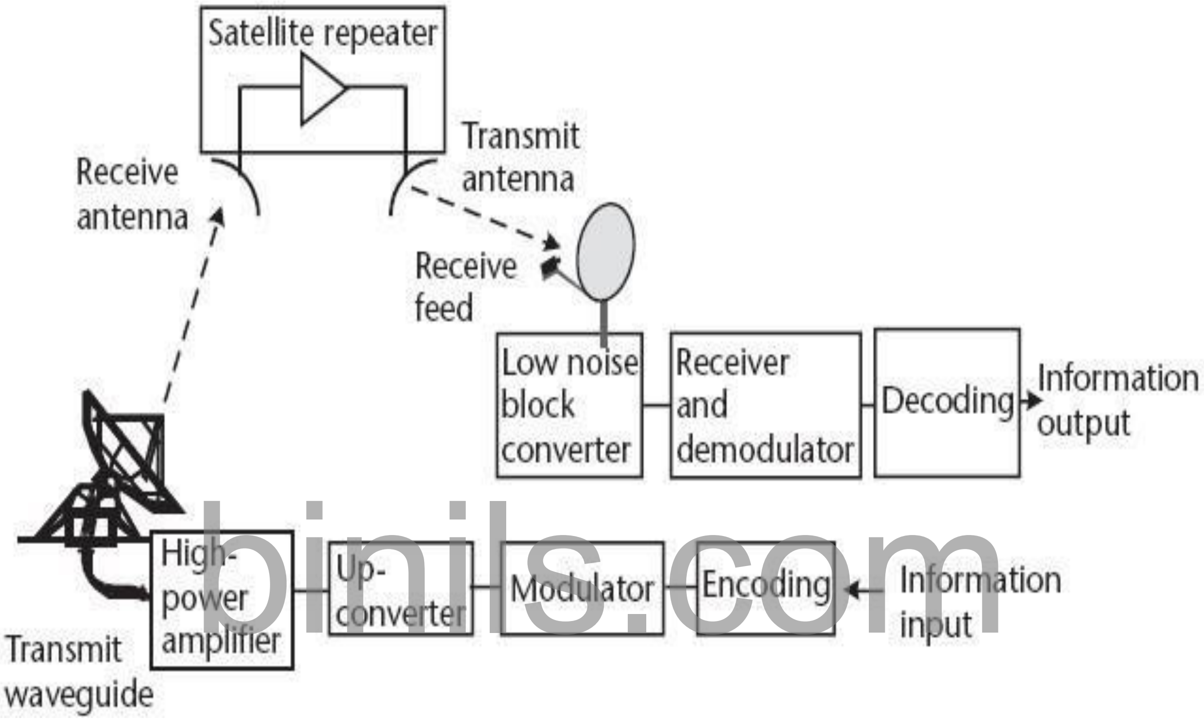
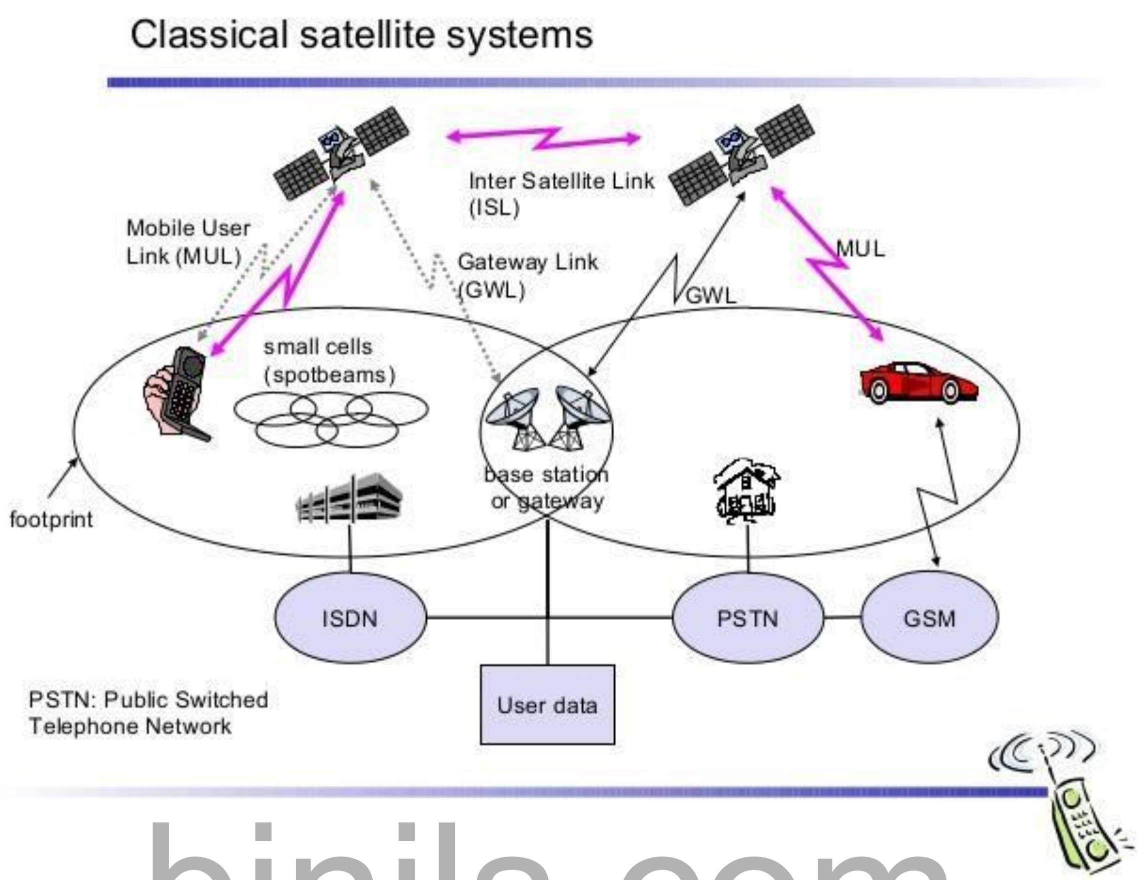
3.5 Link Design with and without frequency reuse

- Intra –orbital links :connect consecutive satellites on the same orbits
- Inter –orbital links :connect two satellites on the different orbits



Design of the Satellite System


Classical satellite systems

PSTN: Public Switched Telephone Network

LNB (LOW NOISE BLOCK DOWN CONVERTER)

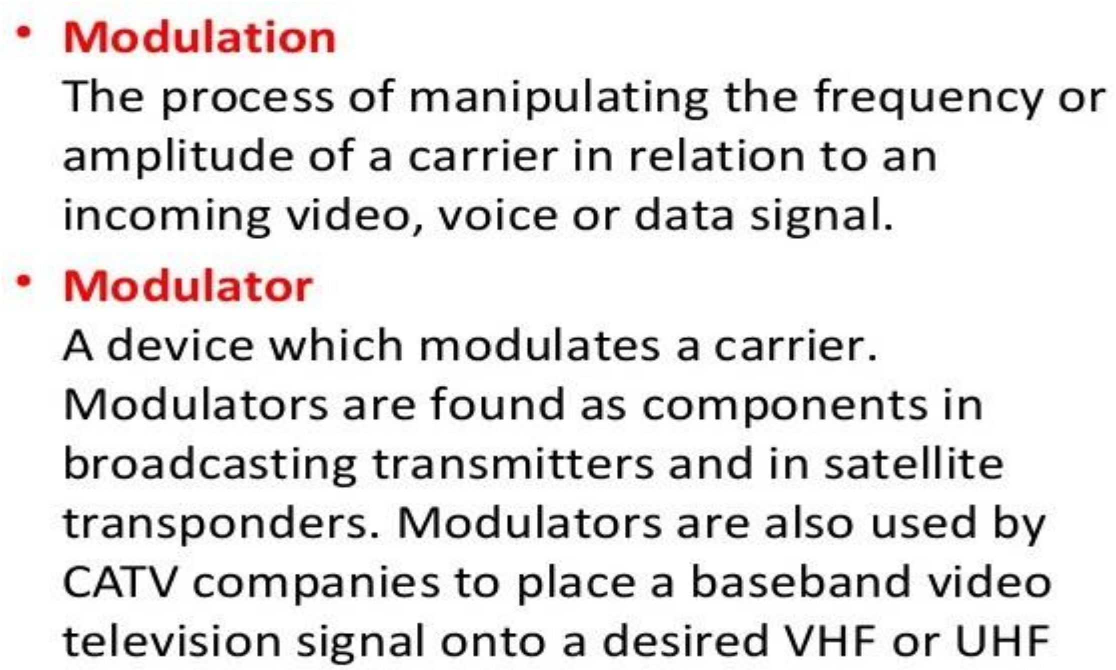
- A device mounted in the dish, designed to amplify the satellite signals and convert them from a high frequency to a lower frequency. LNB can be controlled to receive signals with different polarization. The television signa can then be carried by a double-shielded aerial cable to the satellite receive while retaining their high quality. A universal LNB is the present standard version, which can handle the entire frequency range from 10.7 to 12.75 Gl and receive signals with both vertical and horizontal polarization.

Demodulator

A satellite receiver circuit which extracts or "demodulates" the "wanted "signals from the received carrier.

Decoder

- A box which, normally together with a viewing card, makes it possible to view encrypted transmissions. If the transmissions are digital, the decoder usually integrated in the receiver.
- recorded video information to be played back using a television receiver tuned to VHF channel 3 or 4.



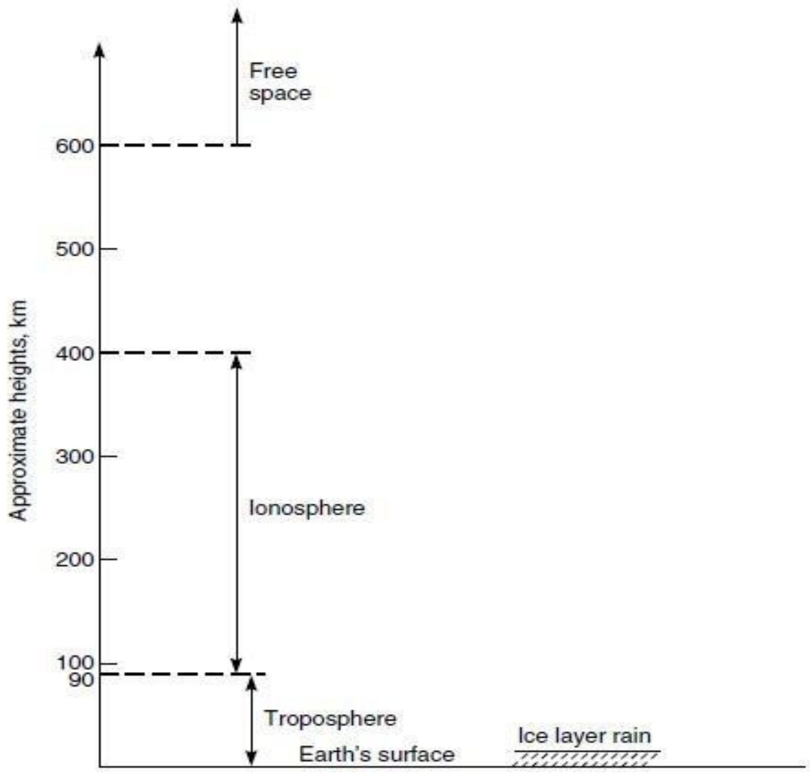
- **Modulation**
  The process of manipulating the frequency or amplitude of a carrier in relation to an incoming video, voice or data signal.
- **Modulator**
  A device which modulates a carrier. Modulators are found as components in broadcasting transmitters and in satellite transponders. Modulators are also used by CATV companies to place a baseband video television signal onto a desired VHF or UHF

Atmospheric Layers

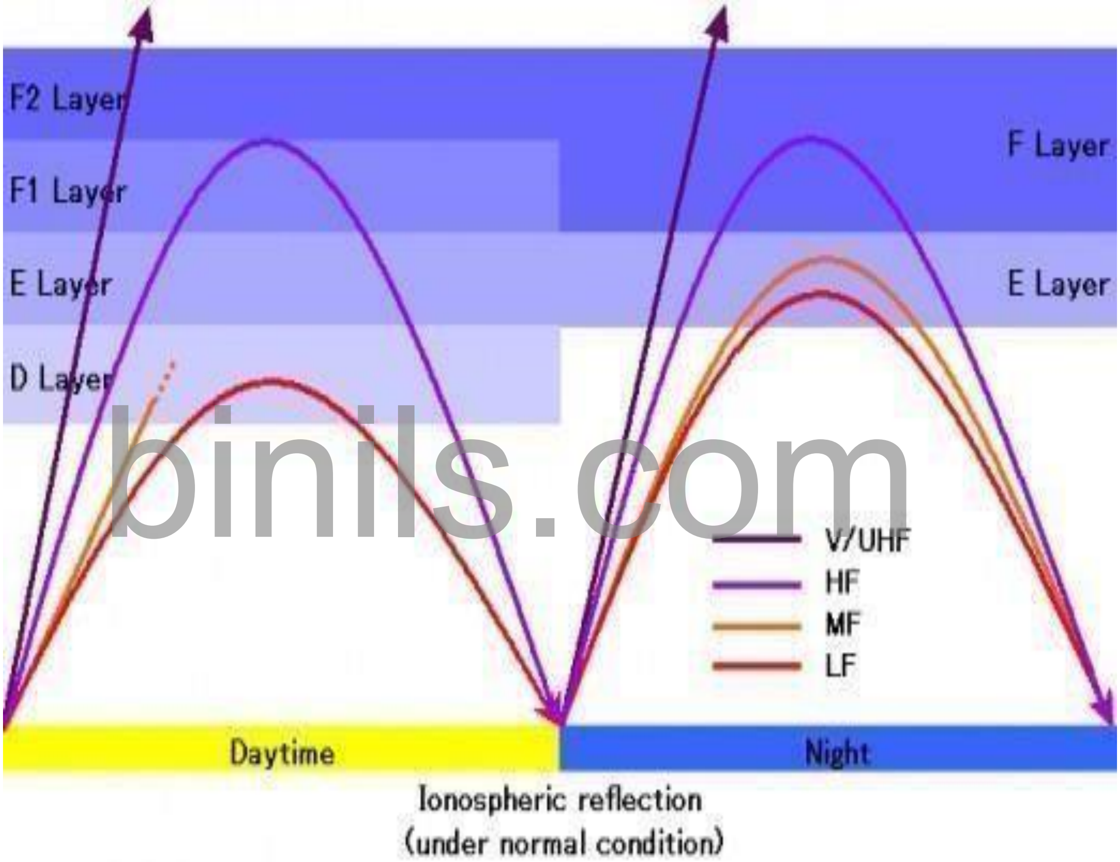
A signal traveling between an earth station and a satellite must pass through theearth's atmosphere, including the ionosphere, as shown

Atmospheric Losses

- Losses occur in the earth's atmosphere as a result of energy absorption by the atmospheric gases.
- The weather-related losses are referred to as *atmospheric attenuation* and the absorption losses by gases are known as *absorption.* **Atmospheric scintillation:**
- This is a fading phenomenon, the fading period being several tens of seconds.
- It is caused by differences in the atmospheric refractive index, which in turn results in focusing and defocusing of the radio waves, which follow different ray paths throughthe atmosphere.
- Fade margin in the link power-budget calculations are used for Atmospheric Scintillaton.

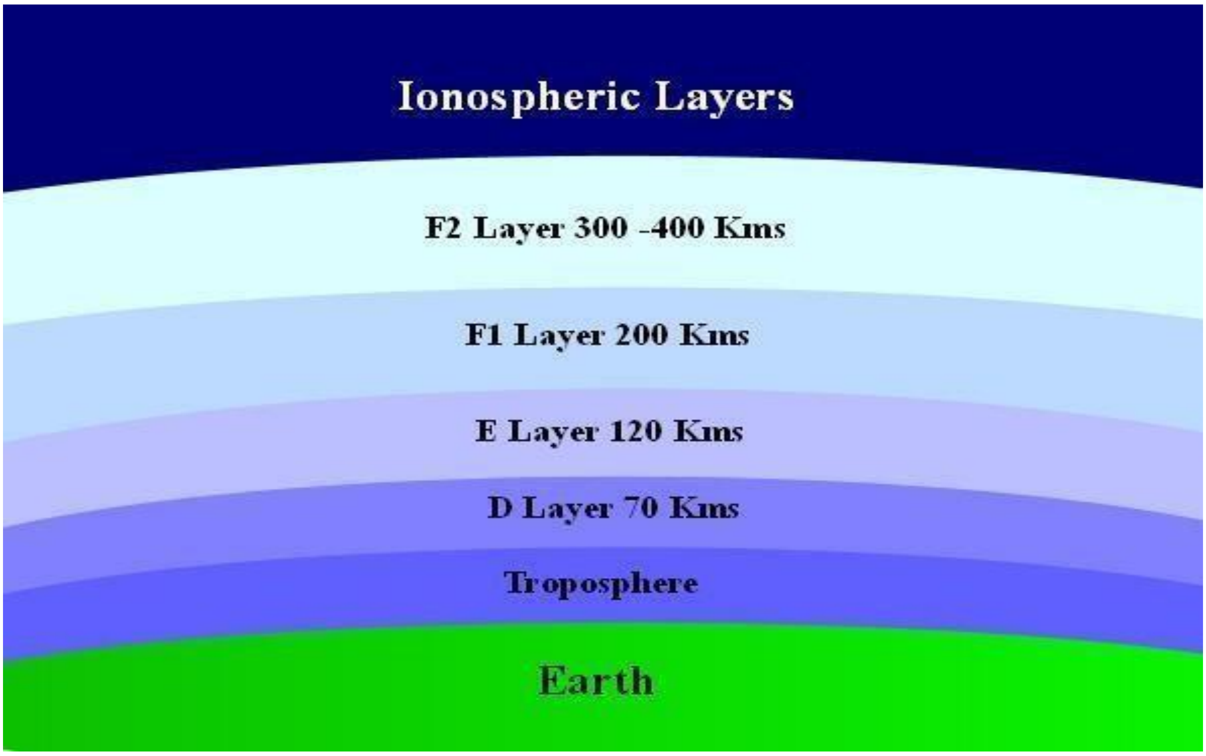

Free space
600
500
400
300
200
100
90
Approximate heights, km
Ionosphere
Troposphere
Earth's surface
Ice layer rain

3.6 Ionospheric Effects

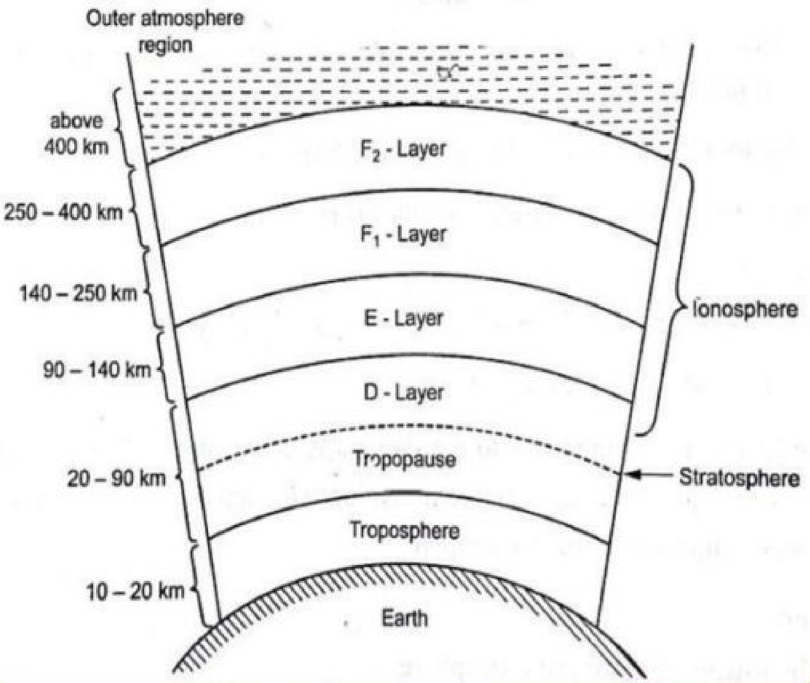
- Radio waves traveling between satellites and earth stations must pass through the ionosphere.
- The ionosphere is the upper region of the earth's atmosphere, which has been ionized, mainly by solar radiation.
- 

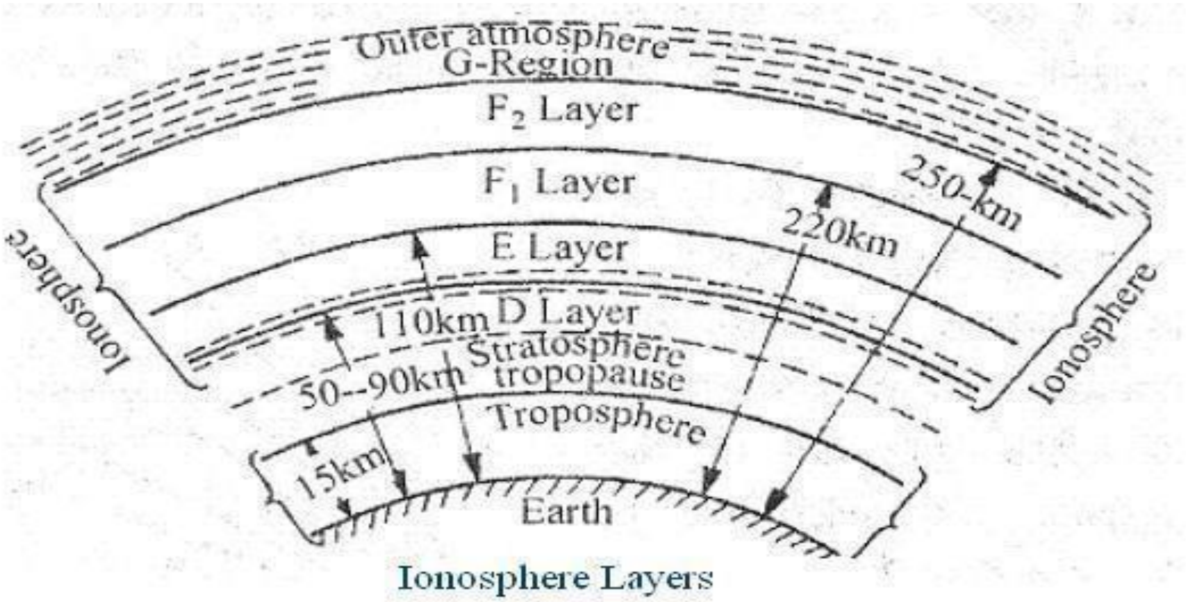
Ionospheric reflection
(under normal condition)

Ionospheric Layers



The Ionosphere layers

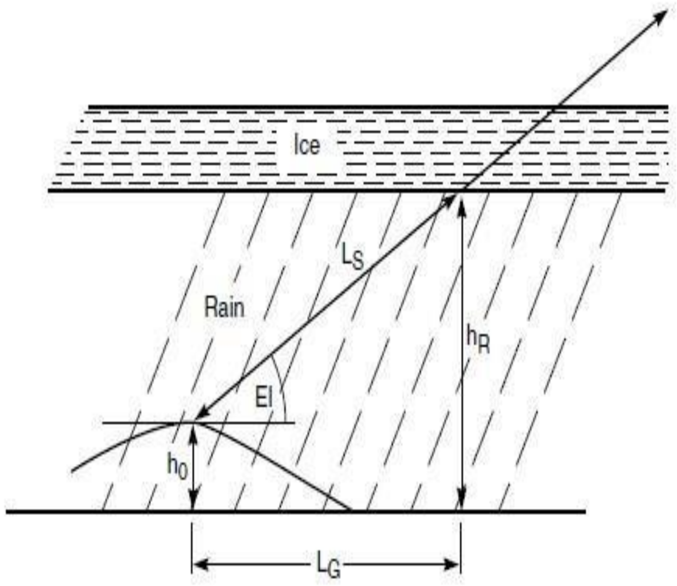




Ionosphere Layers

3.7 Rain Induced Attenuation

- Rain attenuation is a function of *rain rate*. The rain rate is measured in millimeters per hour. The total attenuation is givenas $A=\alpha L$ dB
- *α-Specfic attenuation*
- *L- Effective path length* of the signal through the rain
- The geometric, or slant, path length is shown as L_S. This depends on the antenna angle of elevation and the *rain height* h_R, which is the height at which freezing occurs.



$$L_S = \frac{h_R - h_O}{\sin El}$$

- The effective path length is given in terms of the slant length by
  $L = L_S r_p$
- where r_p is a *reduction factor* which is a function of the percentage time *p* and L_G, the horizontal projection of L_S. $L_G = L_S \cos El$
- With all these factors together into one equation, the rain attenuation in decibels is given by,

Link budget calculations

$$A_p = aR_p{}^b L_S r_p \text{ dB}$$

Equivalent Isotropic Radiated Power:

- A key parameter in link budget calculations is the equivalent isotropic radiated power (EIRP).
- An isotropic radiator with an input power equal to GP_S would produce the same flux density. Hence this product is referred toas the equivalent isotropic radiated power.

- EIRP = GP_{S},

  G= Gain and P_S *= Power Supplied.*

Free Space Loss

- 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 as

$$\Psi_M = \frac{\text{EIRP}}{4\pi r^2}$$

The power delivered to a matched receiver is this power flux d
ty multiplied by the effective aperture of the receiving antenna, g
by Eq. The received power is therefore

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

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

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

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

3.8 Interferance

- With many telecommunications services using radio transmissions, interference between services can arise in a number of ways.

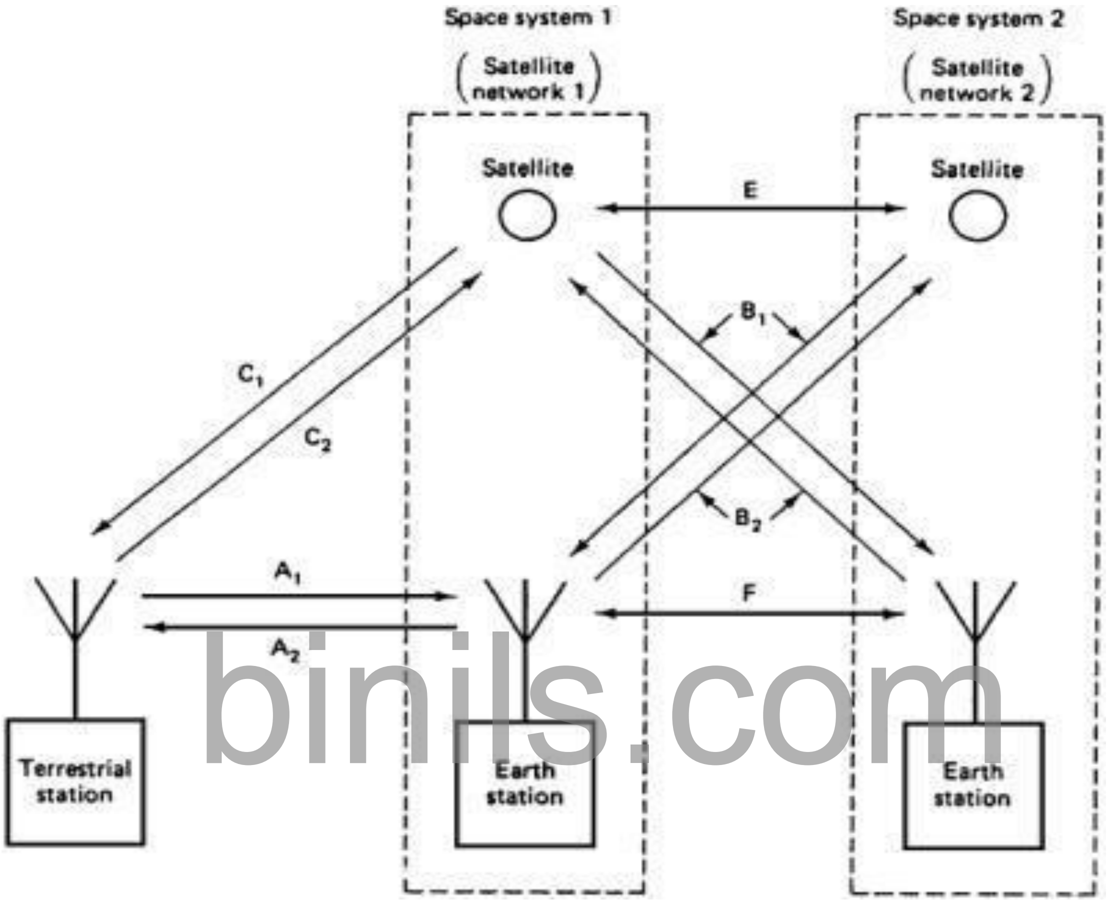
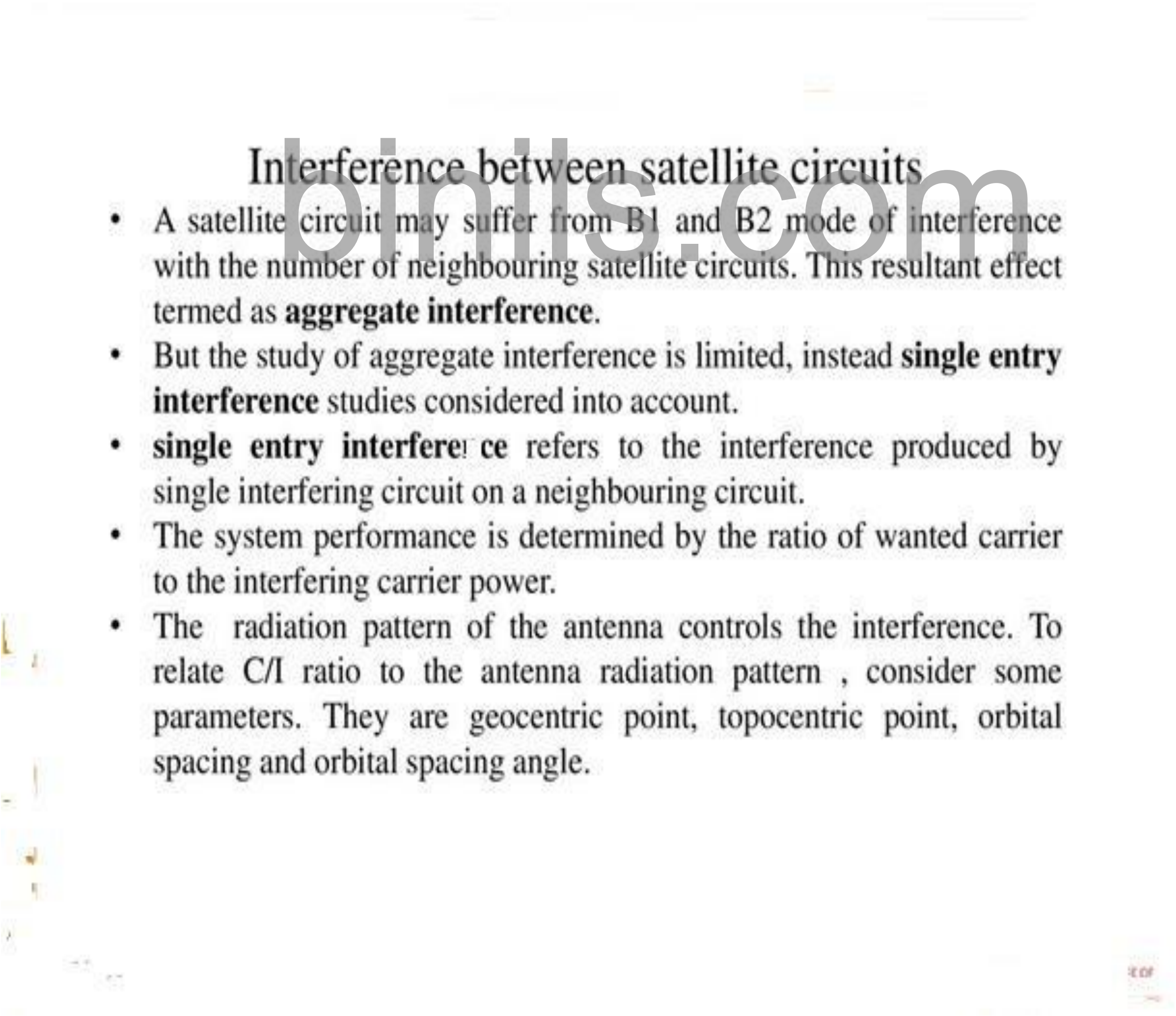


Fig (a)
Possible interference modes between satellite circuits and a terrestrial station

Fig. (a) are classified by the International Telecommunications Union (ITU, 1985) as follows: A1: terrestrial station transmissions, possibly causing interference to reception by an earth station A2: 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: terrestrialstation 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



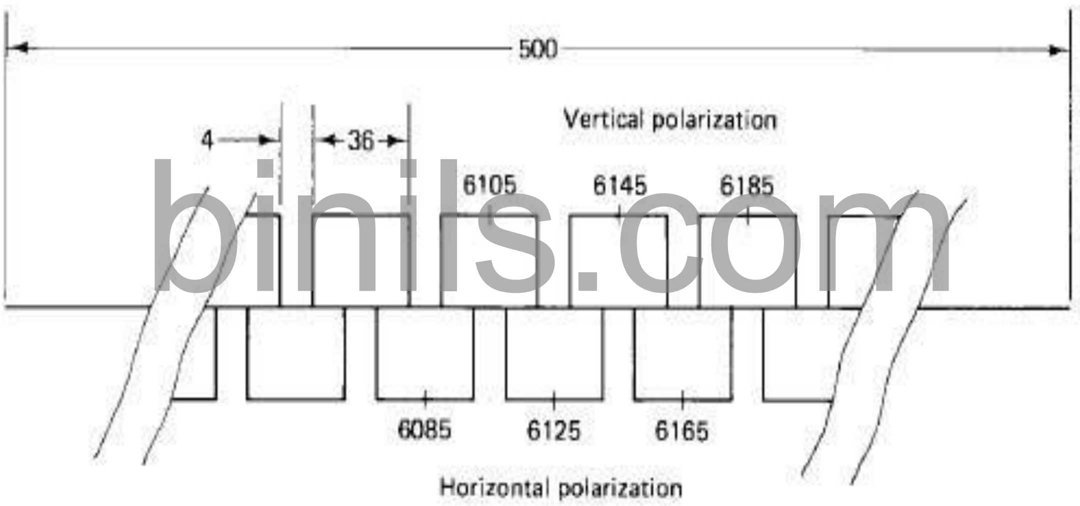
Interference between satellite circuits

- A satellite circuit may suffer from B1 and B2 mode of interference with the number of neighbouring satellite circuits. This resultant effect termed as **aggregate interference**.
- But the study of aggregate interference is limited, instead **single entry interference** studies considered into account.
- **single entry interference** refers to the interference produced by single interfering circuit on a neighbouring circuit.
- The system performance is determined by the ratio of wanted carrier to the interfering carrier power.
- The radiation pattern of the antenna controls the interference. To relate C/I ratio to the antenna radiation pattern , consider some parameters. They are geocentric point, topocentric point, orbital spacing and orbital spacing angle.

Combined [C/I] due to interference on both uplink anddownlink

Interference may be considered as a form of noise, and 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 and thedownlink ratios are combined in exactly the same manner described for noise, resulting in Here, power ratios must be used, not decibels, and the subscript “ant” denotes the combined ratio at the output of station B receiving antenna

3.9 Link Design With and without Frequency Reuse

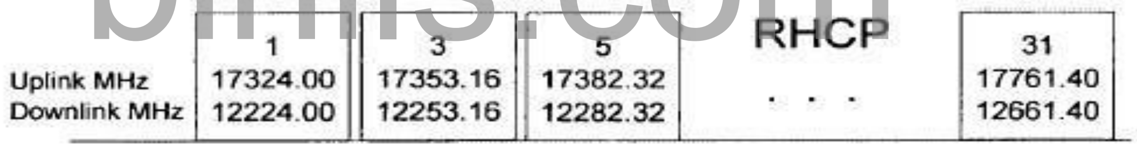


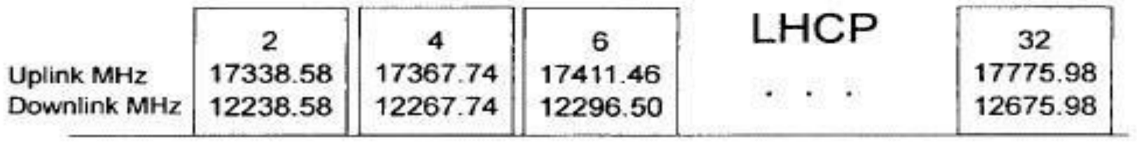
- Frequency reuse is employed to reduce the crosspolarization caused by ionosphere, ice crystals in the upper atmosphere and

- rain, when the wave being transmitted from satellite to earth station.

- Frequency reuse achieved with spot-beam antennas, and these may be combined with polarization reuse to provide an effective bandwidth.
- The bandwidth allocated for C band service is 500 MHz, and this is divided into sub bands, one for each transponder. A typical transponder bandwidth is 36 MHz, and allowing for a 4-MHz guard band between transponders, 12 such transponders can be
- accommodated in the 500-MHz bandwidth. this number can be doubled. Polarization isolation refers to the fact that carriers, which may be on the same frequency but with opposite senses of polarization, can be isolated from one another by receiving

- With antennas linear match polarized carriers can be separated in this way, and with circular polarization, left-hand circular and right-hand circular polarizations can be separated. Because the carriers with opposite senses of polarization may overlap in frequency, this technique is referred to as *frequency reuse*





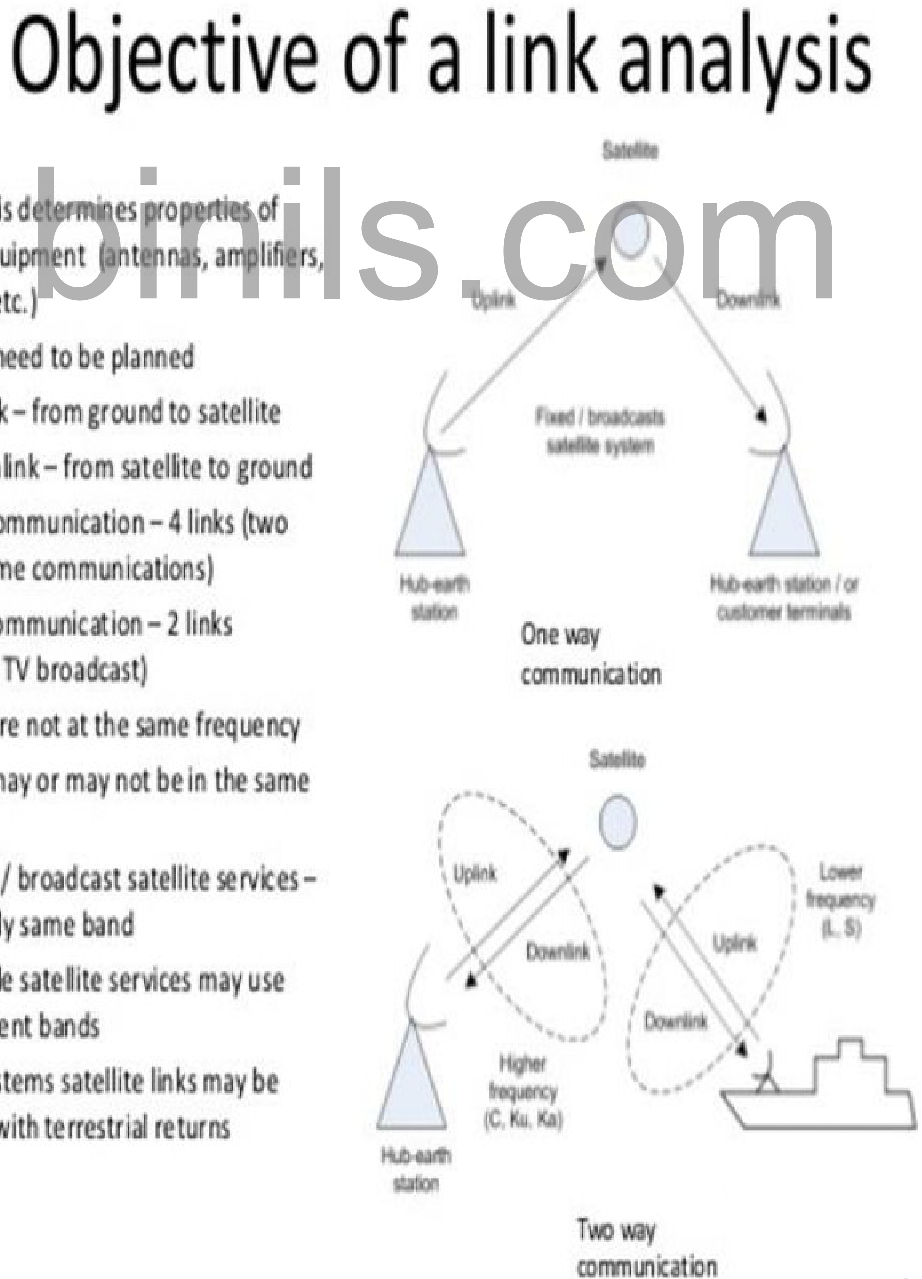
1 Basic link analysis

Design of the **satellite** link, first **transmission** formula , up link , down link. ....**Communication**

satellites bring the world to you anywhere and any time User Link (MUL) Gateway Link

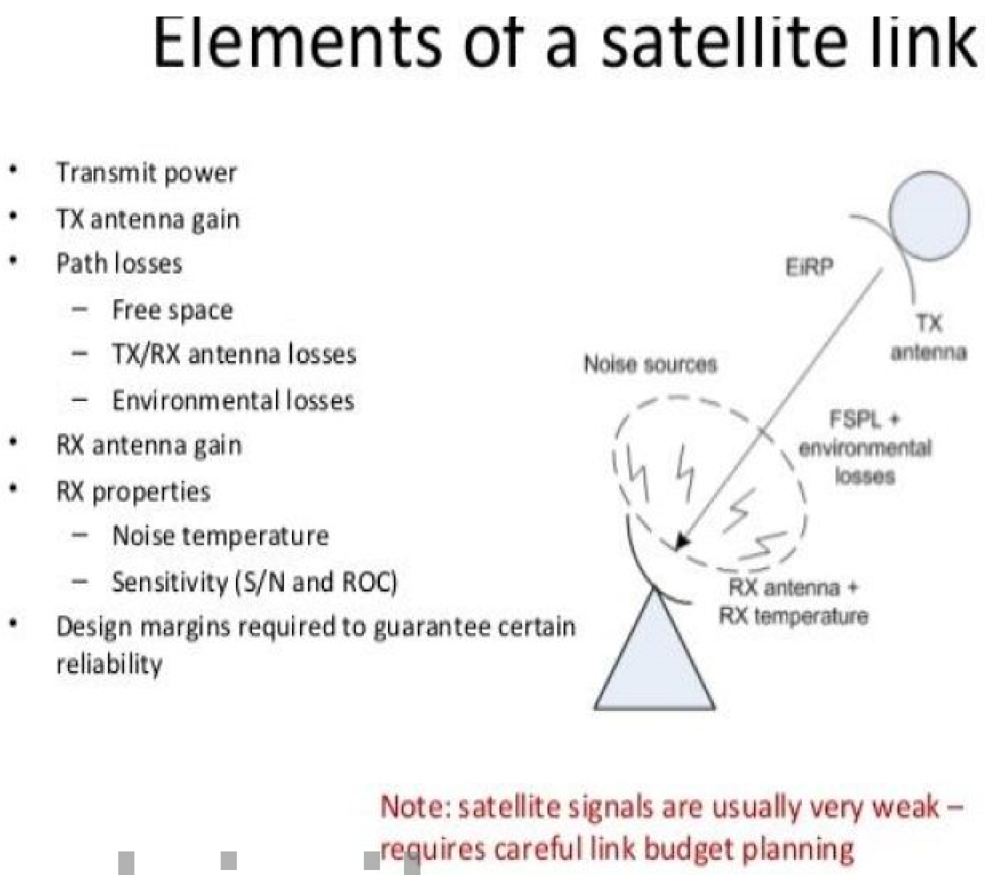
(GWL) MUL GWL small cells (spot beams) **base** station Objective of a **link analysis** • • • • • •

•**Link analysis** determines properties of **satellite** ..



Objective of a link analysis

- Link analysis determines properties of satellite equipment (antennas, amplifiers, data rate, etc.)
- Two links need to be planned
  - Uplink – from ground to satellite
  - Downlink – from satellite to ground
- Two way communication – 4 links (two way maritime communications)
- One way communication – 2 links (example – TV broadcast)
- Two links are not at the same frequency
- Two links may or may not be in the same band
  - Fixed / broadcast satellite services – usually same band
  - Mobile satellite services may use different bands
- In some systems satellite links may be combined with terrestrial returns



Elements of a satellite link

- Transmit power
- TX antenna gain
- Path losses
  - Free space
  - TX/RX antenna losses
  - Environmental losses
- RX antenna gain
- RX properties
  - Noise temperature
  - Sensitivity (S/N and ROC)
- Design margins required to guarantee certain reliability

Note: satellite signals are usually very weak – requires careful link budget planning

2 Basic Transmission Theory

- These will include all the parameters such as:
  - ✓ Flux density
  - ✓ EIRP
  - ✓ power received
  - ✓ power transmit
  - ✓ System noise temperature
  - ✓ Carrier to noise power ratio

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 a total power P Wattsuniformly in all directions
- Such source is called isotropic.

- At a distance R meters from isotropic source, flux density

crossingthe surface F= Pt / 4 πR2 (W/m2)

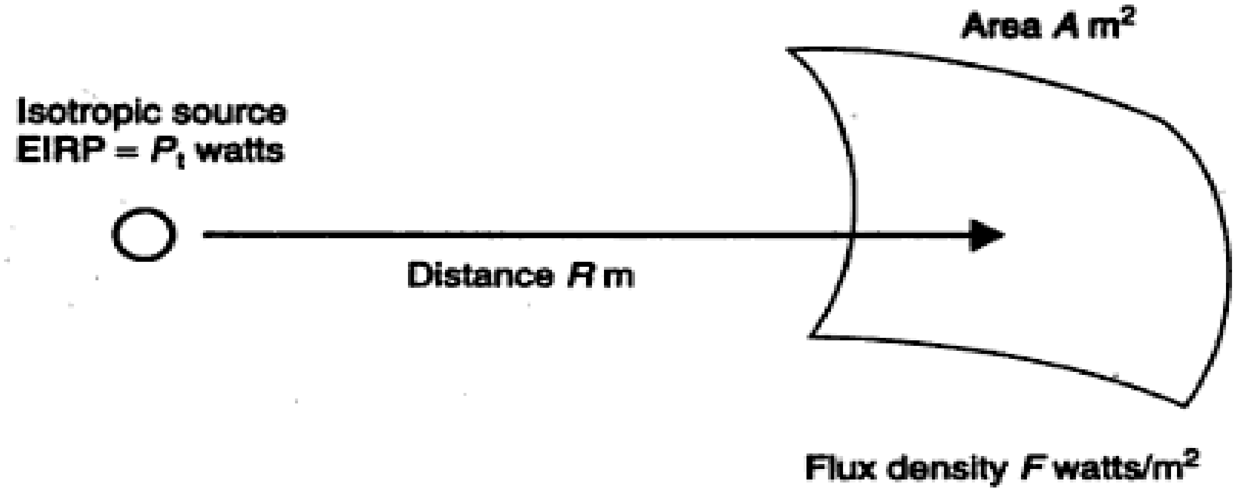


FIGURE 4.2 Flux density produced by an isotropic source.

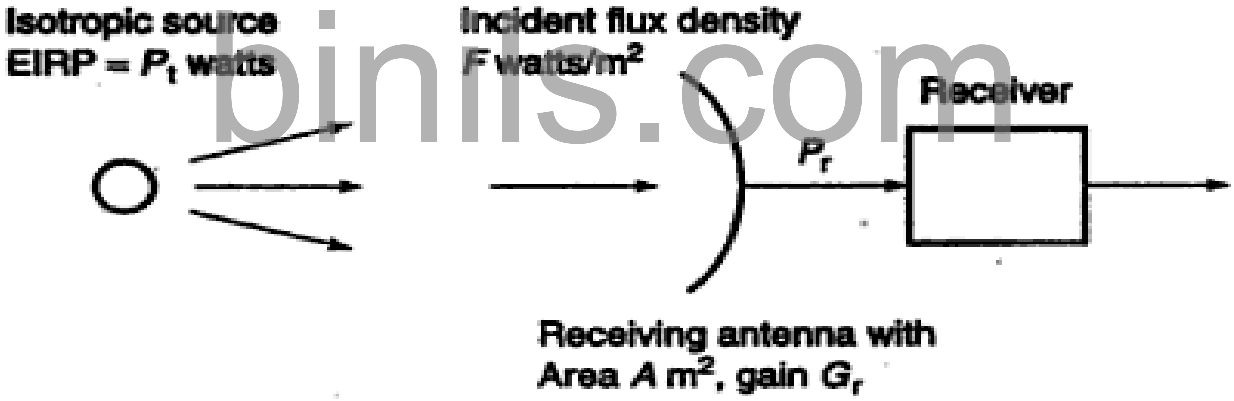


FIGURE 4.3 Power received by an ideal antenna with area A m^2. Incident flux density is $F = P_t/4\pi R^2$ W/m^2. Received power is $P_r = F \times A = P_t A/4\pi R^2$ W.

For a transmitter with output Pt watts driving a lossless antenna with gain Gt , the f lux density distance R meters is

F= Pt Gt / 4 πR2 (W/m2)

- The product Pt Gt is called effective isotropic radiated power or EIRP, itdescribes the combination of transmitting power & antenna gain in terms of an equivalent isotropic sourcewith power Pt Gt watts

- If we had an ideal receiving antenna with an aperture of A m2we would collect power Pr watts given by Pr = F * A watts

  A practical antenna with physical aperture area of A m2 will not deliverpower 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 Ae isAe = ηA A Where ηA aperture efficiency of the antenna.

For parabolic reflector For Horn antennas ηA = 50 to 75%

ηA = 90%

- Thus the power received by real antenna with effective aperture area Aem2 is

  Pr = Pt Gt Ae / 4 πR2 (watts) (A)

- A fundamental relation in antenna theory is gain & area of an antenna arerelated by G = 4π Ae / λ2
- Substituting above equation in equation (A) gives

  Pr = [Pt Gt Gr/ (4 πR / λ) 2 watts

- This expression is known as link equation & essential in calculation ofpower received in any radio link
- The term (4 πR / λ.) 2 is known as path loss Lp
- Collecting various factors, we can write Power received = (EIRP * Receiving antenna gain / path loss)watts
- In decibel, we have Pr = EIRP + Gr – Lp .... (B)

  Where , EIRP= 10log10 (Pt Gt)
  dBw Gr = 10log10 (4π Ae
  /λ2)dB Lp = 10log10 (4 πR
  /λ) 2 dB

Equation B represents an idealized case, in which there are no additional losses in the link.

- In practice, we need to take account of a more complex situation in which we have losses in atmosphere due to attenuation by oxygen, watervapor and rain, losses in the antennas at each end of the link.
- So equation B can be written as Pr = EIRP + Gr – Lp – La - Lta-LradBW

where La = attenuation in atmosphere

Lta= losses associated with transmitting antennaLra= losses associated with receiving antenna

The received power, Pr is commonly referred to as carrier power, C.

- In both of the modulation schemes, the amplitude of the carrier is not changed when data are modulated onto the carrier, so carrier power C isalways equal to received power Pr.

System Noise Temperature & G/T ratio:

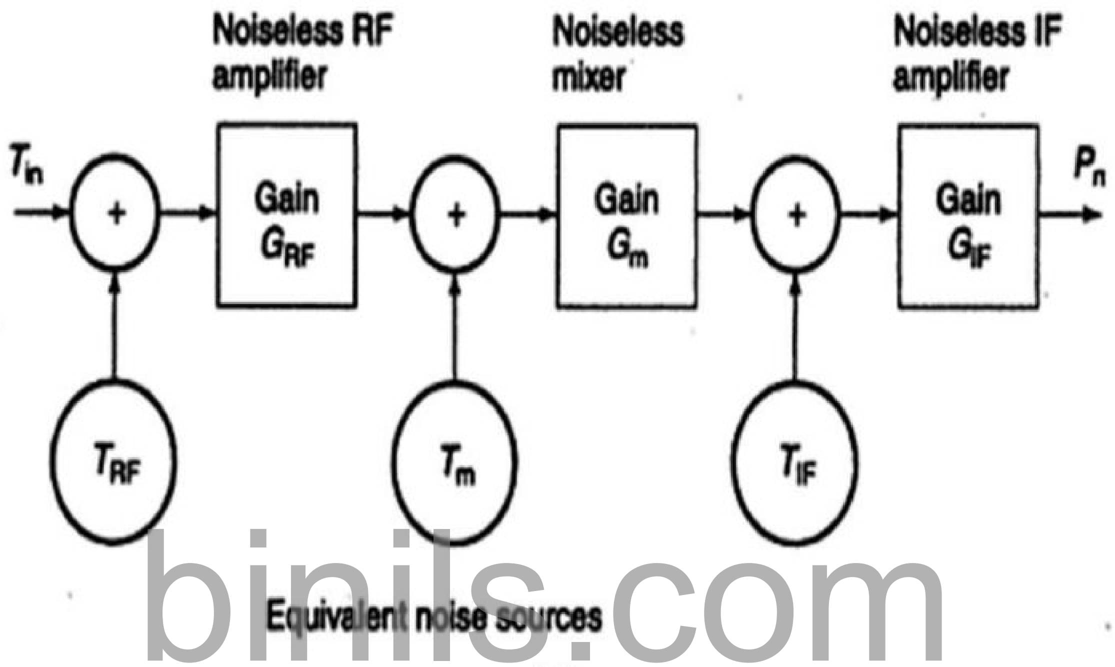
- Noise Temperature
- Noise temperature provides a way of determining how much thermal noise is generated by active and passive devices in the receiving system..
- The noise power is given byPn = kTn B

Where

k= Boltzmann’s constant= 1.38 *10-23J/K =-228.6 dBW/K/HzTn = Noise temperature of source in K

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

- System noise temperature Ts , is the noise temperature of noise source atthe input of noiseless receiver, which gives same noise power as the original receiver, measured at the output of receiver Calculation of System noise temperature:



(a)

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 thatthe block produce same noise at its output as the device it replaces.

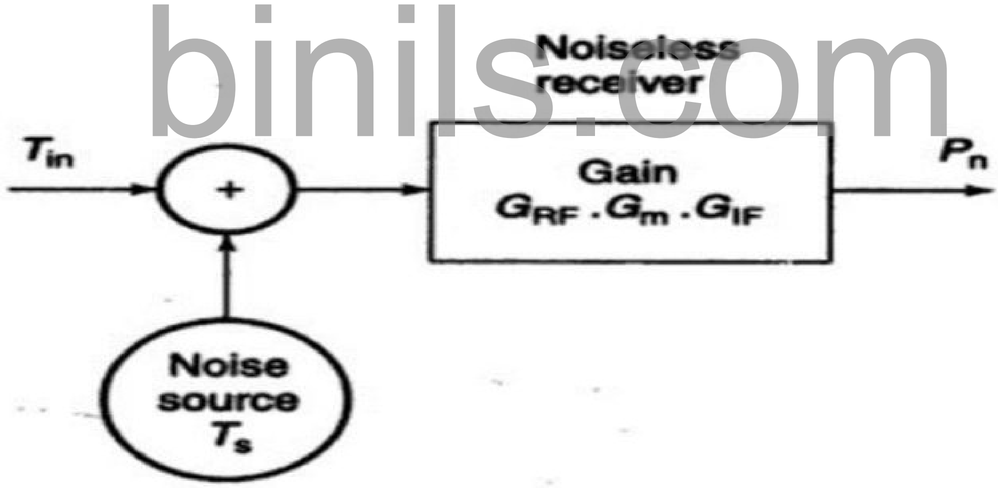
- The total noise power at the output of the IF amplifier of the receiver isgiven by

$$P_n = G_{IF}kT_{IF}B_n + G_{IF}G_mkT_mB_n + G_{IF}G_mG_{RF}kB_n(T_{RF} + T_{in})$$

This equation can be written as

$$\begin{aligned} P_n &= G_{IF}G_mG_{RF}[(kT_{IF}B_n)/(G_{RF}G_m) + (kT_mB_n)/G_{RF} + (T_{RF} + T_{in})] \\ &= G_{IF}G_mG_{RF}kB_n[T_{RF} + T_{in} + T_m/G_{RF} + T_{IF}/(G_{RF}G_m)] \end{aligned}$$

The single source of noise shown in above figure withnoise temperature Ts generates the same noise power Pn at its output



$$P_n = G_{IF}G_mG_{RF}kT_sB_n$$

$$kT_sB_n = kB_n[(T_{in} + T_{RF} + T_m/G_{IF} + T_{IF}/G_mG_{RF})]$$

So the system noise temperature is

$$T_s = [T_{in} + T_{RF} + T_m/G_{RF} + T_{IF}/(G_mG_{RF})]$$

Noise Figure

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

NF = (S/N)in /(S/N)out

Noise Temperature

- Noise temperature is more useful in satellite communication

systems, it isbest to convert noise figure to noise temperature, T

T = T0 (NF- 1)

- Where

NF is a linear ratio, not in decibels

T0 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

$$\frac{C}{N} = \left[\frac{P_tG_tG_r}{kT_sB_n}\right]\left[\frac{\lambda}{4\pi R}\right]^2 = \left[\frac{P_tG_t}{kB_n}\right]\left[\frac{\lambda}{4\pi R}\right]^2\left[\frac{G_r}{T_s}\right]$$

3 Downlink Design:

The design of any satellite communication is based on two objectives: a)meeting a minimum C/N ratio for a specified percentage of time, and b)carrying the maximum revenue earning traffic at minimum cost.

Any satellite link can be designed with very large antennas to achieve high C/N ratios under all conditions, but the cost will be high. The art of good system design is to reach the best compromise of system parameters that meets thespecificationat the lower cost.

Link Budget :

C/N ratio calculation is simplified by the use of link budgets.A link budget is a tabular method for evaluating the received power and noise power. Link budgets invariably use decibel units for all quantities so that signal and noise powers can be calculated by addition and subtraction.Since it is usually impossible to design a satellite link at the first attempt, link budgets make the task much easier because, once a link budget has been established, it is easy to change any of the parameters and recalculate the result.

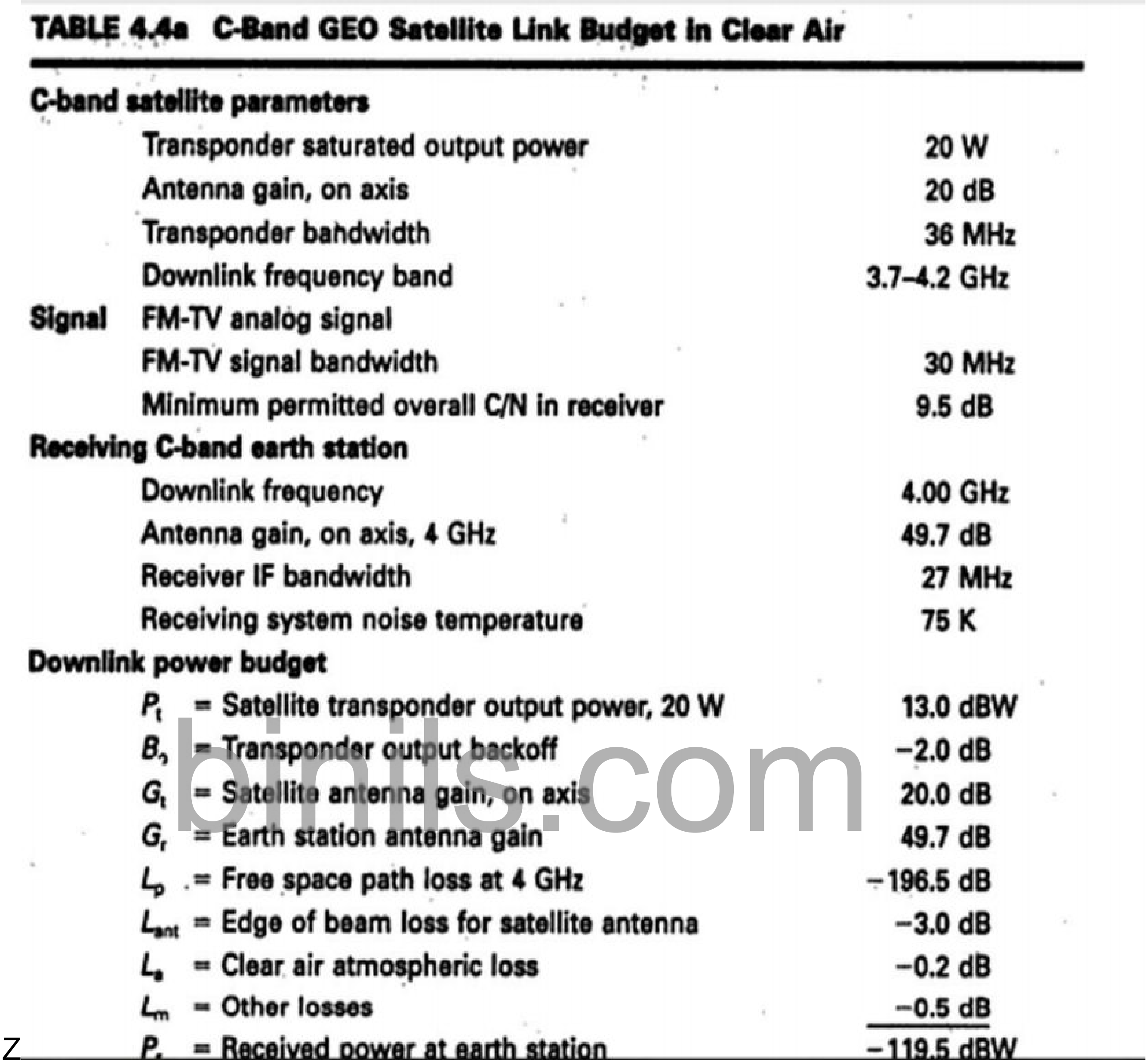


TABLE 4.4a C-Band GEO Satellite Link Budget in Clear Air

C-band satellite parameters		
	Transponder saturated output power	20 W
	Antenna gain, on axis	20 dB
	Transponder bandwidth	36 MHz
	Downlink frequency band	3.7–4.2 GHz
Signal	FM-TV analog signal	
	FM-TV signal bandwidth	30 MHz
	Minimum permitted overall C/N in receiver	9.5 dB
Receiving C-band earth station		
	Downlink frequency	4.00 GHz
	Antenna gain, on axis, 4 GHz	49.7 dB
	Receiver IF bandwidth	27 MHz
	Receiving system noise temperature	75 K
Downlink power budget		
	P_t = Satellite transponder output power, 20 W	13.0 dBW
	B_o = Transponder output backoff	−2.0 dB
	G_t = Satellite antenna gain, on axis	20.0 dB
	G_r = Earth station antenna gain	49.7 dB
	L_p = Free space path loss at 4 GHz	−196.5 dB
	L_{ant} = Edge of beam loss for satellite antenna	−3.0 dB
	L_a = Clear air atmospheric loss	−0.2 dB
	L_m = Other losses	−0.5 dB
	P_r = Received power at earth station	−119.5 dBW

Z

Downlink noise power budget in clear air

k	= Boltzmann's constant	−228.6 dBW/K/Hz
T_s	= System noise temperature, 75 K	18.8 dBK
B_n	= Noise bandwidth, 27 MHz	74.3 dBHz
N	= Receiver noise power	−135.5 dBW

C/N ratio in receiver in clear air

$$C/N = P_r - N = -119.5 \text{ dBW} - (-135.5 \text{ dBW}) = 16.0 \text{ dB}$$

3.4 Uplink Design:

- The Uplink design is easier than the downlink, since an accurately specified carrier power must be presented at the satellite transponder and it is often feasible to use much higher power transmitters at earth stations than can be usedon a satellite.
- The cost of transmitters tend to be high compared with the cost of receivingequipment in satellite communication system.

Earth station transmitter power is set by the power level required at the input to the transponder.

Analysis of the uplink requires calculation of the power level at the input to the transponder so that uplink C/N ratio can be found.

The link equation is used to make this calculation. Let (C/N)up be the specified C/N ratio in the transponder, measured in an noise bandwidth Bn Hz of the transponder. The noise power referred to the transponder input is N_{xp} W where

$$N_{xp} = k + T_{xp} + B_n \text{ dBW} \tag{4.36}$$

where T_{xp} is the system noise temperature of the transponder in dBK and B_n is in units of dBHz.

The power received at the input to the transponder is P_{rxp} where

$$P_{rxp} = P_t + G_t + G_r - L_p - L_{up} \text{ dBW} \tag{4.37}$$

where P_tG_t is the uplink earth station EIRP in dBW, G_r is the satellite antenna gain in dB in the direction of the uplink earth station and L_p is the path loss in dB. The factor L_{up} dB accounts for all uplink losses other than path loss. The value of $(C/N)_{up}$ at the LNA input of the satellite receiver is given by

$$C/N = 10 \log_{10}[Pr/(kT_sB_n)] = P_{rxp} - N_{xp} \text{ dB} \tag{4.38}$$

The earth station transmitter output power P_t is calculated from Eq. (4.23) using the given value of C/N in Eq. (4.38) and the noise power N_{xp} calculated from Eq. (4.36). Note that the received power at the transponder input is also given by

$$P_{rxp} = N + C/N \text{ dBW} \tag{4.39}$$

At frequencies above 10 GHz, propagating disturbances in the form of fading inrain causes the received power level at the satellite to fall. This lowers the uplink C/N ratio in the transponder ,which lowers the overall (C/N)o ratio in theearth station receiver.

Design for Specified C/N:

- When more than one C/N ratio is present in the link, we can add the individual C/N ratios reciprocally to obtain overall C/N ratio denoted as (C/N)o
- The overall (C/N)o ratio is

(C/N)o = 1/ [1/(C/N)1 + 1/(C/N)2 + ____]

- This sometimes referred as reciprocal C/N formula.
- The C/N values must be linear ratios, not decibel
- values.(C/N)o = C/(N1 + N2 +___)

In dB units :

(C/N)o = C dBW – 10log10 (N1 +N2 +_____) dB

C/N ratio at the receiver always yield (C/N)o , the combination of transponderand earth station C/N ratios

.

Satellite Communication Link Design Procedure:

1.Determine the frequency band in which system must operate. Comparativedesigns may be required to help make the selection.

2.Determine the communications parameters of the satellite. Estimate anyvalues that are not known.

3.Determine the parameters of the transmitting andreceiving earth stations.

4.4.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 outputbackoff.

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. Changeparameters of the system as required to obtain acceptable (C/N)0 or S/N or BER values. This may require several trial designs. Determine the propagation conditions under which the link must operate.Calculate outage times for the uplinks and downlinks.

9. Redesign the system by changing some parameters if the link margins are inadequate. Check that all parameters are reasonable, and that the design can beimplemented within the expected budget.

1. Satellite uplink and downlink Analysis and Design:

1.1 Introduction

This chapter describes how the link-power budget calculations are made. These calculations basically relate two quantities, the transmit power and the receive power, and show in detail how the difference between these two powers is accounted for.

Link-budget calculations are usually made using decibel or decilog quantities. These are explained in App. G. In this text [square] brackets are usedto denote decibel quantities using the basic power definition.

Where no ambiguity arises regarding the units, the abbreviation dB is used. For example, Boltzmann's constant is given as 228.6 dB, although, strictly speaking, this should be given as 228.6 deci logs relative to 1 J/K.

1.2 Equivalent Isotropic Radiated Power

A key parameter in link-budget calculations is the *equivalent isotropic radiated power*, conventionally denoted as EIRP. From Eqs, the maximum power flux density at some distance *r* from a transmitting antenna of gain *G* i

An isotropic radiator with an input power equal to GP*S* would produce the sameflux density.

1.3 Transmission Losses

The [EIRP] may be thought of as the power input to one end of the transmissionlink, and the problem is to find the power received at the other end. Losses will occur along the way, some of which are constant. Other losses can only be estimated from statistical data, and some of these aredependent on weather conditions, especially on rainfall.

The first step in the calculations is to determine the losses for *clear-weather* or *clear-sky conditions*. These calculations take into account the losses, including those calculated on a statistical basis, which do not vary significantly with time. Losses which are weather-related, and other losses which fluctuate with time, are then allowed for by introducing appropriate *fade margins* into the transmission equation.

Free-space transmission:

As a first step in the loss calculations, the power loss resulting from the spreadingof the signal in space must be determined.

Feeder losses:

Losses will occur in the connection between the receive antenna and the receiver proper. Such losses will occur in the connecting waveguides, filters, and couplers.Thesewill be denotedby RFL,or[RFL]dB, for*receiver feeder losses*.

Antenna misalignment losses:

When a satellite link is established, the ideal situation is to have the earth station and satellite antennas aligned for maximum gain, as shown in Fig.

The off-axis loss at the satellite is taken into account by designing the link for operation on the actual satellite antenna contour; this is described in more detail in later sections. The off-axis loss at the earth station is referred to as the *antenna pointing loss*. Antenna pointing losses are usually only a few tenths of a decibel; In addition to pointing losses, losses may result at the antenna from misalignment of the polarization direction (these are in addition to the polarization losses The polarization misalignment losses are usually small, and it will be assumed that the antenna misalignment losses, denoted by [AML], include both pointing and polar- ization losses resulting from antenna misalignment. It should be noted

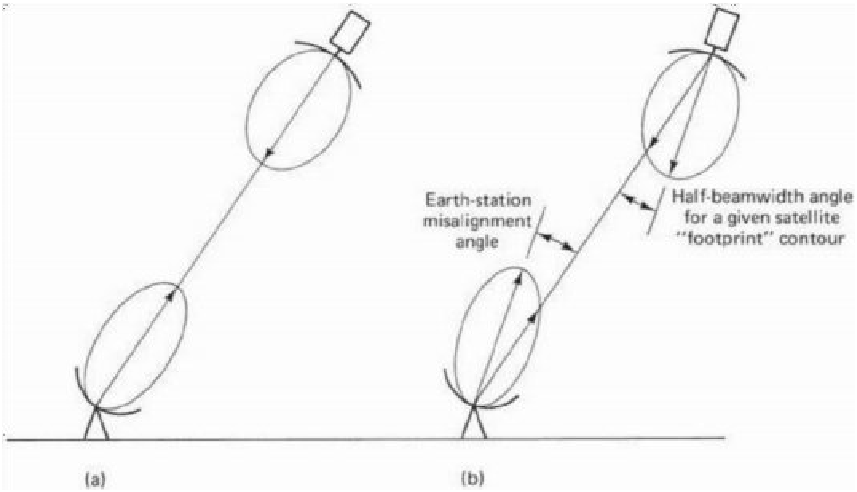


Figure 2.15 (*a*) Satellite and earth-station antennas aligned for maximum gain; (*b*) earth station situated on a given satellite “footprint,” and earth-station antenna misaligned.

. The Link-Power Budget Equation:

Now that the losses for the link have been identified, the power at the receiver, which is the power output of the link, may be calculated simply as [EIRP] [LOSSES] [*GR*], where the last quantity is the receiver antenna gain.

Note carefully that decibel addition must be used. The major source of loss in any ground-satellite link is the free-space spreading loss [FSL], the basic link- power budget equation taking into account this loss only. However, the other losses also must be taken into account, and these are simply added to [FSL]. Thelosses for clear-sky conditions are

[LOSSES] = [FSL] + [RFL] + [AML] + [AA] - [PL] equation for the received power is then

[*PR*] = [EIRP] x [*GR*] - [LOSSES]

where [PR] received power, dBW
[EIRP] equivalent isotropic radiated power, dBW [FSL] free-spacespreading loss, dB

[RFL] receiver feeder loss, dB

[AML] antenna misalignment loss, dB

[AA] atmospheric absorption loss, dB [PL] polarization mismatch loss, dB

2 Amplifier noise temperature

Consider first the noise representation of the antenna and the *low noise amplifier* (LNA) shown in Fig. 2.15. The available power gain of the amplifier is denoted as *G*, and the noise power output, as *P*no.

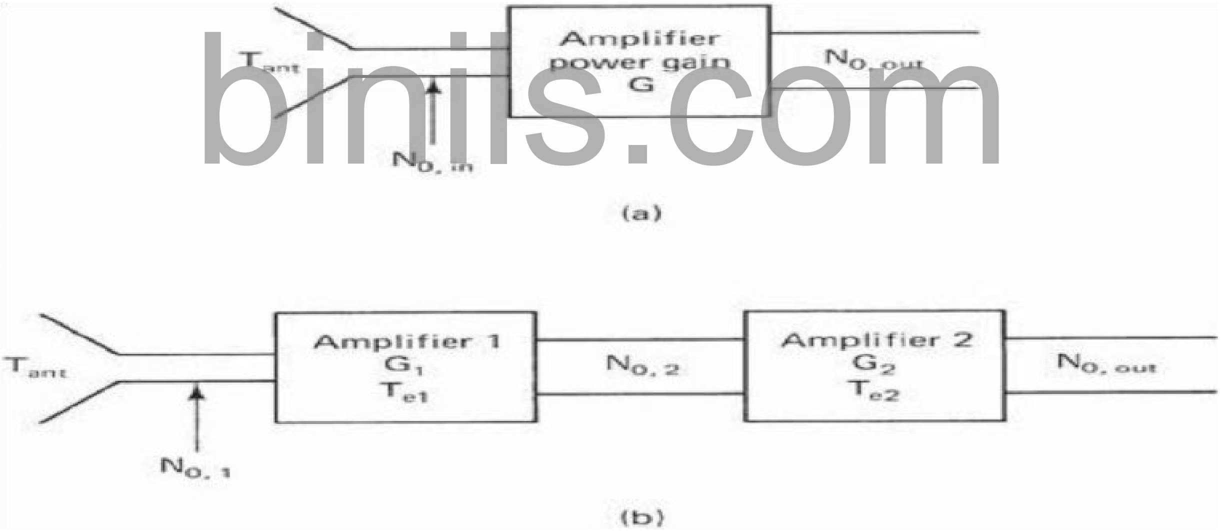


Figure LNA Amplifier gain

Figure Source of Dennis Roddy –Satellite Communication ,4th Edition

For the moment we will work with the noise power per unit bandwidth, which issimply noise energy in joules as shown by Eq. The input noise energy coming from the antenna is *N*0,ant = *kT*ant