MODULE-2
Satellite Subsystems

- **Satellite Subsystems:** Transponders, Satellite antennas (concept only), Satellite Control System, Power system, Telemetry, Tracking and Command system (TTC), Structures, Thermal Control System, Reliability, Steps in satellite mission realization. Test and Evaluation of the Satellite components, Satellite subsystems and Satellite as a system.
- **Radio wave Propagation:** Atmospheric Losses, Ionospheric effects, Rain Attenuation, Other Propagation Impairments.
- (Text Book 1 & 3)

TT&C Subsystem

The telemetry, tracking, and command subsystem performs several routine functions aboard the spacecraft.

The telemetry, or telemetering, could be interpreted as *measurement at a distance.*

it refers to the overall operation of generating an electrical signal proportional to the quantity being measured and encoding and transmitting this to a distant station, which for the satellite is one of the earth stations.

Data which are transmitted as telemetry signals include attitude information such as

that obtained from sun and earth sensors;
environmental information such as the magnetic field intensity and direction,
the frequency of meteorite impact,
spacecraft information such as temperatures, power supply voltages and stored-fuel pressure. so on;

How it is done?

Certain frequencies have been designated by international agreement for satellite telemetry transmissions.

During the transfer and drift orbital phases of the satellite launch, a special channel is used along with an omnidirectional antenna.

Once the satellite is on station, one of the normal communications transponders may be used along with its directional antenna, unless some emergency arises which makes it necessary to switch back to the special channel used during the transfer orbit.

Command

Command -> It is a signal semn by the earth station to the satellite in response to the telemetry signal received by satellite

Telemetry and command may be thought of as complementary functions.

The telemetry subsystem transmits information about the satellite to the earth station, while the command subsystem receives command signals from the earth station, often in response to telemetered information.

The command subsystem demodulates and, if nec essary, decodes the command signals and routes these to the appropriate equipment needed to execute the necessary action. Thus attitude changes may be made, communication transponders switched in and out of circuits, antennas redirected, and station keeping maneuvers carried out on command.

It is important to prevent unauthorized commands from being received and decoded, for this reason, the command signals are often encrypted.

Encrypt is derived from a Greek word *kryptein,* meaning *to hide,* and represents the process of concealing the command signals in a secure code. This differs from the normal process of encoding, which is one of converting characters in the command signal into a code suitable for transmission.

Tracking

Tracking of the satellite is accomplished by having the satellite transmit beacon signals which are received at the TT&C earth stations.

Tracking is important during the transfer and drift orbital phases of the satellite launch.

Once it is on station, the position of a geostationary satellite will tend to be shifted as a result of the various disturbing forces

Therefore, it is necessary to be able to track the satellite's movement and send correction signals as required.

How it is done?

Tracking beacons may be transmitted

in the telemetry channel,

or by pilot carriers at frequencies in one of the main communications channels,

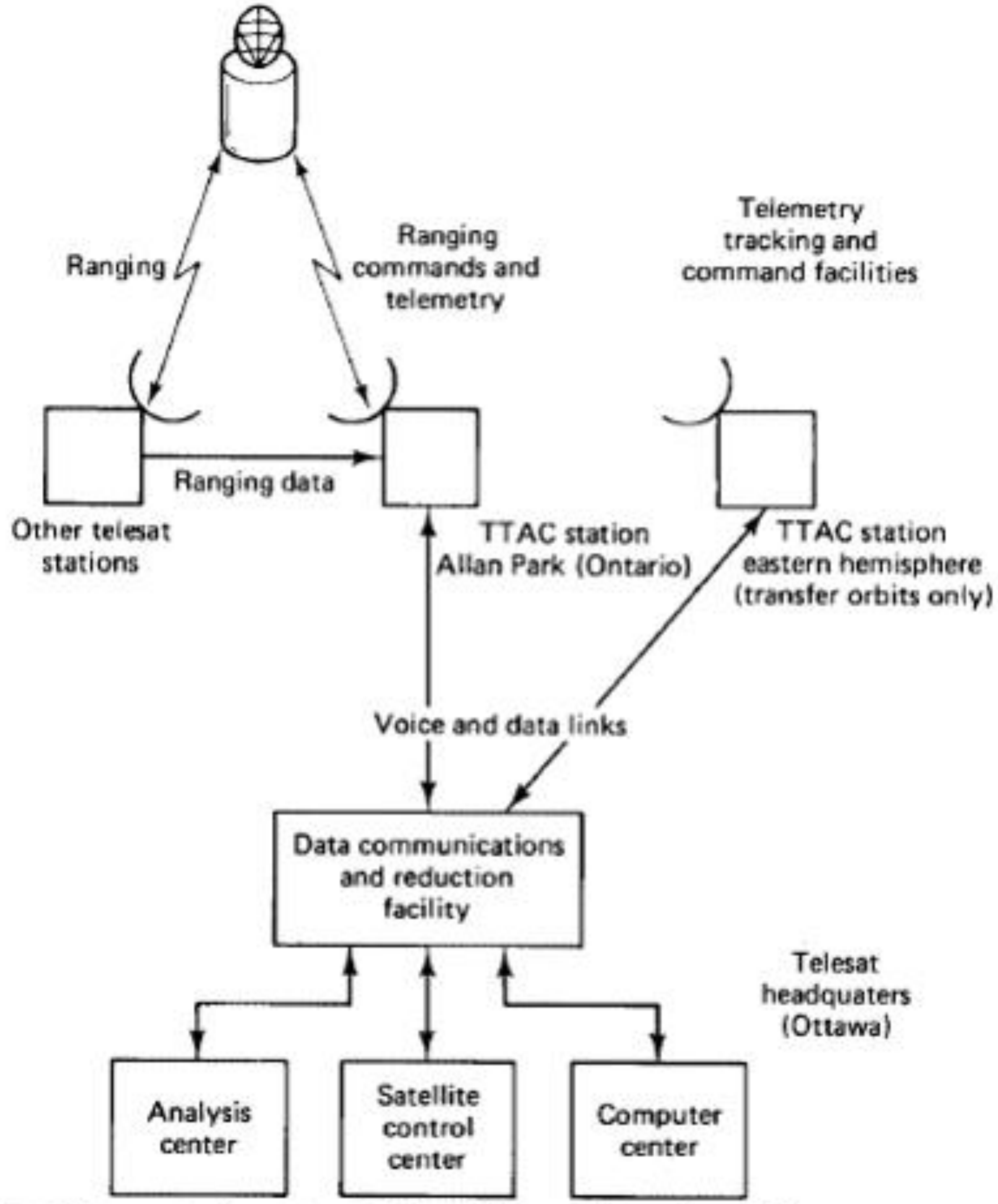
or by special tracking antennas.

Satellite range from the ground station is also required from time to time.

This can be determined by measurement of the propagation delay of signals especially transmitted for ranging purposes.

The telemetry, tracking, and command functions are complex operations which require special ground facilities in addition to the TT&C subsystems aboard the satellite.

Figure shows block diagram of the TT&C facilities used by Canadian Telesat for its satellites.



Satellite control system. (*From Telesat Canada, 1983; courtesy of Telesat Canada.*)

Example 4.8

Calculate the reliability of a command receiver for 6 years lifetime given that the MTBF of the batch of receiver is 35000 hours.

Calculate $\lambda = \frac{1}{MTBF} = \frac{1}{35000}$; and given $T = 6 \times 365 \times 24$ hours (both MTBF and T must be in same units ie. in hours)

$R = e^{-\lambda T}$ Substituting the values for λ and T,

$$\text{we get } R = \exp\left[\frac{-6 \times 365 \times 24}{35000}\right] = e^{-1.502}$$

Note: R value range is from 0 to 1.

Example 4.12

MTBF of a transistor amplifier is 80, 000 hours. Calculate the reliability of 5 amplifiers connected in cascade (in series) for 10 years of operations

As these are connected in series, the overall reliability will be

$R = (e^{-\lambda T})^5$; Substituting the values for $\lambda = \dfrac{1}{MTBF}$ and T in hours, we get R value

Soln:

λ= 1/MTBF=1.25 x10^-5

T=10 x365x24 =87600 hours

R=0.3345^5

i.e. R=4.19x10^-3

Radio wave Propagation

A signal traveling between an earth station and a satellite must pass through the earth's atmosphere, including the ionosphere, as shown in Fig. 4.1, and this can introduce certain impairments, which are summarized in Table 4.1.

Some of the more important of these impairments will be described in this chapter.

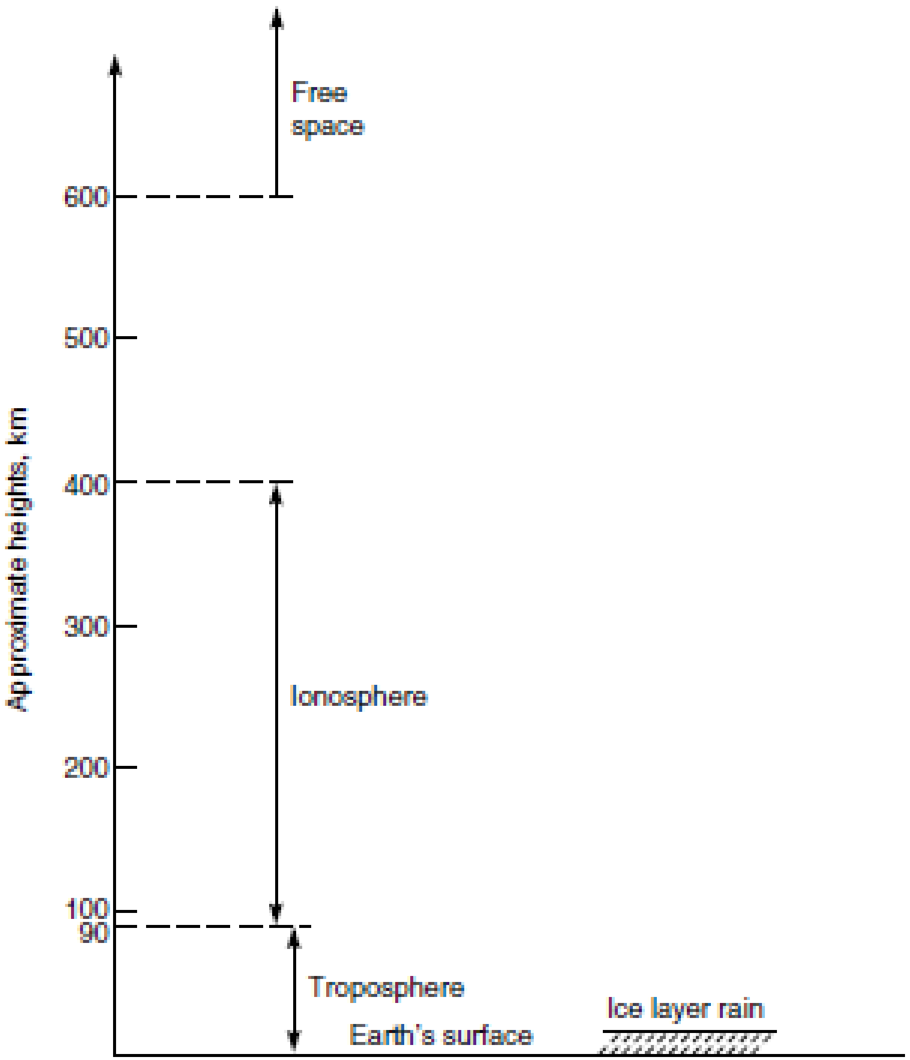


Figure 4.1 Layers in the earth's atmosphere.

TABLE 4.1 Propagation Concerns for Satellite Communications Systems

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

SOURCE: Brussard and Rogers, 1990.

Losses occur in the earth's atmosphere as a result of energy absorption by the atmospheric gases. These losses are treated quite separately from those which result from adverse weather conditions, which of course are also atmospheric losses. To distinguish between these, the weather-related losses are referred to as *atmospheric attenuation* and the absorption losses simply as *atmospheric absorption*.

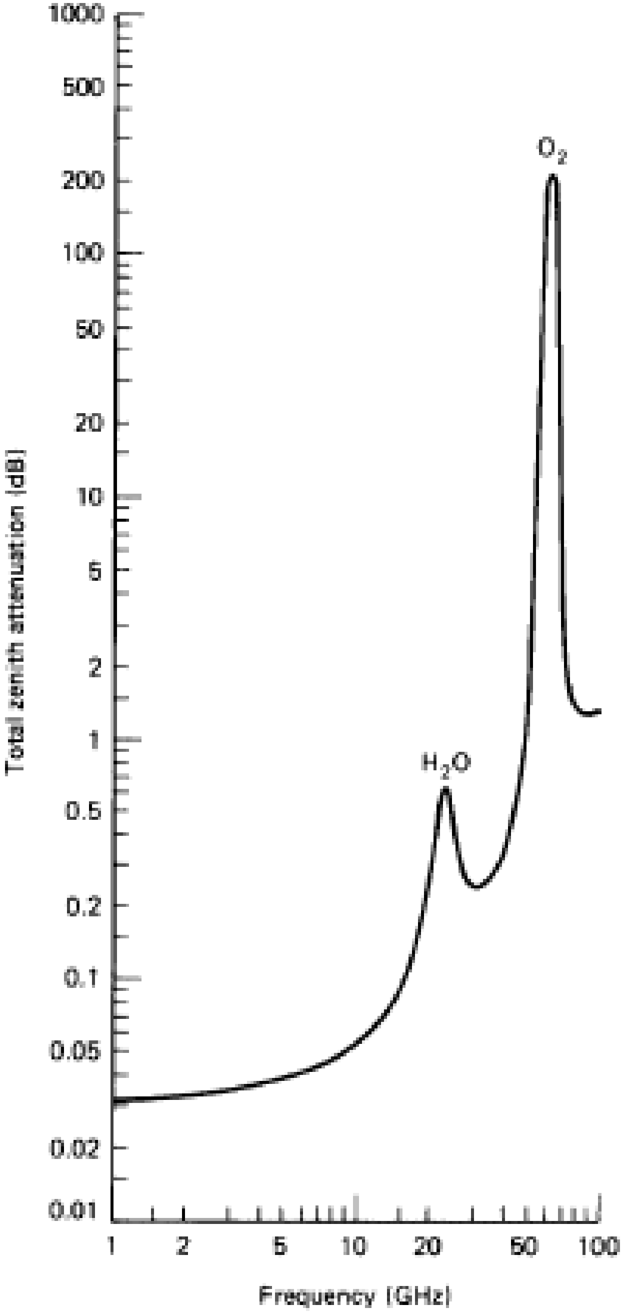


Figure 4.2 Total zenith attenuation at ground level: pressure = 1 atm, temperature = 20°C, and water vapor = 7.5 g/m^3. (*Adapted from CCIR Report 719-2, with permission from International Telecommunication Union.*)

$$[AA] = [AA]_{90} \operatorname{cosec} \theta \tag{4.1}$$

where θ is the angle of elevation. An effect known as *atmospheric scintillation* also can occur. This is a fading phenomenon, the fading period being several tens of seconds (Miya, 1981). 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 through the atmosphere. It may be necessary to make an allowance for atmospheric scintillation, through the introduction of a fade margin in the link power-budget calculations.

Rain Attenuation

Rain attenuation is a function of *rain rate* which is 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 cal culations relating to radio wave attenuation, the rain rate is measured in millimeters per hour.

In taht the percentage of time that specified values are exceeded is of interest

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 given by

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

where a and b depend on frequency and polarization.

Values for a and b are available in tabular form in a number of publications.

Table 4.2 have been abstracted from Table 4-3 of Ippolito (1986)

The subscripts h and v refer to horizontal and vertical polarizations respectively.

TABLE 4.2 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

SOURCE: Ippolito, 1986, p. 46.

The subscripts h and v refer to horizontal and vertical polarizations respectively.

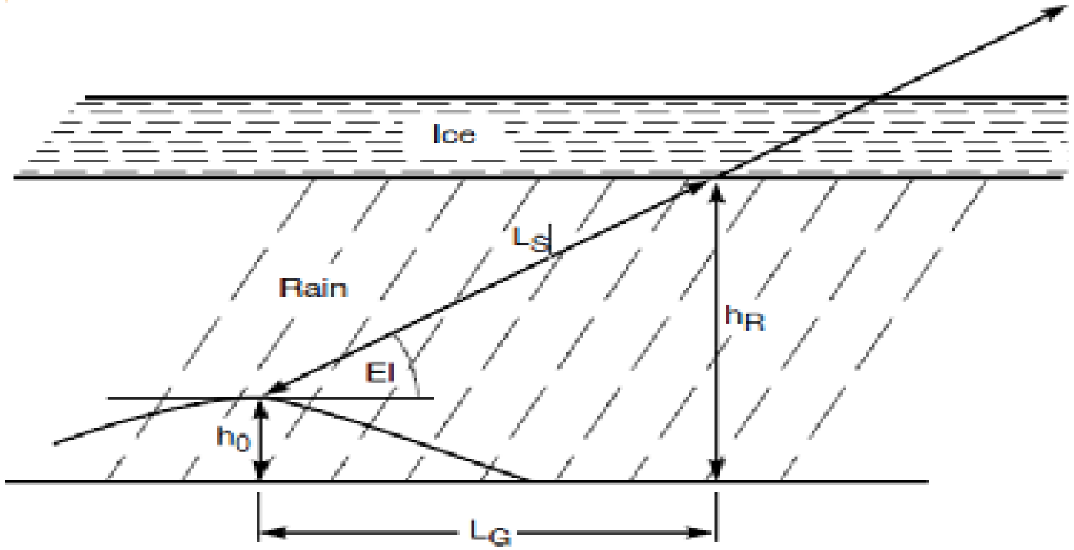
Once the specific attenuation is found, the total attenuation is deter mined as

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

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

as the rain density is unlikely to be uniform over the actual path length, an effective path length must be used rather than the actual (geo metric) length.

Figure below shows the geometry of the situation.



Path length through rain.

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

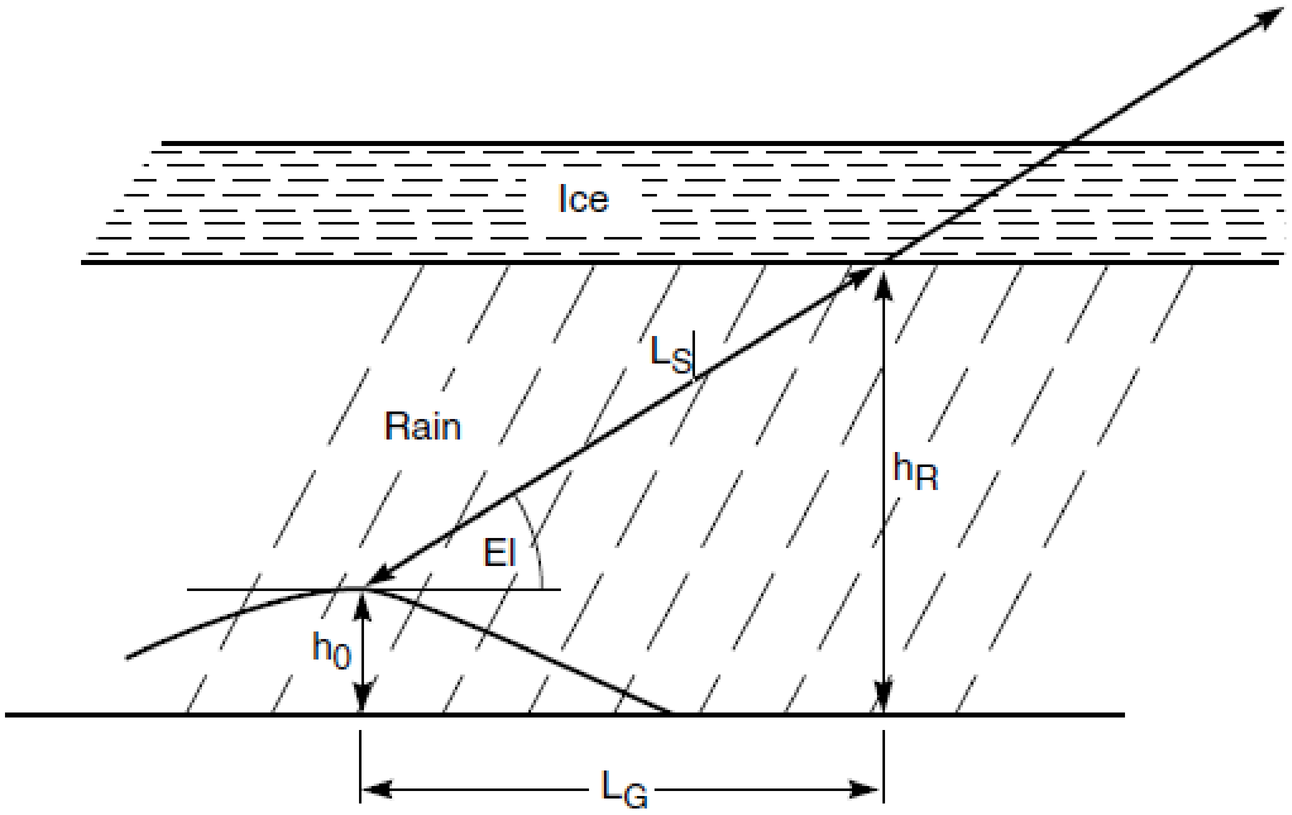


Figure 4.3 Path length through rain.

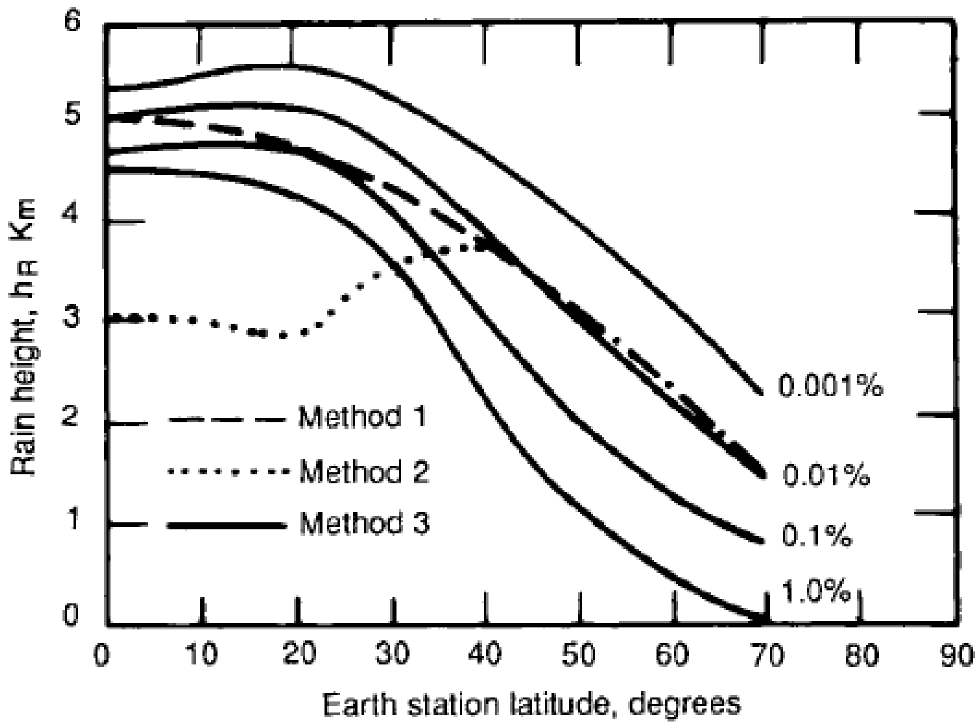


Figure 4.4 Rain height as a function of earth station latitude for different climatic zones.

L_S is Geo metric, or slant, path length

L_S depends on the antenna angle of elevation θ and the *rain height* h_R.

h_R is the height at which freezing occurs.

Figure 4.4 shows curves for h_R for different climatic zones.

In this figure, three methods are labeled:

Method 1—*maritime cli mates*

Method 2—*tropical climates*;

Method 3—*continental climates.*

For 3rd method curves are shown for p values of 0.001, 0.01, 0.1, and 1 percent.

For small angles of elevation ($El < 10°$), the determination of L_S is complicated by earth curvature

for $El \geq 10°$, a flat earth approximation may be used,

from Fig. 4.3 it is seen that

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

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

L_G ,is the horizontal projection of L_S.

From Fig. 4.3 the horizontal projection is seen to be $L_G = L_S \cos El$

The reduction factors are given in Table 4.3.

With all these factors together into one equation,

the rain attenuation in decibels is given by $A_p = aR_p{}^b L_S r_p$ dB

TABLE 4.3 Reduction Factors

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

SOURCE: Ippolito, 1986.

Example 4.1 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.

Given:

$El := 50 \cdot deg$ $h_O := 0.6$ km $h_r := 3$ km $R_{01} := 10$ mm/hour

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

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

From Table 4.3, the rate reduction factor is

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

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

For horizontal polarization, from Table 4.2 at $f = 12$ GHz $\quad a_h = .0188 \quad b_h = 1.217$

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

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

- Similarly for vertical polarisation
- av=0.0168   bv=1.2
- Alpha=0.01516
- A(db)=alpha L=