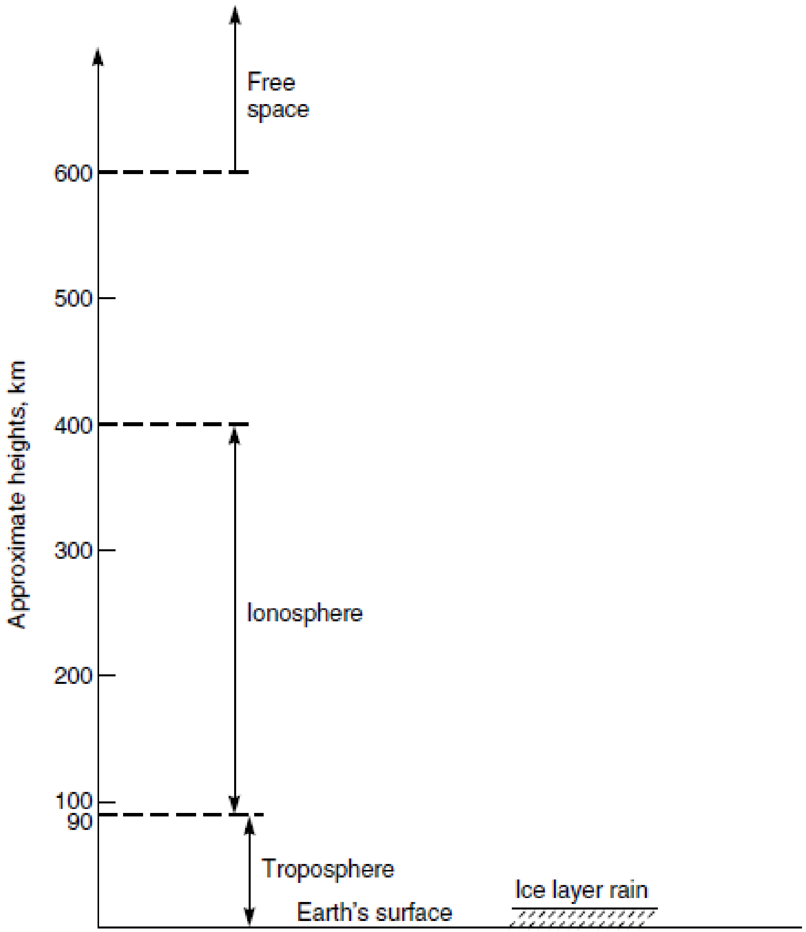
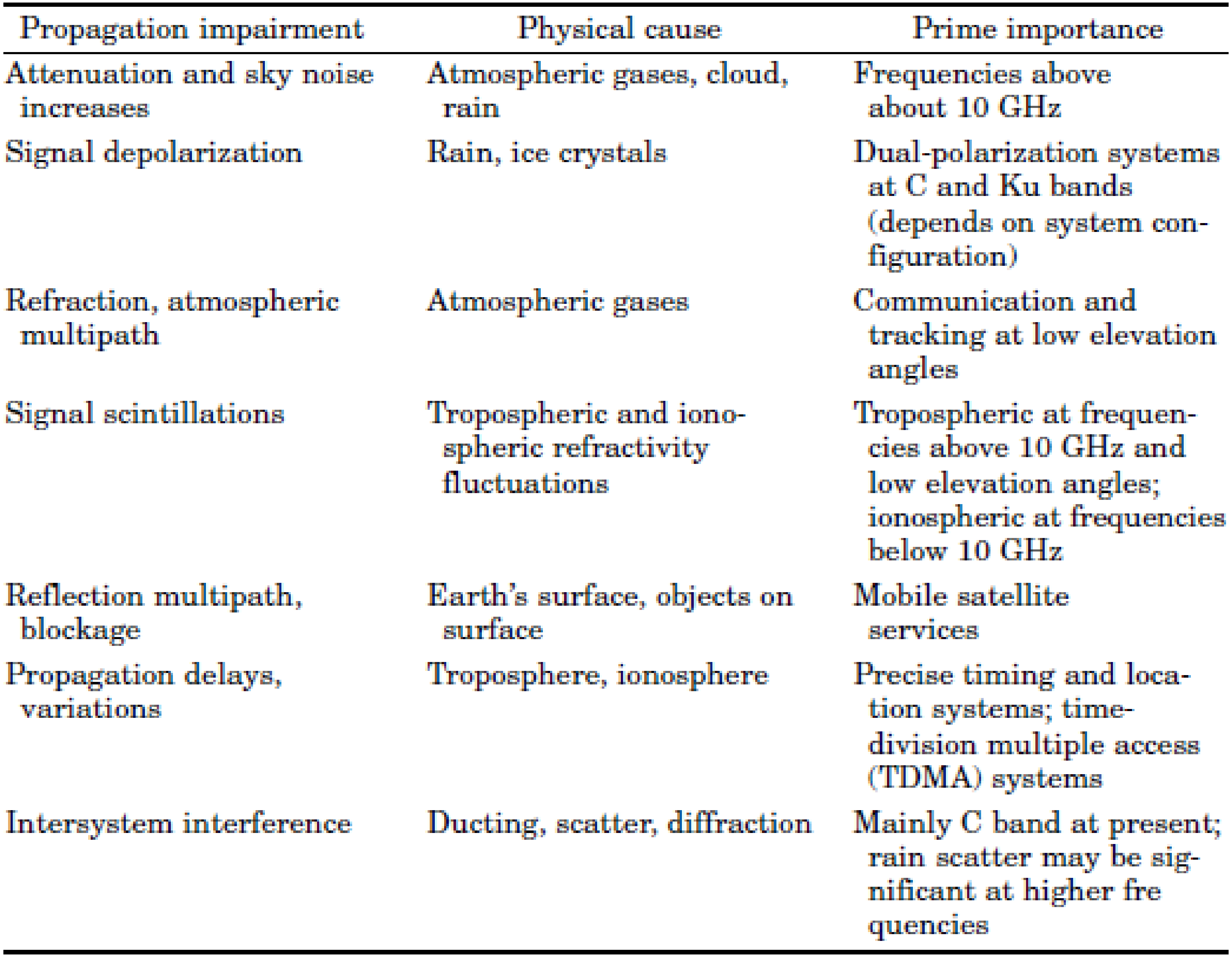
Satellite Link Design

Atmospheric Layers

- A signal traveling between an earth station and a satellite must pass through the earth's atmosphere, including the ionosphere, as shown in below figure.



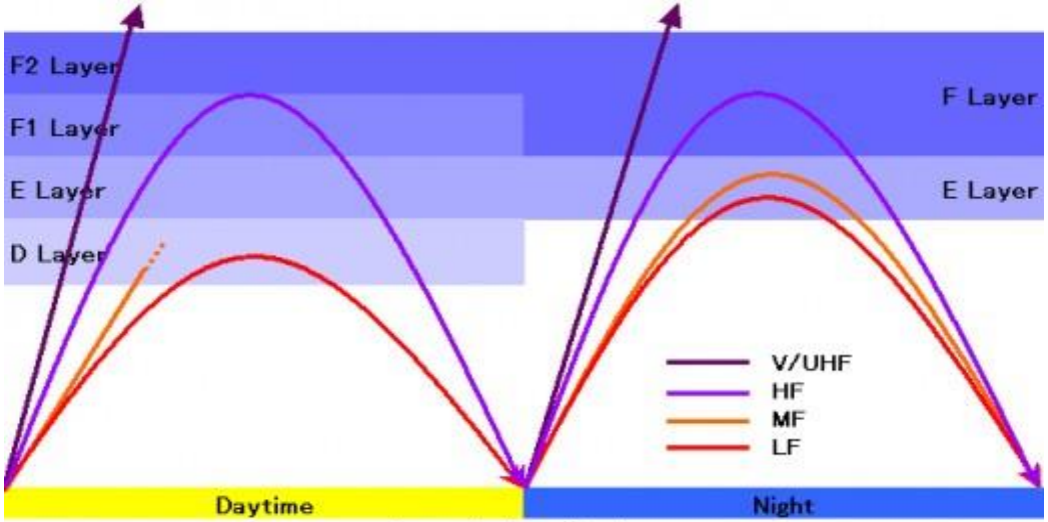
Propagation Concerns for Satellite Communications Systems



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 frequencies

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 *atmospheric 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 through the atmosphere.
  - Fade margin in the link power-budget calculations are used for Atmospheric Scintillation.

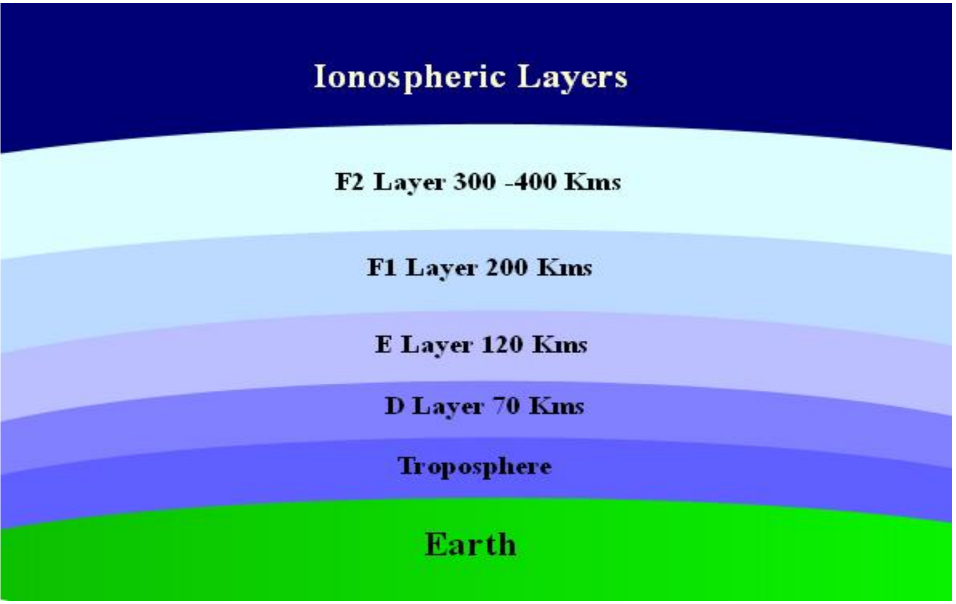


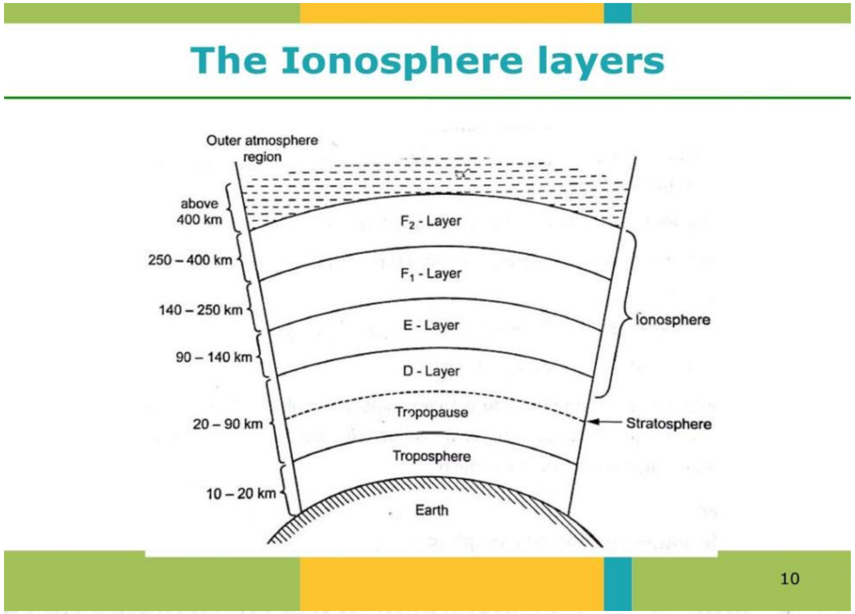
Ionospheric reflection
(under normal condition)

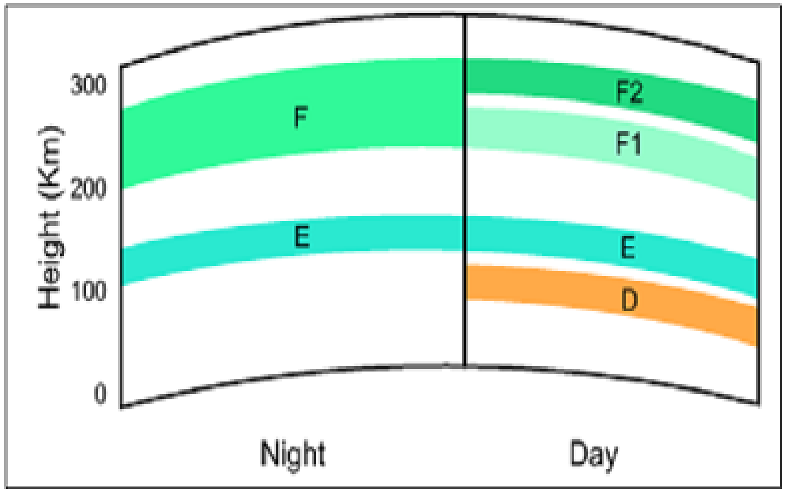
Ionospheric Effects

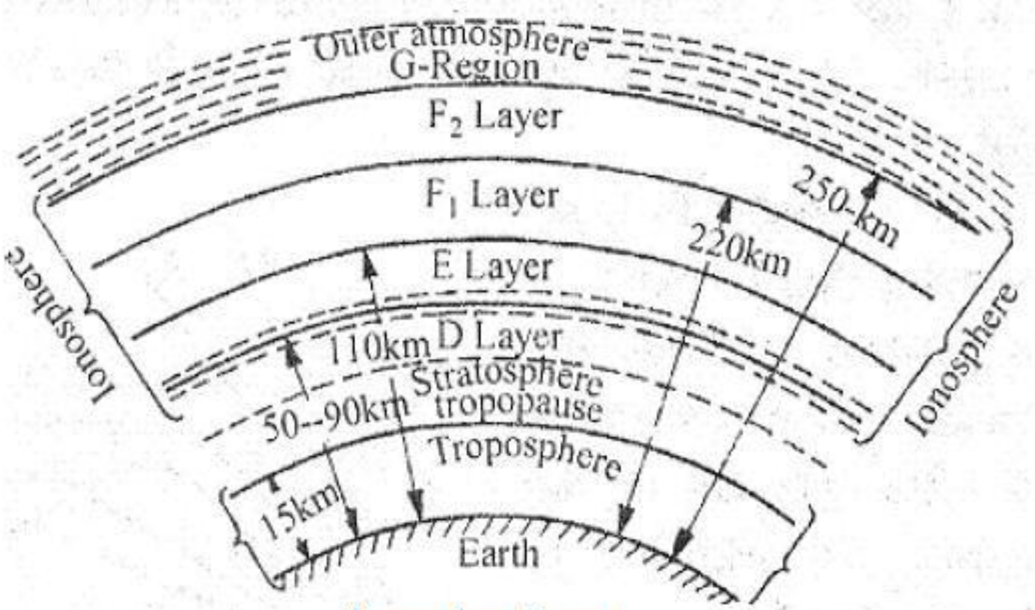
- Radio waves traveling between satellites and earth stations must pass through the ionosphere.
- The ionosphere is the upper region of the earth's atmosphere, which has been ionized, mainly by solar radiation.
- The free electrons in the ionosphere are not uniformly distributed but form in layers, which effect the signal.
- The effects include *scintillation, absorption, variation in the direction of arrival, propagation delay, dispersion, frequency change,* and *polarization rotation.*
- All these effects decrease as frequency increases. only the polarization rotation and scintillation effects are of major concern for satellite communications.
- Ionospheric scintillations are variations in the amplitude, phase, polarization, or angle of arrival of radio waves. They are caused by irregularities in the ionosphere which change with time. The main effect of scintillations is fading of the signal. The fades can be quite severe, and they may last up to several minutes.

Ionospheric Layers









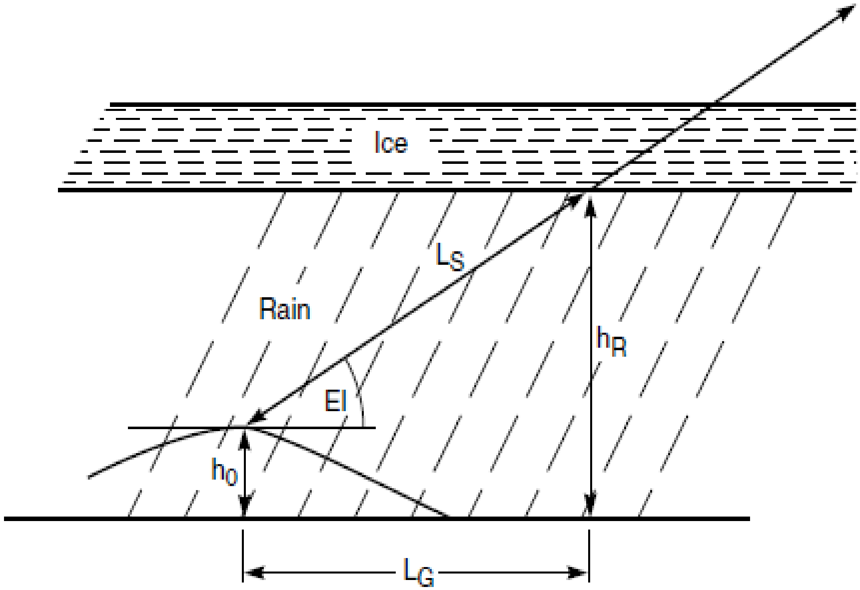
Ionosphere Layers

Rain Attenuation

- Rain attenuation is a function of *rain rate.* The rain rate is measured in millimeters per hour. The total attenuation is given as $A=\alpha L$ dB $\alpha = aR_p^{\,b}$ dB/km

  α - *specific 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,

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

Link budget calculations

- **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 to as 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 density multiplied by the effective aperture of the receiving antenna, given by Eq. The received power is therefore

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

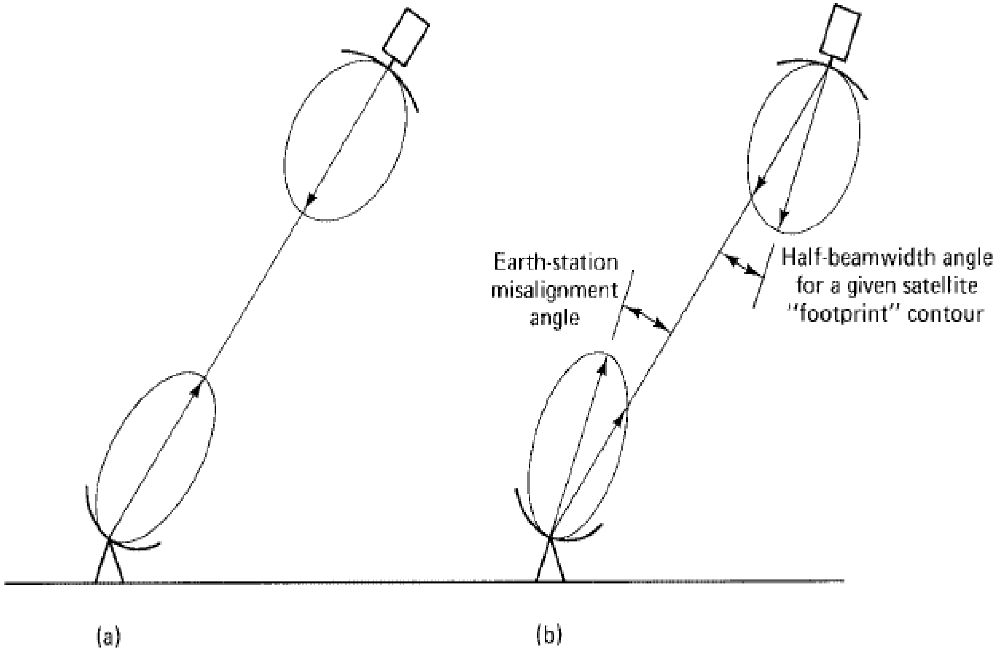
$$[P_R] = [\text{EIRP}] + [G_R] - 10\log\left(\frac{4\pi r}{\lambda}\right)^2$$

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

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

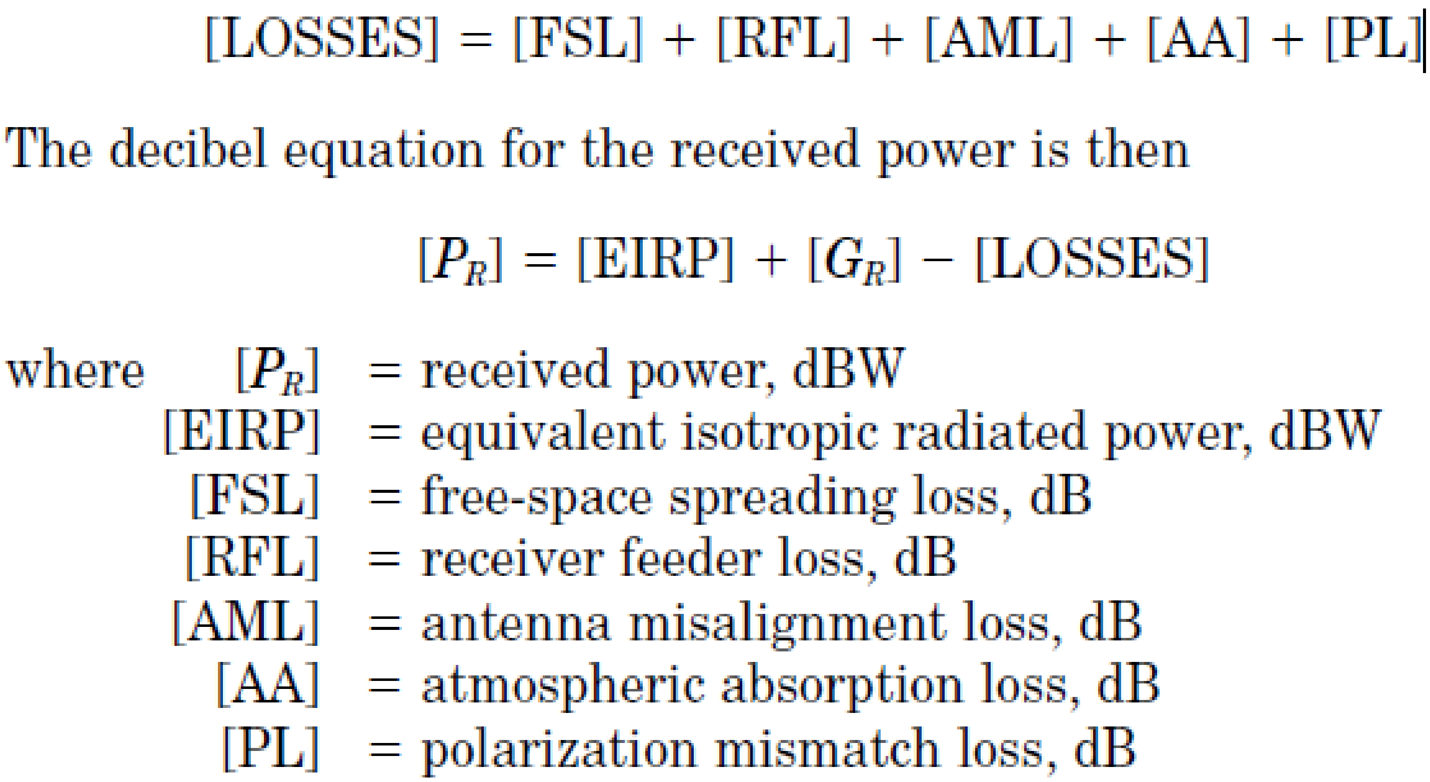
Losses

- **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. These will be denoted by RFL, or [RFL] dB, for *receiver feeder losses.*
- **Antenna misalignment losses:**
  - There are two possible sources of off-axis loss, one at the satellite and one at the earth station. The off-axis loss at the earth station is referred to as the *antenna pointing loss*



Link-Power Budget Equation

- 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

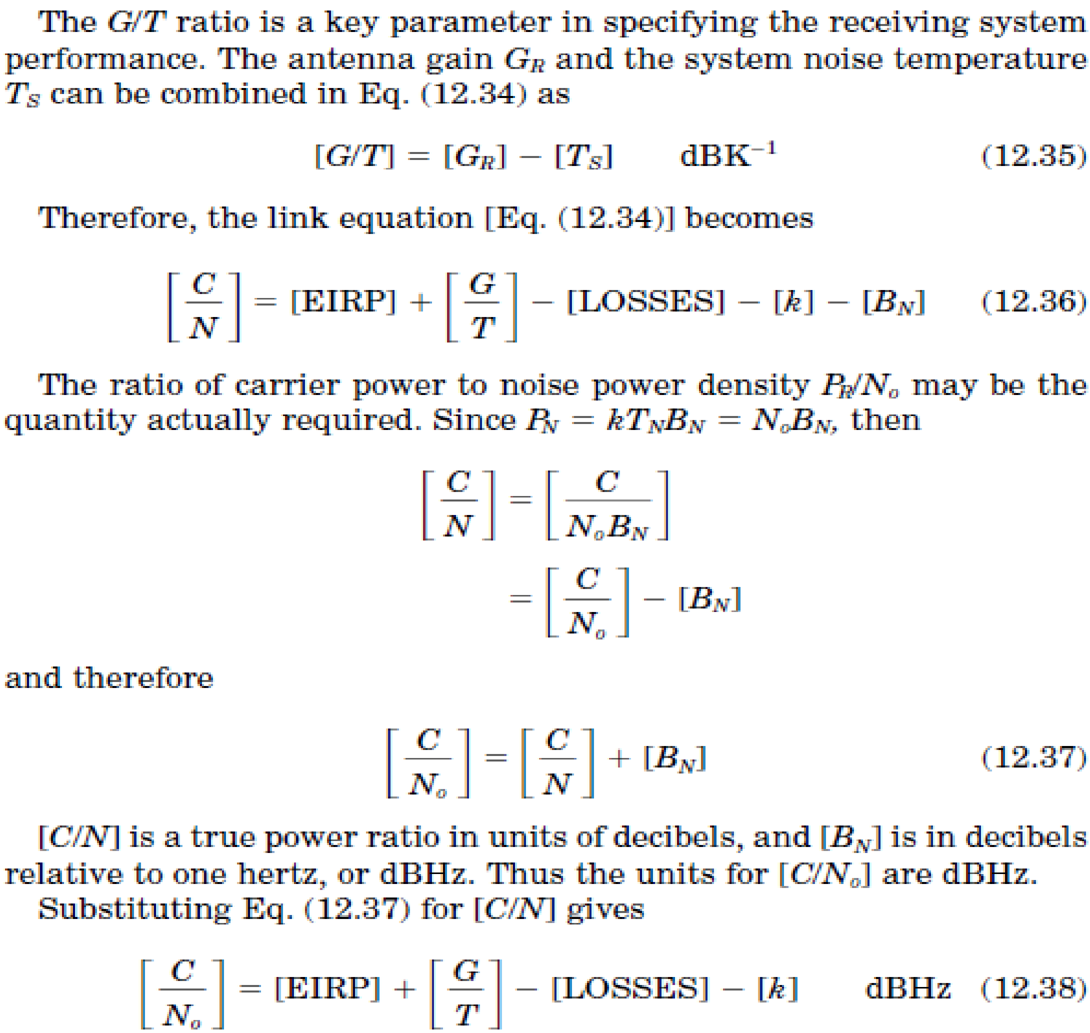
$[G_R]$ = Receiver antenna gain

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.

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

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



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 Eq. (12.34) as

$$[G/T] = [G_R] - [T_S] \qquad \mathrm{dBK}^{-1} \qquad (12.35)$$

Therefore, the link equation [Eq. (12.34)] becomes

$$\left[\frac{C}{N}\right] = [\mathrm{EIRP}] + \left[\frac{G}{T}\right] - [\mathrm{LOSSES}] - [k] - [B_N] \qquad (12.36)$$

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

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

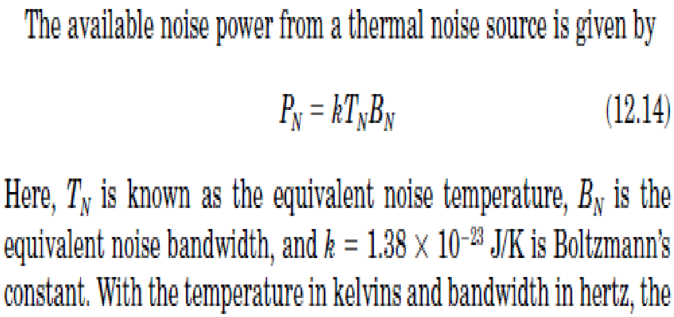
and therefore

$$\left[\frac{C}{N_o}\right] = \left[\frac{C}{N}\right] + [B_N] \qquad (12.37)$$

$[C/N]$ 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.

Substituting Eq. (12.37) for $[C/N]$ gives

$$\left[\frac{C}{N_o}\right] = [\mathrm{EIRP}] + \left[\frac{G}{T}\right] - [\mathrm{LOSSES}] - [k] \qquad \mathrm{dBHz} \qquad (12.38)$$



The available noise power from a thermal noise source is given by

$$P_N = kT_NB_N \qquad (12.14)$$

Here, T_N is known as the equivalent noise temperature, B_N is the equivalent noise bandwidth, and $k = 1.38 \times 10^{-23}$ J/K is Boltzmann's constant. With the temperature in kelvins and bandwidth in hertz, the

Uplink and Downlink

- **Uplink:**

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

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

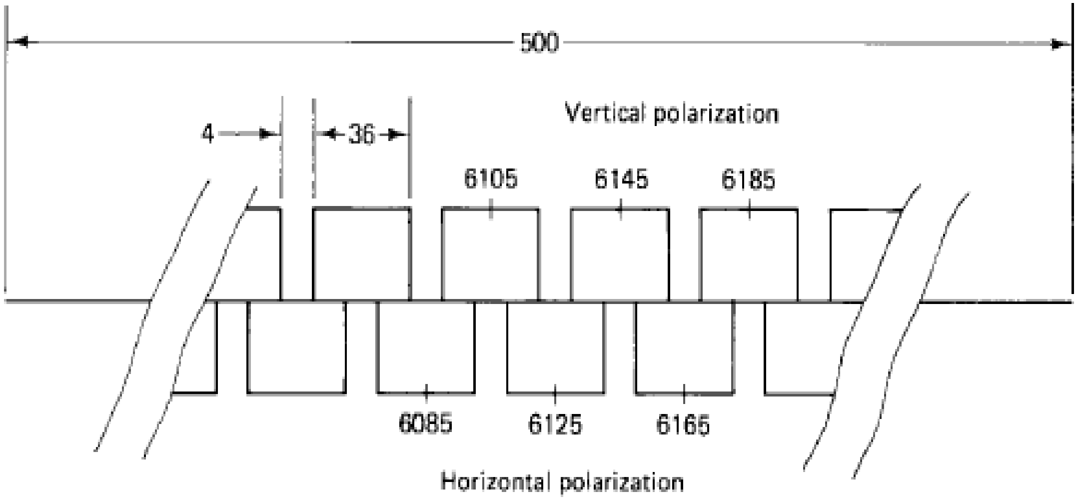
- **Downlink**

The satellite is transmitting the signal and the earth station is receiving it

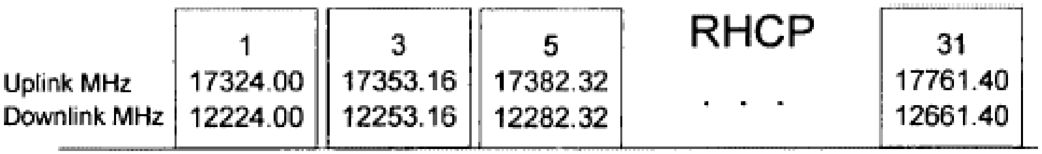
$$\left[\frac{C}{N}\right]_D = [\mathrm{EIRP}]_D + \left[\frac{G}{T}\right]_D - [\mathrm{LOSSES}]_D - [k] - [B]$$

Frequency Reuse

- Frequency reuse is employed to reduce the cross-polarization 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.

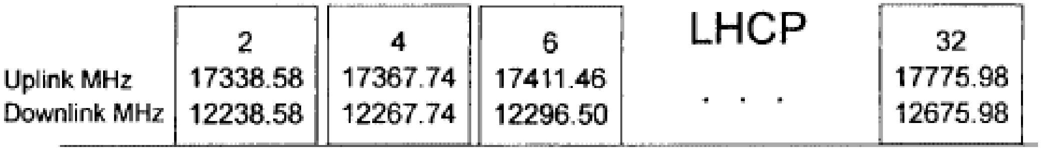


- The bandwidth allocated for C band service is 500 MHz, and this is divided into sub bands, one for each transponder. A typical transponder bandwidth is 36 MHz, and allowing for a 4-MHz guard band between transponders, 12 such transponders can be accommodated in the 500-MHz bandwidth.
- By making use of *polarization isolation,* 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 antennas matched to the incoming polarization.
- With linear polarization, vertically and horizontally 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*



RHCP

	1	3	5	. . .	31
Uplink MHz	17324.00	17353.16	17382.32		17761.40
Downlink MHz	12224.00	12253.16	12282.32		12661.40



LHCP

	2	4	6	. . .	32
Uplink MHz	17338.58	17367.74	17411.46		17775.98
Downlink MHz	12238.58	12267.74	12296.50		12675.98