{oD} \cdot L \cdot (C_u + N_{ou} \times B)}{P_T G_T G_R}}$$

$$\frac{C}{N_o} = \frac{C_u}{N_{ou} + \frac{N_{oD}(C_u + N_{ou} \times B)}{C_D}}$$

$$\frac{C}{N_o} = \frac{\left(\frac{C}{N_o}\right)_u \cdot \left(\frac{C}{N_o}\right)_D}{\left(\frac{C}{N_o}\right)_D + \left(\frac{C}{N_o}\right)_u + B} \quad \text{--- (6)}$$

In most of the cases B is much smaller than $\left(\frac{C}{N_o}\right)_u$ and $\left(\frac{C}{N_o}\right)_D$ so Eqn (6) gives.

$$* \quad \boxed{\left(\frac{C}{N_o}\right)_T^{-1} = \left(\frac{C}{N_o}\right)_u^{-1} + \left(\frac{C}{N_o}\right)_D^{-1}} \quad \text{--- (7)}$$

required → (C/N)

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(6)

Normally, $\left(\frac{C}{N_o}\right)_u >> \left(\frac{C}{N_o}\right)_D$

$$\left(\frac{C}{N_o}\right)_T^{-1} \cong \left(\frac{C}{N_o}\right)_D^{-1} \quad \text{— (8)}$$

So the Complete link design depends on the quality of downlink and especially on $\left(\frac{C}{N_o}\right)_D$

To include the effects of interfering signals Eqn. (7) may be written as:→

$$\left(\frac{C}{N}\right)_{\text{Net uplink}} = \left[\left(\frac{C}{N}\right)_u^{-1} + \left(\frac{C}{I}\right)_u^{-1}\right]^{-1} \quad \text{— (9)}$$

I = Represents the noise power involved with the interfering signals.

Then $\left(\frac{C}{N}\right)_I$ = Carrier to noise ratio of the interference signal for uplink.

Similarly for downlink

$$\left(\frac{C}{N}\right)_{\text{Net downlink}} = \left[\left(\frac{C}{N}\right)_D^{-1} + \left(\frac{C}{I}\right)_D^{-1}\right]^{-1} \quad \text{— (10)}$$

from Eqn (7), the net Carrier to noise ratio is given by :- Eqn (9) + (10)

$$\left(\frac{C}{N}\right)_{\text{Net}} = \left(\frac{C}{N}\right)_{\text{Net uplink}} + \left(\frac{C}{N}\right)_{\text{Net downlink}}$$

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

$$\therefore \left(\frac{C}{N}\right)_{Net} = \left[\left(\frac{C}{N}\right)^{-1} + \left(\frac{C}{I}\right)^{-1}\right]^{-1} \quad -(11)$$

Where, $$\boxed{\left(\frac{C}{I}\right)^{-1} = \left(\frac{C}{I}\right)_u^{-1} + \left(\frac{C}{I}\right)_D^{-1}} \quad -(12)$$

Here, $\left(\frac{C}{N}\right)$ = Carrier to noise ratio of overall link

$\left(\frac{C}{I}\right)$ = Carrier to interference ratio of overall link

if $\left(\frac{C}{I}\right) > \left(\frac{C}{N}\right)$

Satellite link is called noise dominant.

if $\left(\frac{C}{I}\right) < \left(\frac{C}{N}\right)$

Satellite link is called interference dominant.

Problem 1 A geostationary satellite is located at a distance of 3,000 km with an operating freqn 14.25 GHz. The gain of transmitting and receiving antenna are 15 and 20. If the transmitter power is 200 kW. Calculate the power received by the receiving antenna.

Soln. Given that $G_T = 15$, $G_R = 20$

$P_T = 200kW$, $f = 14.25\,GHz$

$R = 3,000\,km$

Received power is given by:-

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi R}\right)^2$$

Where $\lambda = \frac{c}{f} = \frac{3\times10^8}{14.25\times10^9} = 0.021\,m$

Substituting the values in above eqn.

$$P_R = 200\times10^5 \times 15\times20\times \frac{0.021}{(4\times3.14\times3\times10^6)^2}$$

$$P_R = 6\times10^7 \times 10^{-12} \times \frac{0.021}{1419.7824}$$

$$P_R = 0.887\times10^{-8}$$

$$\boxed{P_R = 8.87\times10^{-10}\,W}$$ Ans

Problem 2:- A Satellite earth Station antenna having a gain (maxi) of 80 dB at the operating freqn of 14 GHz, from a Power amplifier and it generate 10 kW at the output. If the feeder loss is 4dB, determine earth Station effective isotropic radiated Power (EIRP).

Soln:- Power at the output of amplifier = 10 kW = 40 dBW

Antenna Gain = 80 dBW

Feeder loss = 4 dBW.

EIRP = [Output Power] + [Antenna gain] − [Feeder loss]

EIRP = 80 + 40 − 4 = 116 dBW Ans

Problem 3:- In a Satellite Communication link, the uplink Carrier to noise ratio $(C/N)_U$ is 20dB where as the downlink Carrier to noise ratio $(C/N)_D$ is 25 dB. Find the [illegible] to noise ratio.

Solⁿ (3) The link Carrier to noise ratio (C/N) is given by:-

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

Given that :-> $\left(\frac{C}{N}\right)_u = 20\,dB = 100$

$$\left(\frac{C}{N}\right)_D = 25\,dB = 316.22$$

Put the above eqⁿ :->

$$\left(\frac{C}{N}\right) = \left[\frac{1}{100} + \frac{1}{316.22}\right]^{-1} = \left(\frac{416.22}{316.22}\right)^{-1}$$

$$\boxed{\frac{C}{N} = 76 = 18.8\,dB}$$ Ans

Problem 4 In the Cascade arrangement of three blocks with their gain and noise figure as $G_1 = 100$, $F_1 = 2$, $G_2 = 10$, $F_2 = 10$, $G_3 = 10$, $F_3 = 15$. Determine the noise figure of the Cascaded arrangement.

Solⁿ 4 The overall noise figure of a Cascaded arrangement of three Stage is given by:-

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2}$$

$$F = 2 + \frac{10-1}{100} + \frac{15-1}{100 \times 10}$$

$$F = 2 + 0.9 + 0.014$$

$$\boxed{F = 2.914}$$ Ans

Determine the Power received by a Satellite located at 40000 km from the Surface of Earth. Satellite is operating at a frequency of 11 GHz and has EIRP of 21 dBW. the gain of a receiving antenna is 50.5 dB.

Soln:- Power received is given by:-

$$P_R = EIRP + G_R - \text{Path loss}$$

$$EIRP = 21\,dB$$

$$G_R = 50.5\,dB$$

$$h = 40000\,km$$

Path loss is given by:-

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

$$= \frac{4 \times 3.14 \times 4 \times 10^7}{(2.727 \times 10^{-2})}$$

$$= 20 \log_{10}\left(\frac{4 \times 3.14 \times 4 \times 10^7}{2.727 \times 10^{-2}}\right) dB$$

$$= 205.3\,dB$$

Power received

$$P_R = 21.0 + 50.5 - 205.3$$

$$\boxed{P_R = -133.8\,dBW}$$ Ans

Problem 6 If a Satellite is operating at a distance of 20000 km from the Surface of Earth and radiates a Power of 4 W. If the gain of transmitting antenna is 20 dB, determine the flux density at the receiving Point.

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Ans → Flux density at the receiving Point is given by

$$\phi = \frac{P_t G_t}{4\pi R^2}$$

Given that $P_t = 4W$

$G_t = 20\,dB = 100$

$R = 20000\,km = 2\times10^7\,m$

Put these value in above Eqn, →

$$\phi = \frac{4\times100}{4\times3.14\times(2\times10^7)^2}$$

$$= 7.95\times10^{-14}\,W/m^2$$

$$\boxed{\phi = 7.95\times10^{-14}\,W/m^2}\ \text{Ans}$$

Problem 7 → for a 4 GHz receiver. the following Parameters of gains and noise tempr. are given as :-

$T_{in} = 50K$ $\qquad G_{RF} = 23\,dB$

$T_{RF} = 50K$ $\qquad G_m = 0\,dB$

$T_m = 500K$ $\qquad G_{IF} = 30\,dB$

$T_{IF} = 1{,}000K$

Calculate the System noise tempr.

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The system noise tempr is given by:

$$T_s = T_{RF} + T_{in} + \frac{T_m}{G_{RF}} + \frac{T_{IF}}{G_m G_{RF}}$$

Given that $G_{RF} = 23\ dB = 200$

$G_m = 0\ dB = 1$

Substitute all these values in above eqn:

$$T_s = 50 + 50 + \frac{500}{200} + \frac{1,000}{200}$$

$$T_s = 107.5\ K$$

$$\boxed{T_s = 107.5\ K}$$ Ans