MODULE 2 – LINK DESIGN:

S1: *EIRP, Link Design.*
S2: *Transmission Losses, Link Power Budget equation*
S3: *System Noise, Carrier to noise ratio*

LINK DESIGN & EIRP:

This Module describes how link-power budget calculations are done. These calculations generally relate two quantities, the transmission power and the receive power.

This Module also discusses how the difference between these two powers is accounted for. Link-power budget calculations also need the additional losses and noise factor which is incorporated with the transmitted and the received signals. Losses can be of various types, the major ones considered for satellite communication.

Along with losses, this unit also discusses the system noise parameters. Various components of the system add to the noise in the signal that has to be transmitted. Most of the calculations discussed in this unit are in decibel quantities.

SATELLITE LINK

- A satellite link is defined as an Earth station - satellite - Earth station connection.
- The Earth station - satellite segment is called the uplink
- The satellite - Earth station segment is called the downlink

The Earth station design consists of,

- The Transmission Link Design or the Link Budget,
- The Transmission System Design.
- The Link Budget establishes the resources needed for a given service to achieve the performance objectives

DESIGN OF THE SATELLITE LINK

•The satellite link is probably the most basic in microwave communications since a line-of-sight path typically exists between the Earth and space.

• This means that an imaginary line extending between the transmitting or receiving Earth station and the satellite antenna passes only through the atmosphere and not ground obstacles.

• Free-space attenuation is determined by the inverse square law, which states that the power received is inversely proportional to the square of the distance.

• There are, however, a number of additional effects that produce a significant amount of degradation and time variation.

• These include rain, terrain effects such as absorption by trees and walls, and some less-obvious impairment produced by unstable conditions of the air and ionosphere.

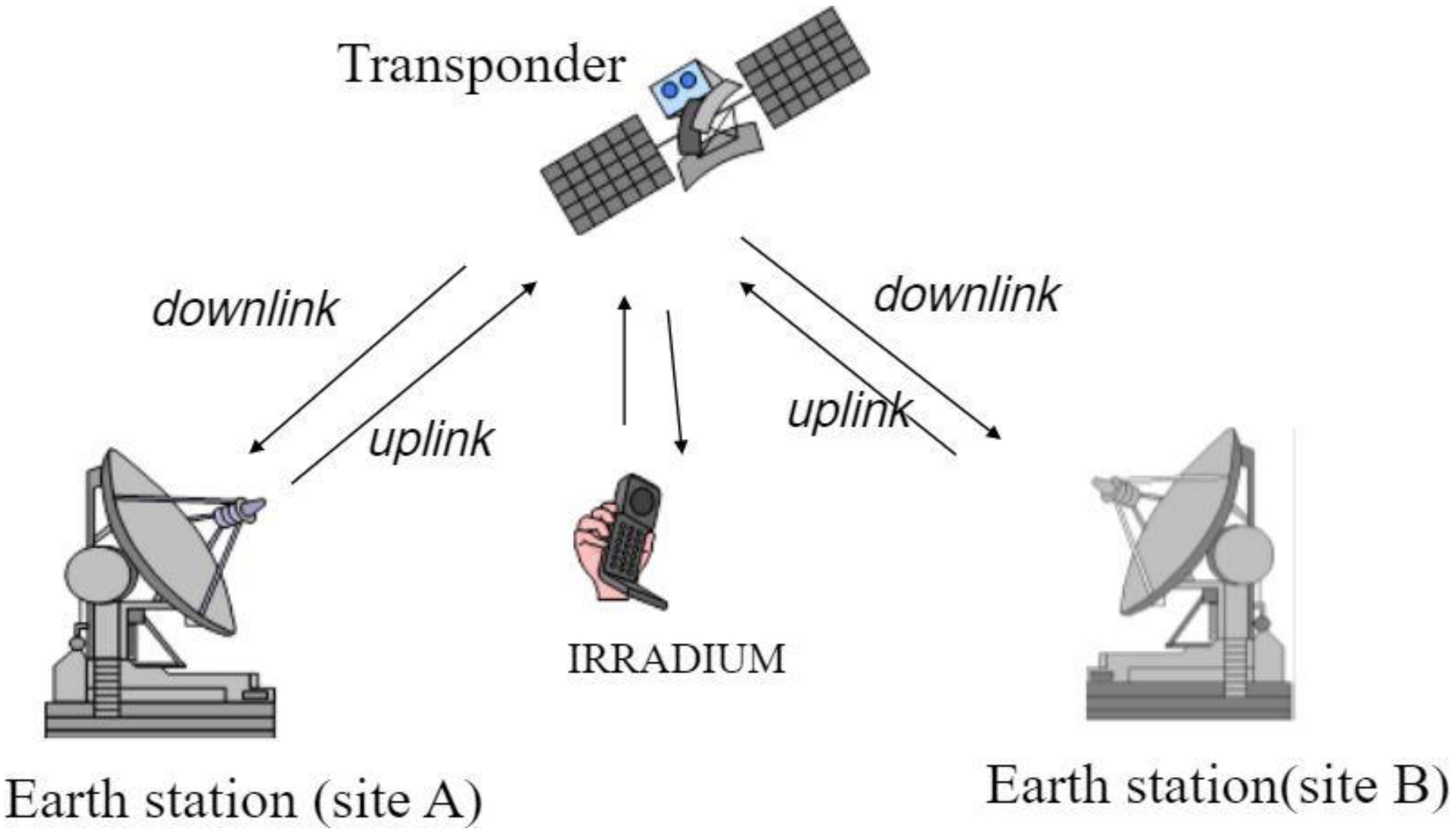
• It is the job of the communication engineer to identify all of the significant contributions to performance and make sure that they are properly taken into account.

• The required factors include the performance of the satellite itself

• The configuration and performance of the uplink and downlink Earth stations, and

• The impact of the propagation medium in the frequency band of interest.

LINK DESIGN



Transponder
downlink
uplink
downlink
uplink
IRRADIUM
Earth station (site A)
Earth station(site B)

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The result in the overall performance is presented in terms of the ratio of carrier power to noise and, ultimately, information quality •

Any uncertainty can be covered by providing an appropriate amount of link margin, which is over and above the C/N needed to deal with propagation effects and nonlinearity in the Earth stations and satellite repeater.

SATELLITE LINK DESIGN

The four factors related to satellite system design:

1.The weight of satellite
2.The choice frequency band
3.Atmospheric propagation effects
4.Multiple access technique

- The major frequency bands are 6/4 GHz, 14/11 GHz and 30/20 GHz (Uplink/Downlink)
- At geostationary orbit there is already satellites using both 6/4 and 14/11 GHz every 2˚(minimum space to avoid interference from uplink earth stations)

SATELLITE LINK DESIGN METHODOLOGY

The design methodology for a one-way satellite communication link can be summarized into the following steps. The return link follows the same procedure.

- Step 1. Frequency band determination.
- Step 2. Satellite communication parameters determination. Make informed guesses for unknown values.
- Step 3. Earth station parameter determination; both uplink and downlink.
- Step 4. Establish uplink budget and a transponder noise power budget to find (C/N)up in the transponder
- Step 5. Determine transponder output power from its gain or output backoff.

Step 6. Establish a downlink power and noise budget for the receiving earth station

- Step 7. Calculate (C/N)down and (C/N)u for a station at the outermost contour of the satellite footprint.
- Step 8. Calculate SNR/BER in the baseband channel.
- Step 9. Determine the link margin.
- Step 10. Do a comparative analysis of the result vis-à-vis the specification requirements.

- Step 11. Tweak system parameters to obtain acceptable (C/N)0 /SNR/BER values.
- Step 12. Propagation condition determination.
- Step 13. Uplink and downlink unavailability estimation.
- Step 14. Redesign system by changing some parameters if the link margins are inadequate.
- Step 15. Are gotten parameters reasonable? Is design financially feasible?
- Step 16. If YES on both counts in step 15, then satellite link design is successful – Stop.
- Step 17. If NO on either (or both) counts in step 15, then satellite link design is unsuccessful – Go to step 1.

EQUIVALENT ISOTROPIC RADIATED POWER:

The key parameter in link-power budget calculations is the equivalent isotropic radiated power factor, commonly denoted as EIRP. Is the amount of power that a theoretical isotropic antenna (which evenly distributes power in all directions) would emit to produce the peak power density observed in the direction of maximum antenna gain. EIRP can take into account the losses in transmission line and connectors and includes the gain of the antenna.

The EIRP is often calculated in terms of decibels over a reference power emitted by an isotropic radiator with equivalent signal strength. The EIRP allows comparisons between different antennas in satellite communication regardless of type, size or form. **EIRP can be defined as the power input to one end of the transmission link and the problem to find the power received at the other end.**

Maximum power flux density at some distance r from transmitting antenna of gain G is

$$\varphi_m = GP_s / 4\pi r^2$$

Where, G is Gain of the Transmitting antenna and G is in decibels. Ps is Power of the sender (transmitter) and is calculated in watts. key parameter in link budget calculation denoted as EIRP.

An isotropic radiator with input power equal to GP_s would produce the same flux density.

$$EIRP = GP_s$$

This product is known as EIRP

EIRP is often expressed in decibels relative to 1W, or dBW. Let P_s **be in watts; then**

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

TRANSMISSION LOSSES

EIRP is taken as input power to one end of a transmission link and the power received at the other end will not be the same due to different losses.
As EIRP is thought of as power input of one end to the power received at the other, the problem here is to find the power which is received at the other end. Some losses that occur in the transmitting – receiving process are constant and their values can be pre – determined.
Other losses can be estimated from statistical data and a few of them are dependent on the climatic conditions including rain and snow fall. To begin theses computations, generally the constant losses are determined considering a clear sky condition. Below listed are the losses which are generally taken as a constant value.

1. Free space losses [FSL]

This loss is due to the spreading of the signal in space. Going back to the power flux density equation (discussed in unit VI a):

$$\Psi m = EIRP / 4 \pi r^2$$

The power that is delivered to a matched receiver is the power flux density. It is multiplied by the effective aperture of the receiving antenna. Hence, the received power is:

$$A_{eff} = \lambda^2 G_R / 4 \pi$$

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

Where r is distance between transmitter and receiver GR power gain at the receiver In decibels, the above equation becomes:

$$[P_R] = [\mathrm{EIRP}] + [G_R] - 10\log\left(\frac{4\pi r}{\lambda}\right)^2$$

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

$$[P_R] = [\mathrm{EIRP}] + [G_R] - [\mathrm{FSL}]$$

2) Feeder Losses (RFL)

This loss is due to the connection between the satellite receiver device and the receiver antenna is improper. Losses here occur is connecting wave guides, filers and couplers.

The receiver feeder loss values are added to free space loss. Similar losses will occur in filters, couplers and waveguides that connect the transmission antenna to a high-power amplifier output.

3) Antenna Misalignment Losses (AML)

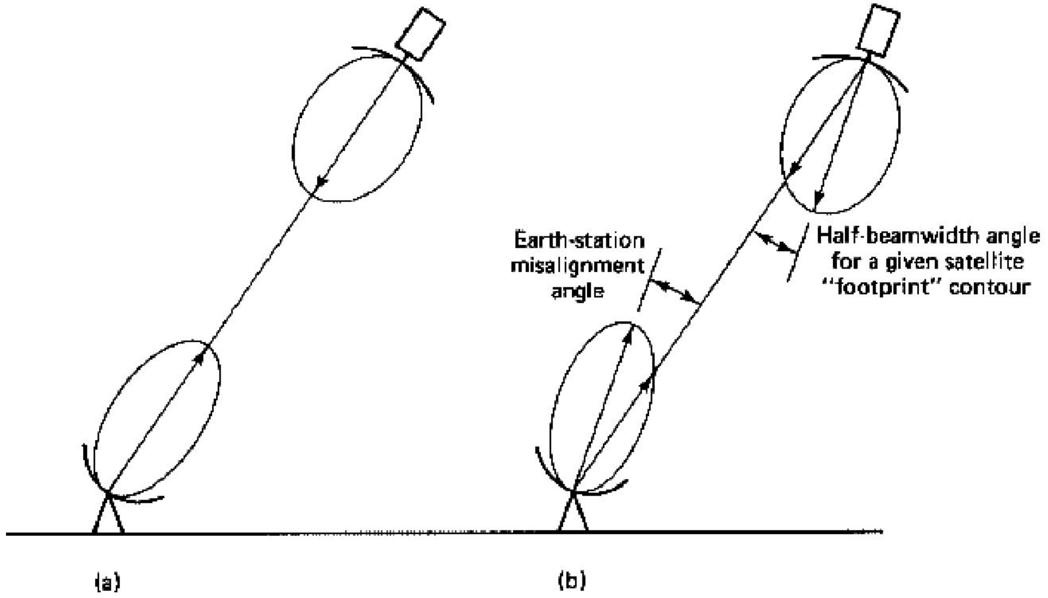
To attain a good communication link, the earth stations antenna and the communicating satellites antenna must face each other in such a way that the maximum gain is attained.

Sometimes, misalignment (also called as off-axis loss) can occur in two ways:

o The off-axis loss at satellite is taken into account by designing the link for operation on the actual satellite contour.

o The off-axis loss at the earth station is referred to as antenna pointing loss. These losses are usually only a few tenths of a decibel.

In addition to pointing losses, losses can occur due to the misalignment of the polarization direction. These losses are generally small and it will be assumed that the antenna misalignment loss includes pointing as well as polarization losses value.



a) Satellite and Earth station's antennas aligned for maximum gain; b) Earth station is situated at the given satellite's footprint it's antenna is misaligned

The value of this loss can be estimated using statistical data which are based on errors that are actually observed or a large number of earth stations.

4) Fixed Atmospheric (AA) and Ionospheric losses (PL):

The gases present in the atmosphere absorb the signals. This kind of loss is usually of a fraction of decibel in quantity. Along with the absorption losses, the ionosphere introduces a good amount of depolarization of signal which results in loss of signal.

LINK - POWER BUDGET EQUATION

The EIRP can be considered as the input power to a transmission link. Due to the above discussed losses, the power at the receiver that is the output can be considered as a simple calculation of EIRP – losses.

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

The received power that is PR:

PR = [EIRP] + [GR] – [Losses]

Where; [PR]is received power in dB.
[EIRP] is equivalent isotropic radiated power in dBW.
[GR]is isotropic power gain at the receiver and its value is in dB.
[FSL] is free-space transmission loss in dB.
[RFL] is receiver feeder loss in dB.
[AA] isAtmospheric absorption loss in dB.
[AML] is Antenna misalignment loss in dB.
[PL] is depolarization loss in dB

<u>Problem:</u>

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 and the antenna pointing loss is 0.5 dB. Depolarization losses may be neglected. Calculate the total link loss for a clear – sky condition.

Solution: the total loss is the sum of all losses:

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

= 207 + 1.5 + 0.5 + 0.5 + 0

= 209.5 dB

Where; [FSL] free-space transmission loss in dB.

[RFL] receiver feeder loss in dB.

[AML] Antenna misalignment loss in dB.

[AA] Atmospheric absorption loss in dB.

[PL] depolarization loss in dB.

SYSTEM NOISE:

Electrical noise is always present at the input and unless the signal is significantly larger than the noise, amplification will be of least help as it will amplify the signal as well as the noise to the same extent. There is a possibility, that after the amplification, the situation can get worst by the noise that will be added by the amplifier.

The main source of noise in the satellite equipment's is the noise arising from the random thermal motion of electrons in the various devices in the receiver. Thermal noise is also generated in the lossy components of the antenna and a thermal – like noise is picked – up by the antenna as radiation.
Power from a thermal noise source is given by:

$$\mathbf{P_N = kT_N\, B_N}$$

Where:
T_N □ noise temperature
B_N □ Noise Bandwidth
k□ Boltzman Constant having the value 1.38 x 10-23 J/k
The main characteristic of thermal noise is that it has a *flat frequency spectrum*; that is, noise power per unit bandwidth is a constant. The noise power per unit bandwidth is termed as *noise power spectral density*.

Denoting this by No

$$\mathbf{N_O = P_N / B_N}$$

Thus,

$$\mathbf{N_O = k\ T_N}\ \text{Joules}$$

Noise temperature is directly proportional to the physical temperature but not always equal.
Noise power per unit bandwidth is always constant.

Problem: An antenna has noise temperature of 35 K and is matched into a receiver which has a noise temperature of 100 K calculate: a) noise power density and b) the noise power for a bandwidth of 36 MHz.

Solution:
a) NO = k TN
= 11.38 x 10-23x (35 + 100) **= 1.86 x 10-21 J**
b) PN = NO BN
= 1.86 x 10-21x 36 x 106 **= 0.067 pW**

1) Antenna Noise

The received signal power is pointless unless compared with the power received from unwanted sources over the same bandwidth. Such noise sources consist of thermal radiation from the earth and sky, cosmic background radiation and random thermal processes in the receiving system

. An additional noise due to non - stationary radio frequency interference from pagers, cellular phones, etc., often needs to be considered, but in this analysis we will concentrate on two classifications of the antennas noise: a) Sky noise, and, b) Noise originating from the antenna losses.

a) *Sky Noise*:

it is a term used to describe microwave radiation which is present throughout the universe and which appears to originate from matter in any form at finite temperature. Such radiation covers wider spectrum. Any absorptive loss mechanism generates thermal noise, there being direct connection between loss and the effective noise temperature. Rainfall introduces attenuation and thus it further degrades transmission in two ways:

1) It attenuates the signal;
2) it introduces noise.

The detrimental effects of rain are much worse at Ku-Band frequencies than at C-band (refer Unit I for Ku and C Band features and bandwidth), and the downlink rain fade margin also must allow the increased noise which is generated.

b) ***Antenna Losses:*** Satellite antennas are generally pointed towards the earth and therefore they receive the full thermal radiation from it. In this case the equivalent noise temperature of the antenna, excluding the antennas losses is approximately 290 K. Antenna losses add to the noise received as radiation and the total antenna noise temperature is the sum of equivalent noise temperatures of all these sources.

2) Antenna Noise Temperature

Antenna noise temperature is the temperature of a theoretical resistor at the input of an ideal noise-free receiver that would generate the same output noise power per unit bandwidth as that at the antenna output at a specified frequency. Antenna noise temperature has contributions from several sources:

- Vast radiation
- Earth heating
- The sun
- Electrical devices
- The antenna itself

The available power gain of the amplifier is denoted as G, and the noise power output as P_{no}.
Considering noise power per unit bandwidth which is noise energy in joules is given by:

$$N_{o,ant} = k\,T_{ant}$$

The output noise energy in $N_{o,out}$ will be $GN_{o,out}$ plus the contribution made by the amplifier. The summation of all the amplifier noise is referred to the input in terms of an equivalent input noise temperature for the amplifier Te.
Thus output could be written as:

$$N_{o,out} = Gk\,(T_{ant} + T_e)$$

The total noise referred to the input is :$N_{o,out}/G$, or

$$N_{o,in} = k\,(T_{ant} + T_e)$$

3) Amplifier in Cascade

A cascade amplifier is any amplifier constructed from a series of amplifiers, where each amplifier sends its output to the input of the next amplifier in a daisy chain.

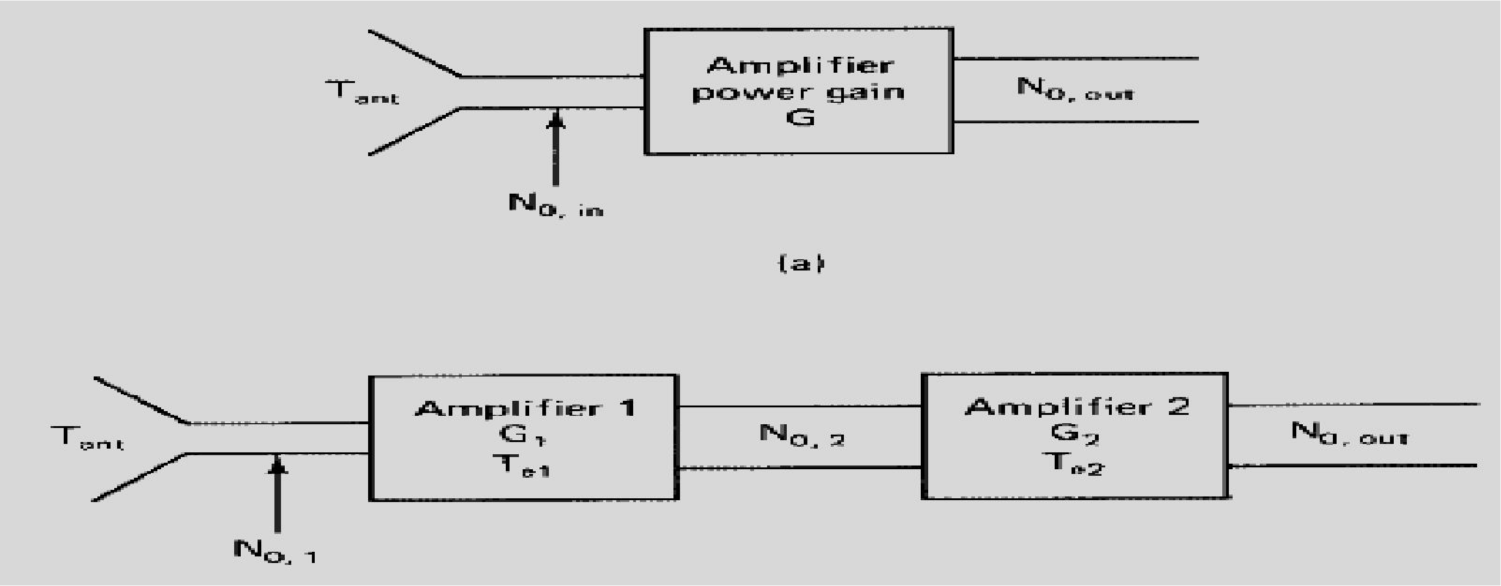
For the arrangement of amplifiers shown in fig; the overall gain can be considered as:

$$G = G1\ G2$$

The noise energy of amplifier 2 referred to its own inputs is imply kTe2.

The noise input to amplifier 2 from the preceding stages is G1 k (Tant + Te1), and thus the total noise energy referred to amplifier 2 input is:

$$N_{o,2} = G_1 k\,(T_{ant} + T_{e1}) + kT_{e2}$$



a) *An amplifier;*

b) ***b) An amplifier in Cascade***

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

$$N_{o,1} = N_{o,2} / G_1$$
$$= k\,(T_{ant} + T_{e1} + T_{e2} / G_1)$$

A system noise temperature may now be defined as T_S by

$$N_{o,1} = k\,T_S$$

and hence it will be seen that T_S is given by:

$$\mathbf{T_S = T_{ant} + T_{e1} + T_{e2} / G_1 + Te3/G1G2}$$

Therefore the result in no. of stages:

$\mathbf{T_S = T_{ant} + T_{e1} + T_{e2} / G_1 + Te3/G1G2 + \ldots\ldots\ldots\ldots}$

4) Noise Factor

Definition: An alternative way of representing amplifier noise is by the means of its noise factor F. for defining it, the source is taken at room temperature, denoted by T_0.

The input noise from such a source is kT_0 and the output noise from the amplifier is:

$N_{o,out} = FGkT_0$

$Gk(T_0+Te) = FGkT_0$

or

$Te = (F-1)\,T_0$

Noise figure = $[F] = 10\log F$

where: G is the available power gain of the amplifier F is its noise factor

5) Noise Temperature of Absorptive Networks

An absorptive network is one which contains resistive elements. These introduce losses by absorbing energy from the signal and converting it into heat. Resistive attenuators, transmission lines and wave guides are all examples of absorptive networks. Even natural phenomenon like rainfall, which absorbs energy from radio signals passing through it can be considered as a form of absorptive network. As these absorptive networks contain resistance, they generate thermal noise.

Absorptive network is one which contains resistive elements. These introduce losses by absorbing energy from the signal and converting it to heat.eg. Resistive attenuators, transmission lines and waveguides. Consider an abs n/w which has a Power Loss L. The Equivalent Noise T of the network

$$T_{nw,0}=T_x(1-1/L)$$

$$T_{nw,i}=T_x(L-1)$$

T_x–temperature of antenna. $T_x=T_0$ (room temperature); then F=L

5) Overall System Noise Temperature

It"s a summation of all the above discussed noise parameters. It is denoted as TS. This parameter of system noise is considered for satellite communication computations.

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

Carrier to noise ratio: A measure of performance of a satellite link is the ratio between carrier power and noise power at the receiver input.

$$[C/N]=[P_R]–[P_N]$$

$$[C/N]=[EIRP]+[G_R]–[LOSSES]–[k]–[T_s]-[B_N]$$

$[G_R]–[T_S]=[G/T]$(antenna gain/noise temperature)

so the link eqn becomes

$$[C/N]=[EIRP]+[G/T]-[LOSSES]-[K]-[B_N]$$

$$[C/N_0]=[C/N]+[BN]$$

$$[C/N_0]=[EIRP]+[G/T]-[LOSSES]-[k]$$

NOISE

Many types of noise are transmission related. Sometimes it's nothing more than a normal noise that sounds louder because of bad bases or because part of the transmission is touching the frame or underbody of the car. Then there are actual components like pumps, planets, final drives etc. that can cause good amount of disturbance in any travelling wave. The idea is to find a way to make the noise change, or stop, and then examine what this change did to affect the noise.

There are several rules that will help isolate the component that is causing the problem. First of all, a component cannot generate a noise if it is not moving. Isolating moving components and calculating statistically the amount of noise they produce can help us estimate the signal loss.

Next, if the noise is pressure related, it will change when the pressure changes. So again, estimation helps in determining the loss that can occur in a particular signal. There is variation in n noise in a particular link while the signal is moving upward and while is it moving downward. Presence and absence of atmospheric pressure, gravity and amount/ impact of sun’s radiation also add to the noise factor of a signal.

CARRIER – TO – NOISE RATIO

A measure of a performance of a satellite link is considered as a ratio of carrier power to noise power at the receiver input along with the link budget calculations which are considered to estimate this ratio.
This ratio is denotes as C/N and is calculated in decibels.

$$C/N = [PR] - [PN] \quad \square\text{(in decibel)}$$

where: C/N □ carrier to noise ratio
PR is Receiver Power
PN is Noise Power

Thus, the resultant C/N can be calculated with the following parameters

$$[C/N] = [EIRP] + [GR] - [LOSSES] - [k] - [TS] - [B_N]$$

To complete the calculations, we need to consider the gain is to temperature ratio as well.
It is commonly denoted ad G/T.
it is denoted as: $[G/T] = [GR] - [TS]$
Thus, the C/N LINK equation could be written as:

$$[C/N] = [EIRP] + [G/T] - [LOSSES] - [k] - [B_N]$$

The ratio of carrier to noise power density PR / PN can be the quantity that is actually required.

Since PN = k TNBN **[$N_O = k\, T_N$]**

then:

$$[C/N] = [C / NO\ BN] = [C / N_0] – [BN]$$

and therefore,

$$[C/No] = [C / N_0] + [BN]$$

[C/N] is true power ratio in units of decibels, and [B_N] is in decibels relative to one hertz or dB Hz. Thus the units for [C/No] are dB Hz.

Applying this value to the above equation, we get:

$$[C/N_0] = [EIRP] + [G/T] - [LOSSES] – [k]$$