SATELLITE COMMUNICATIONS AND GPS

MODULE 2

Module 2

Module 2:

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)

Telemetry, Tracking & Command System (TT&C)

Performs several routine functions aboard. Telemetry or telemetering function may be said as measurement at a distance.

It is overall operation of generating an electrical signal proportional to the measured quantity, encoding, transmitting this to an earth station for example. Transmitted data may be attitude information from sun and earth sensors, environmental information (magnetic field intensity and direction, frequency of mereorite impact etc.), spacecraft information like temperatures, power supply voltages and stored fuel pressure etc. Frequencies are allotted by international agreement for satellite telemetry transmissions.

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

Satellite on station- any normal transponders may be used along with its directional antenna for communication (unless an emergency case) , when it is necessary to switch back to special channel used during transfer orbit.

Telemetry and command -considered as complementary functions. Command subsystem receives command signals from earth station , may be in response to telemetered signal, demodulates and decodes if needed, routes them to appropriate equipment executing the

Command to actions. Attitude changes may be made, transponders switched in and out of ckts, antennas redirected, station keeping maneuvers carried out (response to command).

Contd.

It is necessary to prevent unauthorized commands from being received and decoded, command signals are encoded.

Satellite tracking by TT&C earth station is as per the satellite transmit beacon signals received. During transfer and drift orbital phases of orbital launch it is necessary to send correction signals as required using special tracking antennas. This is done by transmitting tracking beacons in the telemetry channels or by pilot carriers at frequencies in one of main communication channels or by special tracking antennas. Satellite range from time to time is determined from propagation delay of signals specially transmitted.

TT&C operations are complex operations require special ground facilities in addition to TT&C sub system aboard as in fig.7.11.

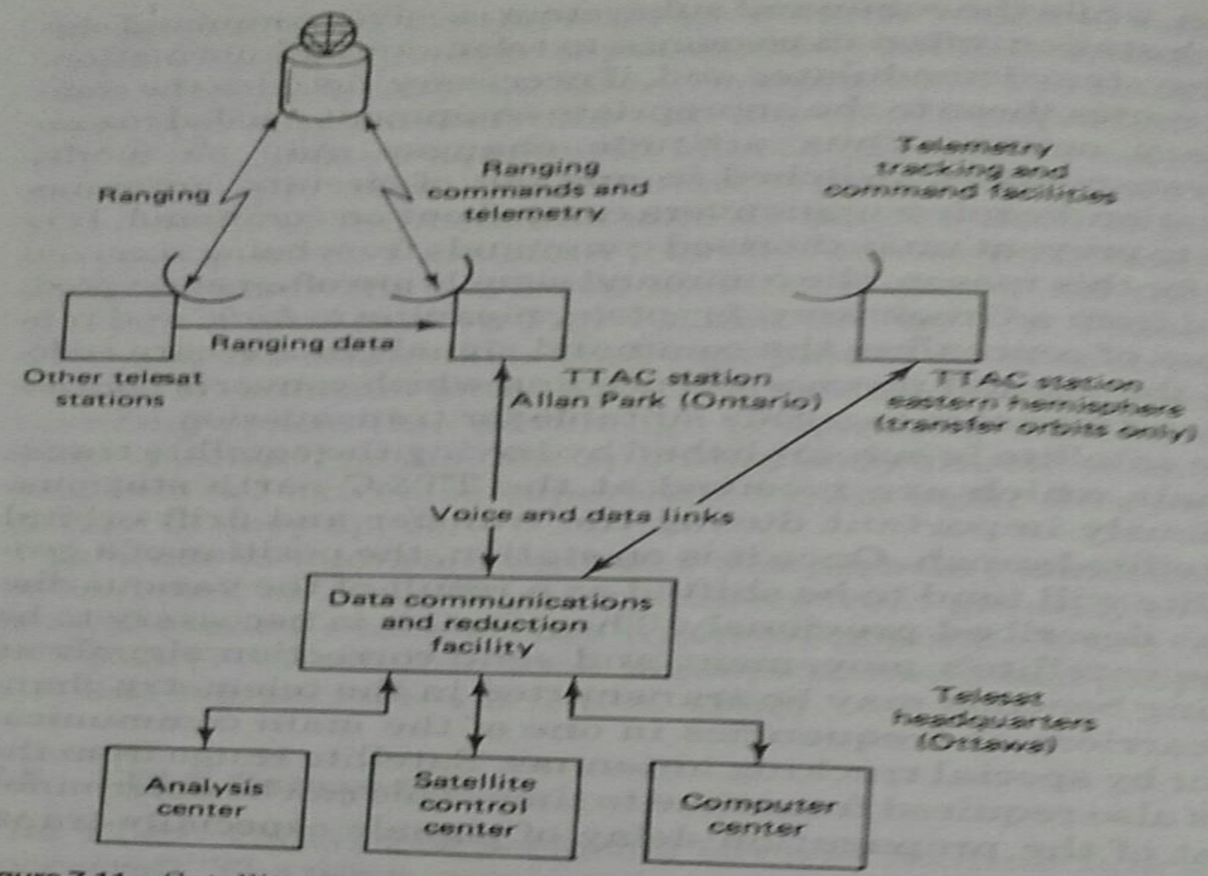


Figure 7.11 Satellite control system. (*Courtesy of Telesat Canada, 1983.*)

Transponders

It is a series of interconnected units forming a single communication channel between receive and transmit antennas in a communications satellite. Some units of a transponders in a given channel may be common to a number of transponders. Thought of as an equipment channel and not a single item of equipment.

C- band service has a bandwidth of 500MHz and divided into sub bands, one for each transponder. Wide band receiver uses only solid state devices. At 6GHz in 6/4-GHz transponders, tunnel diode amplifiers for preamplifiers, and at 14GHz in 14/12-GHz transponders as parametric amplifiers are used. Transponder BW is 36MHz (typ) , allows a guard band of 4MHz between transponders, 12 such transponders are there in 500MHz. Polarization isolation doubles this.

Polarization isolation makes the carriers of same frequency to have Linear ~~polarization, vertically and horizontally polarized carriers can be separated~~ this way. With circular polarization, left hand and right hand polarizations can be separated. But carriers with opposite senses of polarization may overlap in frequency- technique called frequency reuse. See fig. 7.12 plan for a C band communications satellite .

Frequency reuse may also be achieved through spot beam antennas and may be combined with polarization reuse to provide effective BW of 2000MHz from actual BW of 500MHz.

One of the polarization groups in fig.7.13 the channeling scheme for the 12 transponders are shown. For 12 transponder scheme, incoming or uplink frequency range is 5.925- 6.425GHz, carriers received by one or more antennas all of same polarization.

Input filter has a BW of 500MHz feeding the common receiver, rejecting out of band noise and interference from image signals.

Within this 500MHz pass band there are several modulated carriers and all are amplified and frequency converted in common receiver. Frequency conversion shifts carriers to downlink band also of 500MHz wide extending from 3.7 to 4.2 GHz. Here signals are channelized into bands representing individual transponder BWs.

A transponder may handle one modulated carrier such as TV signal or a number of separate carriers simultaneously. Each modulated by its own telephony or other baseband channel.

Wide Band Receiver: Shown in detail in fig.7.14. By providing a duplicate receiver, so if one fails, other automatically switched in, a redundant receiver is achieved. The first stage in receiver is low noise amplifier.

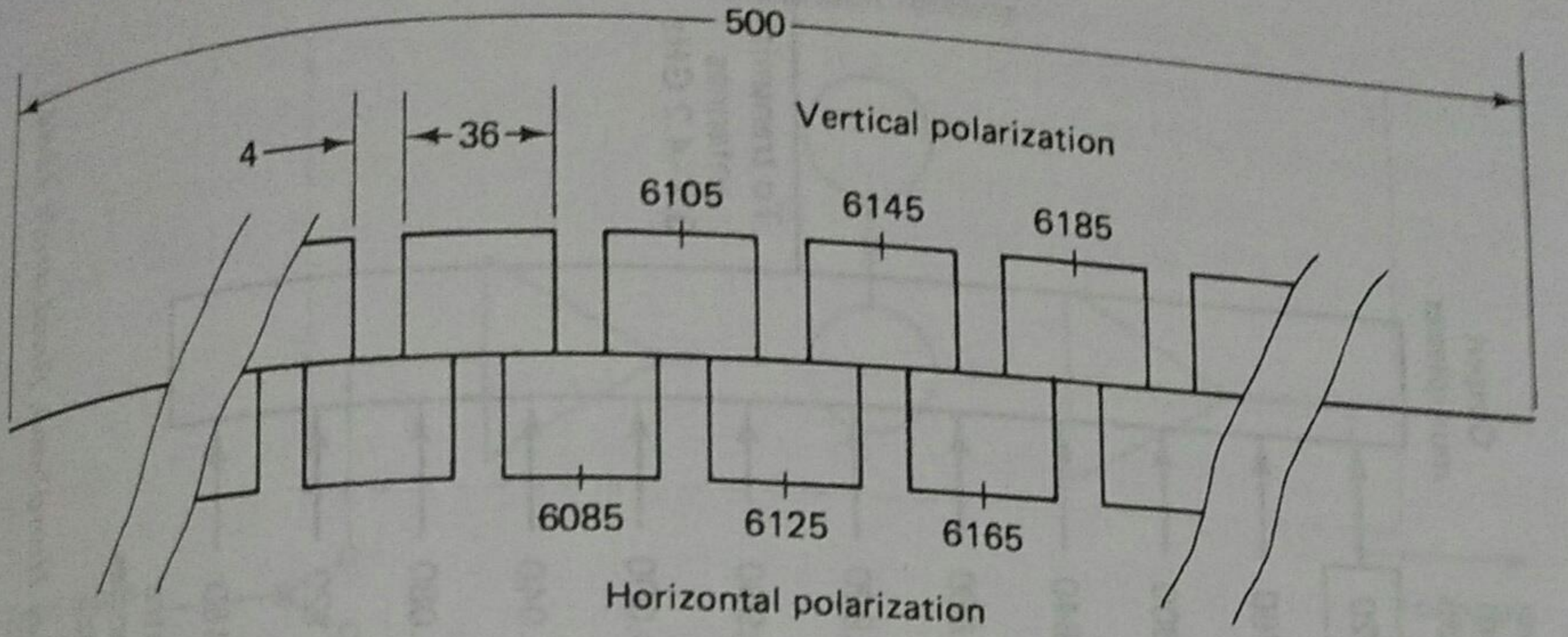


Figure 7.12 Section of an uplink frequency and polarization plan. Numbers refer to frequency in megahertz.

Contd.

All transponders add noise. Usually all noise levels are referred to the LNA input. Equivalent noise is expressed in terms of noise temperature. If receiver is well designed, equivalent noise temperature referred to LNA input is that of LNA alone. Noise added by the antenna is also taken into account. Equivalent noise temperature of a receiver may be of the order of few hundred kelvins.

Adds little noise during carrier amplification and provides sufficient amplification for the carrier to override noise in the mixer stage.

FETs are being used for amplification for better performance in both bands presently. Diodes are used for mixing followed by BJTs at 4GHz and FETs at 12GHz or FETs in both bands.

LNA feeds into a mixer which needs local oscillator (LO) for frequency conversion . Power drive from LO to mixer input is ~10dBm. Requirement of LO is stable frequency and low phase noise. Second amplifier following mixer stage provides an overall gain of ~60dB see fig.7.14. Gain is split between preamplifier at 6GHz and second amplifier at 4GHz to prevent oscillation (not all gain is at the same frequency).

FETs are being used for amplification for better performance in both bands presently. Diodes are used for mixing followed by BJTs at 4GHz and FETs at 12GHz or FETs in both bands.

Input Demultiplexer:Separates broadband input coverage from 3.7-4.2 GHz to transponder frequency channels as in fig.7.13, separate channels 1-12 as per details in fig. 7.15. Channels are arranged usually in odd numbered and even and odd numbered blocks for wider frequency separation between adjacent channels in a group for decreasing adjacent channel interference. Receiver output goes to a power splitter feeding the two separate chains of circulators.

Along each chain full broadband signal is transmitted along each chain using channel filters connected to each circulator as in fig.7.15. Channel filter has a BW of 36MHz (tuned to appropriate center frequency of fig.7.13). Considerable losses in demux are easily made up in the overall gain for the transponder channels.

Satellite Transponder Channels

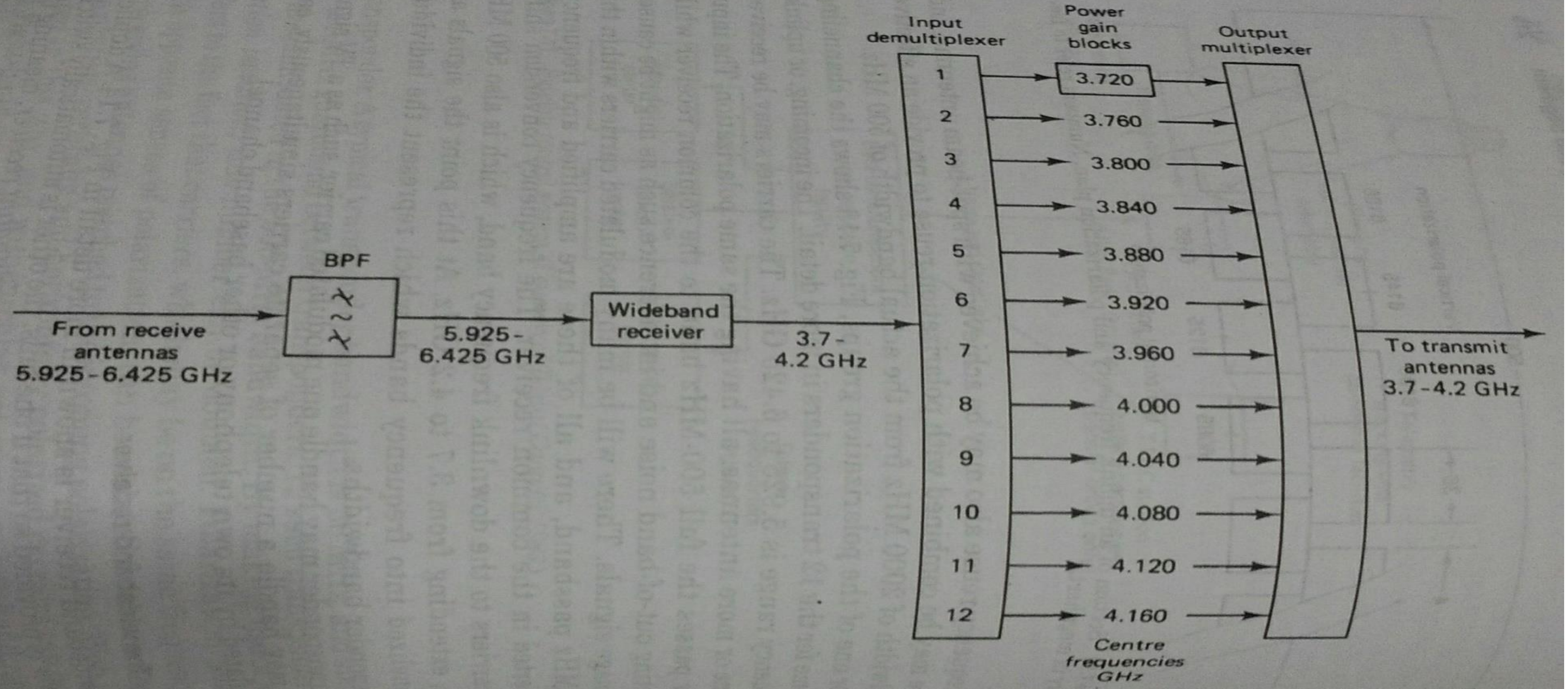


Figure 7.13 Satellite transponder channels. (*Courtesy of CCIR, CCIR Fixed Satellite Services Handbook, final draft 1984.*)

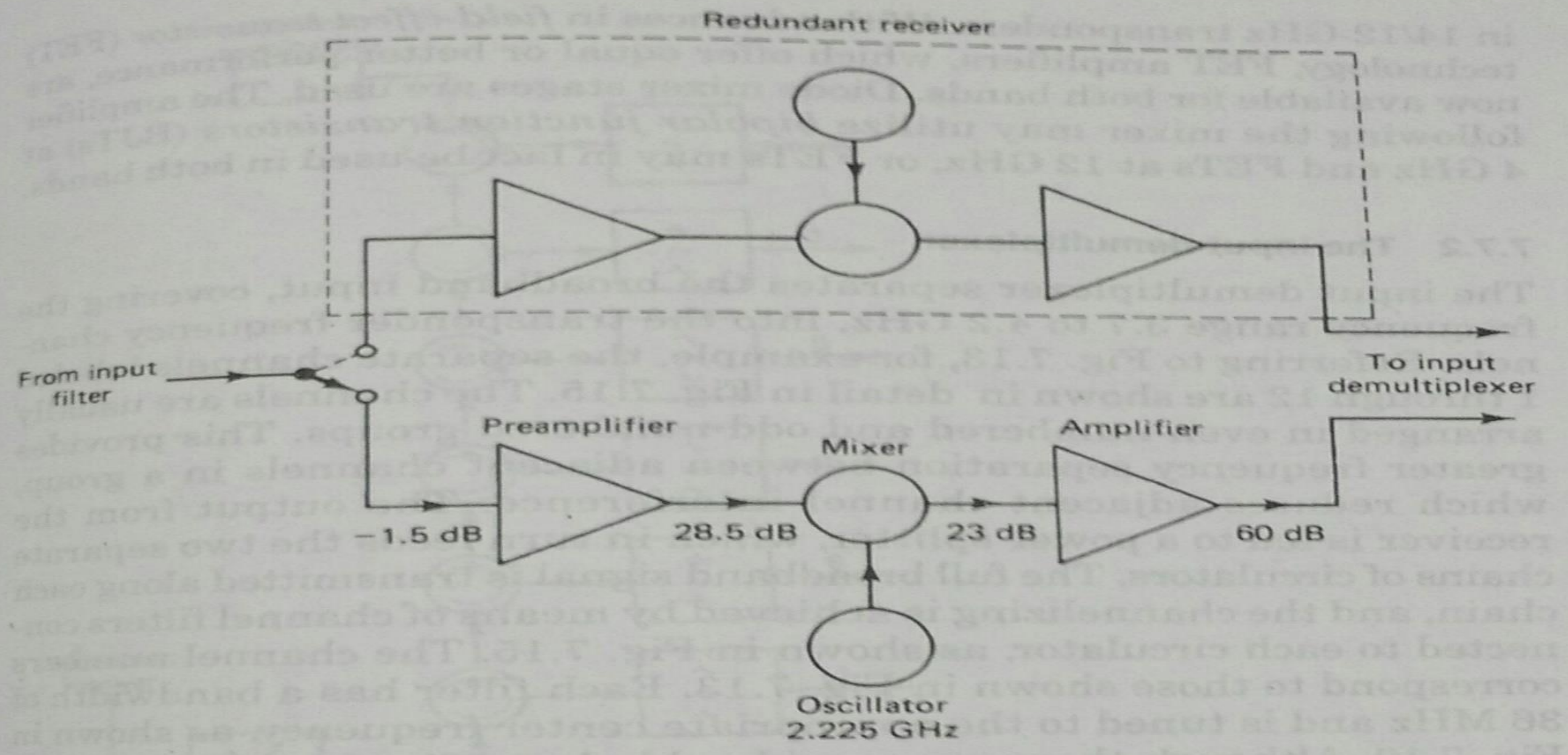


Figure 7.14 Satellite wideband receiver. (*Courtesy of CCIR, CCIR Fixed Satellite Services Handbook, final draft 1984.*)

Input Demultiplexer

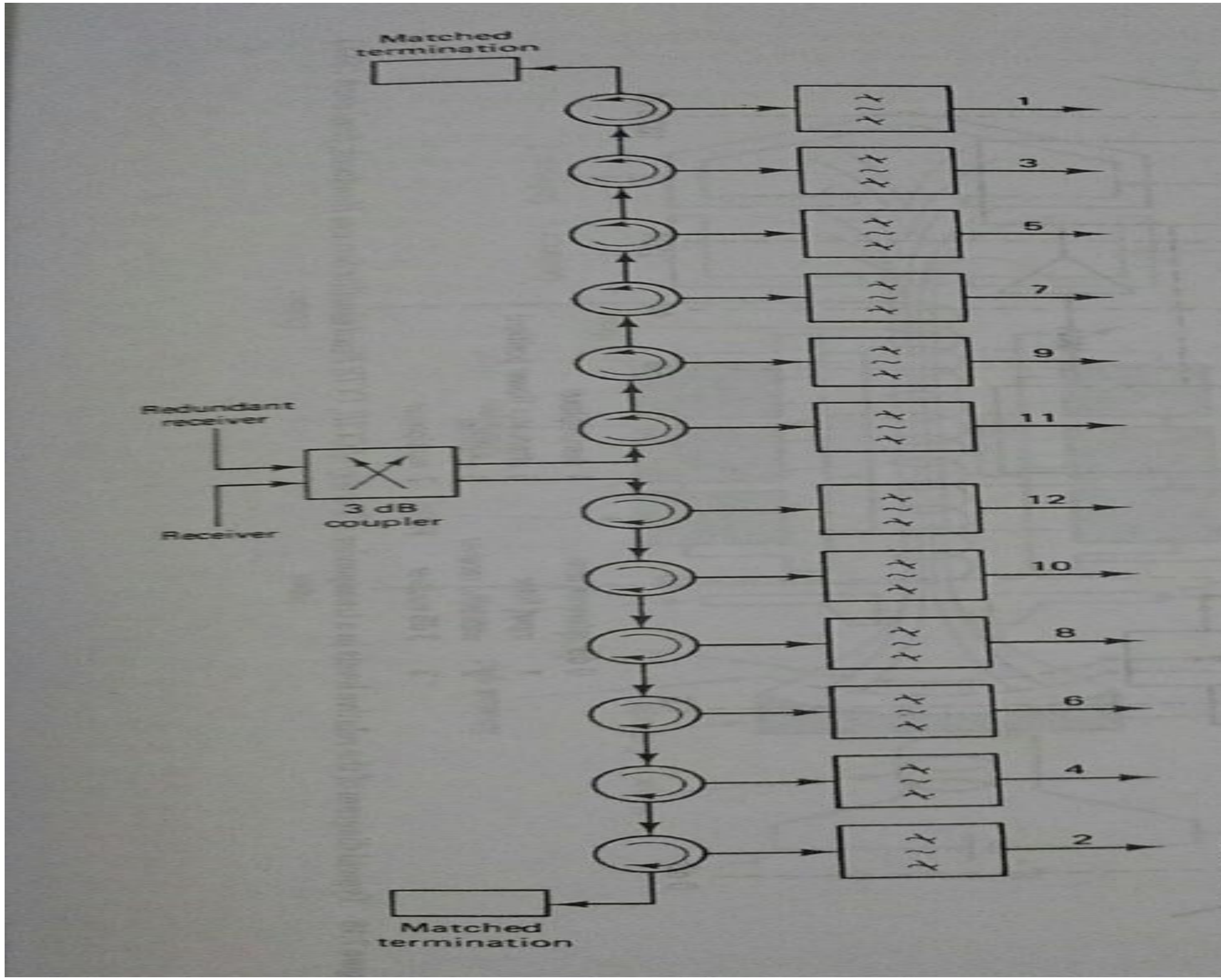


Figure 7.15 Input demultiplex... (Courtesy of CCIR, CCIR Fix... Satellite Services Handbook, fin... draft 1984.)

Reliability, Steps in satellite mission realization. Test and Evaluation of the Satellite components, Satellite subsystems and Satellite as a system. –Refer Book by S K Raman

Ex.4.8. Calculate the reliability of a command receiver for 6 years given that the MTBF of the batch of the receiver is 35000hrs.

Calculate $\lambda = \frac{1}{\text{MTBF}} = \frac{1}{35000}$; 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,

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 $\lambda = \dfrac{1}{\text{MTBF}}$ 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, ie., R=4.19x10^-3

Power Amplifier:

For each transponder channel there is a separate power amplifier, see fig.7.16, it is preceded by input attenuator – for permitting the input drive to each power amplifier (to be adjusted to desired level). Attenuator has a fixed and variable section, fixed attenuation for balancing variations in input attenuation for the same nominal attenuation at the transponder channel (adjustment done during assembly). Variable attenuation for setting for different types of services (operational requirement under the control of ground TT&C station).

Traveling wave tube amplifiers (TWTAs) are used widely in transponders for providing final power output needed for transmit antenna.

TWT Contd.

An electron beam gun assembly consisting of a heater, a cathode and focusing electrodes is used to form an electron beam in a TWT. A magnetic field confines the beam to travel along the inside of a wire helix. For high power tube as in ground stations, magnetic field can be provided by means of a solenoid and dc power supply. This is of large size and consume large power, hence are not used inside satellites, but lower power TWTs are used which employ permanent magnet focusing.

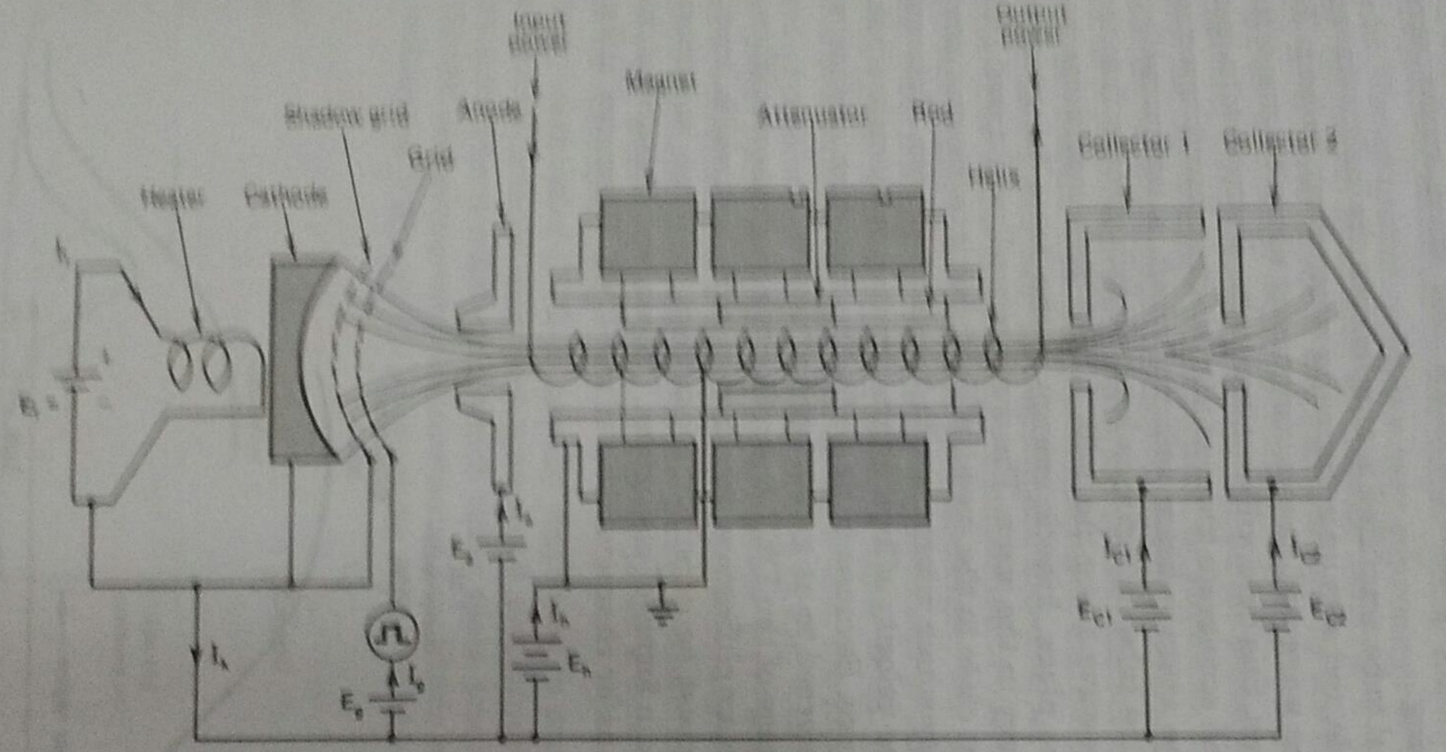


Figure 7.17 Schematic of a TWT and power supplies. (*Courtesy of Hughes TWT and TWTA Handbook; courtesy of Hughes Aircraft Company, Electron Dynamics Division, Torrance, CA.*)

RF signal to be amplified is coupled into the helix at the cathode end, setting up a traveling wave along helix. The electric field of wave has a component along helix axis. Electron bunching occurs along beam.

Average beam velocity is decided by dc potential on tube collector and is slightly > phase velocity of wave along helix. KE in the beam is converted to PE in wave and wave travels ~ at the speed of light, its axial component (velocity < light velocity) interacting with electron beam causes effective reduction in phase velocity.

The reduced phase velocity is due to slow wave structure of helix. TWT has advantages over other tube amplifiers- amplification over wide bandwidth. Distortion must be prevented by carefully selecting input level. Power transfer and phase characteristics of TWT are

Contd.

shown in figs.7.18 and 7.19.

Frequency modulation is used in analog satellite communication circuits. Unwanted AM can also occur which converts it to phase modulation, appearing as noise in FM carrier.

TWT may also be used for amplifying two or more carriers simultaneously , multicarrier operation. Introduces intermodulation distortion due to nonlinear characteristics expressed in Taylor series

.

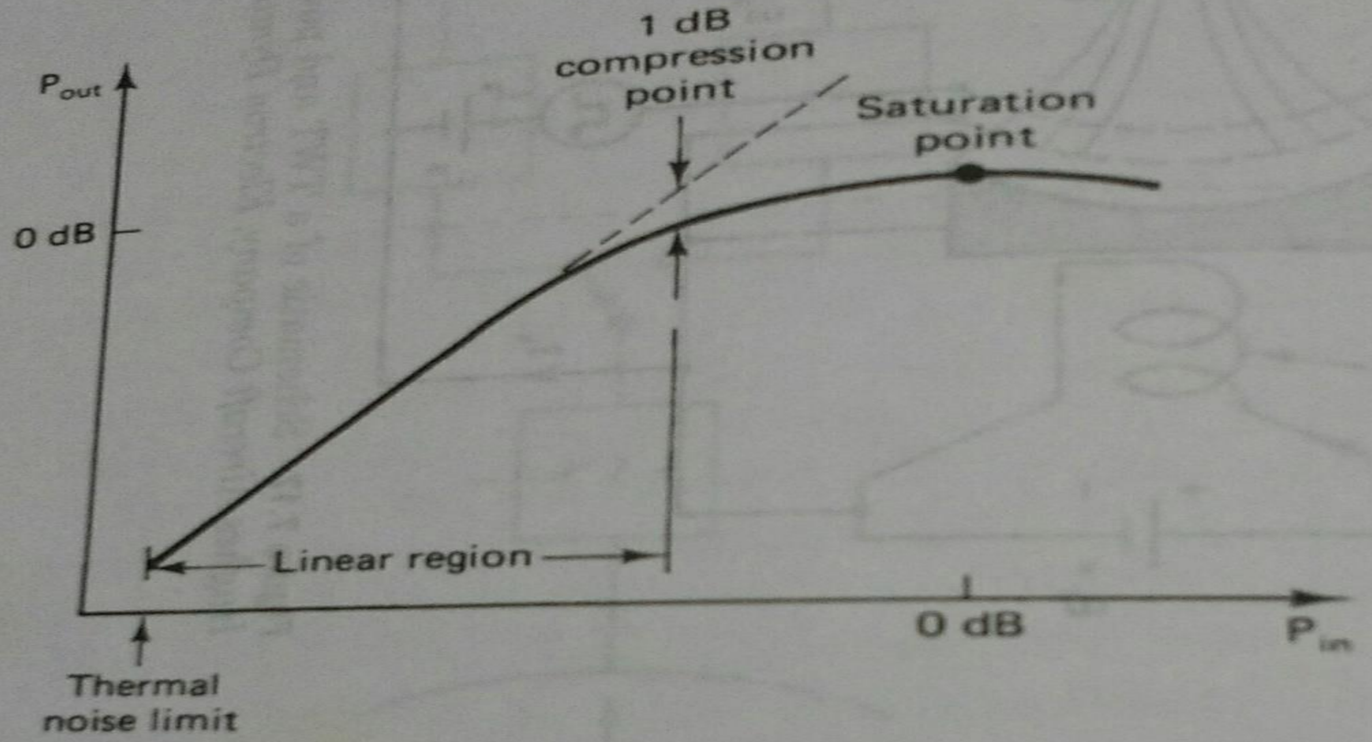


Figure 7.18 Power transfer characteristics of a TWT. The saturation point is used as 0-dB reference for both input and output.

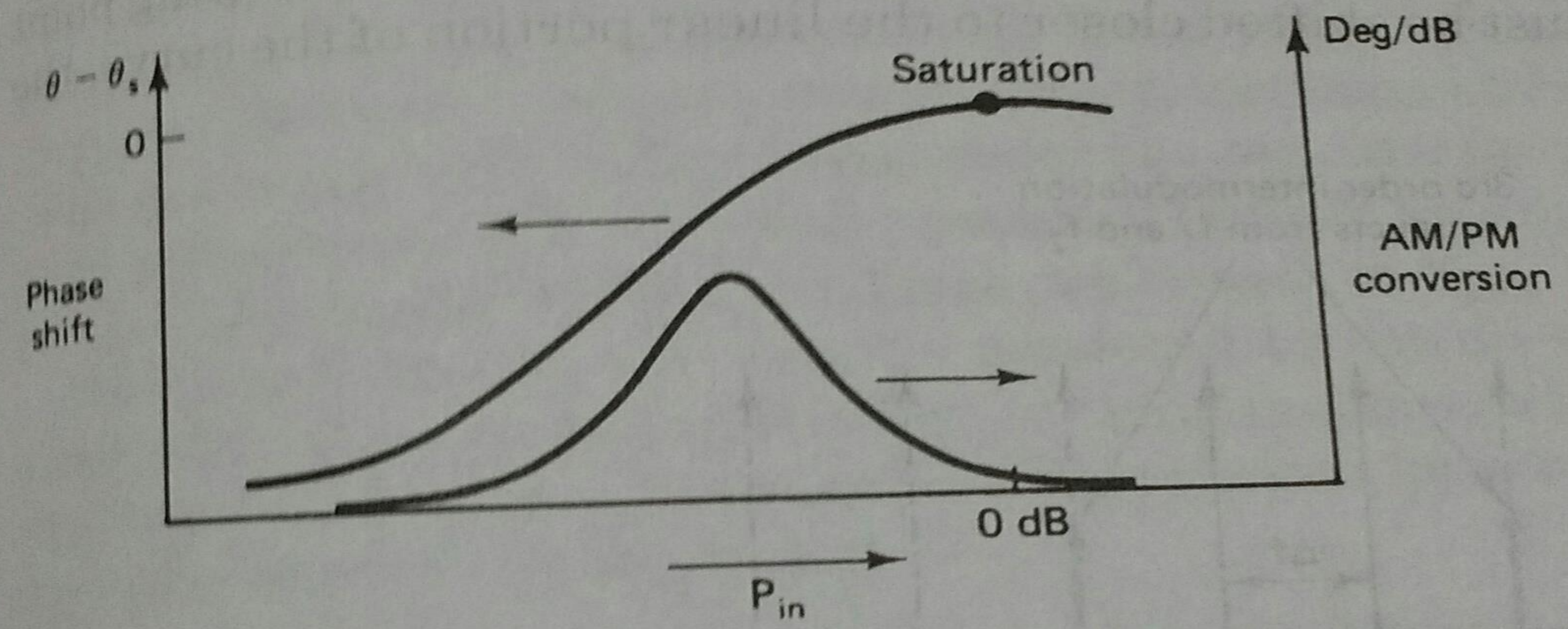


Figure 7.19 Phase characteristics for a TWT. θ is the input-to-output phase shift, and θ_S is the value at saturation. The AM/PM curve is derived from the slope of the phase shift curve.

Satellite Antennas: Antennas onboard must receive uplink and transmit downlink signals. Range of antennas- dipole like ie., omnidirectional to highly directional type required for telecom purposes and TV relay and broadcast. Figs. 7.1, 7.2 and 7.7 give parts of antenna structures for HS 376 and HS 601 satellites.

Reflector type antennas produce directional beams- paraboloidal reflector used commonly.

Gain of paraboloidal reflector relative to an isotropic radiator $G = \eta_I = (\pi D/\lambda)^2$, λ- wavelength of signal, D- reflector diameter η_I = aperture efficiency, 0.55 (typ). The -3dB BW is ~ given by $\theta_{3dB} = 70 \lambda/D$ deg.

Contd.

D/λ is the key factor gain is proportional to sq(D/λ), beam width inversely proportional to D/λ. Gain can be increased by increasing D or beam width can be decreased by decreasing λ. By comparison of C-band and Ku-band, largest reflectors are for those in 6/4GHz band. In 14/12GHz band, comparable performances are for considerably smaller reflectors. Satellites for mobile services use much larger antennas in L-band (reflector areas 100sqm to 200sqm)

Fig.7.22 shows the antenna subsystem of INTELSAT VI satellite. Shows the level of complexity. Largest reflectors are for 6/4GHz hemisphere and zone coverages as in fig.7.23. They are fed from horn arrays and various groups of horns can be excited to produce the required beam shape. Separate arrays are used for Tx and Rx. Each array has 146 dual polarization horns.

Contd.

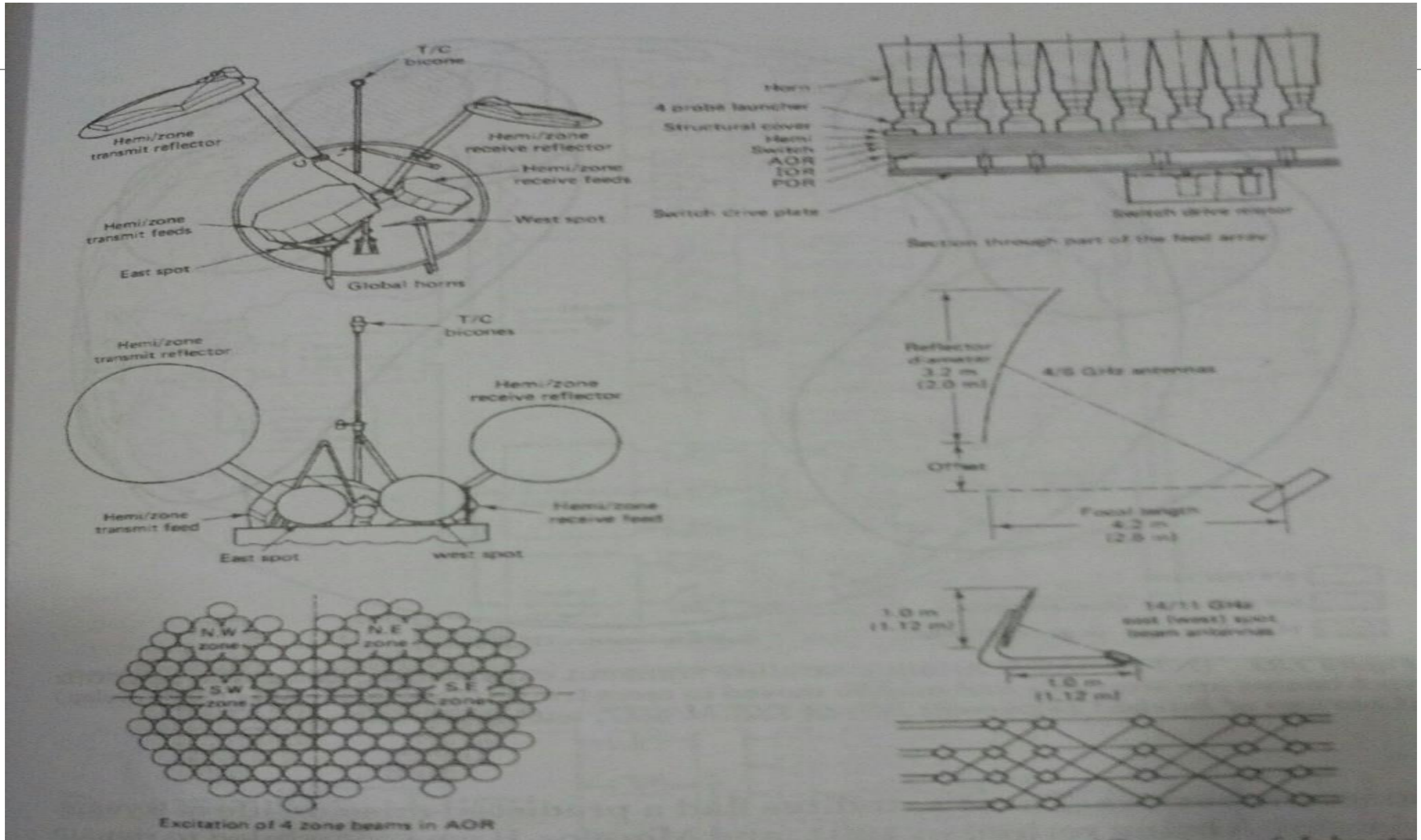


Figure 7.22 The antenna subsystem for the INTELSAT VI satellite. *(Courtesy of Johnston and Thompson, 1982, with permission.)*

Contd.

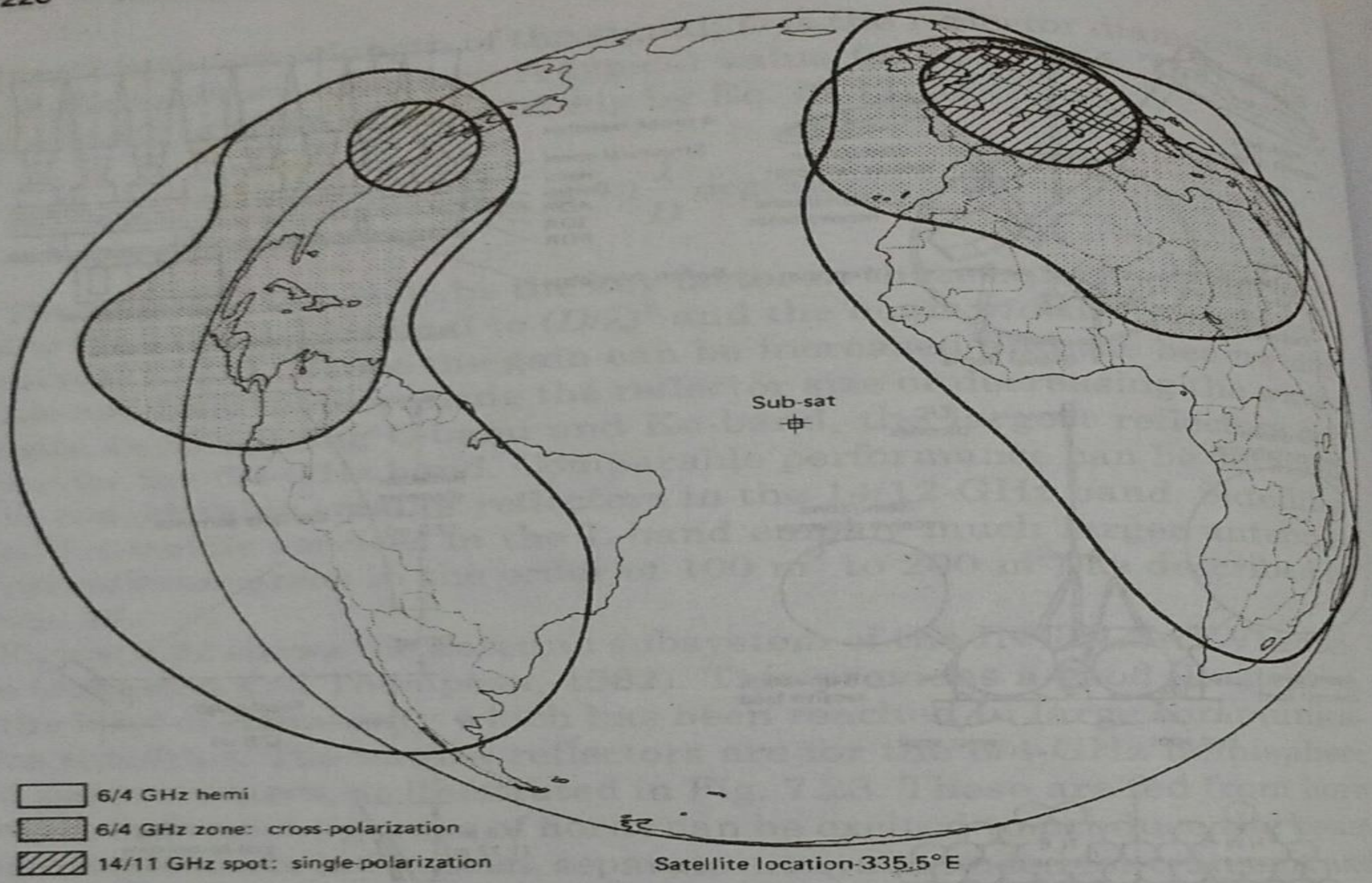


Figure 7.23 INTELSAT V Atlantic satellite transmit capabilities. (Note: The 14/11-GHz spot beams are steerable and may be moved to meet traffic requirements as they develop.) (*Courtesy of Intelsat Document BG-28-72E M/6/77, with permission.*)

Contd.

Circular reflectors are used in 14/11GHz band one for east and one ~~for west to provide spot beams. Beams are fully steerable, each spot~~ is fed by a single horn used for both Tx and Rx.

For global coverage wide beams are produced at 6/4GHz by simple horn antennas. The horns beam signal directly to earth station without reflectors. Fig.7.22 shows a simple bioconical dipole antenna for tracking and control signals.

Power System:

Solar cells are the primary source of energy for satellite system. This energy is used to charge on board batteries. Individual cells generate lesser voltage and power, so they are series, parallel connected to deliver higher power.

Power System Contd.

Fig.7.1 shows the solar cell panels for HS 376 satellite Hughes Aircraft co.) . Spacecraft size 216cm india and 660cm long when fully deployed in orbit.

In launch sequence the outer cylinder is telescoped over the inner one for reducing overall length. During this phase only outer panel generates electrical power. In geostationary orbit the telescoped panel is fully extended so that both are exposed to sun light. Beginning of life panels produce 940 Wdc and may drop to 760W dc power at the end of 10 years.

During eclipse power is supplied from storage batteries (Ni-Cd), provide 830W. At the end of life battery recharge time is <16hr.

HS 376 spacecraft is a spin stabilized spacecraft (the gyroscopic effect of the spin is used for mechanical orientational stability).

Contd.

Arrays are hence are only partially in sunshine at any given time, placing a limitation on time.

HS 376 spacecraft is a spin stabilized spacecraft (the gyroscopic effect of the spin is used for mechanical orientational stability). Arrays are hence are only partially in sunshine at any given time, placing a limitation on time.

For higher powers panels arranged in the form of rectangular solar sails, they must be folded during the launch phase and extended in geostationary orbit.

Fig.7.2 shows HS 601 satellite from Hughes Space and Communications Co, solar sails are seen folded up on each side , when fully extended , stretch to 67ft (20.42m) from tip to tip. HS601 is designed for dc power of 2 to 6kW .

Contd.

Full complement of solar cells are exposed to sun, sails are arranged to rotate to track, they are capable of greater power output than cylindrical arrays of almost same no. of cells.

Comparing cylindrical and solar sail satellites, crossover point is about 2kW, where solar sails are more economical than cylindrical type.

Earth will eclipse geostationary satellites twice a year, during spring and autumnal equinoxes. Daily eclipses start ~23 days before and end ~ 23 days after equinox for both spring and autumn and may last upto 72min at the actual equinox days. See fig.7.3.

To maintain service during eclipse, energy is stored in Ni-Cd batteries (Hughes HS 376 satellite). Ni hydrogen batteries are being developed for drastic power/weight ratio improvement.


390 Chapter Seven

Figure 7.11 The HS 376 satellite. (*Courtesy of Hughes Aircraft Company Space and Communications Group.*)

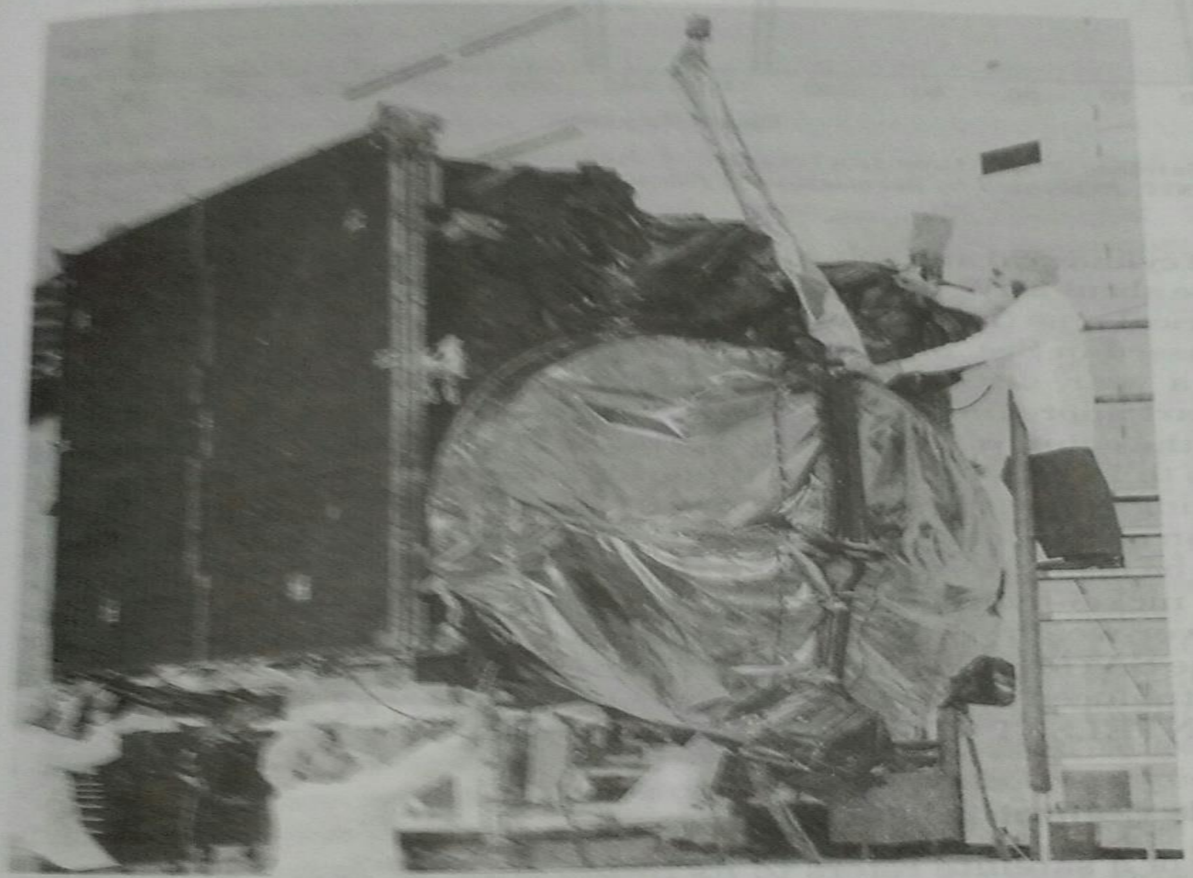


Figure 7.2 Aussat B1 (renamed Optus B), Hughes first HS 601 communications satellite is prepared for environmental testing. (Courtesy of Hughes Aircraft Company Space and Communications Group.)

Contd.

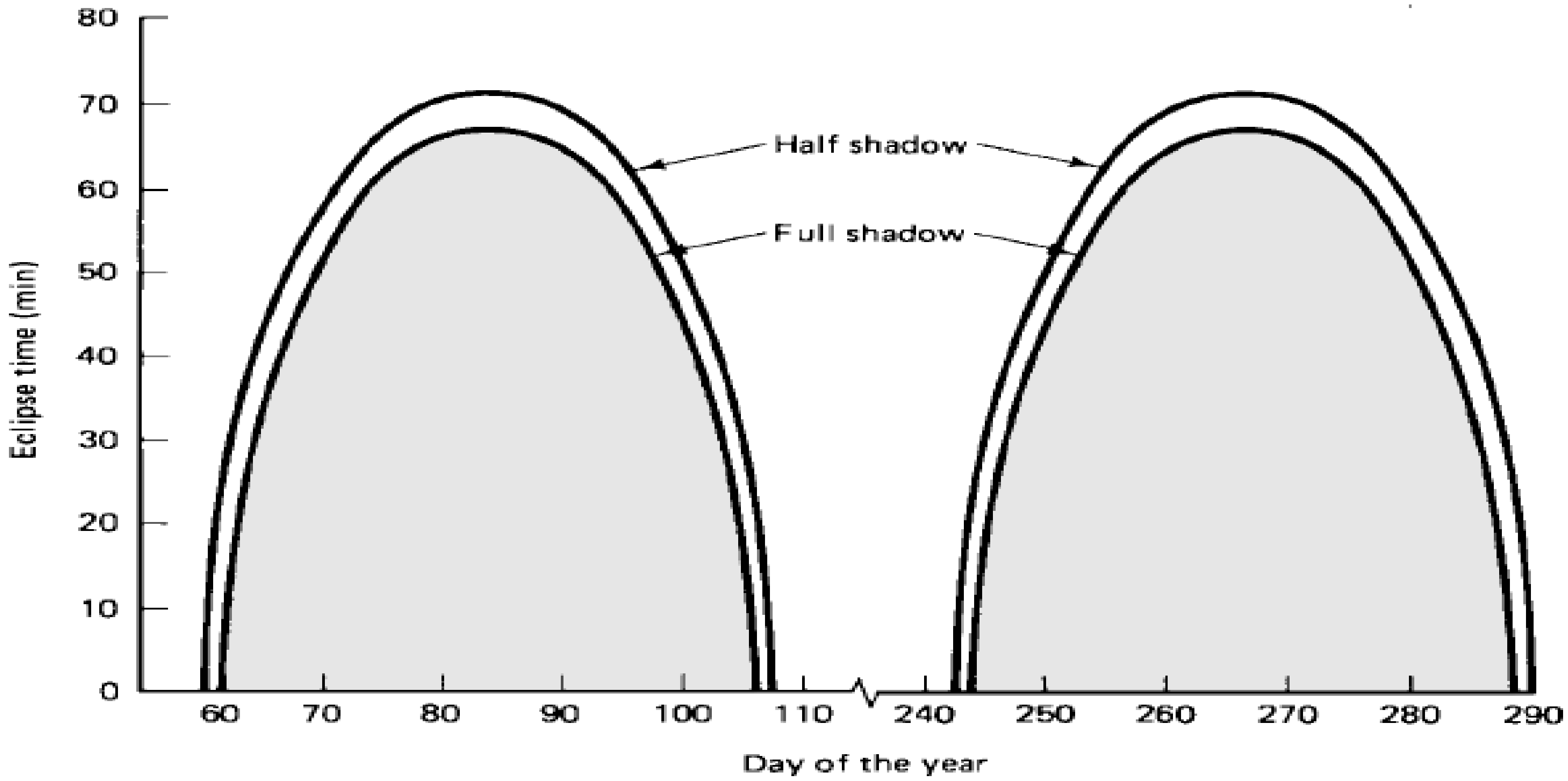
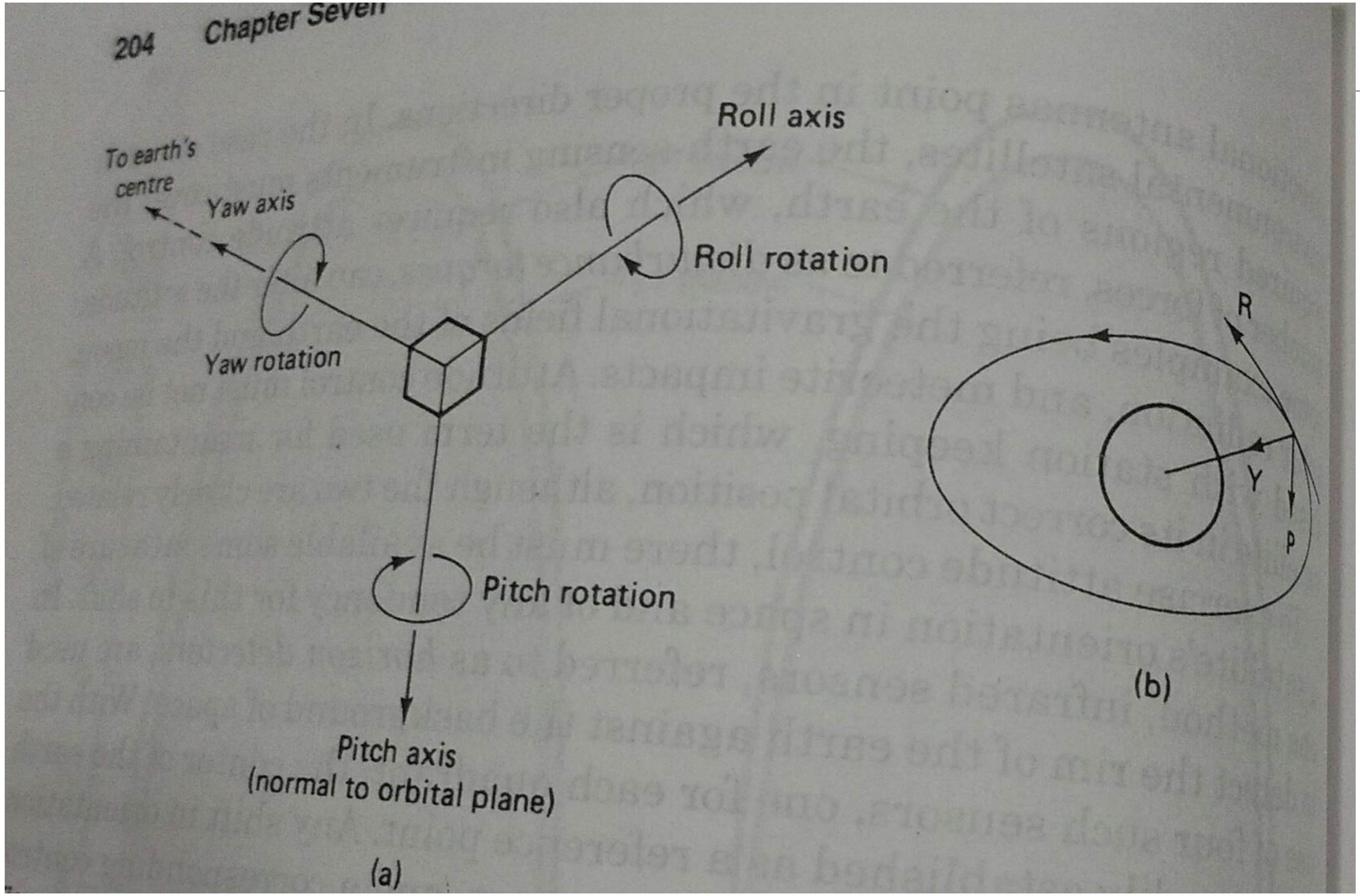


Figure 7.3 Satellite eclipse time as a function of the current day of the year. (*From Spilker, 1977. Reprinted by permission of Prentice-Hall, Englewood Cliffs, NJ.*)

Roll, Pitch and Yaw axes



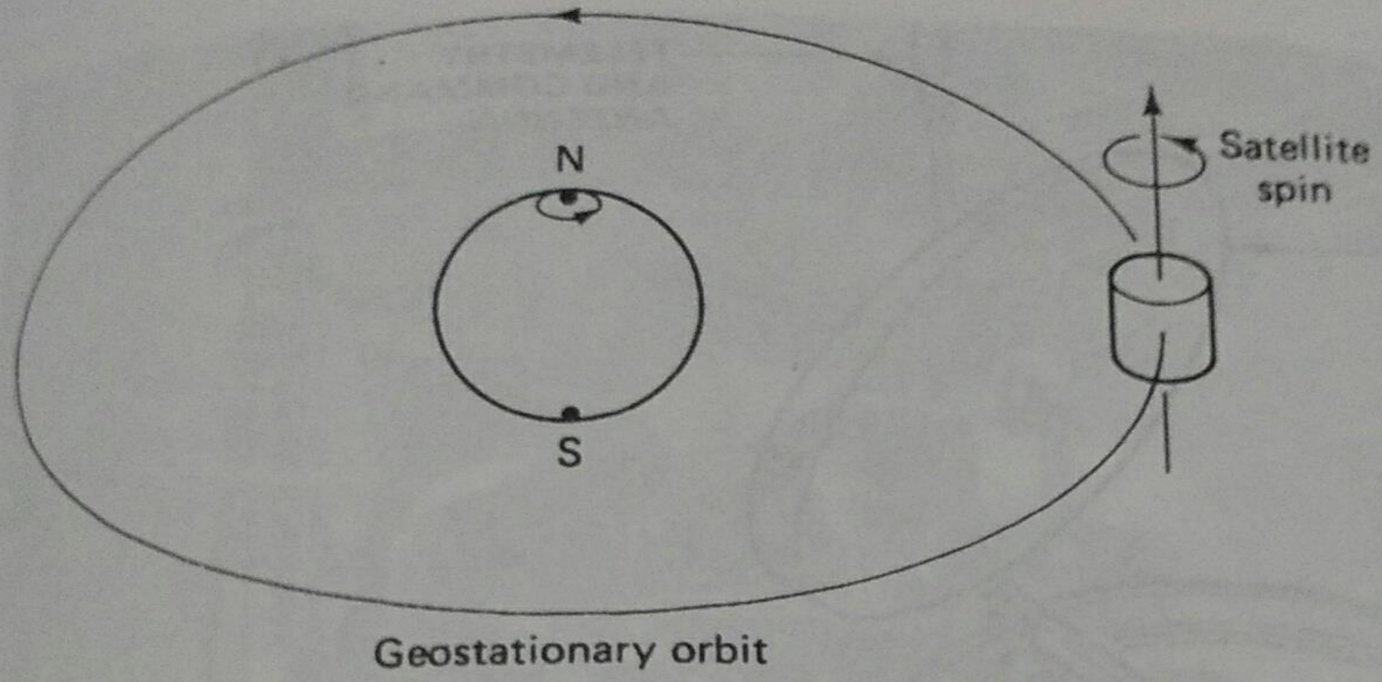


Figure 7.5 Spin stabilization in the geostationary orbit. The spin axis lies along the pitch axis, parallel to the earth's N-S axis.

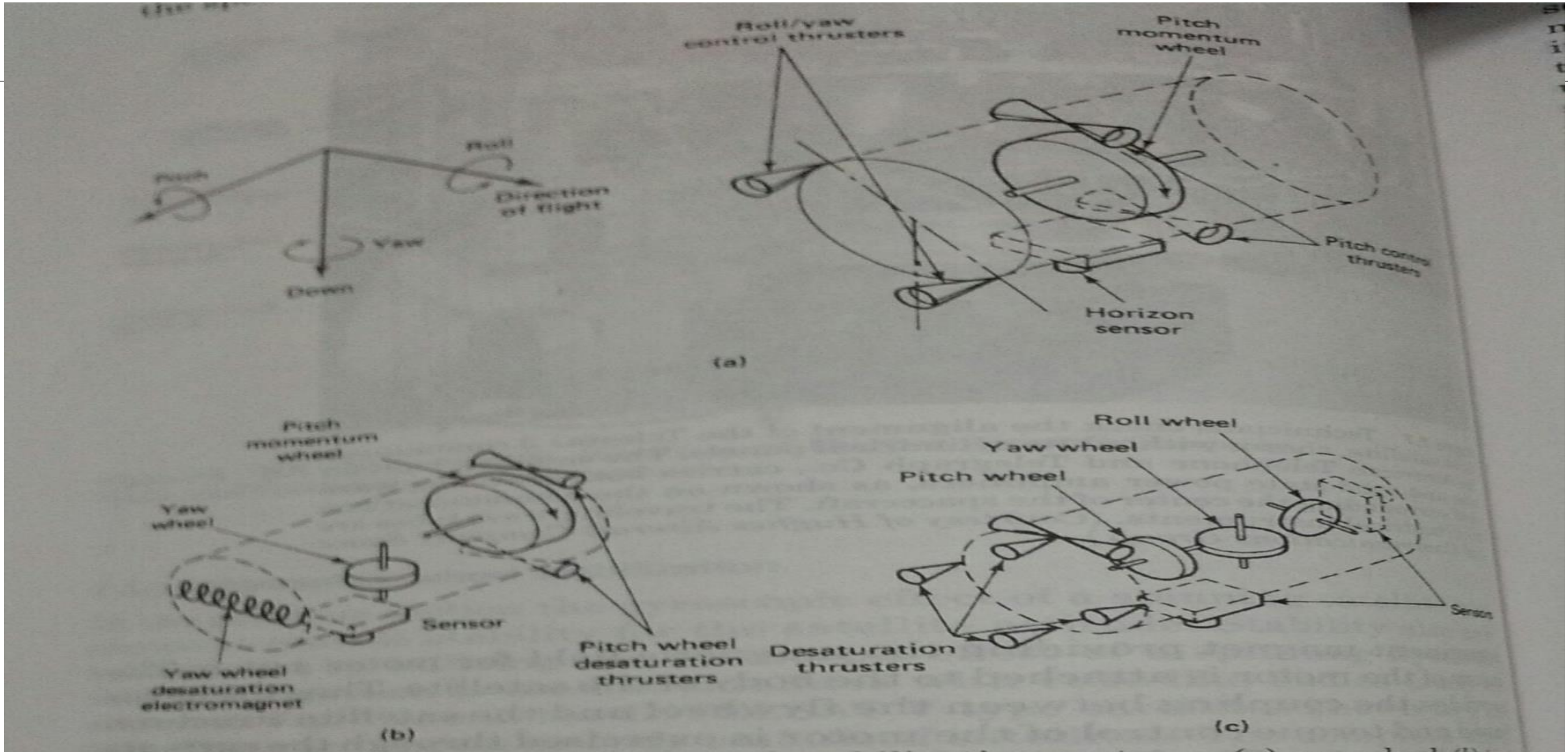


Figure 7.8 Alternative momentum wheel stabilization systems: (*a*) one-wheel, (*b*) two-wheel, (*c*) three-wheel. (*Reprinted with permission from Spacecraft Attitude Determination and Control, edited by James R. Wertz. Copyright, 1984 by D. Reidel Publishing Company, Dordrecht, Holland.*)

Contd.

Spinning satellite stabilization : Achieved with cylindrical satellites. Construction of satellite is such that it is mechanically balanced about a particular axis, then is set spinning around this axis. Geostationary satellites has spin axis set parallel to N-S axis of earth, see fig. 7.5. Spin rate is in the range 50- 100 rev/min, initiated during launch phase by means of small gas jets.

With no disturbance torques, satellite maintains its correct attitude relative to earth. Disturbance torques are both internal and external. In addition to solar radiation, gravitational gradients, meteorite impacts (external), motor bearing friction and movement of satellite elements, ie., antennas give rise to disturbance torques.

All these cause decrease in spin rate, change in direction of angular spin axis. Spin stabilization is by spinning satellite itself.

Contd.

To increase the spin rate again and shift the axis back to its correct N-S orientation, impulse type thrusters or jets are used. A form of wobbling called Nutation can occur due to these disturbances. This must be damped out by means of energy absorbers- nutation dampers.

With INTELSAT I and II omnidirectional antenna is used, the antenna which points along pitch axis also rotates with satellite. More commonly with communication satellites, directional antennas are used and antenna must be despun (for dual- spin construction). Electric motor drive is used for despinning antenna subsystem.

Some dual spin space craft get spin stabilization from spinning flywheel and not by spinning satellite itself (momentum flywheels with momentum bias or average momentum).

Thermal Control

Sun's radiation causes thermal gradients in a satellite. The side ~~subject to radiation heats up and the other side faces space is cold.~~ Added to this, thermal radiation from earth and the fraction of radiation falling on earth (earth's albedo) which is reflected can be considerable for LEO satellites (negligible for geo satellite). Equipments inside satellite generates heat, must be removed. Inside satellite there must be a stable temperature for equipment operation.

Various steps taken for this are thermal blankets and shields may be used for heat insulation . Heat from communication payload are removed by radiation mirrors. Mirrored drums surround communication equipment shelves in each case, provide good radiation paths, allow generated heat to escape to surroundings. Advantage of spinning satellites, the body provides an averaging

Contd.

of temperature extremes due to solar flux and the cold background of deep space.

To maintain constant temperature situation, heaters are switched on (on command from ground generally) to make up for heat reduction due to switch off of transponders (in case), as in INTELSAT VI to maintain propulsion thrusters and line temperatures.

Radio Wave Propagation

Atmospheric losses:

Energy absorption by atmospheric gases causes losses in earth's atmosphere (atmospheric absorption). These are different from atmospheric losses due to adverse weather conditions (atmospheric attenuation).

Variation of atmospheric absorption loss with frequency are shown in fig.4.2 based on statistical data. Two absorption peaks correspond to 22.3GHz due to resonance absorption in water vapor. Second peak at 60GHz due to resonance absorption in oxygen. At frequencies other than these peaks , absorptions are quite low. Graph of fig.4.2 is for an elevation angle of 90deg, at earth station antenna (vertical incidence) denoted by [AA]90 decibels. For elevation angles down to 10deg, approximate relation

[AA]= [AA]90 cosec El   El is angle of elevation.

The effect atmospheric scintillation can also occur, a fading phenomena. Fading period, several tens of seconds, caused by differences in atmospheric refractive index, result of focusing and defocusing of radio waves. These follow different ray paths in atmosphere.

Sometimes necessary to account for atmospheric scintillation by having fade margin in link power budget calculations.

Layers in earth's atmosphere

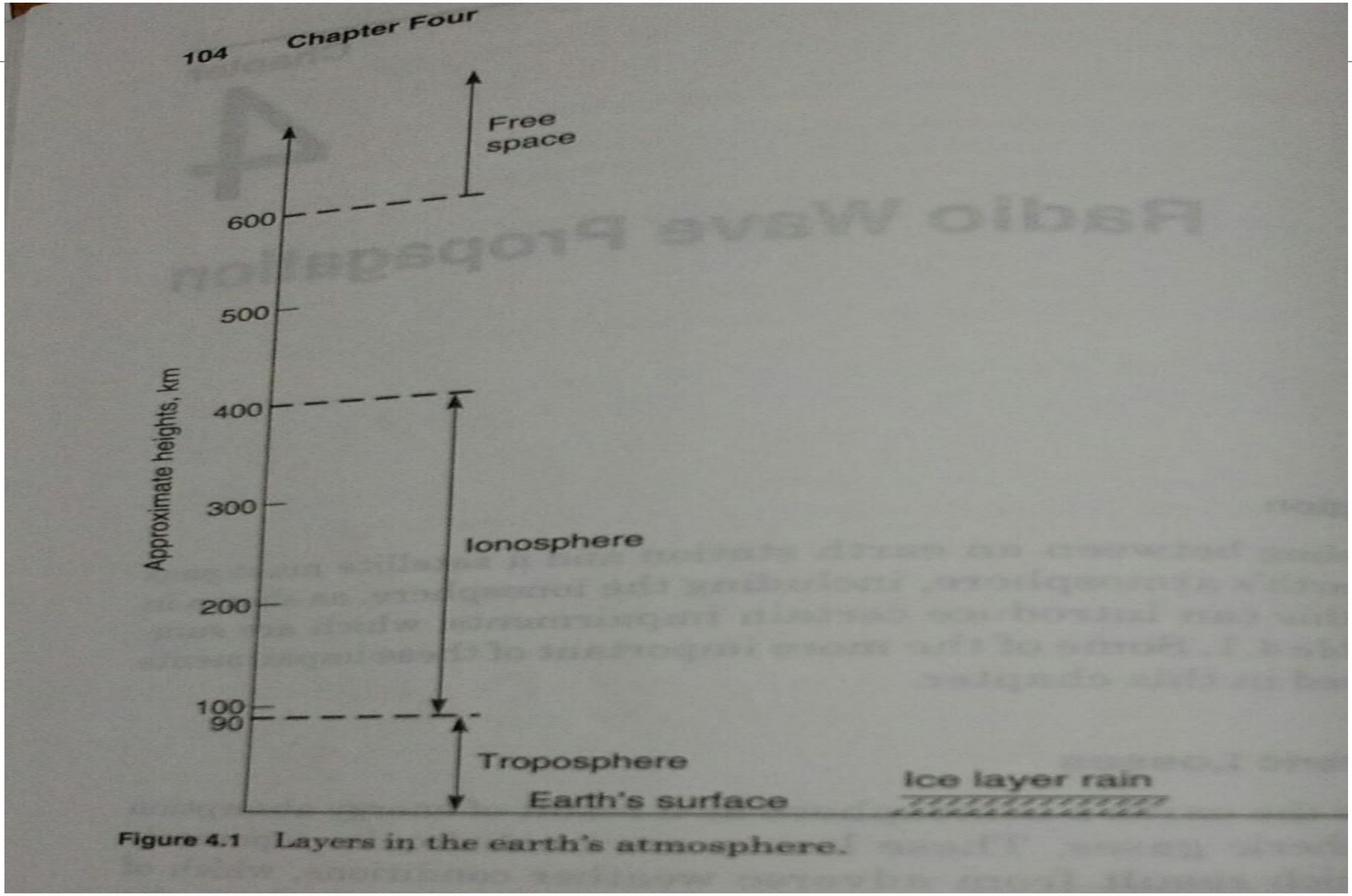


Figure 4.1 Layers in the earth's atmosphere.

Propagation Concerns

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 frequencies

SOURCE: Brussard and Rogers, 1990.

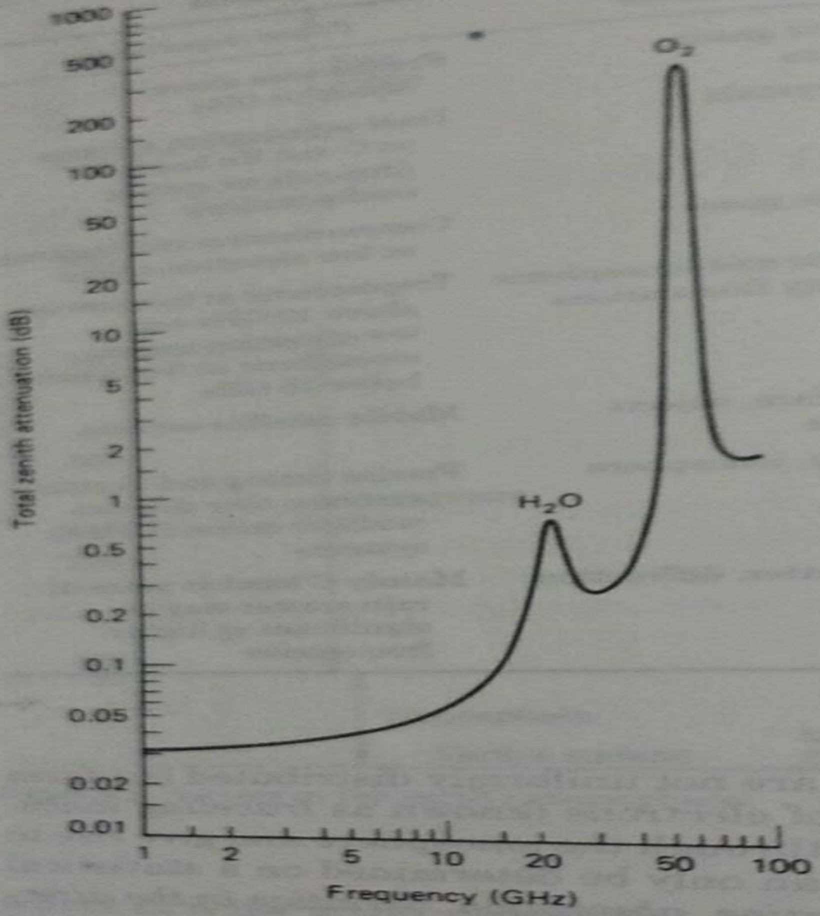


Figure 4.2 Total zenith attenuation at ground level: pressure = 1 atm, temperature = 20°C, and water vapor = 7.5 g/m³. *(Adapted from CCIR Report 719-2, with permission from International Telecommunication Union.)*

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.

Ionospheric Effects

Radio waves between satellite and earth passes through ionosphere, the upper region of earth's atmosphere, ionized mainly due to solar radiation. In ionosphere, free electrons form a layer and are not uniformly distributed.

Clouds of electrons (traveling ionospheric disturbances) travel through ionosphere and cause signal fluctuation, can be found by statistical methods. Scintillation, absorption, variation in the direction of arrival, propagation delay, dispersion, frequency change and polarization rotation.

As the frequency increases, these effects reduce, in~ inverse proportion and of major concern here are polarization and scintillation effects.

Ionospheric scintillations are amplitude variations, phase, polarization

Contd.

Ionospheric scintillations are amplitude variations, variation in phase, polarization or angle of arrival of radio waves, caused by irregularities and in time variations in ionosphere. Scintillation causes fading (mainly) of signal and can be quite severe for upto several minutes. Fade margin due to this as with atmospheric scintillations, are to be allowed in link budget calculations.

Rain Attenuation:

Attenuation is a function of rain rate, rate at which rain water would be collected in a rain gauge situated at the ground in the region of interest (earth station), measured in mm/ hour. % of time for which the specified value is exceeded is of concern. Time % is that of a year (usual) ex: rain rate of 0.001% means, the rai would be exceeded for 0.001% of a year or about 5.3min during any one year $R_{0.001}$.

Percentage time (general) p, rain rate Rp, specific attenuation α is

$\alpha = aR_p^b$ db/km. Factors a and b depend on frequency and polarization are as given in table 4.2. Subscripts h and v refer to horizontal and vertical polarizations.

From specific attenuation, total attenuation is found from,

$A = \alpha L$ dB L= effective path length of signal through rain. Rain density is not uniform throughout path length, effective path length is used instead of actual path length (geometric). See fig.4.3 for this. Geometric or slant path length is Ls, depends on antenna angle of elevation ϴ, rain height h_R height at which freezing occurs.

Fig.4.4 shows curves for h_R for different climatic zones. Method 1 for maritime climates, Method 2- tropical climates, Method 3- contine tal climates. For the last, curves for p of 0.001, 0.01, 0.1 and 1%.

Small angles of elevation (El<10deg), determination of Ls – complicated by earth curvature. For El>10deg, flat earth assumed, fig.4.3 $Ls = (h_R – h_o) / \sin El$, effective path length $L = Ls\ r_p$ by reduction factor, depending on percentage time p and L_G the horizontal projection of Ls.

$L_G = Ls \cos El$ Reduction factors are given in table 4.3.

108

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.

Path length through rain

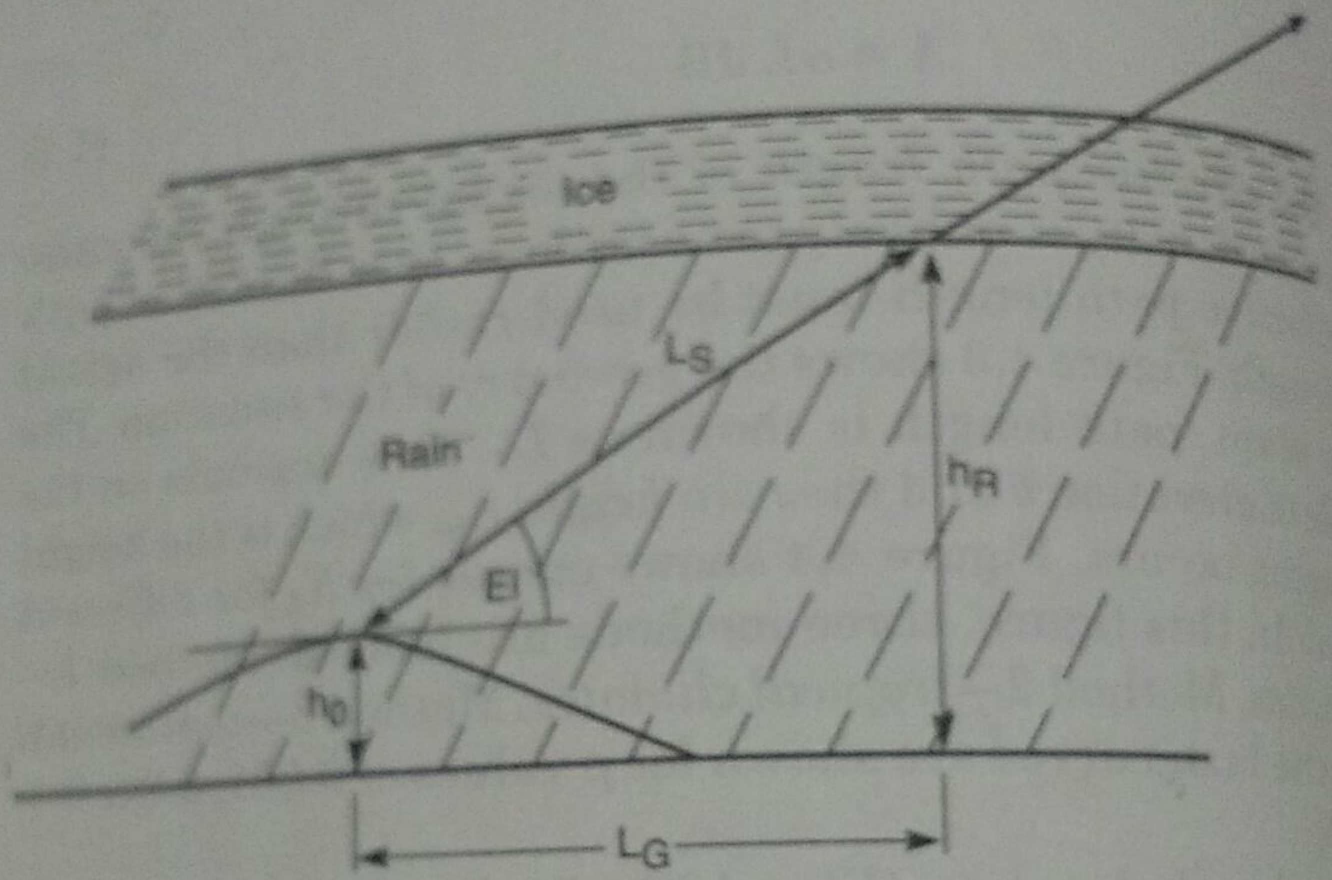


Figure 4.3 Path length through rain.

Rain height as a function of earth station latitude for various climate zones

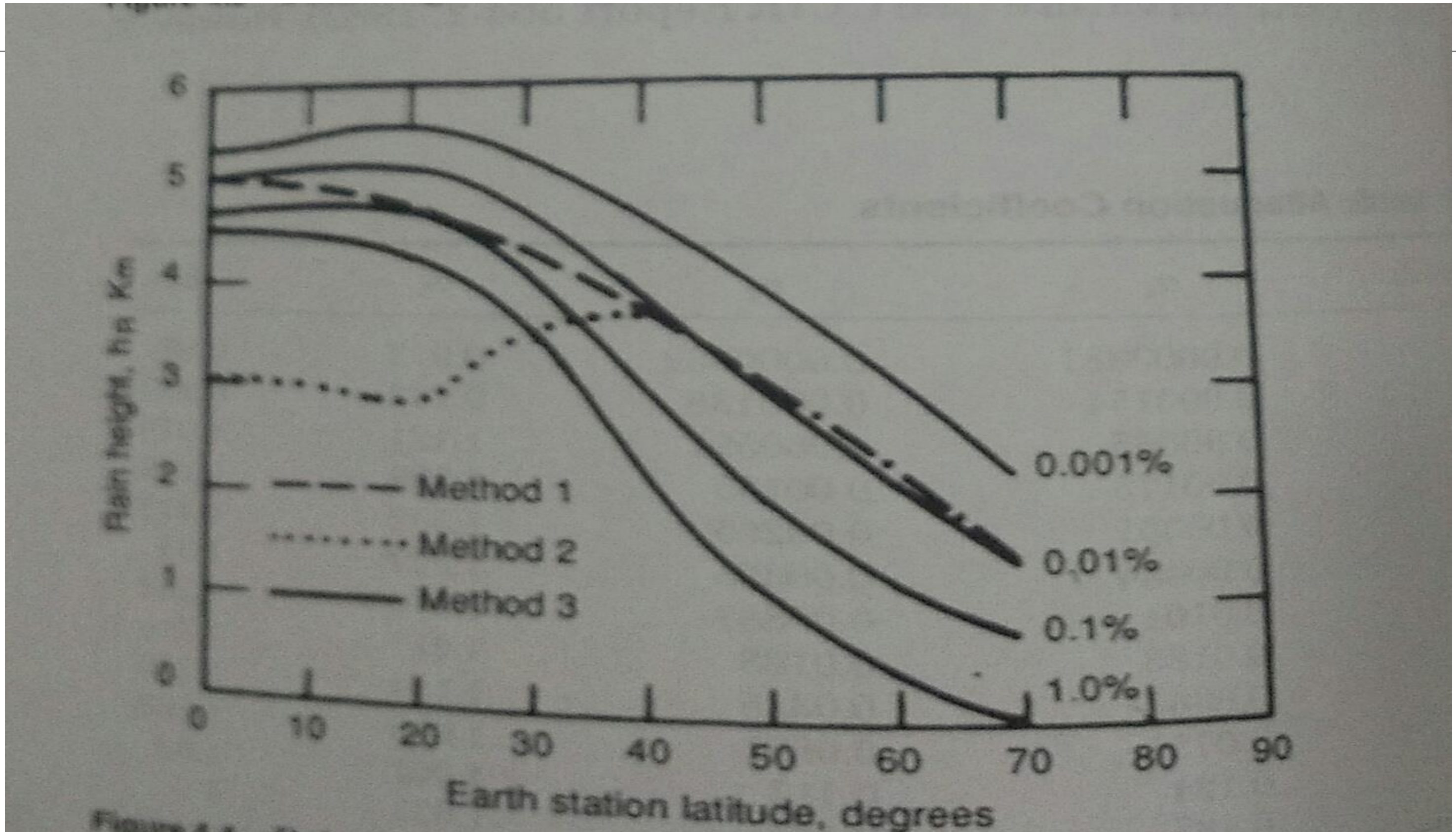


Figure 4.4 Rain height as a function of earth-station latitude for different climatic zones.

Ex: Calculate at 12GHz, for horizontal and vertical polarizations, rain attenuation excceding >0.01% of time in any year, for a point rain rate of 10mm/hour. Earth station altitude is 600m, antenna elevation angle is 50deg. Rain height is 3km.

Given: El=50deg, ho=0.06 ie., 600m, h_R= 3km, R_{01} = 10mm/h

Geometric or slant height of signal= Ls= (h_R- h_o)/sinEl= 3- 0.6/sin 50= 3.13km.

L_G= Ls cosEl = 3.133 cos 50 = 2.014km (horizontal projection)

From Table 4.3 for p=0.01%, r_{o1} = 90/(90+4L_G)= 0.9178

For horizontal polarization from table 3.2 at f= 12GHz, a_h=0.018, b_h=1.217, Ap= a_h R_{o1}^b_h Ls r_{o1} = 0.0188 x 10^1.217 x 3.133x 0.9178= 0.891dB.

Contd.

For vertical polarization: From table 3.2 at f= 12GHz, a_v=0.0168, b_v=1.2

$A_p = a_v R_{01}$^b_v $L_s r_{01}$ = 0.0168 x 10^1.2 x 3.133 x 0.9178= 0.766dB.

For circular polarization, equations are

$a_c = (a_h + a_v)/2 = (0.0188+0.0168)/2 = 0.0178$
$b_c = (a_h b_h + a_v b_v)/2a_c = (0.0188 \times 1.217 + 0.0168 \times 1.2)/2 \times 0.0178 = 1.209$

Rain attenuation due to circular polarization Ap= Ap= $a_c R_{01}$^b_c $L_s r_{01}$ =0.0178x 10^1.209x 3.133x 0.9178= 0.828dB.

Problem 4.7: Compare the specific attenuation for vertical and horizontal polarizations at a frequency of 4GHz, rain rate =8mm/h which is exceeded for 0.01% of the year.

Soln: $\alpha = a\ Rp\text{^}b$ dB/km

From table 4.2 at 4GHz, a_h=0.00065 b_h= 1.121, a_v=0.00065, b_v= 1.015

For horizontal polarization $\alpha_h= a_h\ Rp\text{^}b_h$ =0.00065 x 8^1.121= 6.687x10^-3 dB/km. Effective path length in rain= 3km, Rain attenuation A_p= 6.687x10^-3x 3=0.020061dB

$\alpha_v= a_v\ Rp\text{^}b_v$ =0.00065x 8^1.015=5.525x 10^-3dB/km, A_p= 5.525x10^-3x 3= 0.016575dB

Compared at 12GHz, from table 4.2 a_h=0.0188 b_h= 1.217, a_v=0.0168, b_v= 1.2

$\alpha_h= a_h\ Rp\text{^}b_h$ = 0.0188 x 8^1.217= 0.23617 dB/km Rain attenuation Ap= 2.3617x10^-1 x3km= 0.7085dB.

$\alpha_v= a_v\ Rp\text{^}b_v$ = 0.0168 x 8^1.2=0.203712dB/km Ap= 0.203712x3=0.6111dB