Unit-3 Satellite Link Design

Basic Transmission Theory:

→ The calculation of the power received by an earth station from a satellite transmitter is fundamental to the understanding of satellite communications.

→ There are two approaches to this calculation, the use of flux density and the link equation.

→ Consider a transmitting source, in free space, radiating a total power (P_t) watts uniformly in all directions (isotropic source). *(physically cannot be realized)*

→ At a distance (R) meters from isotropic source transmitting RF power P_t watts, the flux density crossing the surface of a sphere with radius R is given by.

$$F = \frac{P_t}{4\pi R^2} \; W/m^2 \qquad (1)$$

→ All real antennas are directional and radiate more power in some directions than in others.

→ Any real antenna has a gain $G(\theta)$, defined as the ratio of power per unit solid angle radiated in a direction θ to the average power radiated per unit solid angle.

$$G(\theta) = \frac{P(\theta)}{P_0/4\pi} \quad \text{— (2)}$$

where,

$P(\theta) \rightarrow$ power radiated per unit solid angle by antenna.

$P_0 \rightarrow$ total power radiated by antenna.

$G(\theta) \rightarrow$ gain of antenna at an angle θ.

→ The reference ~~angle~~ for the angle θ is usually taken to be the direction in which maximum power is radiated, often called the boresight direction of the antenna.

→ The gain of the antenna is then the value of $G(\theta)$ at angle $\theta = 0^\circ$, and is a measure of the increase in flux density radiated by the antenna over that from an ideal isotropic antenna radiating the same total power.

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

$$F = \frac{P_t G_t}{4\pi R^2} \ W/m^2 \quad \text{— (3)}$$

→ The product $P_t G_t$ is often called the effective isotropically radiated power (EIRP).

→ If we had an ideal receiving antenna with an aperture ①
area of A m^2, as shown in Fig, we would collect
power P_r watts given by

$$P_r = F \times A \text{ watts}$$

→ A practical antenna with a physical aperture area of A_r m^2 will not deliver the power given in Eq. Some of the energy incident on the aperture is reflected away from the antenna, and some is absorbed by lossy components. This reduction in efficiency is described by using an effictive aperture A_e where

$$\cancel{A_e = \eta A}$$

$$A_e = \eta_A A_r$$

and η_A is the aperture efficiency of the antenna².

→ Thus the power received by a real antenna with a physical receiving area A_r and effective aperture area A_e m^2 is

$$P_r = \frac{P_t G_t A_e}{4\pi R^2} \text{ watts}$$

→ A fundamental relationship in antenna theory² is that the gain and area of an antenna are reflected by

$$G = 4\pi A_e / \lambda^2$$

where λ is the wavelength (in meters) at the frequency of operation

substituting for A_e in Eq gives

$$\boxed{P_r = \frac{P_t G_t G_r}{(4\pi R/\lambda)^2}} \text{ watts}$$

This expression is known as the link equation, and it is essential in the calculation of power received in any radio link.

→ The term $[4\pi R/\lambda]^2$ is known as the path loss L_p.

collecting the various factor, we can write

$$\text{Power received} = \frac{\text{EIRP} \times \text{Receiving antenna gain}}{\text{path loss}} \text{ watts}$$

In communication systems, decibel quantities are commonly used to simplify equations like eq. In decibel terms, we have

$$\boxed{P_r = \text{EIRP} + G_r - L_p} \text{ dBW}$$

where

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

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

path loss $L_p = 10 \log_{10} [(4\pi R/\lambda)^2] = 20 \log_{10} (4\pi R/\lambda) \text{ dB}$

equation represents an idealized case, in which there are no additional losses in the link. It describes transmission between two ideal antennas in otherwise empty space. In practice, we will need to taken account of a more complex situation in which we have losses in the atmosphere due to attenuation by oxygen, water vapor, and rain, losses in the antennas at each end of the link, and possible reduction in antenna gain due to mis-pointing. (2)

more generally, Eq can be written

$$\boxed{P_r = EIRP + G_r - L_p - L_a - L_{ta} - L_{ra}} \text{ dBW}$$

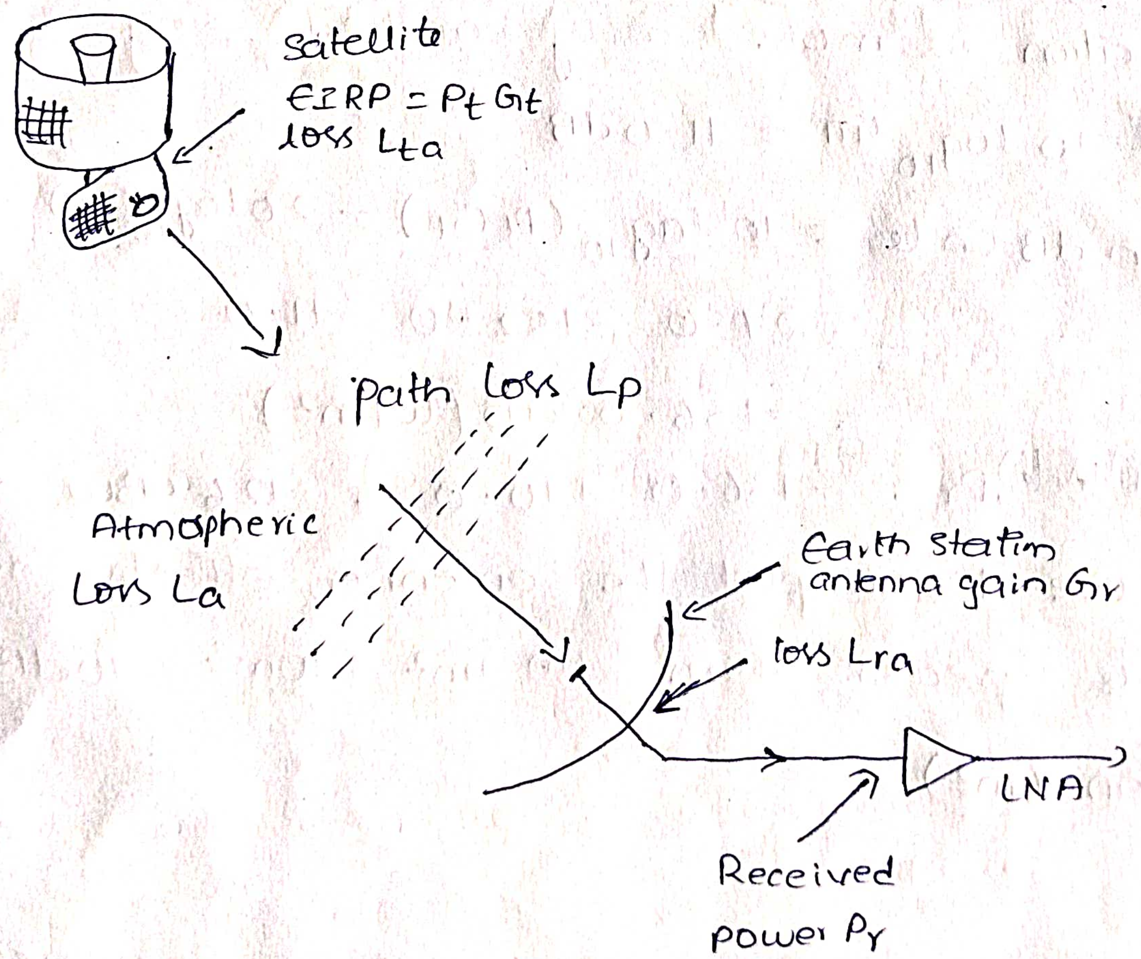
where

L_a = attenuation in atmosphere

L_{ta} = Losses associated with transmitting antenna

L_{ra} = Losses associated with receiving antenna

The conditions in Eq are illustrated in Fig



Problem: A satellite at a distance of 40,000 km from a point on the earth's surface radiates a power of 10W from an antenna with a gain of 17dB in the direction of the observer. Find the flux density at the receiving point, and the power received by an antenna at this point with an effective area of $10 m^2$

Using eq

$$F = P_t G_t / (4\pi R^2) = 10 \times 50 / (4\pi \times (4 \times 10^7)^2).$$

$$= 2.49 \times 10^{-14} \ w/m^2$$

The power received with an effective collecting area of $10 m^2$ is therefore, $P_r = F \times A_e$

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

The calculation is more easily handled using decibels

Noting that $10 \log_{10} 4\pi = 11.0 dB$

$$F \text{ in dB units} = 10 \log_{10} (P_t G_t) - 20 \log_{10} (R) - 11.0$$

$$= 27.0 - 152.0 - 11.0$$

$$= -136.0 \ dB(w/m^2)$$

Then, $P_{r(dB)} = F(dB) + A_e(dB)$, $P_r = -136.0 + 10.0 = -126 \ dBW$

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

Example :-

The satellite in Example operates at the frequency of 11 GHz. The receiving antenna has a gain of

52.3 dB. Find the received power.

using Eq and working in decibels

P_r = EIRP + G_r − path loss (dBW)

EIRP = 27.0 dBW

G_r = 52.3 dB

path loss = $(4\pi R/\lambda)^2$ = $20\log_{10}(4\pi R/\lambda)$ dB

= $20\log_{10}[(4\pi \times 4\times10^{7})/(2.727\times10^{-2})]$ dB

= −205.3 dB

P_r = 27.0 + 52.3 − 205.3 = −126.0 dBW

we have the same answer as in Example because the figure of 52.3 dB is the gin of a 10 m^2 aperture at a frequency of 11 GHz.

System Noise Temperature and G/T Ratio :-

1 Noise Temperature :-

→ Noise Temperature is a useful concept in Communications receivers, since it provides a way of determining how much thermal noise is generated in the receiving system.

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

The noise power is given by

$$\boxed{P_n = k\,T_p\,B_n} \quad \text{--- (1)}$$

Where,

k = Boltzmann's Constant = 1.39×10^{-23} J/K.

T_p = physical Temperature of Source in kelvin degrees.

B_n = noise bandwidth (Hz).

P_n → Available noise power (W)

→ In Satellite communication systems, there are weak signals (because of large distances involved) and must make the noise level as low as possible to meet the C/N ratio requirements.

→ This is done by making the bandwidth in the receiver, usually set by the IF amplifier stages, to be just large enough to allow the signal (Carrier and sidebands) to pass unrestricted, while keeping the noise power to the lowest value possible.

→ To determine the performance of a receiving system, the total thermal noise power ~~[illegible]~~ need to be found against which the signal must be demodulated.

→ It can be done by determing system noise temperature T_s..

→ T_s is the noise temperature of a noise source, located at the input of a noiseless receiver, which gives the same noise power as the original receiver, measured at the output of the receiver and usually includes noise from the antenna.

→ If the overall end-to-end gain of the receiver is G_{rx} (G_{rx} is a ratio, not in decibels) and its narrowest bandwidth is B_n Hz, the noise power at the demodulator input is

$$\boxed{P_{no} = k\, T_s\, B_n\, G_{rx} \text{ Watts.}} \quad \text{—— (2)}$$

Where, G_{rx} is the gain of the receiver from RF input to demodulator input.

→ The noise power referred to the input of the receiver is P_n where,

$$\boxed{P_n = k\, T_s\, B_n \text{ watts.}} \quad \text{—— (3)}$$

→ let the antenna deliver a signal power P_r watts to the receiver RF input.

→ The signal power at the demodulator input is $P_r G_{rx}$ watts, representing the power contained in the carrier and sidebands. after amplification and frequency conversion within the receiver.

→ Hence, the carrier-to-noise ratio at the demodulator is given by,

$$\boxed{\frac{C}{N} = \frac{P_r G_{rx}}{k T_s B_n G_{rx}} = \frac{P_r}{k T_s B_n}} \quad \text{—— (4)}$$

(2) Calculation of System Noise Temperature:

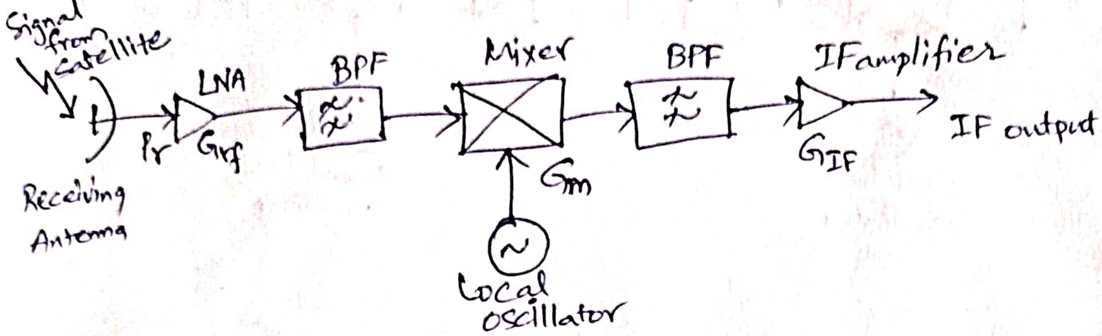


Figure 1. Simplified earth station receiver.

→ Figure 1. shows simplified communications receiver with an RF amplifier and single frequency conversion, from its RF input to the IF output.

→ This the form used for all radio receivers, with few exceptions, known as superhet (shortform of superheterodyne).

→ The superhet receiver has three main subsystems, a front end (RF amplifier, mixer and local oscillator) an IF amplifier (IF amplifiers and filters), and a demodulator.

→ The RF amplifier in a satellite communications receiver must generate as little noise as possible, so it is called a low noise amplifier or LNA.

→ The mixer and local oscillator form a frequency conversion stage that downconverts the RF signal to a fixed intermediate frequency (IF), where the signal can be amplified and filtered accurately.

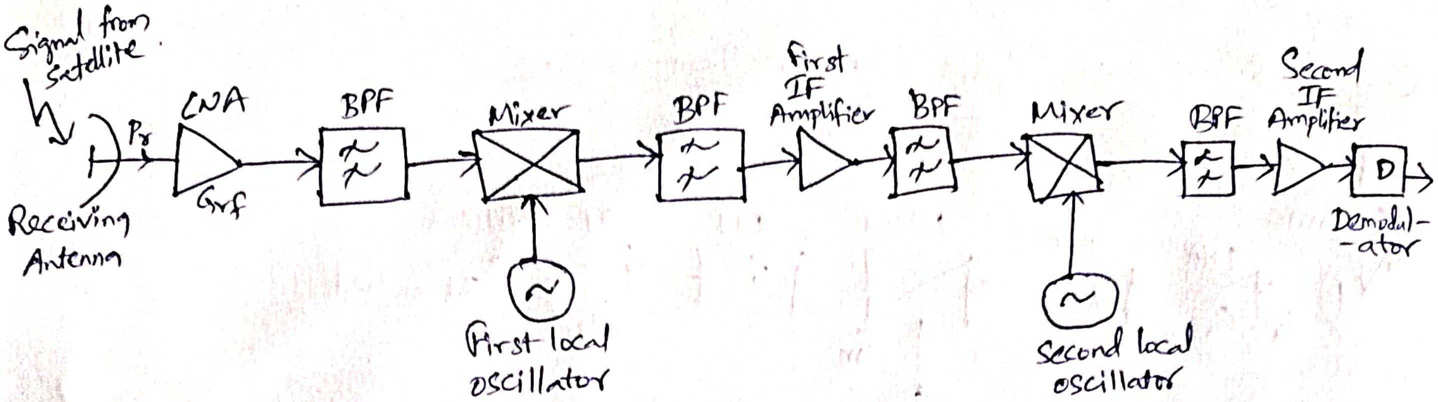


Figure 2. Double conversion earth station receiver.

→ Many earth station receivers use the double superhet configuration shown in figure 2.

→ The front end of the receiver is mounted behind the antenna feed and converts the incoming RF signal to a first IF ~~to~~ ~~the~~ signal.

→ The RF amplifier has a high gain and the mixer is followed by a stage of IF amplification. This section of the receiver is called a "low noise block converter" (LNB).

→ The IF signal is sent over a coaxial cable to a set-top receiver that contains another down-converter and a tunable local oscillator.

→ The local oscillator is tuned to convert the incoming signal from first IF amplifier to a second IF frequency and amplified further and guided to a demodulator.

→ The equivalent circuits in fig.4.7 can be used to represent a receiver for the purpose of noise analysis.

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

3

→ The entire receiver is then reduced to a single equivalent noiseless block with the same end-to-end gain as the actual receiver and a single noise source at its input with temperature T_n

→ The total noise power at the output of the IF amplifier of the receiver in Figure 4·7 a is given by

$$P_n = G_{IF} K T_{IF} B_n + G_{IF} G_m K T_m B_n + G_{IF} G_m G_{RF} K B_n (T_{RF} + T_{in}) \quad (4\text{-}15)$$

→ where G_{RF}, G_m, and G_{IF} are the gains of the RF amplifier, mixer, and IF amplifier, and T_{RF}, T_m, and T_{IF} are their equivalent noise temperatures

→ T_{in} is the noise temperature of the antenna, measured at its output port.

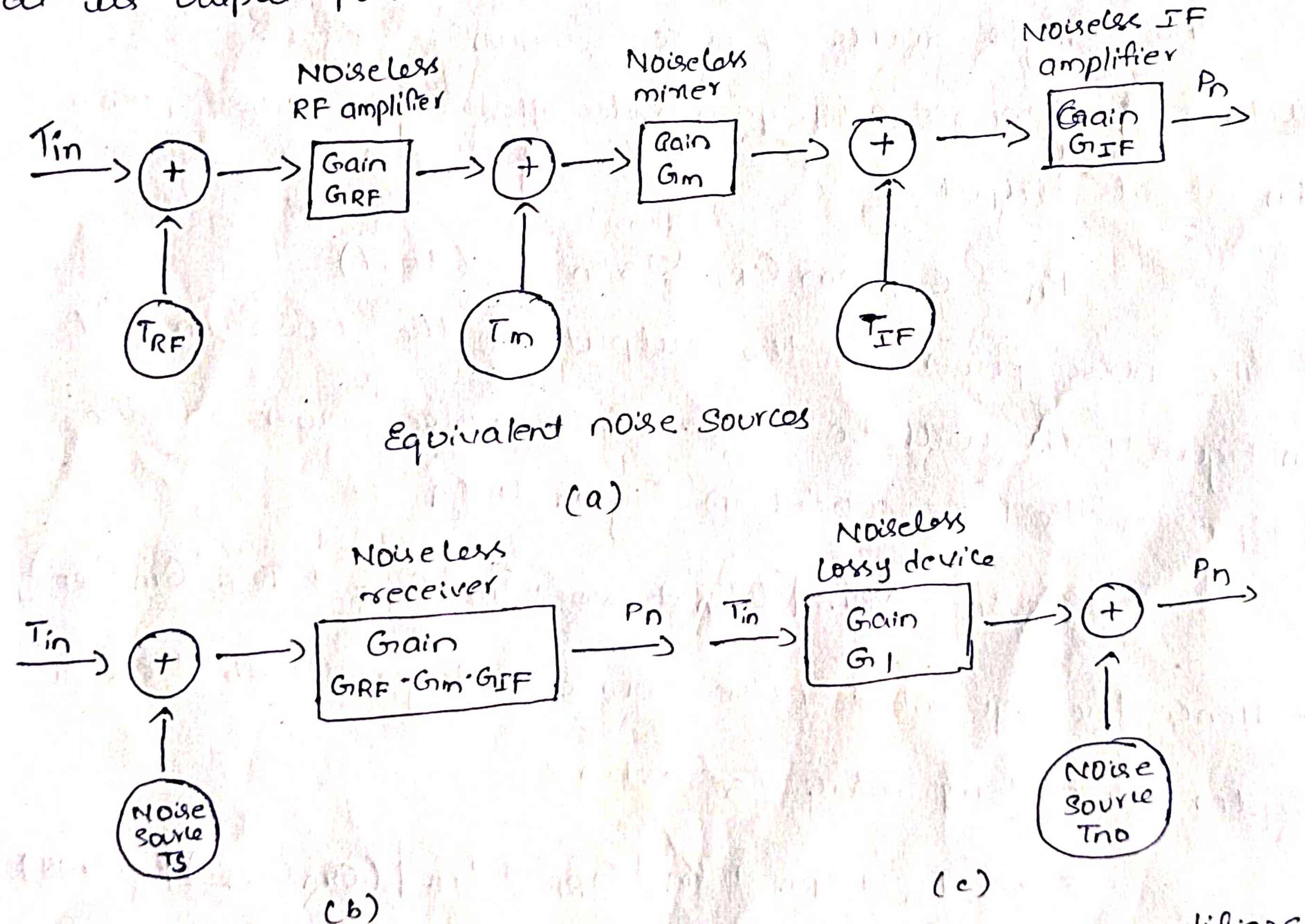


Figure 4·7 (a) Noise model of receiver. The noisy amplifiers and downconverter have been replaced by noiseless units with equivalent noise generators at their inputs.

(b) Noise model of receiver

All noisy units have been replaced by one noiseless amplifier, with a single noise source T_s as its input.

(c) Noise model for a lossy device :

-> The lossy device has been replaced by a lossless device, with a single noise source T_{no} at its output

Equation (4.15) can be rewritten as

$$P_n = G_{IF} G_m G_{RF} [(KT_{IF} B_n) / (G_{RF} G_m) + (KT_m B_n) / G_{RF} + KB_n (T_{RF} + T_{in})]$$

$$= G_{IF} G_m G_{RF} KB_n [T_{RF} + T_{in} + T_m / G_{RF} + T_{IF} / (G_{RF} G_m)] \quad (4.16)$$

The single source of noise shown in Figure 4.7b with noise temperature T_s generates the same noise power P_n at its output if

$$P_n = G_{IF} G_m G_{RF} KT_s B_n \quad (4.17)$$

-> The noise power at the output of the noise model in Figure 4.7b will be same as the noise power at the output of the noise model in Figure 4.7a if

$$KT_s B_n = KB_n [(T_{in} + T_{RF} + T_m / G_{IF} + T_{IF} / G_m G_{RF})]$$

-> Hence the equivalent noise source in Figure 4.7b has a system noise Temperature T_s where

$$T_s = [T_{in} + T_{RF} + T_m / G_{RF} + T_{IF} / (G_m G_{RF})] \quad (4.18)$$

succeeding stages of the receiver contribute less and less noise to the total system noise temperature

-> Frequently, when the RF amplifier in the receiver

front end has a high gain, the noise contributed by (4)
the IF amplifier and later stages can be ignored and the
system noise temperature is simply the sum of the antenna
noise temperature and the LNA noise temperature, so

$T_S = T_{antenna} + T_{LNA}$

→ The noise model shown in Figure 4.7b replaces all the individual sources of noise in the receiver by a single noise source at the receiver input.

→ This assumes that all the noise comes in from the antenna or is internally generated in the receiver.

→ In some circumstances, we need to use a different model to deal with noise that reaches the receiver after passing through a lossy medium.

→ waveguide and rain losses are two examples.

→ when rain-drops cause attenuation, they radiate additional noise whose level depends on the attenuation.

→ we can model the noise emission as a noise source placed at the "output" of the atmosphere, which is the antenna aperture.

→ The noise model for an equivalent output noise source is shown in Figure 4.7c, and produces a noise temperature T_{no} given by

$$T_{no} = T_P (1 - G_1) \qquad (4.19)$$

where G_1 is the linear gain (less than unity, not in decibels) of the attenuating device or medium, and T_P is the physical temperature in degrees kelvin of the device or medium

For an attenuation of A dB, the value of G_1 is given by

$$G_1 = 10^{A/10}$$

Noise Figure and Noise Temperature

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

→ The operational noise figure (NF) is defined by the following formula[4]:

$$NF = \frac{(S/N)_{in}}{(S/N)_{out}} \qquad (4.21)$$

→ Because noise temperature is more useful in satellite communication systems, it is best to convert noise figure to noise Temperature, T_d.

The relationship is

T_0 → reference temperature usually 290 K.

$$T_d = T_0(NF - 1) \qquad (4.22)$$

G/T Ratio for Earth stations

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

$$\frac{C}{N} = \left[\frac{P_t G_t G_r}{K T_s B_n}\right]\left[\frac{\lambda}{4\pi R}\right]^2 = \left[\frac{P_t G_t}{K B_n}\right]\left[\frac{\lambda}{4\pi R}\right]^2 \left[\frac{G_r}{T_s}\right] \qquad (4.23)$$

Thus $C/N \propto G_r/T_s$, and the terms in the square brackets are all constants for a given satellite system. The ratio G_r/T_s, which is usually quoted as simply G/T in decibels, with units dB/K, can be used specify the quality of a receiving earth station or a satellite receiving system, since increasing G_r/T_s increases the received C/N ratio.

Design of Downlinks

-> 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 the specification at the lowest cost.

-> All satellite communications links are affected by rain attenuation

-> In the 6/4 GHz band the effect of rain on the link is small

-> In the 14/11 GHz (Ku) band, and even more so in the 30/20 GHz (Ka) band, rain attenuation becomes all important

-> Satellite links are designed to achieve reliabilities of 99.5 to 99.99%, averaged over a long period of time

-> That means the C/N ratio in the receiver will fall below the minimum permissible value for proper operation of the link for between 0.5 and 0.01% of the specified time; the link is then said to suffer on outage

-> Rain attenuation is a very variable phenomenon, both with time and place.

-> C-band links can be designed to achieve 99.99% reliability because the rain attenuation rarely exceeds 1 or 2 dB.

-> The time corresponding to 0.01% of a year is 52 min; at this level of probability the rain attenuation statistics are ~~usually~~ usually not stable and wide fluctuations occur from year to year

→ Most ka-band links cannot be designed to achieve 99.99% reliability because rain attenuation generally exceeds 10 dB, and often 20dB, for 0.01% of the time.

→ outage times of 0.1 to 0.5% of a year (8 to 40h) are usually tolerated in ka-band links

→ The allowable outage time for a link depends in part on the traffic carried.

→ Telephone traffic needs real-time channels that are maintained for the duration of a call, so C band or Ku band is used for voice channels with sufficient link margin that outage times are small.

→ Internet transmissions are less affected by short outages and generally do not require a real-time channel, making ka band better suited for internet access

Link Budgets:

→ 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 in a radio link

→ 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.

Examples:-

Table 4.4a and 4.4b show a typical link budget for a C-band downlink using a global beam on a GEO satellite and a 9-m earth station antenna

→ The link budget must be calculated for an individual transponder, and must be repeated for each of the individual links

→ In a two-way satellite communication link there will be four seperate links, each requiring a calculation of C/N ratio.

→ when a bent pipe transponder is used the uplink and downlink C/N ratios must be combined to give an overall C/N. In this section we will calculate the C/N ratio for a single link.

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
Down link 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 back off	-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

Downlink noise power budget in clear air

k	= Boltzmann's constant	-228.6 dBW/k/Hz
T_s	= system noise temperature, 75K	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

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

→ link budgets are usually calculated for a worst case, the one in which the link will have the lowest C/N ratio.

→ Factors which contribute to a worst case scenario include; an earth station located at the Edge of the satellite coverage zone where the received signal is typically 3dB lower than in the center of the zone because of the satellite antenna pattern, maximum path length from the satellite to the earth station, a ~~lowo~~ low elevation angle at

TABLE 4.4b C-Band Downlink Budget in Rain

P_{rca} = Received power at earth station in clear air	−119.5 dBW
A = Rain attenuation	− 1.0 dB
P_{rain} = Received power at earth station in rain	−120.5 dBW
N_{ca} = Receiver noise power in clear air	−135.5 dBW
ΔN_{rain} = increase in noise temperature due to rain	2.3 dB
N_{rain} = Receiver noise power in rain	−133.2 dBW

C/N ration in receiver rain

$$C/N = P_{rain} - N_{rain} = -120.5\ dBW - (-133.2\ dBW) = 12.7 dB$$

the earth station ~~giving the~~ giving the highest atmospheric path attenuation in clear air, and maximum rain attenuation on the link causing loss of received signal power and an increase in receiving system noise temperature.

→ Earth station antennas are assumed to be pointed directly at the satellite, and therefore operate at their on-axis gain

→ If the antenna is mispointed, a loss factor is included in the link budget to account for the reduction in the antenna gain.

→ The calculation of carrier to noise ratio in a satellite link is based on the two equations for received signal power and receiver noise power

→ the received carrier power in dB watts as

$$\boxed{P_r = EIRP + G_r - L_p - L_a - L_{ra} - L_{ta}} \ dBW \qquad (4.24)$$

A receiving terminal with a system noise temperature T_s K and a noise bandwidth B_n Hz has a noise power P_n referred to the output terminals of the antenna where

$$P_n = kT_sB_n \text{ watts} \qquad (4.25)$$

→ The saturated output power of the transponder is 20W = 13 dBW. (4)

→ We will assume an output back-off of 2dB, so that the power transmitted by the transponder is 11 dBW.

→ Hence the on-axis EIRP of the transponder and antenna is $P_t G_t = 11 + 20 = 31$ dBW.

→ The transmitted signal signal is a single 30-MHz bandwidth analog FM-TV channel in this example. [Following common practice for analog TV transmission, the receiver noise bandwidth is set to 27 MHz, slightly less than the 30-MHz bandwidth of the FM-TV signal.

→ The receiving earth station has an antenna with an aperture diameter of 9m and a gain of 49.7 dB at 4GHz, and a receiving system noise temperature of 75K in clear air conditions.

→ The G/T ratio for this earth stations is $G/T = 49.7 - 10\log_{10} 75 = 30.9\ dBK^{-1}$,

→ The maximum path length for a GEO satellite link is 40,000 km, which gives a path loss of 196.5 dB at 4 GHz ($\lambda = 0.075$m)

→ At C band, propagation losses are small, but the slant path through the atmosphere will suffer a typical attenuation of 0.2dB in clear air.

→ We will allow an additional 0.5-dB margin in the link design to account for miscellaneous losses, such as antenna mispointing, polarization mismatch, and antenna degradation, to ensure that the link budget is realistic.

→ The earth station receiver C/N ratio is first calculated for clear air conditions, with no rain in the slant path.

→ The C/N ratio is then recalculated taking account of the effects of rain

→ The minimum permitted overall C/N ratio for this link is 9.5dB, corresponding to the FM threshold of an analog satellite TV receiver.

→ Table 4.4a shows that we have a downlink C/N of 16.0 dB in clear air, giving a link margin of 6.5dB.

→ This link margin is available in clear air conditions, but will be reduced when there is rain in the slant path.

→ Heavy rain in the slant path can cause up to 1dB of attenuation at 4GHz

→ Using the output noise model discussed in the previous section with a medium temperature of 273 K, and a total slant path loss for clear air (0.2dB) plus rain (1dB) of 1.2dB (ratio of 1.32), the sky noise temperature in rain is

$$T_{sky} = 273 \times (1 - 1/1.32) = 66K.$$

→ In general in clear air the sky noise temperature is about 13K.

→ The noise temperature of the receiving system has therefore increased by (66 - 13)K = 53K to 75K + 53K = 128 K with 1dB rain attenuation in the slant path. from a clear air value of 75K. This is a increase in system noise temperature of 2.3dB.

$10 \log(75) = 18.75\text{ dB}$
$10 \log(128) = 21.07\text{dB}$

$21.07 - 18.75 = 2.32\text{dB}$

→ The received carrier power is reduced by 1dB because of the rain attenuation and the system noise temperature is increased by 2.3 dB. Table 4.4b shows the new downlink budget in rain.

→ The C/N ratio in rain has a margin of 3.2dB over the minimum permissible C/N ratio of 7.5 dB for an analog FM - TV transmission.

→ The C/N margin will translate into a higher than needed S/N ratio in the TV baseband signal, and can be traded off against earth station antenna gain to allow the use of smaller (and therefore lower cost) antenna.

UPLINK DESIGN

→ The uplink design is easier than the downlink in many cases, 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 that can be used on a satellite

→ However, VSAT systems use earth stations with small antennas and transmitter powers below 5W, giving low uplink EIRP.

→ satellite telephone handsets are restricted to transmitting at power levels below 1W because of the risk of em radiation hazards.

→ In mobile systems the uplink from the satellite telephone is usually the link with the lowest C/N ratio

→ The cost of transmitters tends to be high compared with the cost of receiving equipment in satellite communication systems.

→ The major growth in satellite communications has been in point-to-multipoint transmission, as in cable TV distribution and direct broadcast satellite television.

→ one high-power transmit earth station provides service via a DBS satellite to many low-cost receive-only stations, and the high cost of the transmitting station is only a small part of the total network cost.

→ The satellite transponder is a quasilinear amplifier and the received carrier level determines the output level.

→ where a traveling wave tube is used as the output high-power amplifier (HPA) in the transponder, as is often the case, and FDMA is employed, the HPA must be run with a predetermined backoff to avoid inter modulation products appearing at the output

→ The output backoff is typically 1 to 3 dB when more than one signal is present in the transponder, and is determined by the uplink carrier power level received at the spacecraft.

→ Accurate control of the power transmitted by the earth station is therefore essential, which is easily achieved in a fixed network of earth stations.

→ where a very large number of earth stations access a single transponder using FDMA, such as in some USAT networks and intelsat satellites, transponder output backoff of 5 to 7 dB may be required to maintain inter modulation products at a sufficiently low level 10.

-) Even with a single access to the transponder (i.e., only one carrier present) some backoff is normally applied to avoid the PM-AM conversion that occurs when modulated signals are transmitted through nonlinear devices.

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

-) This can be done in one of two ways:

-) Either a specific flux density is required at the satellite, or a specific power level is required at the input to the transponder.

-) Early Intelsat C-band satellites required high flux densities to saturate their transponders, in the range -73.7 to -67.5 dBW/m^2, depending on the transponder gain setting.

-) This is a high flux density which requires a large earth station and a powerful transmitter generating up to 3kW.

-) Domestic GEO satellites operating into North America generally require lower flux densities allowing the use of smaller earth station antennas.

-) At C band, a typical uplink earth station transmits 100W with a 9-meter antenna, giving a flux density at the satellite of -100 W/m^2

-) Although flux density at the satellite is a convenient way to determine earth station transmit EIRP requirements, analysis of the uplink requires calculation of the power level at the input to the transponder so that the uplink C/N ratio can be found.

→ The link equation is used to make this calculation, using either a specified transponder C/N ratio or a required transponder output power level.

→ when a C/N ration is speciefied for the transponder the calculation of required transmit power is straight forward.

→ let $(C/N)_{up}$ be the specified C/N ratio in the transponder, measured in a noise bandwidth B_n Hz.

→ The Bandwith B_n Hz is the bandwidth of the band-pass filter in the IF stage of the earth station receiver for which the uplink signal is intended.

→ Even if B_n is much less than the transponder bandwidth, it is important that the uplink C/N ratio be calculated in the bandwidth of the receiver, not the bandwidth of the transponder.

→ The noise power reffered to the transponder input is N_{xp} W where

$$\boxed{N_{xp} = k + T_{xp} + B_n} \text{ dBW} \qquad (4.36)$$

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

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

$$\boxed{P_{rxp} = P_t + G_t + G_r - L_p - L_{up}} \text{ dBW} \qquad (4.37)$$

7

where $P_t G_t$ is the uplink earth station EIRP in dBW, G_r is the ~~sta~~ 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

$$\boxed{(C/N)_{up} = 10\log_{10}[P_r/(kT_s B_n)] = P_{rxp} - N_{xp}} \text{ dB} \qquad (4.38)$$

in dB

~~-> when~~

-> with a small-diameter earth stations, a higher power earth station transmitter is required to acheive a similar satellite EIRP.

-> This has the disadvantage that the interference level at adjacent satellite rises, since the small earth stations antenna inevitably has a wider beam

-> Thus it is not always possible to trade off transmitter power against uplink antenna size.

-> There is a specification for transmit station antenna patterns, designed to minimize interference from adjacent uplinks.

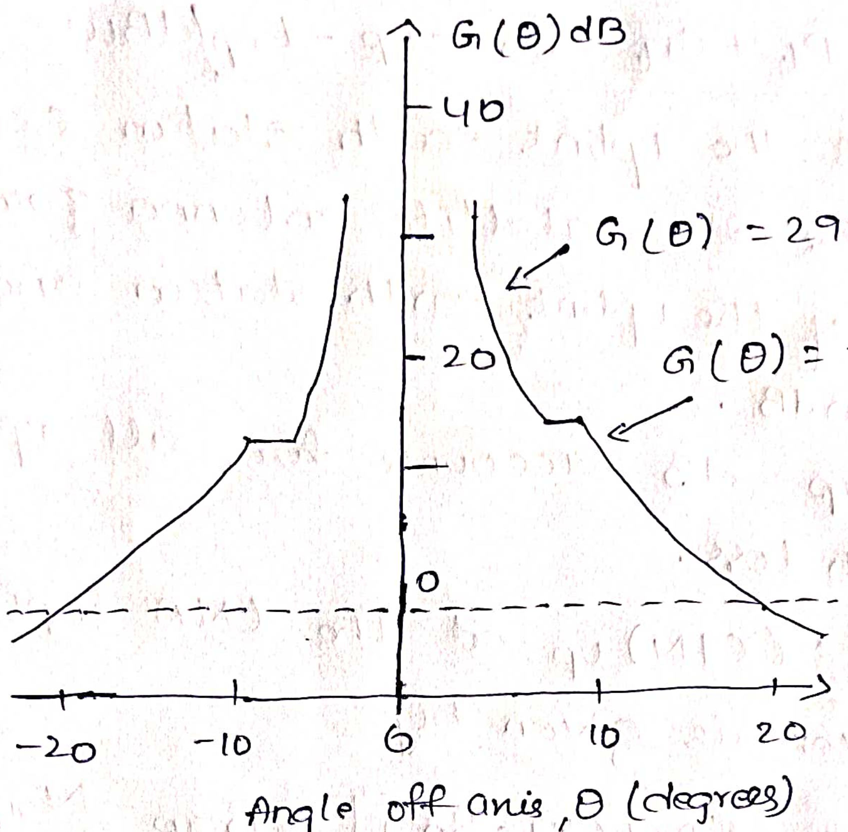


Figure 4.10 ITU-R specifications on the sidlobe envelope of transmit antenna patterns fo 2° GEO satellite spacing

→ It is the uplink interference problem that determines the satellite spacing and limits the capacity of the geostationary orbit in any frequency band.

→ To increase the capacity of the crowded geostationary orbit arc south of the United states, the FCC introduced new regulations in 1983 requiring better control of 6-GHz earth station antenna transmit patterns so that inter satellite spacing could be reduced to 2°.

→ At frequencies above 10 GHz, for example, 14.6 GHz and 30 GHz, propagation disturbances in the form of fading in rain cause the received power level at the satellite to fall

→ This lowers the up-link C/N ratio in the transponder, which lowers the overall $(C/N)_0$ ratio in the earth station receiver when a linear (bent pipe) transponder is used on the satellite.

→ Uplink power control (UPC) can be used to combat uplink rain attenuation.

→ The transmitting earth station monitors a beacon signal from the satellite, and watches for reductions in power indicating rain fading on the down link.

→ Automatic monitoring and control of transmitted uplink power is used in 14-GHz uplink earth stations to maintain the uplink C/N ratio in the satellite transponder during periods of rain attenuation.

→ New generations of Ka-band satellites employ uplink power level detection at the satellite.

→ A control link to each uplink earth station closes the loop.

E> Since the downlink is always at a different frequency from the uplink, a downlink attenuation of A dB must be scaled to estimate uplink attenuation.

→ The scaling factor used is typically $(f_{up}/f_{down})^a$

where a ~~kf~~ is typically between 2.0 and 2.4.

→ For Example, a uplink station transmitting at 14.0 GHz to a ku-band satellite monitors the satellite beacon at 11.45 GHz.

→ The uplink attenuation is therefore given by

$$A_{up} = A_{down} \times (f_{up} / f_{down})^{a} \text{ dB} \qquad (4.41)$$

where A_{up} is the estimated uplink rain attenuation and A_{down} is the measured downlink rain attenuation

→ For a value of a = 2.2 and $(f_{up} / f_{down}) = 1.222$

the factor $(f_{up} / f_{down})^{a}$ is 1.56.

→ Hence a downlink rain attenuation of 3dB would give an estimated uplink attenlation of 4.7 dB.

→ This uplink attenuation value applies only to rain and does not include gaseous attenlation or ~~os~~ scintillation, which requires different scaling ratios].

→ Uplink power control cannot be applied until a certain amount of ~~tra~~ attenuation has built up in the link.

→ This is typically around 2dB for the downlink due to measurement inaccuracies, corresponding to about 3dB for a ka-band uplink.

→ As rain begins to affect the link between the earth station and satellite, the uplink C/N ratio in the transponder will fall until UPC starts to operate in the earth station transmitter.

→ The transponder C/N ratio will then remain relatively constant until the UPC system reaches the maximum available transmit power.

→ Further attenuation on the uplink will cause the C/N ratio in the transponder to fall.

→ A transponder of a KU-band geosatellite has a received power of 2×10^{-13} W & its receiving antenna has a gain of 26dB on axis. Calculate the power output of a uplink transmitter ~~that gives~~ operating at 14.30 GHz when the earth station antenna has a gain of 50dB and there is a 2dB loss in waveguide run between transmitter and antenna. Assume that the atmosphere introduces a loss of 1dB.

Sol :- Given, $P_r = 2 \times 10^{-13}$ W

$G_r = 26$ dB

$f_{up} = 14.30$ GHz.

$G_t = 50$ dB

$L_w = 2$ dB

$L_a = 1$ dB.

$R = 38,500$ km (Geo satellite)

We have,

$$P_r = P_t + G_t + G_r - L_p - L_a - L_w \quad (dB)$$

$$\Rightarrow P_t = P_r - G_t - G_r + L_p + L_a + L_w$$

$$P_t = -127 dB - 50 dB - 26 dB + 207.2 dB + 1 dB + 2 dB$$

$$P_t (dB) = 7.2 \, dB$$

$$P_t = 10^{7.2/10} = 5.2 \, W \quad \text{(normal value)}.$$

$$\Rightarrow P_t = 5.2 \, W$$

(3dB)

Design of satellite links for specified C/N.

→ When a complete satellite link is engineered, the noise in the earth station IF amplifier will have contributions from the receiver itself, the receiving antenna; sky noise, the satellite transponder from which it receives the signal, and adjacent satellites and transmitters which share the same frequency band.

→ A method is used for adding these noise contributions together, which was the standard technique recommended by International Telecommunications Union (ITU).

→ 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.

⇒ The overall C/N ratio denoted by $(C/N)_o$ is what would be measured in the earth station at the output of IF amplifier is given by

$$(C/N)_o = \left[\frac{1}{\frac{1}{(C/N)_1} + \frac{1}{(C/N)_2} + \cdots} \right] \quad \text{—} (1)$$

→ where C/N ratios should be linear values not in decibels.

→ Since the noise power in the individual C/N ratios is referenced to the carrier power at that point, all the C values in eq. 1 are same.

$$\therefore \quad (C/N)_o = \left[\frac{C}{N_1 + N_2 + \cdots} \right] \quad - (2)$$

→ To calculate the performance of a satellite link we must therefore determine the uplink $(C/N)_{up}$ ratio in transponder & downlink $(C/N)_{dn}$ in ~~ea~~ earth station receiver.

→ There are some useful rules of thumb for estimating $(C/N)_o$ from two C/N values.

1. If the C/N values are equal, as in the example above, $(C/N)_o$ is 3dB lower than either value.
2. If one C/N value is 10dB smaller than the other value, $(C/N)_o$ is 0.4dB lower than the smaller of C/N values.
3. If one C/N value is 20dB ~~or~~ more greater than the other C/N value, the overall $(C/N)_o$ is equal to the smaller of the two C/N values within the accuracy of decibel calculations ($\pm$ 0.1 dB).

Examples

→ If $(C/N)_{dn}$ ratio is 20dB & $(C/N)_{up}$ ratio is 20dB then

$$(C/N)_0 = \left[\frac{1}{\frac{1}{(C/N)_{up}} + \frac{1}{(C/N)_{dn}}}\right]$$

$(C/N)_{dn} = 20\ dB$ in normal it is $10^{20/10} = 100$

||ly $(C/N)_{up} = 20\ dB$ will be 100

$$\therefore (C/N)_0 = \left[\frac{1}{\frac{1}{100} + \frac{1}{100}}\right] = \frac{1}{0.01 + 0.01} = 50$$

⇒ $(C/N)_0$ in dB becomes $10 \log_{10}(50) = 17\ dB$

Satellite Commonication Link Design Procedure;

→ The design procedure for a one-way satellite communication link can be summarized by the following 10 steps. The return link design follows the same procedure.

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

2) Determine the communications parameters of the satellite. Estimate any values that are not known.

3) Determine the parameters of the transmitting and receiving earth stations.

(4) Start at the transmitting earth station. Establish an uplink budget and a transponder noise power budget to find $(C/N)_{up}$ in the transponder.

(5) Find the output power of the transponder based on transponder gain or output backoff.

(6) Establish a downlink power and noise budget for the receiving earth station. Calculate $(C/N)_{dn}$ and $(C/N)_0$ for a station at the edge of coverage zone (Worst case).

(7) Calculate $(C/N)_0$ & find the link margins.

(8) Evaluate the result and compare with the specification requirements. Change parameters of the system as required to obtain acceptable $(C/N)_0$ values. This may require several trial designs.

(9) Determine the propagation conditions under which the link must operate. Calculate uplinks and downlinks with attenuation.

(10) Redesign the system by changing some parameters if the link margins are inadequate. Check that all parameters are reasonable, and that the design can be implemented within the expected budget.

System Design Examples, [System & Satellite Specification]

① KU-band Satellite Parameters.

→ Geostationary at 73° W longitude, 28 KU-band transponders

Total RF output power = 2.24 KW

Antenna Gain, on axis (Tx & Rx) = 31 dB

Receive system noise temperature = 500 K

Transponder saturated output power = 80 W (KU band)

Transponder bandwidth = 54 MHz (KU band).

→ Signal Compressed digital Video signals with transmitted symbol rate of 43.2 Msps

Minimum permitted overall $(C/N)_o$ in receiver = 9.5 dB

→ Transmitting KU-band earth station

Antenna Diameter = 5 m

Aperture Efficiency = 68%.

Uplink frequency = 14.15 GHz

Required C/N in KU-band transponder = 30 dB

Transponder HPA output backoff = 1 dB

Miscellaneous uplink losses = 0.3 dB

location: −2 dB contour of satellite receiving antenna

→ Receiving KU-band earth station

Downlink frequency = 11.45 GHz

Receiver IF noise bandwidth = 43.2 MHz

Antenna noise temperature = 30 K

LNA noise temperature = 110 K

Required overall $(C/N)_o$ in clear air = 17 dB

Miscellaneous downlink losses = 0.2 dB

location: − 3 dB Contour of Satellite transmitting antenna.

→ Ku-band Clear air attenuation

Uplink → 0.7 dB & downlink = 0.5 dB

KU-Band Uplink Design:

Given, $(C/N)_{up} = 30$ dB

find P_t to achieve 30dB $(C/N)_{up}$.

→ Uplink Noise Power Budget is

$$N = k + T_s + B_n \quad (dB)$$

$k = -228.6$ dBW/K/Hz.

$T_s = 500K$ in dB T_s is 27.0 dBK

$B_n = 43.2$ MHz in dB B_n is 76.4 dBHz.

$$\therefore N = -228.6 + 27 + 76.4 = -125.2 \text{ dBW}$$

WKT,

$$(C/N) = P_r - N \text{ in dB}$$

$$\therefore 30 = P_r - (-125.2)$$

$$\Rightarrow P_r = 30 - 125.2 = -95.2 \text{ dBW}$$

WKT,

$$P_r = P_t + G_t + G_r - L_p - L_{ant} - L_m \quad (dB)$$

We have, Uplink Power budget (P_r):

$P_r = -95.2$ dB

$G_r = 31$ dB

$L_{ant} = 2$ dB

$L_m = 1$ dB

Find G_t :-

WKT, $G_t = \eta_A (\pi D/\lambda)^2$

$\eta_A = 68\%$

$f = 14.15\, GHz$

$\Rightarrow \lambda = \frac{c}{f} = \frac{3\times10^8}{14.15\times10^9} = 0.0212\, m$

$D = .5\, m$

$\therefore G_t = 0.68(\pi(5)/0.0212)^2 = 373.3\times10^3$

G_t in dB $= 10 \log(373.3\times10^3) = 55.7\, dB.$

Similarly,

$L_p = 10 \log\left[(4\pi R/\lambda)^2\right] = 207.2\, dB$

$\therefore P_t = P_r - G_t - G_r + L_p + L_{ant} + L_m$ (dB)

$\Rightarrow P_t = -95.2 - 55.7 - 31 + 207.2 + 2 + 1$

$\Rightarrow P_t = 28.3\, dBW$

$\therefore P_t$ in W $= 10^{28.3/10} = 10^{2.83} = 675\, W$

KU-band ~~Down~~ Downlink Design:

W.K.T., $(C/N)_o = \left[\frac{1}{1/(C/N)_{up} + 1/(C/N)_{dn}}\right]$

Given, $(C/N)_o = 17\, dB$ & $(C/N)_{up} = 30\, dB$

$\downarrow$ $10^{1.7} = 50$ (normal Value) $\quad$ $\downarrow$ $10^{3} = 1000$ (normal Value)

$$\Rightarrow \frac{1}{(C/N)_o} = \left[\frac{1}{(C/N)_{dn}} + \frac{1}{(C/N)_{up}}\right]$$

$$\Rightarrow \frac{1}{(C/N)_{dn}} = \frac{1}{50} - \frac{1}{1000} = 0.019$$

$\Rightarrow (C/N)_{dn} = 52.6$ in dB it is 17.2 dB

Downlink noise power budget.

$N = K + T_s + B_n$

$K = -228.6$ dBW/K/Hz

$T_s = 30K + 110K = 140K$ in dB it is 21.5 dBK

$B_n = 43.2$ MHz in dB it is 76.4 dBHz

$\therefore N = -228.6 + 21.5 + 76.4 = -130.7$ dBW

$\Rightarrow P_r = 17.2 - 130.7 = -113.5$ dBW

P_t from Transponder is 80W in dB it is 19 dBW

back off is 1dB

$\therefore P_t = 19\,dB - 1\,dB = 18\,dB$.

Downlink Power budget (P_r)

We have, $P_t = 18$dB, $G_t = 31$dB, $G_r = ?$, $L_p = 205.4$dB with $f = 11.45$ GHz,

$L_{ant} = 3$dB, $L_m = \cancel{\ }$ 0.7dB

find G_r with $P_r = -113.5$ dBW

& also earth station diameter D

i.e., $P_r = P_t + G_t + G_r - L_p - L_{ant} - L_m$ (dB)

$-113.5 = 18 + 31 + G_r - 205.4 - 3 - 0.7 \Rightarrow G_r = 46.6$dB in normal

G_r is $= 10^{46.6/10} = 10^{4.66}$

$\therefore G_r = 45{,}709$

Now, finally using $G_r = \eta_A (\pi D/\lambda)^2$ find D? at 11.45 GHz

$\boxed{\text{By default } \eta_A = 65\%}$

we get, $D = 2.21$ m