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Satellite Communication

Propagation effects and Satellite link design

Rain Attenuation

Rain attenuation is a function of rain rate. By rain rate is meant the rate at which rainwater would accumulate in a rain gauge situated at the ground in the region of interest (e.g., at an earth station). In calculations relating to radio wave attenuation, the rain rate is measured in millimeters per hour.

Of interest is the percentage of time that specified values are exceeded. The time percentage is usually that of a year; for example, a rain rate of 0.001 percent means that the rain rate would be exceeded for 0.001 percent of a year, or about 5.3 min during any one year. In this case the rain rate would be denoted by $R_{0.001}$. In general, the percentage time is denoted by p and the rain rate by R_p.

The specific attenuation α is

$$\alpha = aR_p{}^b \text{ dB/km}$$

where a and b depend on frequency and polarization. Values for a and b are available.
The subscripts h and v refer to horizontal and vertical polarizations respectively.

Once the specific attenuation is found, the total attenuation is deter- mined as

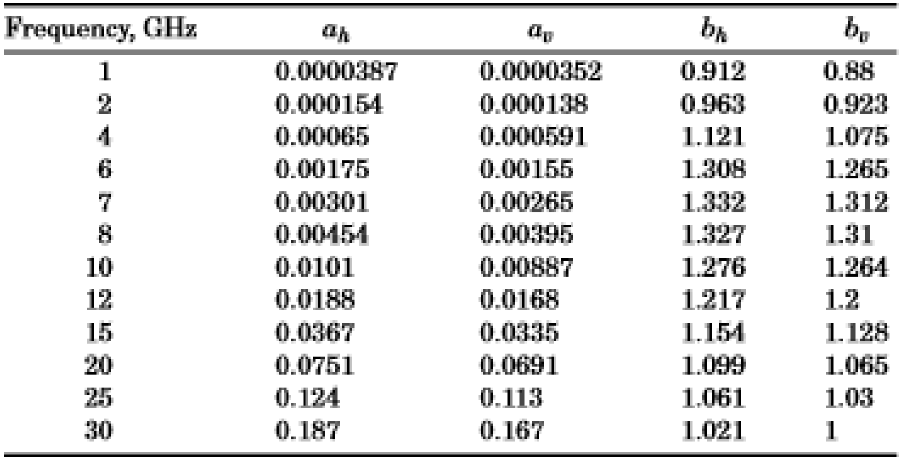
$$\alpha = aL \text{ dB}$$

where L is the effective path length of the signal through the rain.

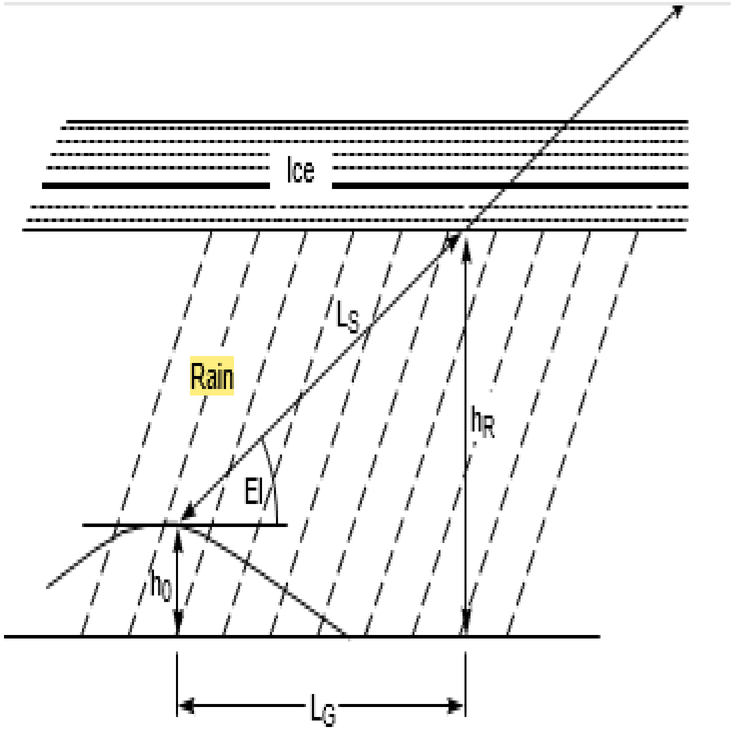
The geo- metric, or slant, path length is shown as L_S

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

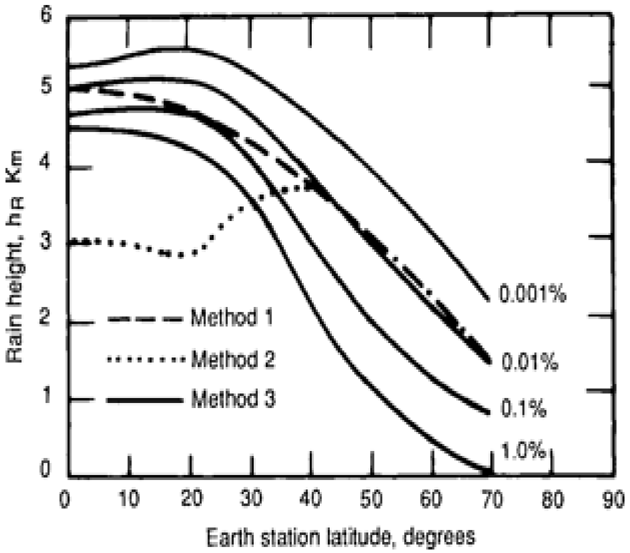
Specific attenuation coefficients



Frequency, GHz	a_h	a_v	b_h	b_v
1	0.0000387	0.0000352	0.912	0.88
2	0.000154	0.000138	0.963	0.923
4	0.00065	0.000591	1.121	1.075
6	0.00175	0.00155	1.308	1.265
7	0.00301	0.00265	1.332	1.312
8	0.00454	0.00395	1.327	1.31
10	0.0101	0.00887	1.276	1.264
12	0.0188	0.0168	1.217	1.2
15	0.0367	0.0335	1.154	1.128
20	0.0751	0.0691	1.099	1.065
25	0.124	0.113	1.061	1.03
30	0.187	0.167	1.021	1



Path length through rain



Rain height as a function of earth station latitude for different climatic zone

The effective path length is given in terms of the slant length by

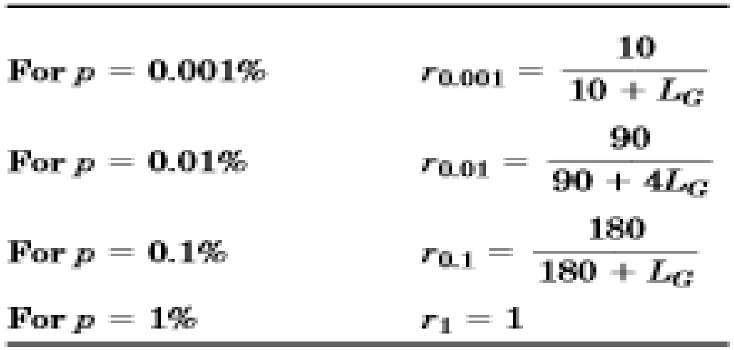
$$L = L_S r_p$$

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.

From Fig. the horizontal projection is seen to be

$$L_G = L_S \cos El$$

Reduction factors



For $p = 0.001\%$	$r_{0.001} = \frac{10}{10 + L_G}$
For $p = 0.01\%$	$r_{0.01} = \frac{90}{90 + 4L_G}$
For $p = 0.1\%$	$r_{0.1} = \frac{180}{180 + L_G}$
For $p = 1\%$	$r_1 = 1$

The rain attenuation in decibels is given by

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

Calculate, for a frequency of 12 GHz and for horizontal and vertical polarizations, the rain attenuation which is exceeded for 0.01 percent of the time in any year, for a point rain rate of 10 mm/h. The earth station altitude is 600 m, and the antenna elevation angle is 50 degrees. The rain height is 3 km.

$$\mathrm{El} := 50 \cdot \mathrm{deg} \quad h_O := .6 \quad h_r := 3 \quad R_{01} := 10$$

All lengths and heights are in kilometers, and rain rate is in millimeters per hour

$$L_S := \frac{h_r - h_O}{\sin(El)} \qquad L_S = 3.133$$

$$L_G := L_S \cdot \cos(El) \qquad L_G = 2.014$$

$$r_{01} := \frac{90}{90 + 4 \cdot L_G} \qquad r_{01} = 0.918$$

$$L := L_S \cdot r_{01} \qquad L = 2.876$$

For horizontal polarization, from Table at *f* = 12 GHz:

$a_h := .0188 \quad b_h := 1.217$

$$\alpha := a_h \cdot R_{01}^{bh} \qquad \alpha = 0.31 \quad \mathrm{dB/m}$$

$$AdB := \alpha \cdot L \qquad AdB = 0.89$$

For vertical polarization, from Table 3.2 at *f* = 12 GHz:

$a_v := .0168 \qquad b_v := 1.2$

$$\alpha := a_v \cdot R_{01}^{b_v} \qquad \alpha = 0.266 \quad \mathrm{dB/m}$$

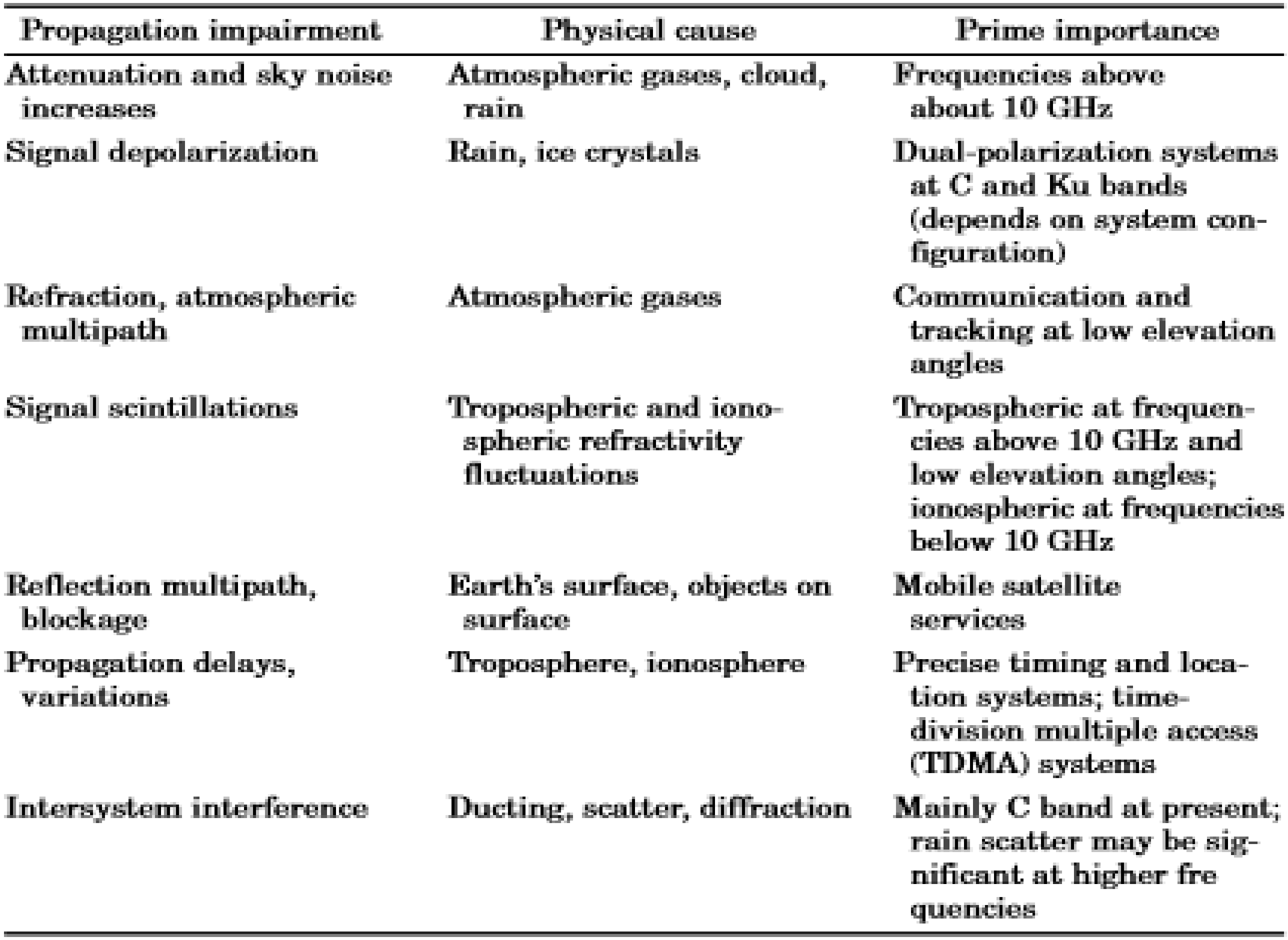
$$\mathrm{AdB} := \alpha \cdot L \qquad \mathrm{AdB} = 0.77$$

The corresponding equations for circular polarization are

$$a_c = \frac{a_h + a_v}{2}$$

$$b_c = \frac{a_h b_h + a_v b_v}{2 a_c}$$

Propagation concerns for satellite communication



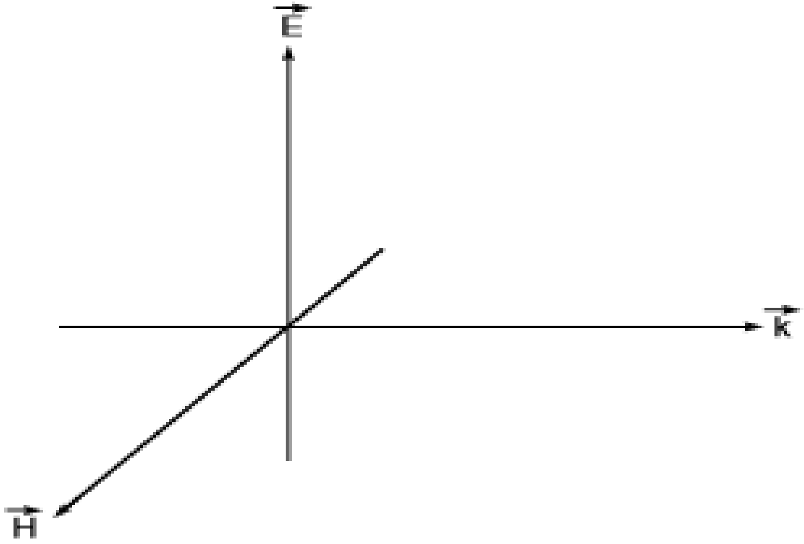
Propagation impairment	Physical cause	Prime importance
Attenuation and sky noise increases	Atmospheric gases, cloud, rain	Frequencies above about 10 GHz
Signal depolarization	Rain, ice crystals	Dual-polarization systems at C and Ku bands (depends on system configuration)
Refraction, atmospheric multipath	Atmospheric gases	Communication and tracking at low elevation angles
Signal scintillations	Tropospheric and ionospheric refractivity fluctuations	Tropospheric at frequencies above 10 GHz and low elevation angles; ionospheric at frequencies below 10 GHz
Reflection multipath, blockage	Earth's surface, objects on surface	Mobile satellite services
Propagation delays, variations	Troposphere, ionosphere	Precise timing and location systems; time-division multiple access (TDMA) systems
Intersystem interference	Ducting, scatter, diffraction	Mainly C band at present; rain scatter may be significant at higher fre quencies

Other Propagation Impairments

Hail, ice, and snow have little effect on attenuation because of the low water content. Ice can cause depolarization

polarization

The direction of the line traced out by the tip of the electric field vector determines the polarization of the wave. Keep in mind that the electric and magnetic fields are varying as functions of time. The magnetic field varies exactly in phase with the electric field, and its amplitude is proportional to the electric field amplitude, so it is only necessary to consider the electric field in this discussion. The tip of the **E** vector may trace out a straight line, in which case the polarization is referred to as linear.



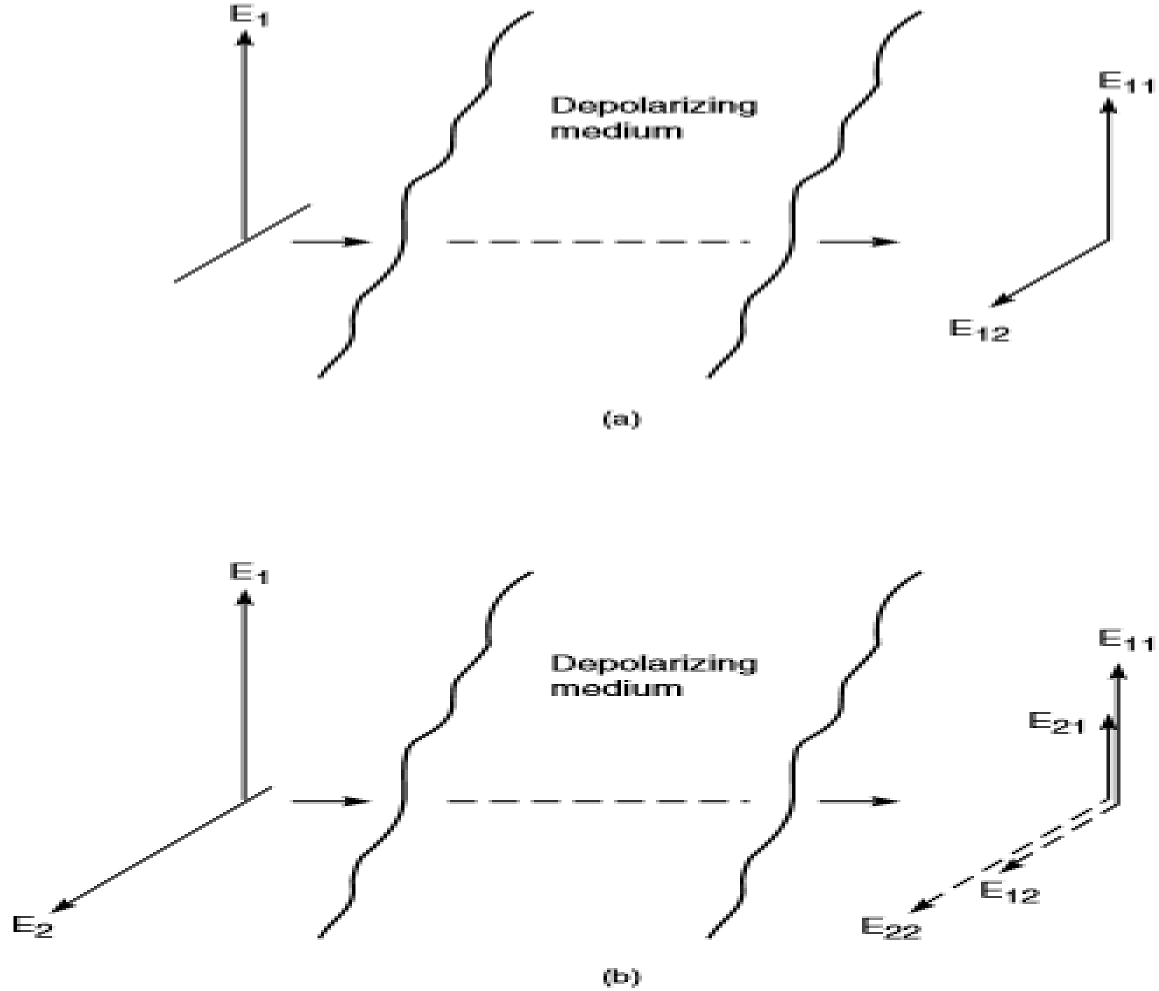
Vector diagram for a transverse electro- magnetic (TEM) wave

Cross-Polarization Discrimination

The propagation path between a satellite and earth station passes through the ionosphere, and possibly through layers of ice crystals in the upper atmosphere and rain, all of which are capable of altering the polarization of the wave being transmitted. An orthogonal component may be generated from the transmitted polarization, an effect referred to as *depolarization.* This can cause interference where orthogonal polarization is used to provide isolation between signals, as in the case of frequency reuse.

Two measures are in use to quantify the effects of polarization interference. The most widely used measure is called cross-polarization dis- crimination (XPD). Figure (a) shows how this is defined. The transmitted electric field is shown having a magnitude E_1 before it enters the medium which causes depolarization. At the receiving antenna the electric field may have two components, a copolar component, having magnitude E_{11}, and a cross-polar component, having magnitude E_{12}. The cross-polarization discrimination in decibels is defined as

$$XPD = 20 \log E11/E12$$



Vectors defining (*a*) cross-polarization discrimination (XPD) (*b*) polarization isolation (I).

The second situation is shown in Fig.b. Here, two orthogonally polarized signals, with magnitudes E_1 and E_2, are transmitted. After traversing the depolarizing medium, copolar and cross-polar components exist for both waves. The polarization isolation is defined by the ratio of received copolar power to received cross-polar power and thus takes into account any additional depolarization introduced by the receiving system . Since received power is proportional

At the same time, a cross-polar component $E_x = E \sin 0_F$ is created, and hence the XPD is

$$XPD = 20 \log Eco/E_x$$

$$= 20 \log (\cot 0_F)$$

Ice Depolarization

An ice layer is present at the top of a rain region, the ice crystals can result in depolarization. The experimental evidence suggests that the chief mechanism producing depolarization in ice is differential phase shift, with little differential attenuation present. This is so because ice is a good dielectric, unlike water, which has considerable losses. Ice crystals tend to be needle shaped or plate like and, if randomly oriented, have little effect, but depolarization occurs when they become aligned. Sudden increases in XPD that coincide with lightning flashes are thought to be a result of the lightning producing alignment. An International Radio Consultative Committee (CCIR) recommendation for taking ice depolarization into account is to add a fixed decibel value to the XPD value calculated for rain. Values of 2 dB are suggested for North America and 4 to 5 dB for maritime regions, and it is further suggested that the effects of ice can be ignored for time percentages less than 0.1 percent

Link-power budget

link-power budget calculations basically relate two quantities, the transmit power and the receive power

Equivalent Isotropic Radiated Power

A key parameter in link budget calculations is the equivalent isotropic radiated power, conventionally denoted as EIRP

The maximum power flux density at some distance *r* from a transmitting antenna of gain *G* is

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

An isotropic radiator with an input power equal to GP_S would produce the same flux density. Hence this product is referred to as the equivalent isotropic radiated power

$$\mathrm{EIRP} = GP_S$$

EIRP is often expressed in decibels relative to one watt, or dBW. Let P_S be in watts; then

$$[\mathrm{EIRP}] = [P_S] + [G] \quad \mathrm{dBW}$$

where $[P_S]$ is also in dBW and $[G]$ is in dB.

A satellite downlink at 12 GHz operates with a transmit power of 6 W and an antenna gain of 48.2 dB. Calculate the EIRP in dBW.

solution

$$\begin{aligned}[\mathrm{EIRP}] &= 10 \log 6 + 48.2 \\ &= 56 \text{ dBW}\end{aligned}$$

The [EIRP] can be considered as the input power to a transmission link. 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

$$[\text{EIRP}] - [\text{LOSS- ES}] + [G_R]$$

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], However, the other losses also must be taken into account, and these are simply added to [FSL]. The losses for clear-sky conditions are

$$[\text{LOSSES}] = [\text{FSL}] + [\text{RFL}] + [\text{AML}] + [\text{AA}] + [\text{PL}]$$

The decibel equation for the received power is then

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

where $[P_R]$ = received power, dBW

[EIRP] = equivalent isotropic radiated power, dBW

[FSL] = free-space spreading loss, dB

[RFL] = receiver feeder loss, dB

[AML] = antenna misalignment loss, dB

[AA] = atmospheric absorption loss, dB

[PL] = polarization mismatch loss, dB

A satellite link operating at 14 GHz has receiver feeder losses of 1.5 dB and a free-space loss of 207 dB. The atmospheric absorption loss is 0.5 dB, and the antenna pointing loss is 0.5 dB. Depolarization losses may be neglected. Calculate the total link loss for clear-sky conditions.

Solution

The total link loss is the sum of all the losses:

$$[LOSSES] = [FSL] + [RFL] + [AA] + [AML] = 207 + 1.5 + 0.5 + 0.5$$

$$= 209.5 \text{ dB}$$

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 ratio. Conventionally, the ratio is denoted by C/N (or CNR), which is equivalent to P_R/P_N. In terms of decibels

$$\left[\frac{C}{N}\right] = [P_R] - [P_N]$$

$$\left[\frac{C}{N}\right] = [\mathrm{EIRP}] + [G_R] - [\mathrm{LOSSES}] - [k] - [T_S] - [B_N]$$

The G/T ratio is a key parameter in specifying the receiving system performance. The antenna gain G_R and the system noise temperature T_S can be combined in above Eq.

$$[G/T] = [G_R] - [T_S] \quad \mathrm{dBK}^{-1}$$

Therefore, the link equation

$$\left[\frac{C}{N}\right] = [\mathrm{EIRP}] + \left[\frac{G}{T}\right] - [\mathrm{LOSSES}] - [k] - [B_N]$$

The ratio of carrier power to noise power density P_R/N_o may be the quantity actually required. Since $P_N = kT_N B_N = N_o B_N$, then

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

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

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

[C/N] is a true power ratio in units of decibels, and $[B_N]$ is in decibels relative to one hertz, or dBHz. Thus the units for $[C/N_o]$ are dBHz.

$$\left[\frac{C}{N_o}\right] = [\text{EIRP}] + \left[\frac{G}{T}\right] - [\text{LOSSES}] - [k] \qquad \text{dBHz}$$

For a satellite circuit the individual link carrier-to-noise spectral density ratios are: uplink 100 dBHz; downlink 87 dBHz. Calculate the combined C/N_o ratio.

solution

$$\frac{N_o}{C} = 10^{-10} + 10^{-8.7} = 2.095 \times 10^{-9}$$

$$\left[\frac{C}{N_o}\right] = -10 \log \left(2.095 \times 10^{-9}\right) = 86.79 \text{ dBHz}$$

Reference

Dennis Roddy, “Satellite Communication”, 4th Ed., McGraw Hill, 2008