Module-3

Satellite Link Design

* The Space Link

As in any other communication system, the ultimate goal of a Satellite system is to provide a satisfactory transmission quality for signals relayed between earth stations.

The satellite link consists of an uplink & a Downlink. Signal quality over the uplink depends on the strength of the transmitted signal. Because of the long distance between the geostationary satellite & the earth station, the power of the signal diminishes hence the signal received by the satellite in the uplink & the earth station in the downlink are very weak & are easily disturbed by AWGN (Additive white Gaussian Noise). In addition, the uplink signal may be contaminated by signals transmitted by other earth stations to adjacent satellites and the downlink signal may be contaminated by signals coming from adjacent satellites.

The link power budget calculations basically relate two quantities, i.e., the transmit power & the receive power. and it shows how the difference between these two powers is accounted for.

* Equivalent Isotropic Radiated power [EIRP]

A key parameter in the link budget calculations is the EIRP. W.K.T, the maximum power flux density at some distance 'r' from a transmitting antenna of Gain 'G' is

$$\Psi_M = \frac{G P_s}{4\pi r^2} \longrightarrow (1)$$ where P_s – Transmit/radiated Power

An isotropic radiator with an input power equal to GP_s would produce the same flux density. Hence this product is referred to as the equivalent isotropic radiated power or EIRP,

$$EIRP = G P_s \longrightarrow (2)$$

EIRP is often expressed in decibels relative to one watt or dBW. Let P_s be in watts. then

$$[EIRP] = [G] + [P_s] \text{ dBW} \longrightarrow (3)$$

where $[G]$ is in dB & $[P_s]$ is in dBW.

For a paraboloidal antenna, the isotropic power gain is given by,

$$G = \eta \left(\frac{\pi D}{\lambda}\right)^2 \longrightarrow (4)$$

This equation may be rewritten in terms of frequency, as

$$G = \eta (10.472 f D)^2 \longrightarrow (5) \quad \left\{ \because G = \eta \left[\frac{\pi \times D \times f \times 10^9}{3 \times 10^8}\right]^2 \right\}$$

where f is the carrier frequency in GHz,

D is the reflector diameter in meters.

η is the aperture efficiency. $[\eta = 0.55 \text{ to } 0.73]$.

With the Diameter D in feet & all other quantities as before, the power gain $G = \eta (3.192 f D)^2 \longrightarrow (6)$

Problems -

1) A Satellite downlink at 12 GHz operates with a transmit power of 6 W and an antenna gain of 48.2 dB. calculate the EIRP in dBW.

Sol

$$[EIRP] = [P_s] + [G] \text{ dBW}.$$

Sol. $[EIRP] = 10\log 6 + 48.2$

$= 55.98\ dBW$

2) Calculate the gain of a 3-m paraboloidal antenna operating at a frequency of 12 GHz. Assume an aperture efficiency of 0.55.

Sol. Given, $D = 3m$, $f = 12\ GHz$, $\eta = 0.55$.

$$G = \eta\,(10.472 f D)^2$$

$$= 0.55 \times (10.472 \times 12 \times 3)^2$$

$$G = 78167.63$$

Gain in dB, $[G] = 48.93\ dB$

[Definition of EIRP - EIRP is defined as the product of transmitter power & the antenna gain in a given direction relative to an isotropic antenna of a radio transmitter.]

* Transmission Losses.

The [EIRP] may be thought of as the power input to one end of the transmission link and the problem is to find the power received at the other end. Some losses which remain constant can be taken into account easily. The losses which are weather related & other losses which fluctuate with time are taken by introducing appropriate fade margins into the transmission equation.

1) Free Space Transmission

As a first step in the loss calculations, the power loss resulting from the Spreading of the Signal in Space must be determined. The power flux density at the receiving antenna is given by.

$$\Psi_M = \frac{EIRP}{4\pi r^2} \longrightarrow (1)$$

The power delivered to the matched load (receiver) is the product of this power flux density & the effective aperture of the receiving antenna. ie.

Received power, $P_R = \Psi_M A_{eff} \longrightarrow (2)$

Substituting eq. (1) in (2), we get

$$P_R = \frac{EIRP}{4\pi r^2} \cdot A_{eff}$$

W.K.T $A_{eff} = \frac{\lambda^2 G_R}{4\pi}$

$$\therefore P_R = \frac{EIRP}{4\pi r^2}\left(\frac{\lambda^2 G_R}{4\pi}\right)$$

$$P_R = (EIRP)(G_R)\left(\frac{\lambda}{4\pi r}\right)^2 \longrightarrow (3)$$

where, r is the distance between the transmit and receive antennas & G_R is the isotropic power gain of the receiving antenna.

The RHS of eq (3) is seperated into three terms associated with the transmitter, receiver & free Space respectively.

$\therefore$ The received power in dB notation, $[P_R] = [EIRP] + [G_R] - 10\log\left(\frac{4\pi r}{\lambda}\right)^2 \longrightarrow (4)$

The received power in dBW is given by the sum of the transmitted EIRP in dBW plus the receiver antenna gain in dB minus a third term which represents the free space loss in dB.

The Free Space loss component in decibels is given by

$$[FSL] = 10\log\left(\frac{4\pi r}{\lambda}\right)^2 \longrightarrow (5)$$

Substituting $\lambda = \frac{c}{f}$ with frequency in MHz & distance 'r' in Kms. The

$$[FSL] = 20\log\left(\frac{4\pi \times r \times 10^3 \times f \times 10^6}{3\times 10^8}\right)$$

$$= 20\log r + 20\log f + 20\log\left[\frac{4\pi \times 10^3 \times 10^6}{3\times 10^8}\right]$$

$$= 20\log r + 20\log f + 20\log 41.98$$

$$[FSL] = 20\log r + 20\log f + 32.44 \rightarrow (6)$$

Equation (4) can be written as

$$[P_R] = [EIRP] + [G_R] - [FSL] \longrightarrow (7)$$

The received power $[P_R]$ will be in dBW when the [EIRP] is in dBW & [FSL] in dB.

Equation (7) shows that the received power is increased by increasing antenna gain. W.K.T the antenna gain is inversely proportional to the square of the wavelength. Hence it might be thought that increasing the frequency of operation would increase the received power.

Equation (5) shows that the free space loss is also inversely proportional to the square of the wavelength, so these two effects cancel.

For a constant EIRP, the received power is independent of frequency of operation.

If the transmit power is ~~stated~~ a specified constant, rather than the EIRP, then the received power will increase with increasing frequency for given antenna dish sizes at the transmitter and receiver.

2) Feeder Losses

Feeder losses are the losses that occur in the connection between the receive antenna & the receiver proper. Such losses will occur in the connecting waveguides, filters & couplers. These will be denoted by [RFL] dB i.e. Receiver Feeder Loss. Similar losses will occur in the filters, couplers & waveguides connecting the transmit antenna to the High power Amplifier output.

3) Antenna Misalignment Losses.

When a satellite link is established, the ideal situation is to have the earth station & the satellite antennas aligned for maximum gain, as shown in below figure 1(a). There are 2 possible sources of off-axis loss, one at the satellite & other at the earth station as shown in figure 1(b).

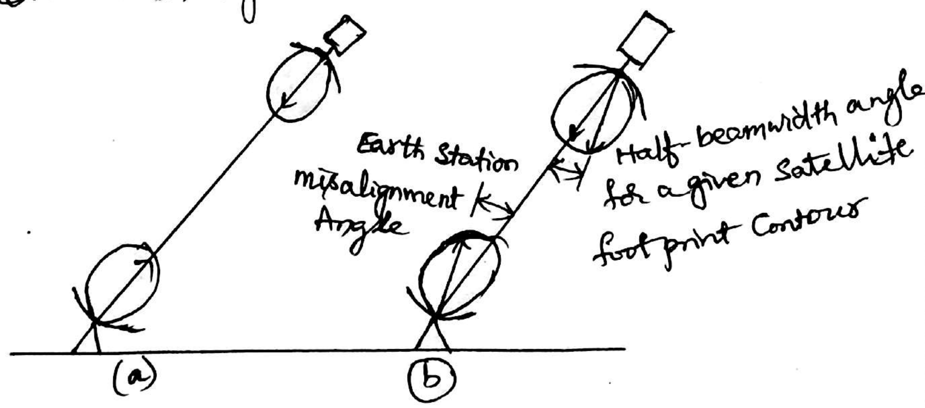


fig (1) a) Satellite & Earth station antennas aligned for maximum gain.
(b) Earth station situated on a given satellite foot print & earth station antenna misaligned.

The off-axis loss at the Satellite is taken into account by designing the link for operation on the actual Satellite antenna Contour.

The off axis loss at the earth station is referred to as the antenna pointing loss.

In addition to pointing losses, losses may result at the antenna from misalignment of the polarization direction. The polarization misalignment losses are usually Small. & it will be assumed that the antenna misalignment losses, denoted by [AML] include both pointing & polarization losses resulting from antenna misalignment.

4) Fixed Atmospheric and Ionospheric Losses.

Atmospheric gases result in losses by absorption & it will be denoted by [AA]. Ionosphere introduces a depolarization loss & it is denoted by [PL].

* Link-power Budget Equation.

The [EIRP] can be considered as the input power to a transmission link.

The power at the receiver, which is the power output of the link, is given as $[P_R] = [EIRP] + [G_R] - [\text{Losses}]$. $\longrightarrow$ (1)

above equation (1) is the basic link-power budget equation taking into the [FSL] loss only.

The other losses also must be taken into account & these are added to [FSL]. The losses for clear-sky Conditions are

$$[Losses] = [FSL] + [RFL] + [AML] + [AA] + [PL] \rightarrow (2)$$

where, [FSL] = Free space spreading loss, dB

[RFL] = Receiver feeder loss, dB

[AML] = Antenna misalignment loss, dB

[AA] = Atmospheric absorption loss, dB.

[PL] = Polarization mismatch loss, dB.

Example problem

1) A satellite link operating at 14 GHz has receiver feeder losses of 1.5 dB and a free-space loss of 207 dB. The atmospheric absorption loss is 0.5 dB, & the antenna pointing loss is 0.5 dB. Depolarization losses may be neglected. Calculate the total link loss for clear-sky conditions.

Sol The total link loss,

$$[Losses] = [FSL] + [RFL] + [AA] + [AML] + [PL]$$

$$= 207 + 1.5 + 0.5 + 0.5 = 209.5 \text{ dB}.$$

---

* System Noise

Electrical noise is always present in a communication system. Noise impede the reception of the wanted signal & is the limiting factor in detecting it. As the signal strength is extremely weak, amplification will be of no help as it will amplify the signal & noise to the same extent.

The major source of electrical noise in equipment is the thermal noise produced by the random motion of electrons in various resistive & active devices in the receiver. Thermal noise is also generated in the lossy components of antennas, & thermal like noise is picked up by the antennas as radiation.

The available noise power from a thermal noise source is given by $P_N = K T_N B_N \rightarrow (1)$

Where T_N - Equivalent noise temperature.

B_N - Equivalent noise bandwidth.

$K = 1.38 \times 10^{-23} J/K$ - Boltzmann's Constant.

The main characteristic of thermal noise is that it has a flat frequency spectrum. i.e., the noise power per unit bandwidth is a constant.

The noise power per unit bandwidth is termed the noise power spectral density, $N_0 = \frac{P_N}{B_N}$

$$N_0 = \frac{K T_N \cancel{B_N}}{\cancel{B_N}} = K T_N \text{ Joules} \rightarrow (2)$$

The noise temperature is directly related to the physical temperature of the noise source but is not always equal to it. The noise temperature of various sources which are connected together can be added directly to give the total noise.

Problem -

1) An antenna has a noise temperature of 35K & is matched into a receiver which has a noise temperature of 100K. Calculate
a) the noise power density & (b) the noise power for a bandwidth of 36 MHz.

$N_0 = KT_N$

Sol. a) Noise power density, $N_0 = (35+100) \times 1.38 \times 10^{-23}$

$N_0 = 1.86 \times 10^{-21}$ Joules.

b) Noise power, $P_N = K T_N B_N$

$\Rightarrow P_N = N_0 B_N$

$\underline{P_N} = 1.86 \times 10^{-21} \times 36 \times 10^6 = \underline{0.0696 \times 10^{-12}}\ W$

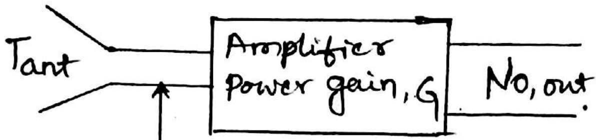
In addition to these thermal noise sources, intermodulation distortion in high power amplifiers can result in signal products which appear as noise & is referred to as intermodulation noise.

→ <u>Antenna Noise</u>

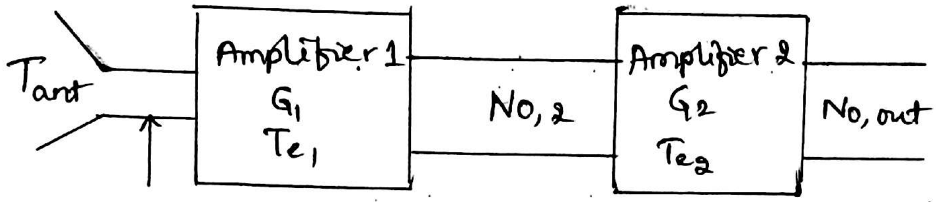
Refer text book

Amplifier Noise temperature

Consider the noise representation of the antenna & the low noise amplifier (LNA) as shown in fig 1(a).



a) an amplifier



b) Two amplifiers in cascade.

fig - circuit used in finding equivalent noise temperature of (a) & (b).

The available power gain of the amplifier is denoted as G & the noise power output as P_{no}. The input noise energy per unit bandwidth coming from the antenna is

$$N_{o,ant} = KT_{ant} \longrightarrow (1)$$

The output noise energy $N_{o,out}$ will be $GN_{o,ant}$ plus the contribution made by the amplifier. Now, all the amplifier noise, wherever it occurs in the amplifier, may be referred to the input in terms of an equivalent input noise temperature for the amplifier T_e.

$\therefore$ The o/p noise is. $N_{o,out} = GN_{o,ant} + GN_{o,amplr}$

$$= GKT_{ant} + GKT_e$$

$$N_{o,out} = GK(T_{ant} + T_e) \longrightarrow (2)$$

T_e will be in the range of 35 to 100K.

3) Amplifiers in cascade

The cascade connection is shown in the figure 1(b). For the cascade connection arrangement, the overall gain is

$$G = G_1 G_2$$

The noise energy of amplifier 2 referred to its own input is $K T_{e_2}$. $\rightarrow (1)$

The noise input to amplifier 2 from the preceding stages is $G_1 K (T_{ant} + T_{e_1})$. $\rightarrow (2)$

∴ The total noise energy referred to amplifier 2 input is.

$$N_{o,2} = G_1 K (T_{ant} + T_{e_1}) + K T_{e_2} \rightarrow (3)$$

This noise energy may be referred to amplifier 1 input by dividing by the available power gain of amplifier 1.

$$N_{o,1} = \frac{N_{o,2}}{G_1}$$

$$N_{o,1} = K\left(T_{ant} + T_{e_1} + \frac{T_{e_2}}{G_1}\right) \rightarrow (4)$$

A system noise temperature may be defined as T_s, by

$$N_{o,1} = K T_s . \rightarrow (5)$$

$$\Rightarrow T_s = T_{ant} + T_{e_1} + \frac{T_{e_2}}{G_1} \rightarrow (6)$$

This is a very important result, it shows that the noise temperature of the second stage is divided by the power gain of the first stage when referred to the input.

∴ In order to keep the overall system noise as low as possible, the first stage should have high power gain as well as low noise temperature.

The general formula for n stages in Cascade is given by

$$T_s = T_{ant} + T_{e1} + \frac{T_{e2}}{G_1} + \frac{T_{e3}}{G_1 G_2} + \dots \longrightarrow (7)$$

— —

4) <u>Noise Factor</u>.

Noise factor 'F' is an alternative way of representing amplifier noise. Assuming the source at room temperature $T_0 \simeq 290K$., the input noise is KT_0 & the output noise from the amplifier is

$$N_{o,out} = FGKT_0 \longrightarrow (1)$$

where, G = available power gain of the amplifier.

F = Noise factor.

<u>Relationship between noise temperature & noise factor.</u>

Let T_e be the noise temperature of the amplifier & let the source be at room temperature. i.e., $T_{ant} = T_0$. Since the same noise output must be available, it follows that

$$GK(T_0 + T_e) = FGKT_0 \longrightarrow (2)$$

$$T_0 + T_e = FT_0$$

$$T_e = (F-1)T_0 \longrightarrow (3)$$

This relation shows the equivalence between noise factor & noise temperature.

In a practical satellite receiving system, noise temperature is specified for low noise amplifiers & converters, while noise factor is specified for the main receiver unit.

The Noise figure 'F' expressed in decibels as

$$\text{Noise Figure} = [F] = 10 \log F. \longrightarrow (4).$$

Problem -

1) A Low noise Amplifier is connected to a receiver which has a noise figure of 12dB. The gain of the LNA is 40dB. & its noise temperature is 120K. Calculate the overall noise temperature referred to the LNA input.

Sol: Given $[F] = 12\,dB \Rightarrow 10\log F = 12 \Rightarrow \log F = \frac{12}{10}$

$$F = 10^{1.2} = 15.848$$

$\therefore$ Noise figure of 12 dB is a power Ratio of 15.85 : 1.

$$[G] = 40\,dB \Rightarrow 10\log G = 40 \Rightarrow \log G = \frac{40}{10}$$

$$G = 10^4$$

$\therefore$ Gain of 40dB is a power ratio of $10^4 : 1$.

The overall noise temperature referred to the LNA i/p is

$$T_{in} = T_{e_1} + \frac{T_{e_2}}{G_1} + \frac{T_{e_3}}{G_1 G_2} + \cdots$$

we have $T_{e_1} = 120\,K$, $T_0 = 290\,K$. $\quad T_{e_2} = (F-1)\,T_0$

$$T_{e_2} = (15.848 - 1)\,290 = 4306\,K$$

$$\therefore T_{in} = 120 + \frac{4306}{10^4} = 120.43\,K$$

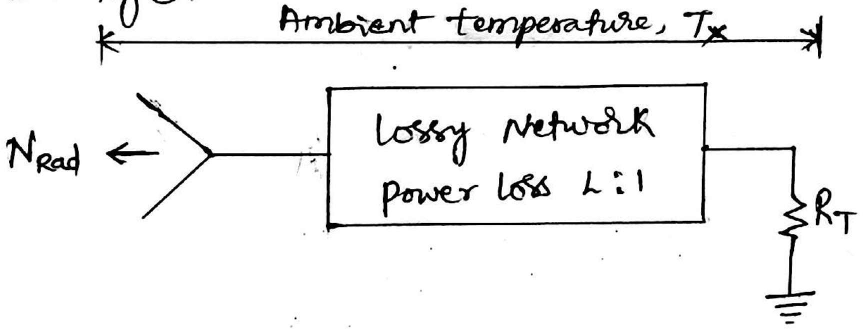
Note - The decibel quantities must be converted to power ratios. Eventhough the main receiver has a very high Noise temperature, its effect is made negligible by the high gain of LNA.

Noise temperature of Absorptive Network

An absorptive network is the one which contains resistive elements. These introduces losses by absorbing energy from the signal & converting it to heat.

Resistive attenuators, transmission lines & waveguides are examples of absorptive networks. The rainfall, which absorbs energy from radio signals passing through it, can be considered as a form of absorptive network. As the absorptive network contains resistance it generates thermal noise.

Consider an absorptive network which has a power loss L, as shown in fig ①.



fig(1) - Network matched at both ends, to a terminating resistor R_T at one end & an antenna at the other end.

The power loss is the ratio of input power to output power & will always be greater than unity.

Let the network be matched at both ends, to a terminating resistor R_T at one end & an antenna at the other end. and let the system be at some ambient temperature T_x.

The noise energy transferred from R_T into the network is KT_x.

Let the network noise be represented at the output terminals i.e. at antenna side by an equivalent noise temperature $T_{NW,0}$. Then the noise energy radiated by the antenna is.

$$N'_{rad} = \frac{KT_X}{L} + KT_{NW,0} \longrightarrow (1)$$

As the antenna is matched to a resistive source at temperature T_X, the available noise energy which is fed into the antenna & radiated is, $N_{rad} = KT_X$. $\longrightarrow (2)$

from equations (1) & (2) we get

$$KT_X = \frac{KT_X}{L} + KT_{NW,0}$$

$$\cancel{K}T_{NW,0} = \cancel{K}\left(T_X - \frac{T_X}{L}\right)$$

$$T_{NW,0} = T_X - \frac{T_X}{L} \Rightarrow T_{NW,0} = T_X\left(1-\frac{1}{L}\right) \rightarrow (3)$$

This is the equivalent noise temperature of the network referred to the output terminals of the network. The equivalent noise at the output can be transferred to the input on dividing by the network power gain, which by definition is $1/L$.

$\therefore$ The equivalent noise temperature of the network referred to the network input is given by.

$$T_{NW,i} = L \times T_{NW,0} = T_X\left(1-\frac{1}{L}\right)L$$

$$= T_X\left(\frac{L-1}{L}\right)L$$

$$\underline{T_{NW,i} = T_X(L-1)} \longrightarrow (4)$$

Equation (4) gives the equivalent noise temperature of a lossy network referred to the input at the antenna when the antenna is used in receiving mode.

If the lossy network is at room temperature i.e. $T_x = T_0$., then Comparing the eq. (4) with $T_e = (F-1)T_0$ [Noise factor equation].

we get, $\underline{F = L} \longrightarrow (5)$

This shows that at room temperature the noise factor of a lossy network is equal to its power loss.

6) ## Overall System Noise temperature

Below fig (1) shows a typical receiving system.

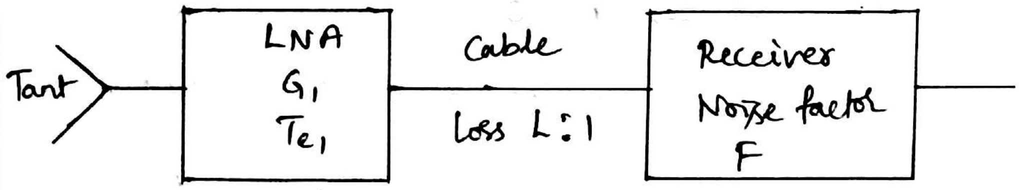


fig (1) Connections used to illustrate the overall noise temperature of System.

For this arrangement, the system noise temperature referred to the input is,

$$T_S = T_{ant} + T_{e1} + \frac{(L-1)T_0}{G_1} + \frac{L(F-1)T_0}{G_1}.$$

problem

1) For the system shown in above fig (1), the receiver noise figure is 12 dB, the cable loss is 5 dB, the LNA gain is 50 dB & its noise

temperature 150 K. The antenna noise temperature is 35 K. Calculate the noise temperature referred to the input.

Sol: Given, $T_e = 150\,K$, $T_{ant} = 35\,K$.

$[F] = 12\,dB \Rightarrow 10\log F = 12 \Rightarrow F = 10^{1.2} = 15.85$

$[L] = 5\,dB \Rightarrow 10\log L = 5 \Rightarrow L = 10^{0.5} = 3.16$

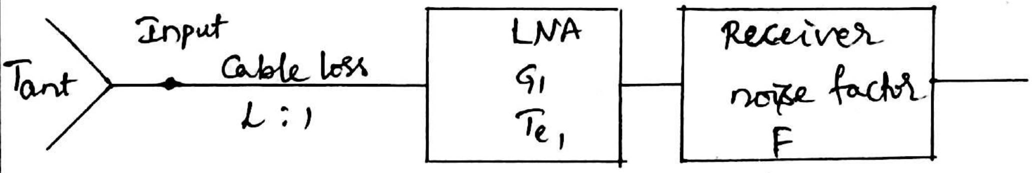
$[G] = 50\,dB \Rightarrow 10\log G = 50 \Rightarrow G = 10^5$, $T_0 = 290\,K$

$T_S = ?$

$$T_S = T_{ant} + T_e + \frac{(L-1)T_0}{G} + \frac{L(F-1)T_0}{G}$$

$$T_S = 35 + 150 + \frac{(3.16-1) \times 290}{10^5} + \frac{3.16 \times (15.85-1)\,290}{10^5} = \underline{\underline{185\,K}}$$

2) For the system shown in below fig, the receiver noise figure is 12 dB, the cable loss is 5 dB, the LNA gain is 50 dB, & its noise temperature is 150 K. The antenna noise temperature is 35 K. Calculate the noise temperature referred to the input.



Sol: Given, $T_e = 150\,K$, $T_{ant} = 35\,K$, $[F] = 12\,dB \Rightarrow F = 15.85$

$[L] = 5\,dB \Rightarrow L = 3.16$, $[G] = 50\,dB \Rightarrow G = 10^5$. $T_0 = 290\,K$

The noise temperature referred to the input $\Big\}$. $T_s = T_{ant} + (L-1)T_0 + L\,T_{e_1} + \dfrac{L(F-1)T_0}{G_1}$

$$T_s = 35 + (3.16-1)\,290 + 3.16 \times 150 + \frac{3.16 \times (15.85-1)\,290}{10^5} = \underline{\underline{1136\,K}}$$

* Carrier to Noise Ratio

A measure of the performance of a satellite link is the ratio of Carrier power to noise power at the receiver output. & the link budget calculations are often concerned with determining this ratio.

This ratio is denoted by C/N or CNR, which is equivalent to P_R/P_N.

In terms of decibels, $\left[\frac{C}{N}\right] = [P_R] - [P_N] \longrightarrow (1)$

W.K.T $[P_R] = [EIRP] + [G_R] - [\text{losses}]$

& $P_N = K T_N B_N \Rightarrow [P_N] = [K] + [T_S] + [B_N]$ $\left\{ \begin{array}{c} \text{Here} \\ T_N = T_S \end{array} \right\}$

$\therefore$ equation (1) becomes,

$$\left[\frac{C}{N}\right] = [EIRP] + [G_R] - [\text{losses}] - [K] - [T_S] - [B_N] \longrightarrow (2)$$

The antenna gain G_R & the System noise temperature T_S can be combined as.

$$[G/T] = [G_R] - [T_S] \quad dBK^{-1}. \longrightarrow (3)$$

$\therefore$ equation (2) becomes

$$\left[\frac{C}{N}\right] = [EIRP] + \left[\frac{G}{T}\right] - [\text{losses}] - [K] - [B_N] \longrightarrow (4)$$

The $\frac{G}{T}$ ratio is a key parameter in Specifying the receiving System performance.

The ratio of carrier power to noise power density P_R/N_0 may be the quantity actually required.

Since $P_N = K T_N B_N$

$\Rightarrow P_N = N_0 B_N$, then

$$\left[\frac{C}{N}\right] = \left[\frac{C}{N_0 B_N}\right] \longrightarrow (5)$$

$$= \left[\frac{C}{N_0}\right] - [B_N]$$

$$\Rightarrow \left[\frac{C}{N_0}\right] = \left[\frac{C}{N}\right] + [B_N] \longrightarrow (6)$$

Substituting equation (4) in eq. (6) gives.

$$\left[\frac{C}{N_0}\right] = [EIRP] + \left[\frac{G}{T}\right] - [\text{Losses}] - [K] \quad \text{dBHz} \longrightarrow (7).$$

---

problem -

1) In a link budget calculation at 12 GHz, the free space loss is 206 dB, the antenna pointing loss is 1 dB & the atmospheric absorption loss is 2 dB. The receiver G/T ratio is 19.5 dB/K, & receiver feeder losses are 1 dB. The EIRP is 48 dBW. Calculate the carrier to noise spectral density ratio.

Sol: Given $f = 12\,GHz$, $[FSL] = 206\,dB$, $[APL] = 1\,dB$, $[AA] = 2\,dB$,

$\left[\frac{G}{T}\right] = 19.5\,dB/K$, $[RFL] = 1\,dB$, $[EIRP] = 48\,dBW$.

$\left[\frac{C}{N_0}\right] = ?$

W.K.T $K = 1.38 \times 10^{-23}$ Joules/K

$[K] = 10 \log 1.38 \times 10^{-23} = -228.6$ decilogs.

$$\left[\frac{C}{N_0}\right] = [EIRP] + \left[\frac{G}{T}\right] - [\text{losses}] - [K]$$

$$= [EIRP] + \left[\frac{G}{T}\right] - \left\{[FSL] + [APL] + [RFL] + [AA]\right\} - [K]$$

$$= 48 + 19.5 - \left\{206 + 1 + 1 + 2\right\} - (-228.6)$$

$$\left[\frac{C}{N_0}\right] = 67.5 - 210 + 228.6 = 86.10 \text{ dBHz}.$$

* The uplink

The uplink of a satellite circuit is the one in which the earth station is transmitting the signal & the satellite is receiving it.

The carrier to noise spectral density ratio for uplink can be written as $\left[\frac{C}{N_0}\right]_U = [EIRP]_U + \left[\frac{G}{T}\right]_U - [losses]_U - [K]$.

In above equation, the values to be used are the earth station EIRP, the satellite receiver feeder losses & satellite receiver G/T. The free space loss & other losses which are frequency dependent are calculated for the uplink frequency. The resulting carrier to noise density ratio appears at the satellite receiver.

i) Saturation flux Density

The Travelling wave Tube Amplifier (TWTA) in a satellite transponder exhibits power output saturation. The flux density required at the receiving antenna to produce saturation ~~Saturation~~ of TWTA is called as Saturation flux density.

The saturation flux density is a specified quantity in link budget calculations, knowing it, one can calulate the required EIRP at the earth station.

We have, the saturation flux density, $\Psi_M = \frac{EIRP}{4\pi r^2} \longrightarrow (1)$

In decibels, $[\Psi_M] = [EIRP] + 10\log\frac{1}{4\pi r^2} \longrightarrow (2)$

We have $[FSL] = 10\log\left(\frac{4\pi r}{\lambda}\right)^2$

$-[FSL] = 10\log\left(\frac{\lambda}{4\pi r}\right)^2$

$$-[FSL] = 10\log\left(\frac{\lambda^2}{4\pi}\right) + 10\log\left(\frac{1}{4\pi r^2}\right)$$

$$\Rightarrow 10\log\left(\frac{1}{4\pi r^2}\right) = -[FSL] - 10\log\left(\frac{\lambda^2}{4\pi}\right) \longrightarrow (3)$$

Substitute eq. (3) in eq. (2), we get

$$[\psi_M] = [EIRP] - [FSL] - 10\log\left(\frac{\lambda^2}{4\pi}\right) \longrightarrow (4)$$

The term $\frac{\lambda^2}{4\pi}$ has dimensions of area & it is the effective area of an isotropic antenna and it is denoted by A_0.

i.e.. $$[A_0] = 10\log\left(\frac{\lambda^2}{4\pi}\right) \longrightarrow (5).$$

with f in GHz., $c = 3\times10^8$ m/sec.

$$[A_0] = 10\log\left(\frac{c^2}{f^2\times4\pi}\right)$$

$$= 10\log\left(\frac{(3\times10^8)^2}{f^2\times(10^9)^2\times4\pi}\right)$$

$$= 10\log\left(\frac{(3\times10^8)^2}{4\pi\times(10^9)^2}\right) + 10\log\frac{1}{f^2}$$

$$= -21.45 - 10\log f^2$$

$$[A_0] = -(21.45 + 20\log f) \longrightarrow (6)$$

Substituting eq. (5) in eq (4). we get

$$[\psi_M] = [EIRP] - [FSL] - [A_0]$$

$$\Rightarrow [EIRP] = [\psi_M] + [A_0] + [FSL] \longrightarrow (7)$$

Taking the other losses into consideration, eq. (7) becomes.

$$[EIRP] = [\Psi_M] + [A_0] + [FSL] + [AA] + [PL] + [AML] \longrightarrow (8)$$

$$\Rightarrow [EIRP] = [\Psi_M] + [A_0] + [Losses] - [RFL] \longrightarrow (9).$$

This is for clear sky condition & gives the minimum value of [EIRP] which the earth station must provide to produce a given flux density at the satellite.

Normally, the saturation flux density will be specified, with saturation values denoted by the subscript 'S'. The equation (9) becomes.

for uplink, $[EIRP_S]_U = [\Psi_S] + [A_0] + [Losses]_U - [RFL] \longrightarrow (10)$.

Problem -

1) An uplink operates at 14 GHz, & the flux density required to saturate the transponder is −120 dBW/m². The free space loss is 207 dB. & the other propagation losses amount to 2 dB. Calculate the earth station [EIRP] required for saturation, assuming clear-sky conditions. Assume [RFL] is negligible.

Sol. Given, $f = 14\,GHz$. $[\Psi_S] = -120\ dBW/m^2$, $[FSL] = 207\,dB$, $[\overset{other}{losses}] = 2\,dB$.

$$[A_0] = -(21.45 + 20\log f) = -(21.45 + 20\log 14) = -44.37\,dB.$$

$$[Losses] = 207 + 2 = 209\,dB.$$

$$[EIRP_S]_U = [\Psi_S] + [A_0] + [Losses] - \cancel{[RFL]}^{\,0}$$

$$= -120 - 44.37 + 209$$

$$[EIRP_S]_U = 44.63\ dBW$$

2) Input Backoff

When the 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 intermodulation distortion. Such multiple carrier operation occurs with frequency Division Multiple Access. & backoff must be allowed for the link budget calculations.

Knowing the saturation flux density for single carrier operation, the input backoff will be specified for multiple carrier operation referred to the single carrier saturation level. The Earth station [EIRP] will have to be reduced by the specified back off (BO), resulting in an uplink value of

$$[EIRP]_U = [EIRP_S]_U - [BO]_i \longrightarrow (1)$$

Although some control of the input to the transponder power amplifier is possible through the ground station TTC, the input backoff is normally achieved through reduction of the [EIRP] of the earth stations actually accessing the transponder.

We have, the carrier to noise spectral density ratio for uplink is

$$\left[\frac{C}{N_0}\right]_U = [EIRP]_U + \left[\frac{G}{T}\right]_U - [losses]_U - [K] \longrightarrow (2)$$

Substituting equation (1) into the above equation, we get

$$\left[\frac{C}{N_0}\right]_U = [EIRP_S]_U - [BO]_i + \left[\frac{G}{T}\right]_U - [losses]_U - [K] \longrightarrow (3)$$

Substituting $[EIRP_S]_U = [\Psi_S] + [A_0] + [losses]_U - [RFL]$ into eq. (3),

we get, $$\left[\frac{C}{N_0}\right]_U = [\Psi_S] + [A_0] - [BO]_i + \left[\frac{G}{T}\right]_U - [K] - [RFL] \longrightarrow (4)$$

problem -

1) An uplink at 14 GHz requires a saturation flux density of $-91.4\, dBW/m^2$. and an input backoff of 11 dB. The satellite G/T is $-6.7\, dBK^{-1}$, & receiver feeder losses amount to 0.6 dB. Calculate the carrier to noise density ratio.

Sol: Given $f = 14\, GHz$, $[\Psi_s] = -91.4\, dBW/m^2$. $[BO]_i = 11\, dB$.

$[G/T]_U = -6.7\, dBK^{-1}$, $[RFL] = 0.6$.

W.K.T $K = 1.38 \times 10^{-23}\, J/K \Rightarrow [K] = 10\log(1.38\times10^{-23}) = -228.6\, dB$.

$$[A_0] = -(21.45 + 20\log f)$$

$$[A_0] = -(21.45 + 20\log 14) = -44.37\, dB$$

$$\therefore \left[\frac{C}{N_0}\right]_U = [\Psi_s] + [A_0] - [BO]_i + \left[\frac{G}{T}\right]_U - [K] - [RFL]$$

$$= -91.4 - 44.37 - 11 - 6.7 + 228.6 - 0.6$$

$$\left[\frac{C}{N_0}\right]_U = 74.53\, dBHz$$

3) The Earth Station HPA

The earth station HPA (High power Amplifier) has to supply the radiated power plus the transmit feeder losses, [TFL] dB. These include waveguide, filter & coupler losses between the HPA output & the transmit antenna.

Referring to the equation $[EIRP] = [P_s] + [G]$, the power output of the HPA is given by,

$$[P_{HPA}] = [EIRP] - [G_T] + [TFL] \longrightarrow (1)$$

The [EIRP] includes any input backoff that is required at the satellite.

The earth station itself may have to transmit multiple carriers & its output will require back off, denoted by $[BO]_{HPA}$. The earth station HPA must be rated for a saturation power output given by

$$[P_{HPA,sat}] = [P_{HPA}] + [BO]_{HPA} \longrightarrow (2)$$

The HPA will be operated at the backed off power level so that it provides the required power output $[P_{HPA}]$. To ensure the operation well into linear region, an HPA with a comparatively high saturation level can be used & a high degree of back off introduced.

Downlink

The downlink of a satellite circuit is the one in which the satellite is transmitting the signal and the earth station is receiving it.

The carrier to noise spectral density ratio for downlink can be written as $$\left[\frac{C}{N_0}\right]_D = [EIRP]_D + \left[\frac{G}{T}\right]_D - [losses]_D - [K] \rightarrow (1)$$

In the above equation (1), the values to be used are the satellite EIRP, the earth station receiver feeder losses, & the earth station receiver G/T. The free space & other losses are calculated for the downlink frequency. The resulting carrier to noise density ratio as given in equation (1) is that which appears at the detector of the earth station receiver.

Assuming that the signal bandwidth B is equal to the noise bandwidth B_N, the carrier to noise ratio is given as

$$\left[\frac{C}{N}\right]_D = [EIRP]_D + \left[\frac{G}{T}\right]_D - [losses]_D - [K] - [B] \longrightarrow (2).$$

Problems

1) A satellite TV signal occupies the full transponder bandwidth of 36 MHz & it must provide a C/N ratio at the destination earth station of 22 dB. Given that the total transmission losses are 200 dB & the destination earth station G/T ratio is 31 dB/K, Calculate the satellite EIRP required.

Sol: Given, $B = 36\ MHz \Rightarrow [B] = 10\log(36\times10^6) = 75.56$, $[K] = -228.6$

$\left[\frac{C}{N}\right]_D = 22$, $[Losses]_D = 200$, $[G/T]_D = 31$, $[EIRP]_D = ?$

we have, $\left[\frac{C}{N}\right]_D = [EIRP]_D + [G/T]_D - [losses]_D - [K] - [B]$.

$$\Rightarrow [EIRP]_D = \left[\frac{C}{N}\right]_D - [G/T]_D + [losses]_D + [K] + [B]$$

$$= 22 - 31 + 200 - 228.6 + 75.56.$$

$$[EIRP]_D = \underline{37.96\ dBW}$$

or $(EIRP)_D = 10^{3.796} = \underline{6.25\ KW}$.

2) A QPSK signal is transmitted by satellite. Raised-cosine filtering is used, for which the rolloff factor is 0.2 & a BER of 10^{-5} is required. For the satellite downlink, the losses amount to 200 dB, the receiving earth station G/T ratio is 32 dBK^{-1}, & the transponder bandwidth is 36 MHz. Calculate (a) the bit rate which can be accomodated and (b) the EIRP required.

Sol: $B = 36\ MHz$, $\rho = 0.2$, $[G/T]_D = 32\ dBK^{-1}$, $BER = 10^{-5}$, $[Losses]_D = 200$

$[K] = -228.6$.

a) $[R_b] = ?$ (b) $[EIRP]_D = ?$

a) We have, $2B = (1+\rho) R_b$

$$\Rightarrow R_b = \frac{2B}{1+\rho} = \frac{2 \times 36 \times 10^6}{1+0.2} = 60 \text{ Mbps.}$$

for $BER = 10^{-5}$, the $[E_b/N_o] = 9.6$.

R_b in decibels, $[R_b] = 10 \log(60 \times 10^6) = 77.78$ dB

b) The required C/N_o ratio is $\left[\frac{C}{N_o}\right] = \left[\frac{E_b}{N_o}\right] + [R_b]$

$$\left[\frac{C}{N_o}\right] = 9.6 + 77.78 = 87.38 \text{ dBHz}$$

$$[EIRP]_D = \left[\frac{C}{N_o}\right] - \left[\frac{G}{T}\right]_D + [\text{losses}]_D + [k]$$

$$= 87.38 - 32 + 200 - 228.6$$

$$[EIRP]_D = 26.78 \text{ dBW.}$$

1) Output Back-off

When the input backoff is employed, a corresponding output backoff must be allowed for in the Satellite EIRP. The output backoff is not linearly related to the input backoff. A rule of thumb is used to take the output backoff as the point on the curve which is 5 dB below the extrapolated linear portion as shown in below fig (1).

Since the linear portion gives a 1:1 change in decibels, the relationship between input & output back off is $[BO]_o = [BO]_i - 5$ dB.

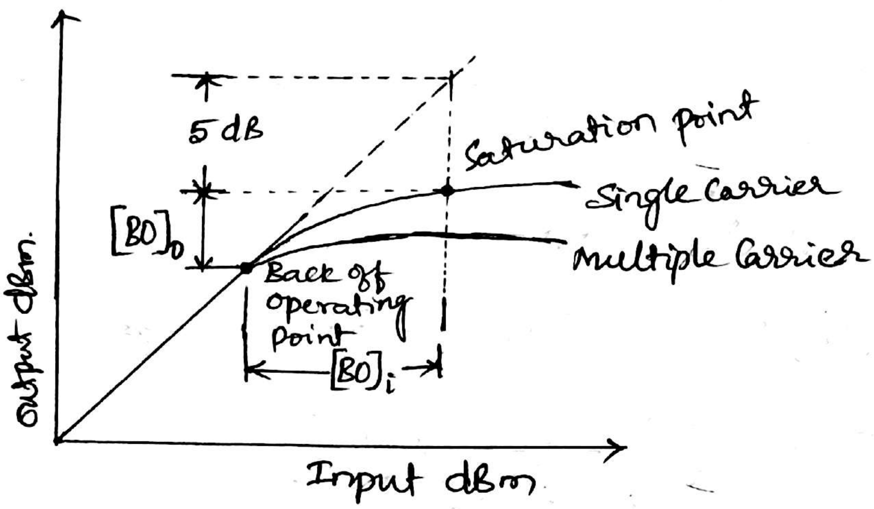


fig ① - Input & output backoff relationship for the satellite travelling wave tube amplifier, $[BO]_i = [BO]_0 + 5$ dB.

If the satellite EIRP for saturation condition is specified as $[EIRP_S]_D$, then $[EIRP]_D = [EIRP_S]_D - [BO]_0$ & the carrier noise density ratio is

$$\left[\frac{C}{N_0}\right]_D = [EIRP_S]_D - [BO]_0 + [G/T]_D - [\text{losses}]_D - [K].$$

For the uplink, the saturation flux density at the satellite receiver is a specified quantity. For the downlink, there is no need to know the saturation flux density at the earth station receiver, since this is a terminal point, & the signal is not used to saturate a power amplifier.

Problem -

1) The specified parameters for a downlink are satellite saturation value of EIRP is 25 dBW, output backoff is 6 dB, free space loss is 196 dB, allowance for other downlink losses

is 1.5 dB and earth Station G/T is 41 dBK^{-1}. Calculate the carrier to noise density ratio at the earth station.

Sol Given $[EIRP]_D = 25$ dBW, $[BO]_0 = 6$ dB, $[FSL] = 196$ dB, other $[losses] = 1.5$ dB

Earth Station $[G/T] = 41$ dBK^{-1}. $[K] = -228.6$, $[C/N_0] = ?$

$$\left[\frac{C}{N_0}\right]_D = [EIRP_S]_D - [BO]_0 + [G/T]_D - [losses]_D - [K]$$

$$= 25 - 6 + 41 - 196 - 1.5 + 228.6$$

$$\left[\frac{C}{N_0}\right]_D = 91.1 \text{ dBHz.}$$

2) Satellite TWTA output

The Satellite power amplifier has to supply the radiated power plus the transmit feeder losses. These losses include the waveguide, filter & Coupler losses between the TWTA output & the Satellite's transmit antenna.

The power output of the TWTA is given by.

$$[P_{TWTA}] = [EIRP]_D - [G_T]_D + [TFL]_D \longrightarrow (1)$$

once $[P_{TWTA}]$ is found, the Saturated power output of the TWTA is given by $[P_{TWTA}]_S = [P_{TWTA}] + [BO]_0 \longrightarrow (2)$

problem -

1) A satellite is operated at an EIRP of 56 dBW with an output back off of 6 dB. The transmitter feeder losses amount to 2 dB, and the antenna gain is 50 dB. Calculate the power output of the TWTA required for full saturated EIRP.

Sol.

$$[P_{TWTA}] = [EIRP]_D - [G_T]_D + [TFL]_D$$

$$= 56 - 50 + 2$$

$$[P_{TWTA}] = \underline{\underline{8\ dBW}} \quad (\text{or } P_{TWTA} = 6.30\ \underline{\underline{W}})$$

$$[P_{TWTA}]_S = [P_{TWTA}] + [BO]_o$$

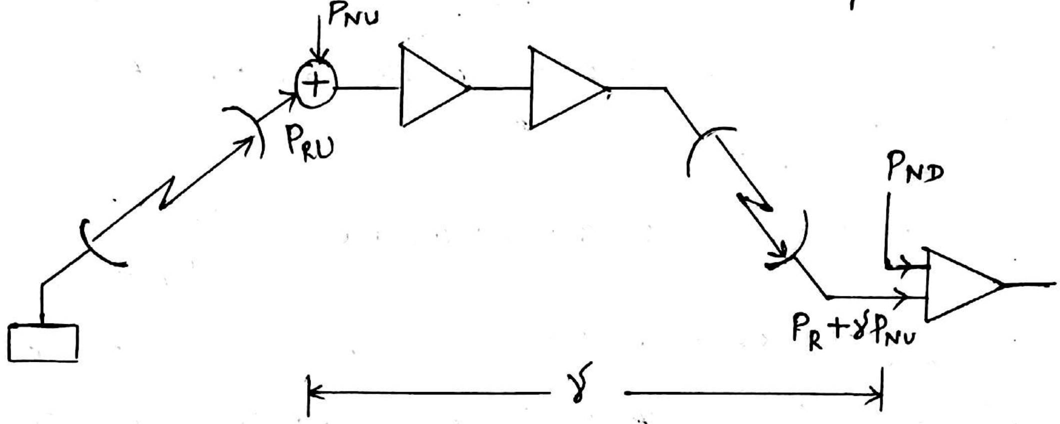
$$= 8 + 6 = \underline{\underline{14\ dBW}}$$

or

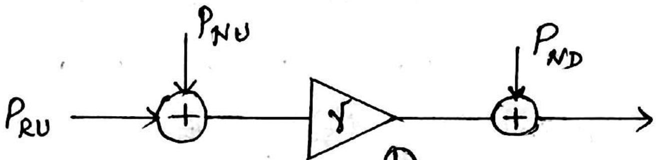
$$P_{TWTA} = 10^{1.4} = \underline{\underline{25.11\ W}}$$

Combined uplink & Downlink C/N Ratio.

The Complete Satellite circuit consists of an uplink & a downlink as shown in below fig. 1(a). Noise will be introduced on the uplink at the satellite receiver input.



(a)



$P_R = \gamma P_{RU}$
$P_N = \gamma P_{NU} + P_{ND}$.

(b)

fig(1) a) Combined uplink & Downlink. (b) Power flow diagram for (a).

The noise power per unit bandwidth is denoted as P_{NU} & the average carrier at the same point is denoted as P_{RU}, the Carrier to Noise ratio on the uplink is $\left(\frac{C}{N_0}\right)_U = \left(\frac{P_{RU}}{P_{NU}}\right)$.

[Note - Here power levels are used].

The Carrier power at the end of the space link is shown as P_R, which is also the received carrier power for the downlink. This is equal to γ times the carrier power input at the satellite, where γ is the system power gain from satellite input to earth station input, as shown in fig 1(a).

The noise at the satellite input also appears at the earth station input multiplied by γ, & the earth station introduces its own noise denoted by P_{ND}.

Thus the end of link noise is $= \gamma P_{NU} + P_{ND}$.

The C/N_0 ratio for the downlink alone, not counting the γP_{NU} contribution is P_R/P_{ND}.

& The combined C/N_0 ratio at the ground receiver $= \dfrac{P_R}{(\gamma P_{NU} + P_{ND})}$.

The combined C/N_0 ratio can be determined interms of the individual link values. To show this, it is more convenient to work with the noise to carrier ratios rather than the carrier to noise ratios.

Denoting the combined noise to carrier ratio by $\frac{N_0}{C}$, the uplink by $\left(\frac{N_0}{C}\right)_U$ & the downlink by $\left(\frac{N_0}{C}\right)_D$, then

$$\frac{N_0}{C} = \frac{P_N}{P_R}$$

$$= \frac{\gamma P_{NU} + P_{ND}}{P_R}$$

$$= \frac{\gamma P_{NU}}{P_R} + \frac{P_{ND}}{P_R}$$

$$= \frac{\gamma P_{NU}}{\gamma P_{RU}} + \frac{P_{ND}}{P_R}$$

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

To obtain the combined value of C/N_0, the reciprocals of the individual values must be added to obtain the N_0/C ratio & then the reciprocal of this is taken to get C/N_0.

problem -

1) For a satellite circuit the individual link Carrier to Noise Spectral density ratios are: uplink 100 dBHz, downlink 87 dBHz. Calculate the Combined C/N_0 ratio.

Sol: Given $\left[\frac{C}{N_0}\right]_U = 100\,dBHz \Rightarrow 10\log\left(\frac{C}{N_0}\right) = 100$

$$\Rightarrow \log\left(\frac{C}{N_0}\right) = \frac{100}{10} \Rightarrow \left(\frac{C}{N_0}\right)_U = 10^{10}$$

$$\therefore \left(\frac{N_0}{C}\right)_U = 10^{-10}$$

$$\left[\frac{C}{N_0}\right]_D = 87\,dBHz \Rightarrow \left(\frac{C}{N_0}\right)_D = 10^{8.7}$$

$$\therefore \left(\frac{N_0}{C}\right)_D = 10^{-8.7}$$

Combined $\frac{N_0}{C}$ ratio, $\left(\frac{N_0}{C}\right) = \left(\frac{N_0}{C}\right)_U + \left(\frac{N_0}{C}\right)_D$

$$= 10^{-10} + 10^{-8.7} = 2.095 \times 10^{-9}$$

$$\left[\frac{C}{N_0}\right] = -10\log\left(2.095 \times 10^{-9}\right) = 86.79\,dBHz.$$

2) A multiple carrier satellite circuit operates in the 6/4 GHz band with the following characteristics.

uplink - Saturation flux density = $-67.5\ dB\,W/m^2$.
input Backoff = 11 dB. Satellite $[G/T] = -11.6\ dBK^{-1}$.

Downlink - Satellite saturation EIRP = 26.6 dBW, output Backoff = 6 dB, free space loss = 196.7 dB, earth station $G/T = 40.7\ dBK^{-1}$. The other losses may be ignored. Calculate the carrier to noise density ratios for both links & the Combined value.

Sol. Combined Noise density to carrier ratio.

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

Uplink

we have $\left[\frac{C}{N_0}\right]_U = [\Psi_S] + [A_0] - [BO]_i + [G/T]_U - [K] - [RFL]$

Given $[\Psi_S] = -67.5$, $[BO]_i = +11$, $\left[\frac{G}{T}\right]_U = -11.6$, $[RFL]=0$, $f=6\,GHz$

$$[A_0] = -(21.45 + 20\log f)$$

$$= -(21.45 + 20\log 6) = -37\ dB.$$

$$K = 1.38\times10^{-23} \Rightarrow [K] = 10\log 1.38\times10^{-23} = -228.6$$

$$\therefore \left[\frac{C}{N_0}\right]_U = -67.5 - 37 - 11 - 11.6 - (-228.6) - 0$$

$\left[\frac{C}{N_0}\right]_U = 101.5\ dB. \longrightarrow$ uplink carrier to Noise density Ratio.

ie., $10\log\left(\frac{C}{N_0}\right)_U = 101.5 \Rightarrow \log\left(\frac{C}{N_0}\right)_U = \frac{101.5}{10} = 10.15$

$$\left(\frac{C}{N_0}\right)_U = 10^{10.15}$$

$$\therefore \left(\frac{N_0}{C}\right)_U = 10^{-10.15}$$

Downlink

we have $\left[\frac{C}{N_0}\right]_D = [EIRP_S]_D - [BO]_o + \left[\frac{G}{T}\right]_D - [Losses]_D - [K]$

Given. $[EIRP_S]_D = 26.6$, $[BO]_o = 6$, $\left[\frac{G}{T}\right]_D = 40.7$, $[Losses]_D = 196.7$

$$[K] = -228.6$$

$$\therefore \left[\frac{C}{N_0}\right]_D = 26.6 - 6 + 40.7 - 196.7 - (-228.6)$$

$= 93.2\ dB \longrightarrow$ Downlink carrier to Noise density Ratio.

i.e. $10\log\left(\frac{C}{N_0}\right)_D = 93.2 \Rightarrow \left(\frac{C}{N_0}\right)_D = 10^{9.32}$

$$\therefore \left(\frac{N_0}{C}\right)_D = 10^{-9.32}$$

$$\text{Combined}\left(\frac{N_0}{C}\right) = \left(\frac{N_0}{C}\right)_U + \left(\frac{N_0}{C}\right)_D$$

$$= 10^{-10.15} + 10^{-9.32}$$

$$\left(\frac{N_0}{C}\right) = 5.49 \times 10^{-10}$$

$\left(\frac{N_0}{C}\right)$ in dB, $\left[\frac{N_0}{C}\right] = 10\log(5.49\times10^{-10})$

$$\left[\frac{N_0}{C}\right] = -92.6 \text{ dBHz}$$

∴ Combined Carrier to Noise density ratio,

$$\left[\frac{C}{N_0}\right] = -10\log(5.49\times10^{-10})$$

$$\left[\frac{C}{N_0}\right] = 92.6 \text{ dBHz.}$$

INTERFERENCE

Interference between satellite circuits & terrestrial station

With many telecommunication services using radio transmissions, interference between earth station, space station & terrestrial stations occur. Earth stations are specifically associated with ground-based microwave line-of-sight circuits.

The possible modes of interference are classified as follows & is shown in fig (1).

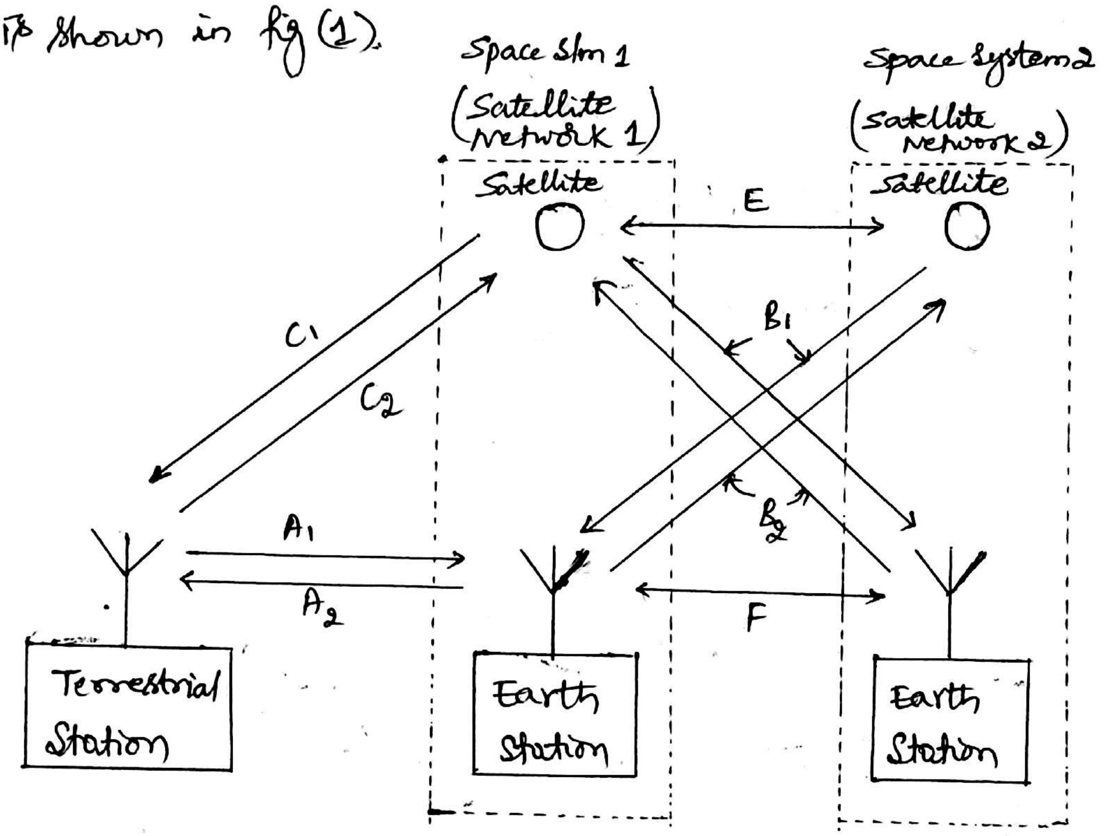


fig (1) - possible interference modes between satellite circuits & a terrestrial station.

A_1 : Terrestrial station transmissions, possibly causing interference to reception by an earth station.

A_2 : Earth station transmissions, possibly causing interference to reception by a terrestrial station.

B1 : space station transmission of one space system, possibly causing interference to reception by an earth station of another space system.

B2 : Earth station transmissions of one space system, possibly causing interference to reception by a space station of another space system.

C1 : space station transmission, possibly causing interference to reception by a terrestrial station.

C2 : terrestrial station transmission, possibly causing interference to reception by a space station.

E : space station transmission of one space system, possibly causing interference to reception by a space station of another space system.

F : Earth station transmission of one space system, possibly causing interference to reception by an earth station of another space system.

A_1, A_2, C_1 & C_2 are possible modes of interference between space & terrestrial services.

B_1 & B_2 are possible modes of interference between stations of different space systems using seperate uplink & downlink frequency bands.

E & F are extensions to B_1 & B_2 where bidirectional frequency bands are used.

→ The radio regulations like ITU specify maximum limits on radiated powers in an attempt to reduce the potential interference to acceptable levels in most situations. When interference still occurs, co-ordination between operations is needed to reduce interference.

For Geostationary satellites, interference modes B_1 & B_2 set a lower limit to the orbital spacing between satellites. To increase the capacity of the geostationary orbit, the Federal Communications Commission (FCC) reduced the orbital spacing from 4° to 2° in the C-band.

Interference with individually owned TVRO receivers also may occur from terrestrial station transmissions in the 6/4 GHz band. Although this may be thought of as an A1 mode of interference, the fact that these home stations are considered by many broadcasting companies to be 'pirates' means that regulatory controls to reduce interference are not applicable.

Intermodulation interference is a type of interference which can occur between two or more carriers using a common transponder in a satellite or a common high power amplifier in an earth station.

* Interference between Satellite circuits (B1 & B2 modes)

A satellite circuit may suffer from B1 & B2 modes of interference from a number of neighbouring satellite circuits, the resultant effect is termed as "Aggregate Interference". The interference produced by a single interfering circuit on a neighbouring circuit is referred as "Single-entry interference". Interference may be considered as a form of noise & with this, the system performance is determined by the ratio of wanted to interfering powers. i.e., the ratio of wanted carrier power to the interfering carrier power or C/I ratio.

The most important factor controlling interference is the radiation pattern of the earth station antenna. Comparatively, large diameter reflectors can be used with earth station antennas, & hence narrow beamwidths can be achieved. for example, a 10-m antenna at 14GHz has a -3dB beamwidth of about 0.15°. This is very much narrower than the 2° to 4° orbital spacing allocated to satellites.

Below fig ① shows the angles subtended by two satellites in geostationary orbit. The orbital seperation is defined as the angle α subtended at the center of the earth, known as the geocentric angle.

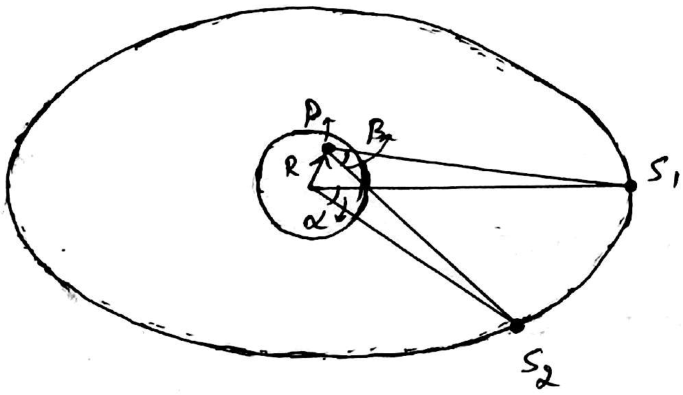


fig ① - Geocentric angle α & the topocentric angle β.

From an earth station at point P, the satellite would appear to subtend an angle β which is referred to as the Topocentric angle.

In all practical situations relating to satellite interference, the topocentric & geocentric angles may be assumed equal & making this assumption leads to an overestimate of the interference.

Consider S_1 as the wanted satellite & S_2 as the interfering satellite. An antenna at 'P' will have its main beam directed at S_1 and an off-axis component at angle θ [topocentric angle or orbital spacing] directed at S_2. When calculating the antenna side lobe pattern, the orbital spacing angle may be used. The orbital spacing angles range from 2° to 4° in 0.5° intervals in the C band.

In fig (2) the satellite circuit being interfered with is that from earth station A via satellite S_1 to receiving station B.

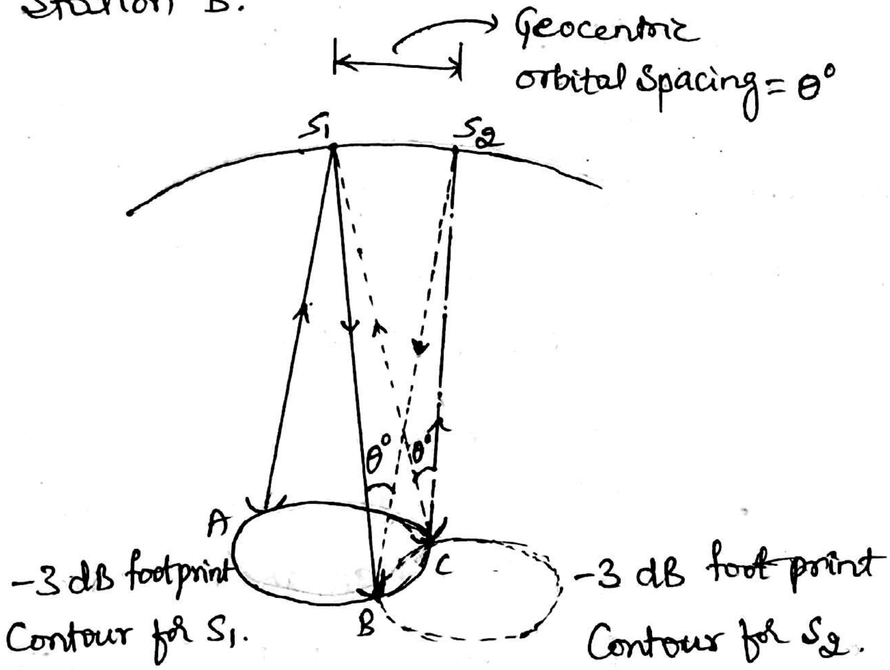


fig (2) - orbital spacing angle

The B1 mode of interference can occur from satellite S_2 into earth station B, & the B2 mode of interference can occur from earth station C into satellite S1. The total single entry interference is the combined effect of these two modes.

As the satellites cannot carry very large antenna reflectors, the beamwidth is relatively wide, even for spot beams. Therefore, in interference calculations, the earth stations will be assumed to be situated on the -3 dB contours of the satellite footprints, in which case the satellite antennas do not provide any gain discrimination between the wanted & the interfering carriers on either transmit or receive.

1) Downlink

The received power equation, $[P_R] = [EIRP] + [G_R] - [Losses]$ may be used to calculate the wanted & interfering downlink carrier powers received by an earth station.

The carrier power $[C]$ in dBW received at earth station B is

$$[C] = [EIRP]_1 - 3 + [G_B] - [FSL] \longrightarrow (1)$$

where, $[EIRP]_1$ = the equivalent isotropic radiated power in dBW from Satellite 1,

-3 dB accounts for the -3 dB contour of the satellite transmit antenna.

$[G_B]$ = Boresight (on-axis) receiving antenna gain at B.

$[FSL]$ = Free space loss in dB.

Similar equation may be used for the interfering carrier $[I]$, except an additional term $[Y]_D$ dB, allowing for polarization discrimination, must be included.

The receiving antenna gain at B is determined by the Offaxis angle θ, giving

$$[I] = [EIRP]_2 - 3 + [G_B(\theta)] - [FSL] - [Y]_D \longrightarrow (2)$$

Assuming [FSL] is same for both paths. & Subtracting eq. (2) from (1) gives

$$[C] - [I] = [EIRP]_1 - [EIRP]_2 + [G_B] - [G_B(\theta)] + [Y]_D$$

or

$$\left[\frac{C}{I}\right]_D = \Delta[E] + [G_B] - [G_B(\theta)] + [Y]_D \longrightarrow (3)$$

Problem

1) The desired Carrier [EIRP] from a Satellite is 34 dBW & the ground Station receiving antenna gain is 44 dB in the desired direction & 24.47 dB toward the interfering Satellite. The interfering Satellite also radiates an [EIRP] of 34 dBW. The polarization discrimination is 4 dB. Determine the carrier to interference ratio at the ground receiving antenna.

Sol Given, $[EIRP]_1 = 34$, $[G_B] = 44$, $[G_B(\theta)] = 24.47$, $[Y]_D = 4$.

$$\left[\frac{C}{I}\right]_D = [EIRP]_1 - [EIRP]_2 + [G_B] - [G_B(\theta)] + [Y]_D$$

$$= (34 - 34) + 44 - 24.47 + 4$$

$$\left[\frac{C}{I}\right]_D = \underline{23.53 \text{ dB}}$$

2) <u>Uplink</u> - A result similar to above equation (3) can be derived for uplink.

In uplink, it is desirable to work with the radiated powers & the antenna transmit gains rather than the EIRPs of the two earth stations.

For the uplink, G_B & $G_B(\theta)$ are replaced by the satellite receive antenna gains, both of which are assumed to be given by the -3 dB contour.

Denoting $\Delta[P]$ as the difference between wanted & interfering transmit powers, $[G_A]$ the boresight transmit antenna gain at A & $[G_C(\theta)]$ the off axis transmit gain at C, the $[C/I]$ ratio can be written as

$$\left[\frac{C}{I}\right]_U = \Delta[P] + [G_A] - [G_C(\theta)] + [Y]_U \longrightarrow (4)$$

<u>problem</u>

1) Station A transmits at 24 dBW with an antenna gain of 54 dB & Station C transmits at 30 dBW. The off-axis gain in the S1 direction is 24.47 dB. & the polarization discrimination is 4 dB. Calculate the $[C/I]$ ratio on the uplink.

Sol. Given $[P]_1 = 24$, $[P]_2 = 30$, $[G_A] = 54$, $[G_C(\theta)] = 24.47$, $[Y]_u = 4$

$$\left[\frac{C}{I}\right]_U = \Delta[P] + [G_A] - [G_C(\theta)] + [Y]_u$$

$$= (24-30) + 54 - 24.47 + 4$$

$$\left[\frac{C}{I}\right]_U = 27.53 \text{ dB}$$

3) Combined [C/I] due to interference on both uplink & downlink.

Interference may be considered as a form of noise & assuming that the interference sources are statistically independent, the interference powers may be added directly to give the total interference at receiver B.

The uplink & downlink ratios are combined to give

$$\left(\frac{I}{C}\right)_{ant} = \left(\frac{I}{C}\right)_U + \left(\frac{I}{C}\right)_D$$

Note - Here, the power ratios must be used, not decibels & the subscript "ant" denotes the combined ratio at the output of station B receiving antenna.

problem

3) Using the uplink & downlink values of [C/I] determined in previous problems 1 & 2, find the overall ratio $[C/I]_{ant}$.

Sol. We have, $[C/I]_U = 27.53\text{ dB} \Rightarrow 10\log\left(\frac{C}{I}\right)_U = 27.53$

$$\log\left(\frac{C}{I}\right)_U = 2.753 \Rightarrow \left(\frac{C}{I}\right)_U = 10^{2.753} \text{ or } \left(\frac{I}{C}\right)_U = 10^{-2.753} = 1.766\times10^{-3}.$$

$$\left[\frac{C}{I}\right]_D = 23.53\text{ dB} \Rightarrow \left(\frac{C}{I}\right)_D = 10^{2.353} \text{ or } \left(\frac{I}{C}\right)_D = 10^{-2.353} = 4.436\times10^{-3}.$$

$$\left(\frac{I}{C}\right)_{ant} = \left(\frac{I}{C}\right)_U + \left(\frac{I}{C}\right)_D$$

$$= 1.766\times10^{-3} + 4.436\times10^{-3}$$

$$\left(\frac{I}{C}\right)_{ant} = 6.202\times10^{-3}$$

$$\therefore \left[\frac{C}{I}\right]_{ant} = -10\log(6.202\times10^{-3})$$

$$= 22.074\text{ dB}$$

4) In a Satellite System, (i) the desired carrier [EIRP] from a Satellite is 31 dBW & the ground station receiving antenna gain is 39 dB in the desired direction & 23.47 dB toward the interfering satellite. The interfering satellite also radiates an [EIRP] of 29 dBW. The polarization discrimination is 3 dB. Calculate the [C/I] ratio at the ground receiving antenna.

(ii) Station A transmits at 22 dBW with an antenna gain of 51 dB & station C transmits at 27 dBW. The off axis gain in the S1 direction is 23.47 dB & the polarization discrimination is 3 dB. Calculate the [C/I] ratio on the uplink.

(iii) Find the overall power ratio $(I/C)_{ant}$ using (i) & (ii).

Sol (i) Given $[EIRP]_1 = 31$, $[EIRP]_2 = 29$, $[G_B] = 39$, $[G_B(\theta)] = 23.47$

$[Y]_D = 3$

$$[C/I]_D = \Delta[E] + [G_B] - [G_B(\theta)] + [Y]_D$$

$$= (31-29) + 39 - 23.47 + 3 = 20.53 \text{ dB}$$

ii) Given $[P]_1 = 22$, $[P]_2 = 27$, $[G_A] = 51$, $[G_C(\theta)] = 23.47$, $[Y]_U = 3$

$$[C/I]_U = \Delta[P] + [G_A] - [G_C(\theta)] + [Y]_U$$

$$= (22-27) + 51 - 23.47 + 3 = \underline{25.53} \text{ dB}$$

iii) Combined ratio, $(I/C)_{ant} = (I/C)_U + (I/C)_D$

$$= 10^{-2.553} + 10^{-2.053}$$

$$(I/C)_{ant} = 0.0116501$$

$$[C/I]_{ant} = -10 \log(0.0116501) = 19.336 \text{ dB}$$