Satellite Communication

5EC5-14

Unit # 4

Typical Phenomena in Satellite Communication:

Solar Eclipse on satellite, its effects, remedies for Eclipse, Sun Transit Outage phenomena, its effects and remedies, Doppler frequency shift phenomena and expression for Doppler shift. Satellite link budget

4.1 Solar Eclipse on satellite:

- A satellite is said to be in eclipse when the earth or moon prevents sunlight from reaching it.
- If the earth's equatorial plane coincides with the plane of earth's orbit around sun, the geostationary orbit will be eclipsed by the earth. This is called the earth eclipse of satellite.
- Solar eclipses are important as they affect the working of the satellite because during eclipse satellite receives no power from its solar panels and it has to operate on its onboard standby batteries which reduce satellite life.
- Satellite failure is more at such times when satellite enters into eclipse (sudden switch to no solar power region) and when it moves out of eclipse (suddenly large amount of solar power is bombarded on satellite) as this creates thermal stress on satellite.
- Eclipse caused by moon occurs when moon passes in front of sun but that is less important as it takes place for short duration (twice in every 24 hours for an average of few minutes).

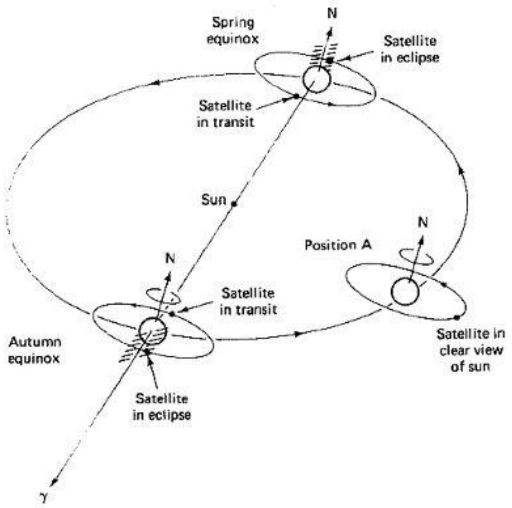


Fig (a)

Way to avoid eclipse during satellite lifetime:

Satellite longitudes which are west rather than east of the earth station are most desirable.

- When satellite longitude is east of the earth station, the satellite enters eclipse during daylight and early morning hours of the earth station. This can be undesirable if the satellite has to operate on reduced battery power
- When satellite longitude is west of the earth station, eclipse does not occur until the earth station is in darkness when usage is likely to be low.

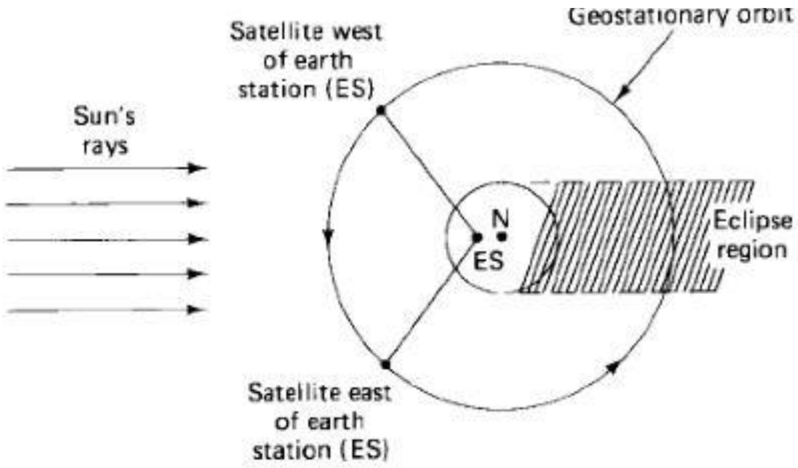


Fig (b)

Sun Transit Outage phenomena:

- Satellites are stationed over the equator. The distance between satellite and Earth is 36,000 Km. Now as we all know sun is full of energy and it emits the heated light of high intensity generates the noise. This noise is called as the thermal noise. So when the sun with its thermal noise aligns with satellite and receiving antenna on earth results loss of signal due to interference is known as Sun outage.
- Sun transit outage is an interruption or distortion of geostationary satellite signals caused by interference from solar radiation. Sun appears to be an extremely noisy source which completely blanks out the signal from satellite. This effect lasts for 6 days around the equinoxes. They occur for a maximum period of 10 minutes.
- Generally, sun outages occur in February, March, September and October. At these times, the apparent path of the sun across the sky takes it directly behind the line of sight between an earth station and a satellite. As the sun radiates strongly at the microwave frequencies used to communicate with satellites (C-band, Ka band and Ku band) the sun swamps the signal from the satellite.

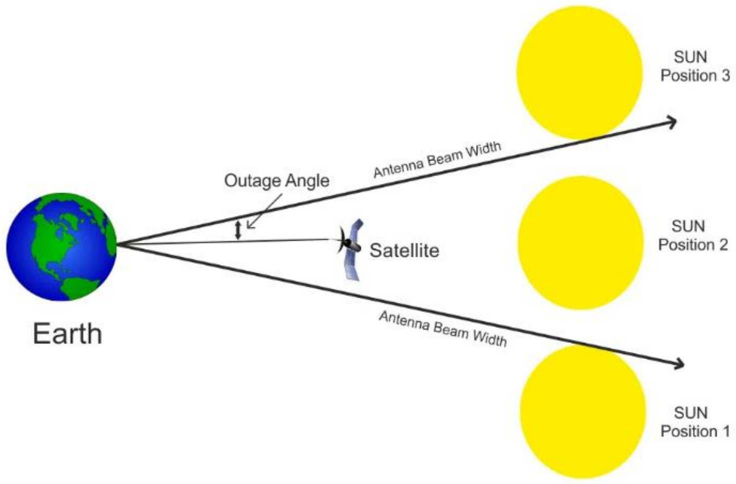
Working of Sun Outage:

As Shown in the figure below there are three positions of sun. In the first position our signal strength is good, but after sometime when sun reaches its second position our receiving signal strength get low or even nil results freezing in services. Because in this position the sun is directly aligned with satellite and receiving antenna result losses in signal due to interference of sun emitted energy with satellite carried signal.

Again, when sun reaches at its third position then signal stand get normal our services started to run properly.

Outage Angle = (11/Frequency*Diameter)+0.25 degree

Frequency is Downlink frequency (GHz) and Diameter of your Receiving Antenna.



Effects of sun transit outage:

The effects of a sun outage can include partial degradation, that is, an increase in the error rate, or total destruction of the signal.

Effect on Indian stock exchanges:

The interference to satellites' signals has been shown to disturb smooth transmission of data of online transactions so, for fairness, the share markets are closed for these short times each year. Trading is normally extended the same day to compensate for the lost time.

Doppler frequency shift phenomena:

The frequency and wavelength of an electromagnetic field are affected by relative motion; This is known as the Doppler effect. Only the radial component of motion produces this phenomenon. The Doppler effect is significant in low-earth-orbit (LEO) satellite systems.

All LEO satellites are constantly moving relative to each other and to points on the surface. This causes variations in the frequencies and wavelengths of received signals. In geostationary satellite systems, Doppler effect is not a factor unless the end user is on board a spacecraft or high-speed aircraft.

Let the Transmitted frequency is f_T and received frequency f_R. The received frequency f_R is higher then f_T when the transmitter is moving towards the receiver and lower then f_T when transmitter is moving away from the receiver.
The mathematically relationship between transmitted f_T and received frequencies f_R is

$$\frac{f_R - f_T}{f_T} = \frac{\Delta f}{f_T} = \frac{V_T}{v_p}$$

$$\Delta f = \frac{V_T f_T}{c} = \frac{V_T}{\lambda}$$

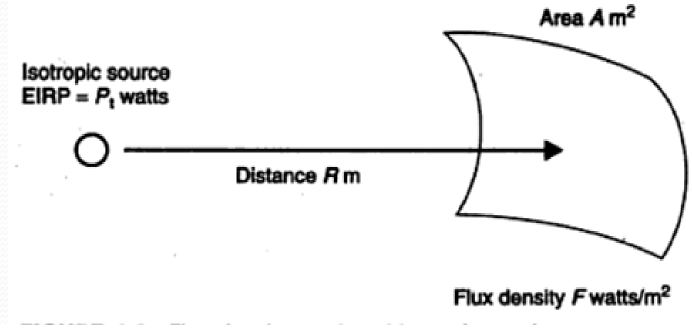
Where V_T = Transmitted Velocity
v_p = C = Speed of Light
λ = wave length of transmitted signal
if transmitter is moving away from receiver then V_T will be negative.

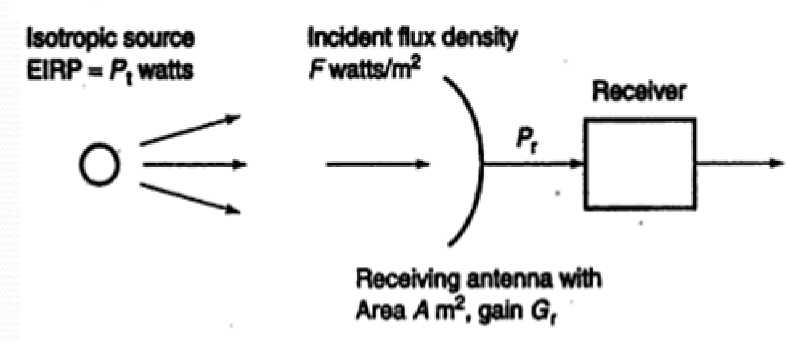
Satellite Link Budget:

Basic Transmission Theory:

- The calculation of power received by an earth station from a satellite is fundamental to the understanding of satellite communication.
- Consider a transmitting source, in free space, radiating total power Pt watts uniformly in all directions.
- Such source is called isotropic.
- At a distance R meters from isotropic source, flux density crossing the surface

$$\mathbf{F = P_t / 4\pi R^2\ (W/m^2)}$$





The received power by Receiving Antenna will be:

$$\mathbf{P_r = F * A \text{ watts}}$$

$$\mathbf{P_r = P_t A / 4 \pi R^2 \text{ watts}}$$

For a transmitter with output P_t watts driving a lossless antenna with gain G_t, the flux density at distance R meters is

$$\mathbf{F = P_t G_t / 4 \pi R^2 \ (W/m^2)}$$

The product $P_t G_t$ is called ***effective isotropic radiated power* or EIRP**, it describes the combination of transmitting power & antenna gain in terms of an equivalent isotropic source with power $P_t G_t$ watts.

A practical antenna with physical aperture area of A m^2 will not deliver power as given in above equation.
Some of the energy incident on aperture is reflected away from the antenna, some is absorbed by lossy components. The *effective aperture* A_e is

$$\mathbf{A_e = \eta_A A}$$

Where $\boldsymbol{\eta_A}$ *aperture efficiency* of the antenna.
For parabolic reflector η_A = 50 to 75%
For Horn antennas η_A = 90%

Thus the power received by real antenna with effective aperture area A_e m^2 is

$\mathbf{P_r = P_t G_t A_e / 4 \pi R^2}$ **(watts)…….. (A)**

A fundamental relation in antenna theory is gain & area of an receiving antenna are related by

$\mathbf{G_r = 4\pi A_e / \lambda^2}$

Substituting above equation in equation (A) gives

$\mathbf{P_r = [P_t G_t G_r / (4 \pi R / \lambda)^2]}$**watts**

This expression is known as link equation & essential in calculation of power received in any radio link.

The term $(4 \pi R / \lambda)^2$ is known as **path loss $\mathbf{L_p}$**. Collecting various factors, we can write Power received.

P_r = (EIRP * Receiving antenna gain / path loss) watts

In decibel, we have

$P_r = EIRP + G_r - L_p$ …………………….. (B)

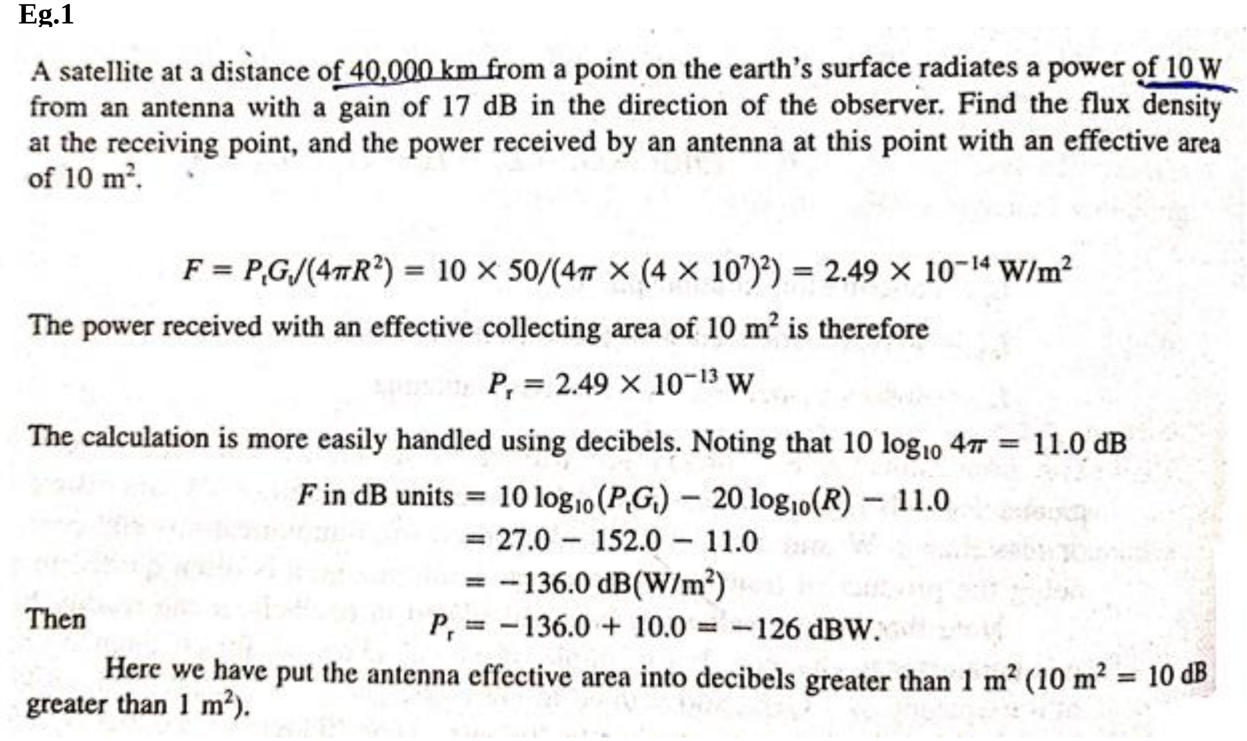
Where EIRP= $10\log_{10}(P_t G_t)$ dBW

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

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

Numericals:

Eg.1



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.

$$F = P_t G_t/(4\pi R^2) = 10 \times 50/(4\pi \times (4 \times 10^7)^2) = 2.49 \times 10^{-14}\ \mathrm{W/m^2}$$

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

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

The calculation is more easily handled using decibels. Noting that $10\log_{10} 4\pi = 11.0$ dB

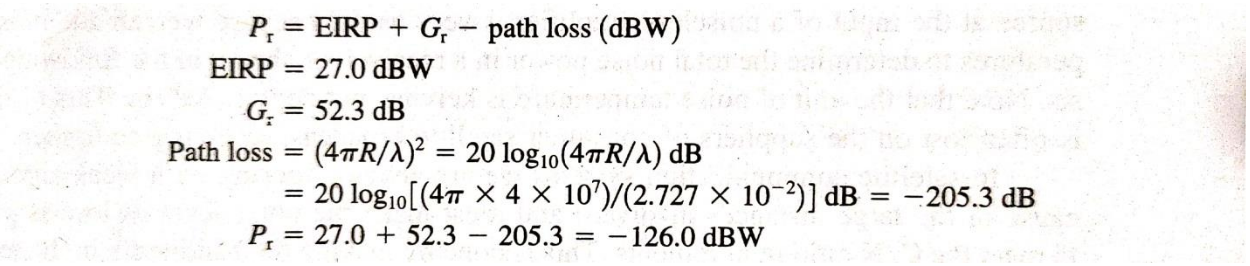
$$\begin{aligned} F \text{ in dB units} &= 10\log_{10}(P_t G_t) - 20\log_{10}(R) - 11.0 \\ &= 27.0 - 152.0 - 11.0 \\ &= -136.0\ \mathrm{dB(W/m^2)} \end{aligned}$$

Then

$$P_r = -136.0 + 10.0 = -126\ \mathrm{dBW}.$$

Here we have put the antenna effective area into decibels greater than 1 m^2 (10 m^2 = 10 dB greater than 1 m^2).

Now from **Eg.1** the satellite is operate at a frequency of 11 GHz. The receiving antenna has a gain of 52.3 dB, Find the received Power.



$$\begin{aligned} P_r &= \mathrm{EIRP} + G_r - \text{path loss (dBW)} \\ \mathrm{EIRP} &= 27.0\ \mathrm{dBW} \\ G_r &= 52.3\ \mathrm{dB} \\ \text{Path loss} &= (4\pi R/\lambda)^2 = 20\log_{10}(4\pi R/\lambda)\ \mathrm{dB} \\ &= 20\log_{10}[(4\pi \times 4 \times 10^7)/(2.727 \times 10^{-2})]\ \mathrm{dB} = -205.3\ \mathrm{dB} \\ P_r &= 27.0 + 52.3 - 205.3 = -126.0\ \mathrm{dBW} \end{aligned}$$

System Noise Temperature & G/T Ratio:

Noise Temperature:

Noise temperature provides a way of determining how much thermal noise is generated by active and passive devices in the receiving system.

At microwave frequencies, a black body with physical temperature, T_p degrees kelvin, generate electrical noise over a wide bandwidth.

The noise power is given by

$$\mathbf{P_n = kT_n B}$$

Where

k= Boltzmann's constant= $1.38 * 10^{-23}$ J/K = -228.6 dBW/K/Hz

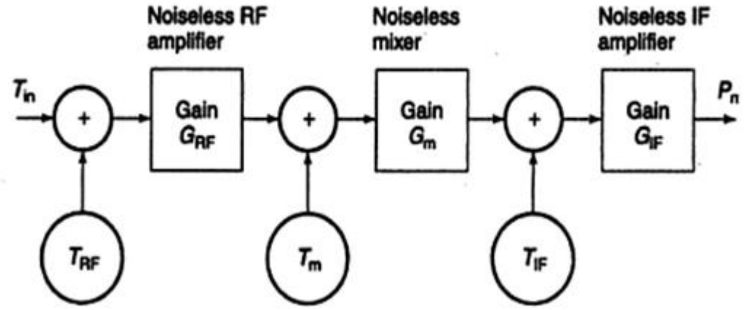
T_n = Noise temperature of source in K

B= noise bandwidth in which noise power is measured, in Hz.

System noise temperature T_s , is the noise temperature of noise source at the input of noiseless receiver, which gives same noise power as the original receiver, measured at the output of receiver.

Calculation of System Noise Temperature:

The noisy devices in the receiver are replaced by equivalent noiseless blocks with the same gain and noise generators at the input to each block such that the block produce same noise at its output as the device it replaces.



Equivalent Noise Sources

The thermal noise in its pre Amplifier is given by

$$\mathbf{P_n = GKT_sB}$$

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

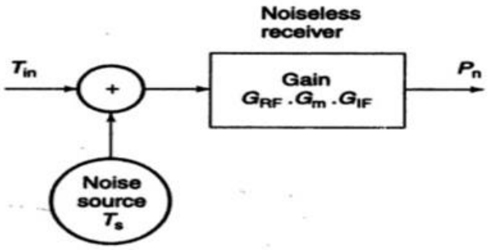
$$P_n = G_{If}KT_{If}B + G_{If}G_mKT_mB + G_{If}G_mG_{RF}KB(T_{RF}+T_{in})$$

$$P_n = G_{If}G_MG_{Rf}\left[\frac{KT_{If}B}{G_{If}G_m} + \frac{KT_mB}{G_{Rf}} + KB(T_{RF}+T_{in})\right]$$

$$P_n = G_{If} G_M G_{Rf} KB \left[T_{Rf} + T_{in} + \frac{T_{if}}{G_m G_{Rf}} + \frac{T_m}{G_{RF}} \right]$$

The single source of noise shown in above figure with noise temperature T_s generates the same noise power P_n at its output

$$P_n = G_{If} G_M G_{Rf} KBT_s$$



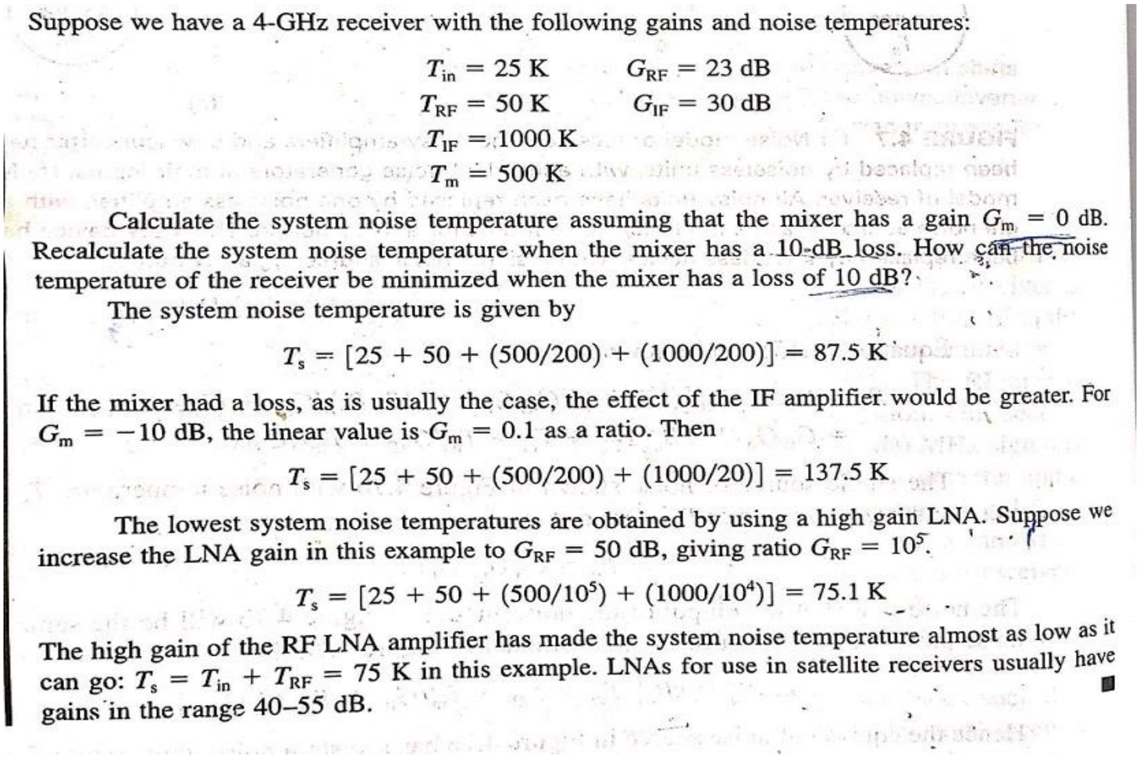
From Above Equation:

$$\mathrm{K}T_s B = KB \left[T_{Rf} + T_{in} + \frac{T_{if}}{G_m G_{Rf}} + \frac{T_m}{G_{RF}} \right]$$

Where Noise Temperature (T_s) is given by

$$T_s = \left[T_{Rf} + T_{in} + \frac{T_{if}}{G_m G_{Rf}} + \frac{T_m}{G_{RF}} \right]$$

Numerical:



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?

The system noise temperature is given by

$$T_s = [25 + 50 + (500/200) + (1000/200)] = 87.5 \text{ K}$$

If the mixer had a loss, as is 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

$$T_s = [25 + 50 + (500/200) + (1000/20)] = 137.5 \text{ K}$$

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 $G_{RF} = 10^5$.

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

The high gain of the RF LNA amplifier has made the system noise temperature almost as low as it can go: $T_s = T_{in} + T_{RF} = 75$ K in this example. LNAs for use in satellite receivers usually have gains in the range 40–55 dB. ■

Noise Figure & Noise Temperature:

Noise figure is used to specify the noise generated within a device.

The operational noise figure is

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

Noise temperature is more useful in satellite communication systems, it is best to convert noise figure to noise temperature, T

$$\mathbf{T = T_0 (NF- 1)}$$

Where:

NF is a linear ratio, not in decibels

T_0 is the reference temperature (290 K)

G/T Ratio for earth stations:

The link equation can be rewritten in terms of (C/N) at the earth stations

$$\frac{C}{N} = \left[\frac{P_t G_t G_r}{k T_s B_n}\right]\left[\frac{\lambda}{4\pi R}\right]^2 = \left[\frac{P_t G_r}{k B_n}\right]\left[\frac{\lambda}{4\pi R}\right]^2\left[\frac{G_r}{T_s}\right]$$

Satellite Communication Link Design Procedure:

1. Determine the frequency band in which system must operate. Comparative designs may be required to help make the selection.
2. Determine the communications parameters of the satellite. Estimate any values that are not known.
3. Determine the parameters of the transmitting and receiving earth stations.
4. Start at the transmitting earth station. Establish an uplink budget and a transponder noise power to find $(C/N)_{up}$ in the transponder.
5. Find the output power of the transponder based on transponder gain or output backoff.
6. Establish a downlink power and noise budget for the receiving earth station. Calculate $(C/N)_{dn}$ and $(C/N)_o$ for a station at the edge of the coverage zone.
7. Calculate S/N or BER in the baseband channel. Find the link margin.
8. Evaluate the result and compare with the specification requirements. Change parameters of the system as required to obtain acceptable $(C/N)_0$ or S/N or BER values. This may require several trial designs.
9. Determine the propagation conditions under which the link must operate. Calculate outage times for the uplinks and downlinks.
10. Redesign the system by changing some parameters if the link margins are inadequate. Check that all parameters are reasonable, and that the design can be implemented within the expected budget.