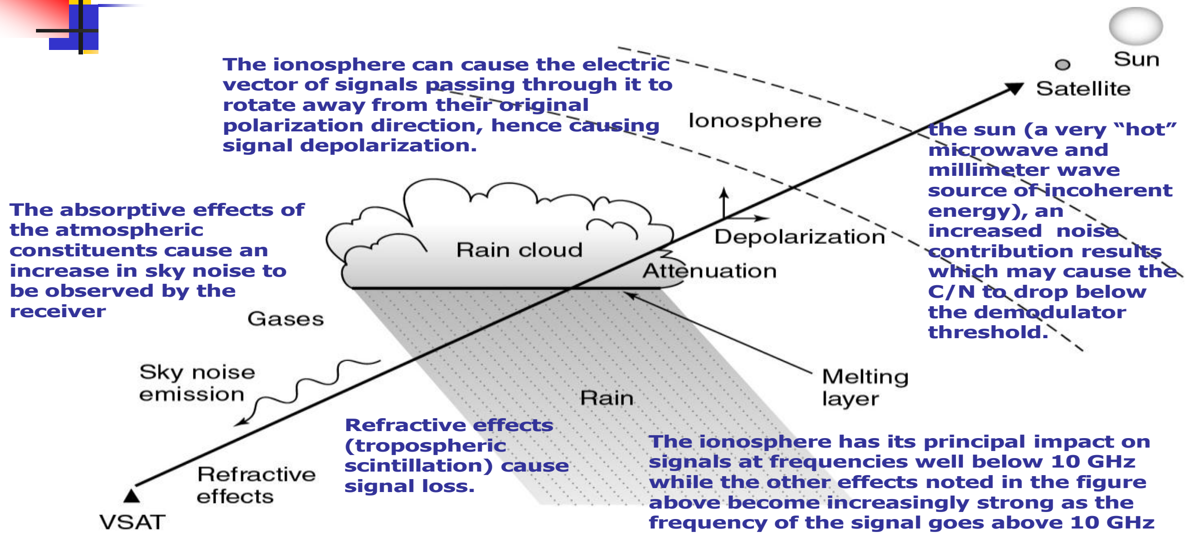
UNIT III

EARTH SEGMENT

Basic Link Analysis, Interference Analysis, Rain Induced Attenuation and Interference, Ionospheric Characteristics, Link Design with and without Frequency Reuse.

Illustration of the various propagation loss mechanisms on a typical earth-space path



The ionosphere can cause the electric vector of signals passing through it to rotate away from their original polarization direction, hence causing signal depolarization.

The absorptive effects of the atmospheric constituents cause an increase in sky noise to be observed by the receiver

the sun (a very "hot" microwave and millimeter wave source of incoherent energy), an increased noise contribution results which may cause the C/N to drop below the demodulator threshold.

Refractive effects (tropospheric scintillation) cause signal loss.

The ionosphere has its principal impact on signals at frequencies well below 10 GHz while the other effects noted in the figure above become increasingly strong as the frequency of the signal goes above 10 GHz

Signal Transmission Link-Power Budget Formula

Link-power budget calculations take into account all the gains and losses from the transmitter, through the medium to the receiver in a telecommunication system. Also taken into the account are the attenuation of the transmitted signal due to propagation and the loss or gain due to the antenna.

The decibel equation for the received power is:

$$[P_R] = [EIRP] + [G_R] - [LOSSES]$$

Where:

$[P_R]$ = received power in dBW
$[EIRP]$ = equivalent isotropic radiated power in dBW
$[G_R]$ = receiver antenna gain in dB
$[LOSSES]$ = total link loss in Db

dBW = 10 $\log_{10}$ (P/(1 W)), where P is an arbitrary power in watts, is a unit for the measurement of the strength of a signal relative to one watt.

Link Budget parameters

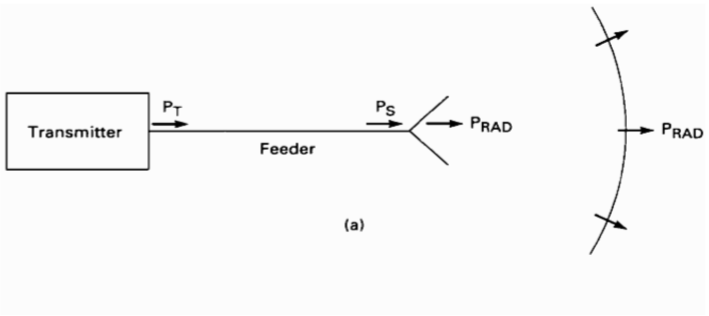
- EIRP
- System noise temperature
- Carrier to thermal noise ratio
- Carrier to noise ratio
- Antenna gain compared to isotropic radiator
- Free space path loss
- Figure of merit for receiving system
- Carrier to noise density ratio
- Transmitter power at the antenna

Signal Transmission Equivalent Isotropic Radiated Power

- An isotropic radiator is one that radiates equally in all directions.
- The power amplifier in the transmitter is shown as generating P_T watts.
- A feeder connects this to the antenna, and the net power reaching the antenna will be P_T minus the losses in the feeder cable, i.e. P_S.
- The power will be further reduced by losses in the antenna such that the power radiated will be P_{RAD} ($< P_T$).

$$P_t = P_{out} / L_t \qquad EIRP = P_t G_t$$

$$Maximum\ flux\ density\ \varphi_m = \frac{Gp_s}{4\pi r^2}$$



Antenna Gain

We need directive antennas to get power to go in wanted direction. Define Gain of antenna as increase in power in a given direction compared to isotropic antenna.

$$G(\theta) = \frac{P(\theta)}{P_0 / 4\pi}$$

- P (θ) is variation of power with angle.
- G (θ) is gain at the direction θ.
- P_0 is total power transmitted.
- sphere = *4p* solid radians

Signal Transmission Link-Power Budget Formula Variables

Link-Power Budget Formula for the received power [P_R]:

$$[P_R] = [EIRP] + [G_R] - [LOSSES]$$

The equivalent isotropic radiated power [EIRP] is:

[EIRP] = [P_S] + [G] dBW, where:

[P_S] is the transmit power in dBW, [G] is the transmitting antenna gain in dB, and **[G_R]** is the receiver antenna gain in dB.

[LOSSES] = [FSL] + [RFL] + [AML] + [AA] + [PL],

where:

[FSL] = free-space spreading loss in dB = P_T/P_R (in watts)
[RFL] = receiver feeder loss in dB
[AML] = antenna misalignment loss in dB
[AA] = atmospheric absorption loss in dB
[PL] = polarization mismatch loss in dB

The major source of loss in any ground-satellite link is the free-space spreading loss. Other effects need to be accounted for in the transmission equation:

L_a = Losses due to attenuation in atmosphere
L_{ta} = Losses associated with transmitting antenna
L_{ra} = Losses associates with receiving antenna
L_{pol} = Losses due to polarization mismatch
L_{other} = (any other known loss - as much detail as available)
Lr = additional Losses at receiver (after receiving antenna)

$$\boxed{P_r = \frac{P_t G_t G_r}{L_p L_a L_{ta} L_{ra} L_{pol} L_{other} L_r}}$$

Some intermediate variables were also defined before:

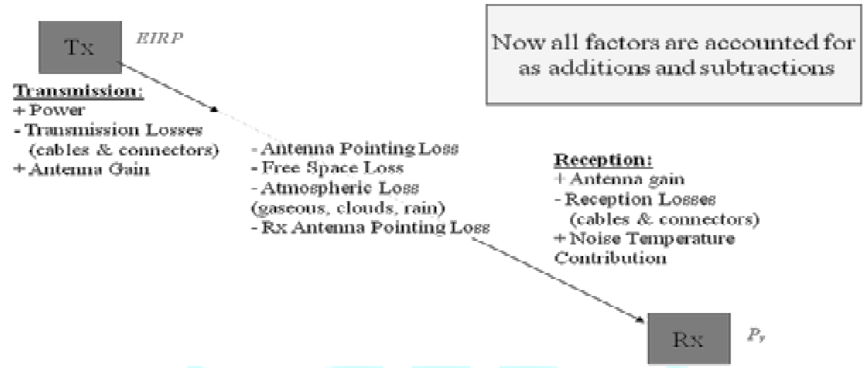
$$P_t = P_{out}/L_t, \quad EIRP = P_t G_t$$

$$P_r = \frac{P_t G_t G_r}{L_p L_a L_{ta} L_{ra} L_{pol} L_{other} L_r}$$

$$= \frac{EIRP \text{ x } G_r}{L_p L_a L_{ta} L_{ra} L_{pol} L_{other} L_r}$$

$$= \frac{P_{out} G_t G_r}{L_t L_p L_a L_{ta} L_{ra} L_{pol} L_{other} L_r}$$

Where: P_t = Power into antenna, L_t = Loss between power source and antenna
$EIRP$ = Effective isotropic radiated power



Translating to dBs

The transmission formula can be written in dB as:

$$P_r = EIRP - L_{ta} - L_p - L_a - L_{pol} - L_{ra} - L_{other} + G_r - L_r$$

The calculation of received signal based on transmitted power and all losses and gains involved until the receiver is called "Link Power Budget", or "Link Budget". The received power Pr is commonly referred to as "**Carrier Power**", ***C.***

Why we need to calculate Link Power Budget

- System performance tied to operation thresholds
- Operation thresholds C_{min} tell the minimum power that should be received at the demodulator in order for communications to work properly
- Operational threshold depend on

Modulation scheme being used	Desired communication quality
Coding Gain	Additional overheads
Channel Bandwidth	Thermal Noise Power

- We need to calculate the link budget in order to verify if we are "closing the link"
  P_r>=C_{min} → Link Closed, P_r<C_{min} → Link not Closed
- Usually we obtain the " Link Margin", which tells how tight we are closing the link
  Margin=P_r-C_{min}
- Equivalently **Margin> 0 → Link Closed, Margin<0 → Link not closed**

PERFORMANCE IMPAIRMENT

SYSTEM NOISE

- ✓ The receiver power in a satellite link is very small, on the order of Pico watts. This by itself would be no problem because amplification could be used to bring the signal strength up to an acceptable level. However, electrical noise is always present at the input, and unless the signal is significantly greater than the noise, amplification will be of no help because it will amplify signal and noise to the same extent. In fact, the situation will be worsened by the noise added by the amplifier.

- ✓ The major source of electrical noise in equipment is that which arises from the random thermal motion of electrons in various resistive and active devices in the receiver. Thermal noise is also generated in the lossy components of antennas, and thermal-like noise is picked up by the antennas as radiation. The available noise power from a thermal noise source is given by

$$\boldsymbol{P_N = K\,T_N\,B_N}$$

- ✓ Here, T_N is known as the equivalent noise temperature, B_N is the equivalent noise bandwidth and k=1.38*10^{-23} J/K is Boltzmann's constant. With the temperature in kelvins and bandwidth in hertz, the noise power will be in watts.

- ✓ The noise power bandwidth is always wider than the - 3dB bandwidth determined from the amplitude-frequency response curve, and a useful rule of thumb is that the noise bandwidth is equal to 1.12 times the -3dB bandwidth, or $\boldsymbol{B_N = 1.12 * 3dB}$. The bandwidths here are in hertz (or a multiple such as MHz).

- ✓ The noise power per unit bandwidth is termed the *noise power spectral density*. Denoting this by N_0

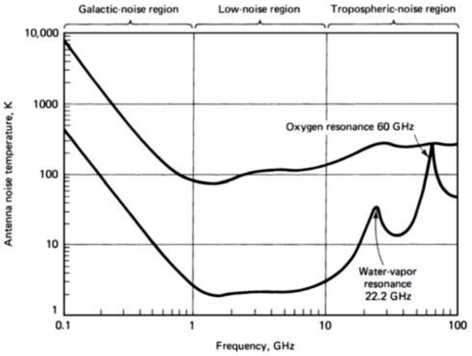
$$\boldsymbol{N_o = \frac{P_N}{B_N} = K\,T_N}$$

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

ANTENNA NOISE

- ✓ Antennas operating in the receiving mode introduce noise into the satellite circuit. Noise therefore will be introduced by the satellite receive antenna and the ground station receive antenna. Although the physical origins of the noise in either case are similar, the magnitudes of the effects differ significantly.
- ✓ The antenna noise can be broadly classified into two groups *noise originating from antenna losses* and *sky noise*.

SKY NOISE: Is a term used to describe the microwave radiation which is present throughout the universe and which appears to originate from matter in any form at finite temperatures. Such radiation in fact covers a wider spectrum than just the microwave spectrum.



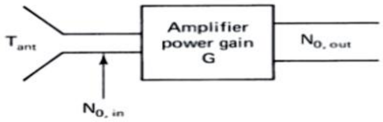
The equivalent noise temperature of the sky, as seen by an earth-station antenna, is shown in Figure. The lower graph is for the antenna pointing directly overhead, while the upper graph is for the antenna pointing just above the horizon. The increased noise in the latter case results from the thermal radiation of the earth, and this in fact sets a lower limit of about 5° at C band and 10° at Ku band on the elevation angle which may be used with ground-based antennas.

The graphs show that at the low-frequency end of the spectrum, the noise decreases with increasing frequency. Where the antenna is zenith pointing, the noise temperature falls to about 3 K at frequencies between about 1 and 10 GHz. This represents the residual background radiation in the universe. Above about 10 GHz, two peaks in temperature are observed, resulting from resonant losses in the earth's atmosphere.

Rainfall introduces attenuation, and therefore, it degrades transmissions in two ways: It attenuates the signal, and it introduces noise. The detrimental effects of rain are much worse at Ku-band frequencies than at C band, and the downlink rain-fade margin, must also allow for the increased noise generated.

AMPLIFIER NOISE TEMPERATURE

- ✓ Consider first the noise representation of the antenna and the *low noise amplifier (LNA)*. The available power gain of the amplifier is denoted as G, and the noise power output, as Pno.



- ✓ For the moment we will work with the noise power per unit bandwidth, The input noise energy coming from the antenna is

$$N_{0,ant} = kT_{ant}$$

- ✓ The output noise energy $N_{0,out}$ will be $GN_{0,ant}$ 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 Te. This allows the output noise to be written as

$$N_{0,out} = Gk\,(T_{ant} + T_e)$$

The total noise referred to the input is simply N0, out/G, or

$$N_{0,in} = k\,(T_{ant} + T_e)$$

Te can be obtained by measurement, a typical value being in the range 35 to 100 K. Typical values for T_{ant} are given in Antenna noise

NOISE FACTOR

- ✓ An alternative way of representing amplifier noise is by means of its *noise factor*, F. In defining the noise factor of an amplifier, the source is taken to be at *room temperature*, denoted by T_0, usually taken as 290K. The input noise from such a source is kT0, and the output noise from the amplifier is

$$N_{0,out} = FGkT_0$$

- ✓ Here, G is the available power gain of the amplifier as before, and F is its noise factor.
- ✓ A simple relationship between noise temperature and noise factor can be derived. Let Te be the noise temperature of the amplifier, and let the source be at room temperature as required by the definition of F. This means that $T_{ant} = T_0$.
- ✓ Since the same noise output must be available whatever the representation, it follow that

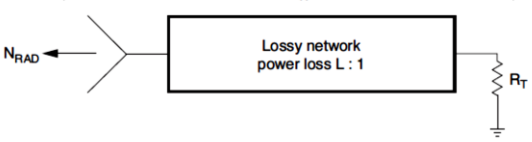
$$Gk\,(T_0 + T_e) = FGkT_0 \qquad \text{or} \qquad \mathbf{T_e = (F - 1)\,T_0}$$

- ✓ This shows the direct equivalence between noise factor and noise temperature. In a practical satellite receiving system, noise temperature is specified for low-noise amplifiers and converters, while noise factor is specified for the main receiver unit. The ***noise figure*** is simply *F* expressed in decibels:

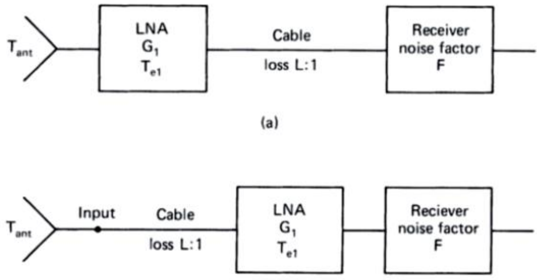
$$\boldsymbol{Noise\ Figure = [F] = 10\log F}$$

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 is to heat. Resistive attenuators, transmission lines and waveguides are all examples of absorptive networks, and even rainfall, which absorbs energy from radio signals passing through it, can be considered a form of absorptive network. Because an absorptive network contains resistance, it generates thermal noise.



Overall system noise temperature



- ✓ Figure shows a typical receiving system, Applying the results of the previous sections yields, for the system nose temperature referred to the input,

$$TS = \text{Tant} + \text{Te1} + \frac{(L-1)T0}{G1} + \frac{L(F-1)T0}{G1}$$

<u>Carrier to Noise Ratio/ Carrier to noise density ratio / Carrier to thermal noise ratio</u>

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 input, and link-budget calculations are often concerned with determining this ration. Conventionally, the ration is denoted by C/N (or CNR), which is equivalent to P_R/P_N. In terms of decibels,

$$\left[\frac{\mathbf{C}}{\mathbf{N_0}}\right] = [\boldsymbol{P_R}] - [\boldsymbol{P_N}]$$

$$\left[\frac{\mathrm{C}}{\mathrm{N_0}}\right] = [\mathrm{EIRP}] + [\mathrm{GR}] - [\mathrm{LOSSES}] - [\mathrm{K}] - [\mathrm{T}_S] - [\mathrm{B}_N]$$

$[C/N_0]$	- Carrier to Noise Ratio
EIRP	- Equivalent Isotropic Radiated Power
K	- Temperature – 228.6 dB J/K (since k= 1.38 x 10^{-23} J/K)
T_N	- Equivalent noise temperature
B_N	- Noise bandwidth
$[G_R/T_s]$	- The G/T ratio is a key parameter is specifying the receiving system performance. The antenna gain G_R and the system noise temperature T_S

- ✓ This equation is correct for either the uplink or downlink, with the caution that the operating values of EIRP and G/T must be used. When modified by atmospheric and other incidental losses, it is applicable to any line-of-sight communication link, either terrestrial or in space.

$$\left[\frac{\mathbf{G}}{\mathbf{T}}\right] = [\boldsymbol{G_R}] - [\boldsymbol{T_S}]$$

$$\left[\frac{\mathrm{C}}{\mathrm{N_0}}\right] = [\mathrm{EIRP}] + \left[\frac{\mathrm{G}}{\mathrm{T}}\right] - [\mathrm{LOSSES}] - [\mathrm{K}] - [\mathrm{B}_N]$$

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

$$P_N = K\,T_N\,B_N = N_0 B_N$$

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

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

$$\left[\frac{\mathbf{C}}{\mathbf{N_0}}\right] = \left[\frac{\mathbf{C}}{\boldsymbol{N}}\right] + [\boldsymbol{B_N}]$$

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

$\left[\frac{C}{N}\right]$ Carrier to Noise power in receiving bandwidth (dB):

Allows simple calculation of margin if:

- ✓ Receiver bandwidth is known
- ✓ Required C/N is known for desired signal type.

$\left[\frac{C}{N_0}\right]$ Carrier to Noise power Density (dB Hz):

Allows simple calculation of allowable receiving bandwidth if:

- ✓ Required C/N is known for desired signal type.
- ✓ Critical for calculations involving carrier recovery loop performance calculations.

$\left[\frac{G}{T}\right]$ Receiving Antenna Gain / System Temperature:

- ✓ Also called as system figure of merit
- ✓ Easily describes the sensitivity of a receive system
- ✓ [G/T] degrades for most systems when rain loss increases; this is caused by the increase in the sky noise component. This is in addition to the loss of received power flux density.
- ✓ Most system require C/N>10dB. Usually C > N+10 dB. and T[k] = T[°C] + 27.

SATELLITE UP LINK/ DOWN LINK

UPLINK AND INPUT BACKOFF

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

$$\left[\frac{C}{N_0}\right]_U = [\mathrm{EIRP}]_U + \left[\frac{G}{T}\right]_U - [\mathrm{LOSSES}]_U - [\mathrm{K}]$$

- ✓ The uplink is often handled by introducing an intermediate parameter, ψ, the flux density required to produce the maximum or saturated transponder output, P_T, for a single carrier. It is a satellite parameter and its use conveniently separates the required satellite level from the rest of the link.

- ✓ **Travelling Wave Tube Amplifier (TWTA)** in a satellite transponder exhibits power output saturation the flux density required at the receiving antenna to produce saturation of the TWTA is termed as the **Saturation Flux Density**.
- ✓ SFD is a specified quantity in link budget calculation & knowing it, one can calculate the required EIRP at the earth station

$$\varphi_m = \frac{EIRP\ (earth\ station)}{4\pi r^2}$$

In decibel $$[\varphi_m] = [EIRP] + 10\log\frac{1}{4\pi r^2}$$

But we have free space loss

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

$$-[FSL] - 10\log\frac{\lambda^2}{4\pi} = 10\log\frac{1}{4\pi r^2}$$

Substitute this in above equation gives,

$$[\varphi_m] = [EIRP] - [FSL] - 10\log\frac{\lambda^2}{4\pi}$$

The $\frac{\lambda^2}{4\pi}$ term has dimensions of area, and in fact, it is the effective area of an isotropic antenna.

$$[A_O] = 10\log\frac{\lambda^2}{4\pi}$$

$$[EIRP] = [\varphi_m] + [FSL] + [A_O]$$

Above equation was derived on the basis that the only loss present was the spreading loss, denoted by [FSL]. But, the other propagation losses are the atmospheric absorption loss, the polarization mismatch loss, and the antenna misalignment loss.

$$[EIRP] = [\varphi_m] + [FSL] + [A_O] + [AA] + [PL] + [AML]$$

In terms of the total losses given by

$$[EIRP] = [\varphi_m] + [A_O] + [LOSSES] - [RFL]$$

This is for clear-sky conditions and 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*.

$$[EIRP]_U = [\varphi_S] + [A_O] + [LOSSES]_U - [RFL]$$

Input back off

As numbers 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* (FDMA).

The point to be made here is that *backoff* (B_O) must be allowed for in the link budget calculations. Suppose that the saturation flux density for single-carrier operation is known. Input BO 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 BO, resulting in an uplink value of

$$[EIRP]_U = [EIRP_S]_U - [B_O]_i$$

Input BO is normally achieved through reduction of the [EIRP] of the earth stations actually accessing the transponder

$$\left[\frac{\mathrm{C}}{\mathrm{N_0}}\right]_U = [\varphi_S] + [A_O] - [B_O]_i + \left[\frac{\mathrm{G}}{\mathrm{T}}\right]_U - [\mathrm{K}] - [RFL]$$

DOWNLINK AND OUTPUT BACKOFF

The downlink of a satellite circuit is the one in which the satellite is transmitting the signal and the earth station is receiving it. Uplink equation can be applied to the downlink, but subscript *D* will be used to denote specifically that the downlink is being considered.

$$\left[\frac{\mathrm{C}}{\mathrm{N_0}}\right]_D = [\mathrm{EIRP}]_D + \left[\frac{\mathrm{G}}{\mathrm{T}}\right]_D - [\mathrm{LOSSES}]_D - [\mathrm{K}]$$

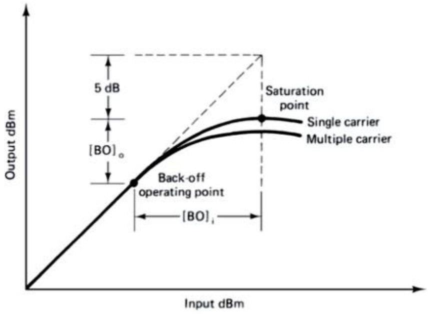
In above Equation, the values to be used are the satellite EIRP, the earth station receiver feeder losses, and the earth-station receiver *G*/*T*. The free space and other losses are calculated for the downlink frequency.

The resulting carrier-to-noise density ratio given by above equation is that which appears at the detector of the earth station receiver. Where the carrier-to-noise ratio is the specified quantity rather than carrier-to-noise density ratio, is used. This becomes, on assuming that the signal bandwidth *B* is equal to the noise bandwidth B_N:

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

Output back off

Where input B_O is employed, a corresponding output B_O must be allowed for in the satellite EIRP. A rule of thumb, frequently used, is to take the output B_O as the point on the curve which is 5 dB below the extrapolated linear portion, as shown in Figure. Since the linear portion gives a 1:1 change in decibels, the relationship between input and output B_O is $\mathbf{[B_O]_0 = [B_O]_i - 5\ dB}$.



If the satellite EIRP for saturation conditions is specified as $[\mathrm{EIRP_S}]_D$, then

$$[\mathrm{EIRP}]_\mathrm{D} = [\mathrm{EIRP_S}]_\mathrm{D} - [\mathrm{B_O}]_0$$

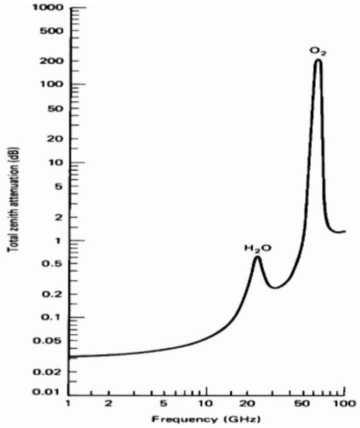
and [C/N] Equation becomes

$$\left[\frac{\mathrm{C}}{\mathrm{N_0}}\right]_D = [\mathrm{EIRP}]_D - [\mathrm{B}_o]_D + \left[\frac{\mathrm{G}}{\mathrm{T}}\right]_D - [\mathrm{LOSSES}]_D - [\mathrm{K}]$$

Propagation factors: Atmospheric Losses

Different types of atmospheric losses can perturb radio wave transmission in satellite systems:

- Atmospheric absorption;
- Atmospheric attenuation;
- Traveling ionospheric disturbances.



Radio Propagation: **Atmospheric Absorption**

- Energy absorption by atmospheric gases, which varies with the frequency of the radio waves.

Two absorption peaks are observed:

- 22.3 GHz from resonance absorption in water vapour (H_2O)
- 60 GHz from resonance absorption in oxygen (O_2)

Radio Propagation: **Atmospheric Attenuation**

Rain is the main cause of atmospheric attenuation (hail, ice and snow have little effect on attenuation because of their low water content).

Total attenuation from rain can be determined by:

$$A = \alpha L \text{ [dB]}$$

Where α [dB/km] is called the specific attenuation

L [km] is the effective path length of the signal through the rain; note that this differs from the geometric path length due to fluctuations in the rain density.

Radio Propagation: **Traveling Ionospheric Disturbances**

Traveling ionospheric disturbances are clouds of electrons in the ionosphere that provoke radio signal fluctuations which can only be determined on a statistical basis.

The disturbances of major concern are:

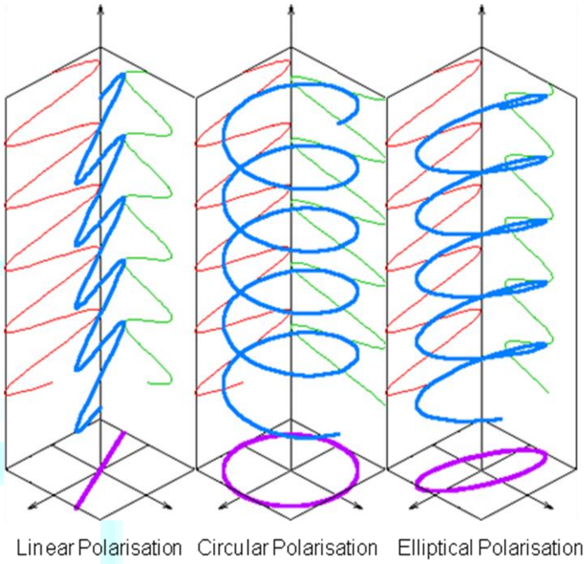
- Scintillation;
- Polarisation rotation.

Scintillations are variations in the amplitude, phase, polarisation, or angle of arrival of radio waves, caused by irregularities in the ionosphere which change over time. The main effect of scintillations is fading of the signal.

Signal Polarisation: **What is Polarisation?**

Polarisation is the property of electromagnetic waves that describes the direction of the transverse electric field. Since electromagnetic waves consist of an electric and a magnetic field vibrating at right angles to each other it is necessary to adopt a convention to determine the polarisation of the signal. Conventionally, the magnetic field is ignored and the plane of the electric field is used.

Signal Polarisation: **Types of Polarisation**



Linear Polarisation (horizontal or vertical):

- The two orthogonal components of the electric field are in phase;
- The direction of the line in the plane depends on the relative amplitudes of the two components.

Circular Polarisation:

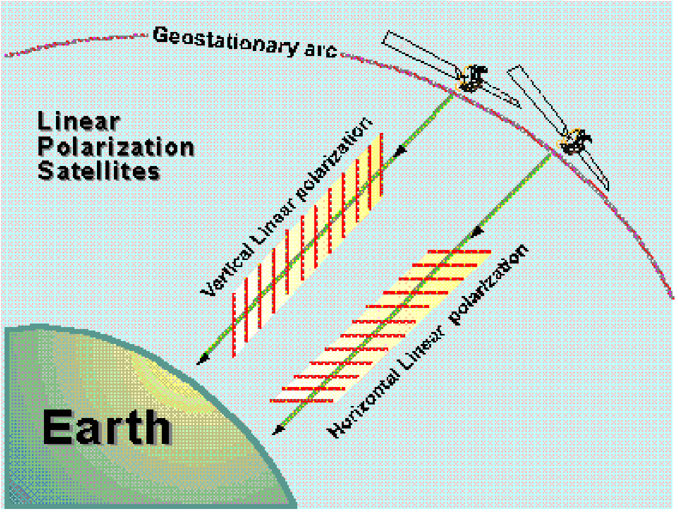
The two components are exactly 90º out of phase and have exactly the same amplitude.

Elliptical Polarisation:

All other cases.

Signal Polarisation: **Satellite Communications**

Alternating vertical and horizontal polarisation is widely used on satellite communications to reduce interference between programs on the same frequency band transmitted from adjacent satellites (one uses vertical, the next horizontal, and so on), allowing for reduced angular separation between the satellites.

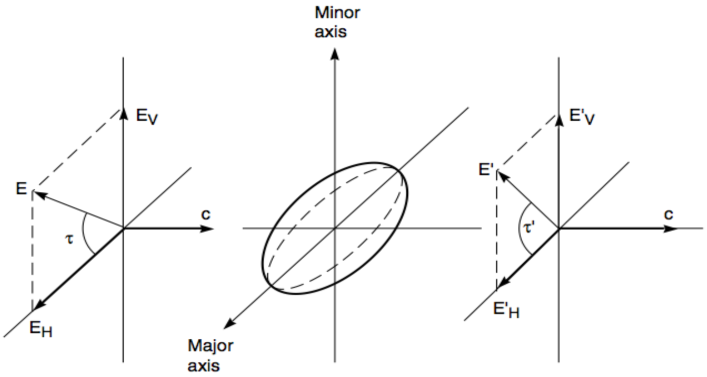


Signal Polarisation: **Depolarisation**

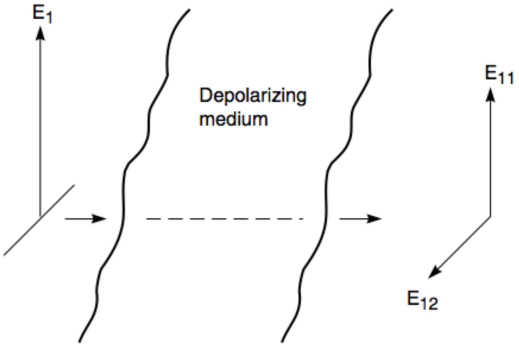
Rain depolarisation:

Since raindrops are not perfectly spherical, as a polarised wave crosses a raindrop, one component of the wave will encounter less water than the other component.

There will be a difference in the attenuation and phase shift experienced by each of the electric field components, resulting in the depolarisation of the wave.



Polarisation vector relative to the major and minor axes of a raindrop.

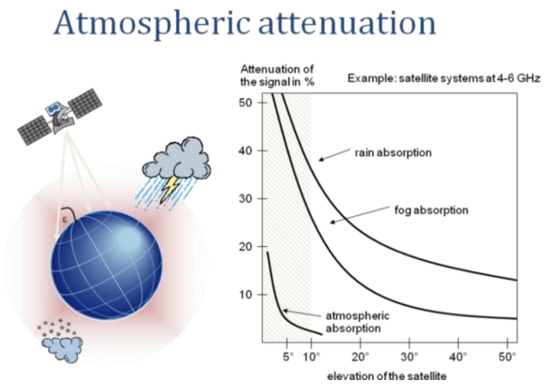


Signal Polarisation: **Cross-Polarisation Discrimination**

Depolarisation can cause interference where orthogonal polarisation is used to provide isolation between signals, as in the case of frequency reuse.

The most widely used measure to quantify the effects of polarisation interference is called Cross-Polarisation Discrimination (XPD):

$$\mathbf{XPD = 20 \log (E_{11}/E_{12})}$$



To counter depolarising effects circular polarising is sometimes used.

Alternatively, if linear polarisation is to be used, polarisation tracking equipment may be installed at the antenna.

EFFECTS OF RAIN

In the C band and, more especially, the Ku band, rainfall is the most significant cause of signal fading. Rainfall results in attenuation of radio waves by scattering and by absorption of energy from the wave.

Rain attenuation increases with increasing frequency and is worse in the Ku band compared with the C band.

This produces a depolarization of the wave; in effect, the wave becomes elliptically polarized. This is true for both linear and circular polarizations, and the effect seems to be much worse for circular polarization (Freeman, 1981).

The *C*/*N*0 ratio for the downlink alone, not counting the *P*NU contribution, is *PR*/*P*ND, and the combined *C*/*N*0 ratio at the ground receiver is

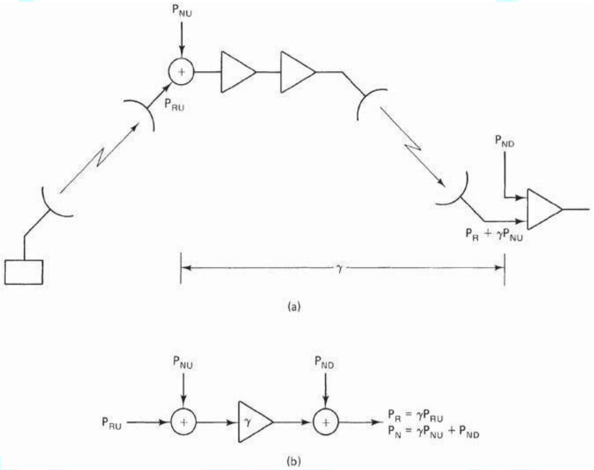


Figure (*a*) Combined uplink and downlink; (*b*) power flow diagram

The reason for this reciprocal of the sum of the reciprocals method is that a single signal power is being transferred through the system, while the various noise powers, which are present are additive. Similar reasoning applies to the carrier-to-noise ratio, *C*/*N*.

INTER MODULATION AND INTERFERENCE

Intermodulation interference is the undesired combining of several signals in a nonlinear device, producing new, unwanted frequencies, which can cause interference in adjacent receivers located at repeater sites.Not all interference is a result of intermodulation distortion. It can come from co-channel interference, atmospheric conditions as well as man-made noise generated by medical, welding and heating equipment.

Most intermodulation occurs in a transmitter's nonlinear power amplifier (PA). The next most common mixing point is in the front end of a receiver. Usually it occurs in the unprotected first mixer of older model radios or in some cases an overdriven RF front-end amp.
Intermodulation can also be produced in rusty or corroded tower joints, guy wires, turnbuckles and anchor rods or any nearby metallic object, which can act as a nonlinear "mixer/rectifier" device.

Test Equipment Measurements on G/T, C/No, EIRP:

Measurement of G/T of small antennas is easily and simply measured using the spectrum analyser method. For antennas with a diameter of less than 4.5 meters it is not normally necessary to point off from the satellite.

A step in frequency would be required into one of the satellite transponder guard bands.

However antennas with a G/T sufficiently large to enable the station to see the transponder noise floor either a step in frequency into one of the satellite transponder guard bands and/or in azimuth movement would be required.

The test signal can be provided from an SES WORLD SKIES beacon.

Procedure:

- Set up the test equipment as shown below. Allow half an hour to warm up, and then calibrate in accordance with the manufacturer's procedures

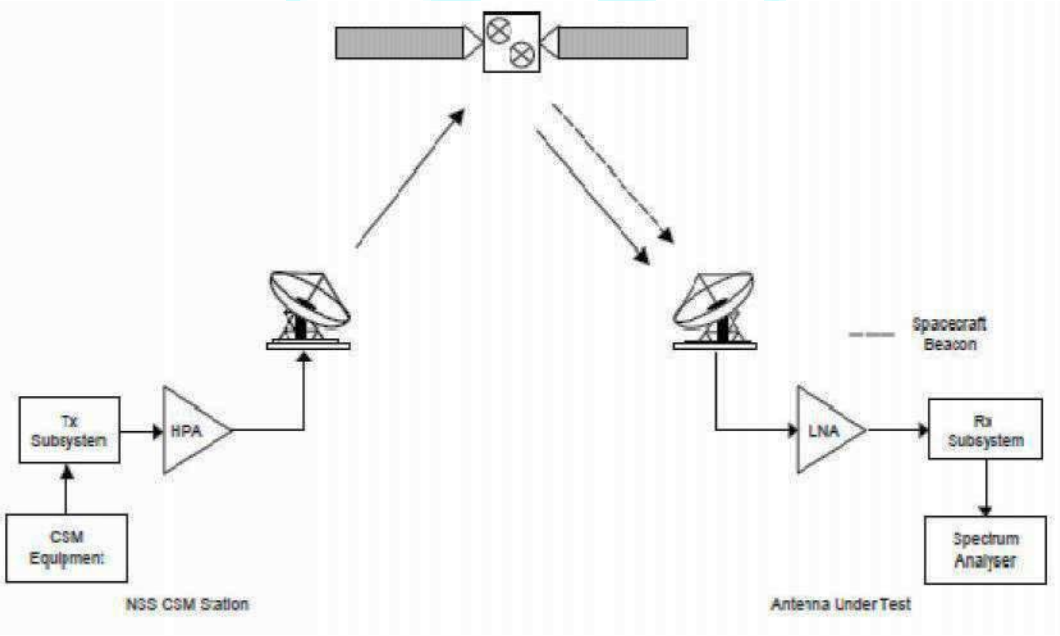


Figure One possible arrangement for Measurement of G/T

- Adjust the centre frequency of your spectrum analyzer to receive the SES WORLD SKIES beacon (data to be provided on the satellite used for testing)
- Carefully peak the antenna pointing and adjust the polarizer by nulling the cross polarized signal. You cannot adjust polarization when using the circularly polarized SES WORLD SKIES beacon.

Configure the spectrum analyser as follows:

Centre Frequency: Adjust for beacon or test signal frequency (to be advised). Use marker to peak and marker to centre functions.

- Frequency Span: 100 KHz
- Resolution Bandwidth: 1 KHz
- Video Bandwidth: 10 Hz (or sufficiently small to limit noise variance)
- Scale: 5 dB/div
- Sweep Time: Automatic
- Attenuator Adjust to ensure linear operation. Adjust to provide the "Noise floor delta" described in steps 7 and 8.

- To insure the best measurement accuracy during the following steps, adjust the spectrum analyser amplitude (reference level) so that the measured signal, carrier or noise, is approximately one division below the top line of the spectrum analyser display.

- Record the frequency and frequency offset of the test signal from the nominal frequency:

  For example, assume the nominal test frequency is 11750 MHz but the spectrum analyser shows the peak at 11749 MHz. The frequency offset in this case is -1 MHz.

- Change the spectrum analyser centre frequency as specified by SES WORLD SKIES so that the measurement is performed in a transponder guard band so that only system noise power of the earth station and no satellite signals are received. Set the spectrum analyser frequency as follows:

  Centre Frequency = Noise slot frequency provided by the PMOC

- Disconnect the input cable to the spectrum analyser and confirm that the noise floor drops by at least 15 dB but no more than 25dB. This confirms that the spectrum analyser's noise contribution has an insignificant effect on the measurement. An input attenuation value allowing a "Noise floor Delta" in excess of 25 dB may cause overloading of the spectrum analyser input. (i) Reconnect the input cable to the spectrum analyser.

- Activate the display line on the spectrum analyser.

- Carefully adjust the display line to the noise level shown on the spectrum analyser. Record the display line level.
- Adjust the spectrum analyser centre frequency to the test carrier frequency recorded in step previous step.
- Carefully adjust the display line to the peak level of the test carrier on the spectrum analyser. Record the display line level.
- Determine the difference in reference levels between steps (l) and (j) which is the (C+N)/N.
- Change the (C+N)/N to C/N by the following conversion:
- This step is not necessary if the (C+N)/N ratio is more than 20 dB because the resulting correction is less than 0.1 dB.

$$\left(\frac{C}{N}\right) = 10\log_{10}\left(10^{\frac{\left(\frac{C+N}{N}\right)}{10}} - 1\right) \quad \text{dB}$$

- Calculate the carrier to noise power density ratio (C/No) using:

$$\left(\frac{C}{No}\right) = \left(\frac{C}{N}\right) - 2.5 + 10\log_{10}(RBW \;\; x \;\; SA_{corr}) \quad \text{dB}$$

The 2.5 dB figure corrects the noise power value measured by the log converters in the spectrum analyser to a true RMS power level, and the SA correction factor takes into account the actual resolution filter bandwidth

Calculate the G/T using the following:

$$\left(\frac{G}{T}\right) = \left(\frac{C}{No}\right) - (EIRP_{SC} - A_{corr}) + (FSL + L_a) - 228.6 \quad \text{dB/K}$$

where,

EIRPSC – Downlink EIRP measured by the PMOC (dBW)
Acorr – Aspect correction supplied by the PMOC (dB)

FSL – Free Space Loss to the AUT supplied by the PMOC (dB) La –
Atmospheric attenuation supplied by the PMOC (dB)

- Repeat the measurement several times to check consistency of the result.

Antenna Gain:

Antenna gain is usually **defined** as the ratio of the power produced by the **antenna** from a far-field source on the **antenna's** beam axis to the power produced by a hypothetical lossless isotropic **antenna**, which is equally sensitive to signals from all directions.

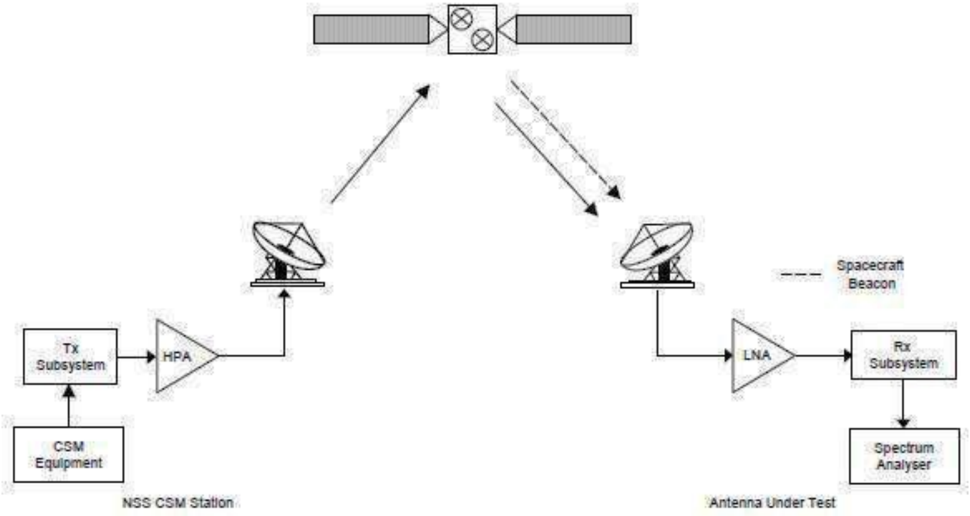


Figure One possible arrangement for Measurement of Antenna Gain

Two direct methods of measuring the Rx gain can be used; integration of the Rx side lobe pattern or by determination of the 3dB and 10dB beamwidths.

The use of pattern integration will produce the more accurate results but would require the AUT to have a tracking system. In both cases the test configurations for measuring Rx gain are identical, and are illustrated in Figure.

In order to measure the Rx gain using pattern integration the AUT measures the elevation and azimuth narrowband (±5° corrected) sidelobe patterns.

The AUT then calculates the directive gain of the antenna through integration of the sidelobe patterns. The Rx gain is then determined by reducing the directive gain by the antenna inefficiencies.

In order to measure the Rx gain using the beamwidth method, the AUT measures the corrected azimuth and elevation 3dB/10dB beamwidths. From these results the Rx gain of the antenna can be directly calculated using the formula below.

$$G = 10\mathrm{Log}_{10}\left[\frac{1}{2}\left(\frac{31000}{(Az_3)(El_3)} + \frac{91000}{(Az_{10})(El_{10})}\right)\right] - F_{Loss} - R_{Loss}$$

where:

G is the effective antenna gain (dBi)
Az3 is the corrected azimuth 3dB beamwidth (°) El3
is the elevation 3dB beamwidth (°)
Az10 is the corrected azimuth 10dB beamwidth (°)
El10 is the elevation 10dB beamwidth (°)
FLoss is the insertion loss of the feed (dB)

RLoss is the reduction in antenna gain due to reflector inaccuracies, and is given by:

RLoss =4.922998677(Sdev f)2 dB

where:

Sdev is the standard deviation of the actual reflector surface (inches)
f is the frequency (GHz)

SYSTEM RELIABILITY AND DESIGN LIFETIME

SYSTEM RELIABILITY

Satellites are designed to operate dependably throughout their operational life, usually a number of years. This is achieved through stringent quality control and testing of parts and subsystems before they are used in the construction of the satellite.

Redundancy of key components is often built in so that if a particular part or subassembly fails, another can perform its functions.In addition, hardware and software on the satellite are often designed so that ground controllers can reconfigure the satellite to work around a part that has failed.

DESIGN LIFETIME

The Milstar constellation has demonstrated exceptional reliability and capability, providing vital protected communications to the warfighter," said Kevin Bilger, vice president and general manager, Global Communications Systems, Lockheed Martin Space Systems in Sunnyvale. "Milstar's robust system offers our nation worldwide connectivity with flexible, dependable and highly secure satellite communications."

The five-satellite Milstar constellation has surpassed 63 years of combined successful operations, and provides a protected, global communication network for the joint forces of the U.S. military. In addition, it can transmit voice, data, and imagery, and offers video teleconferencing capabilities.

The system is the principal survivable, endurable communications structure that the President, the Secretary of Defense and the Commander, U.S. Strategic Command use to maintain positive command and control of the nation's strategic forces.In addition to this 10-year milestone for Flight-5, each of the first two Milstar satellites have been on orbit for over 16 years – far exceeding their 10-year design life.

The next-generation Lockheed Martin-built Advanced EHF satellites, joining the Milstar constellation, provide five times faster data rates and twice as many connections, permitting transmission of strategic and tactical military communications, such as real-time video, battlefield maps and targeting data. Advanced EHF satellites are designed to be fully interoperable and backward compatible with Milstar.

Headquartered in Bethesda, Md., Lockheed Martin is a global security company that employs about 123,000 people worldwide and is principally engaged in the research, design, development, manufacture, integration and sustainment of advanced technology systems, products and services. The Corporation's net sales for 2011 were $46.5 billion.