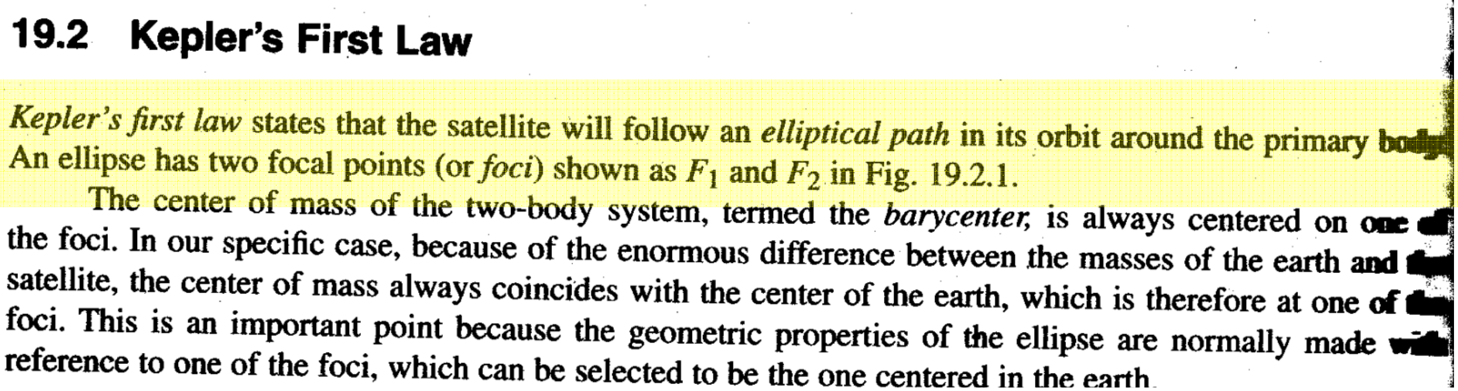
Satellite Communication

Orbits-Kepler's law



19.2 Kepler's First Law

Kepler's first law states that the satellite will follow an *elliptical path* in its orbit around the primary body. An ellipse has two focal points (or *foci*) shown as F_1 and F_2 in Fig. 19.2.1.

The center of mass of the two-body system, termed the *barycenter,* is always centered on one of the foci. In our specific case, because of the enormous difference between the masses of the earth and the satellite, the center of mass always coincides with the center of the earth, which is therefore at one of the foci. This is an important point because the geometric properties of the ellipse are normally made with reference to one of the foci, which can be selected to be the one centered in the earth.

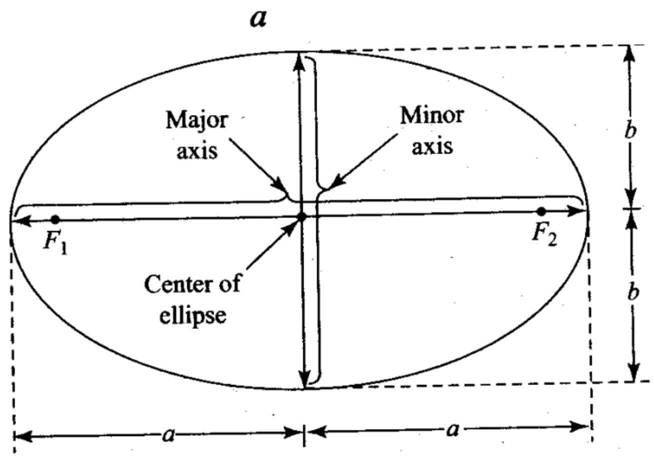
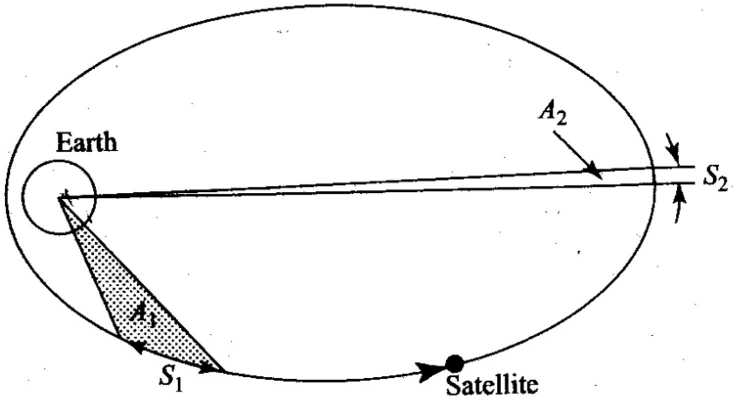


Figure 19.2.1 Foci F_1 and F_2, the semimajor axis a and the semi-minor axis b of an ellipse.

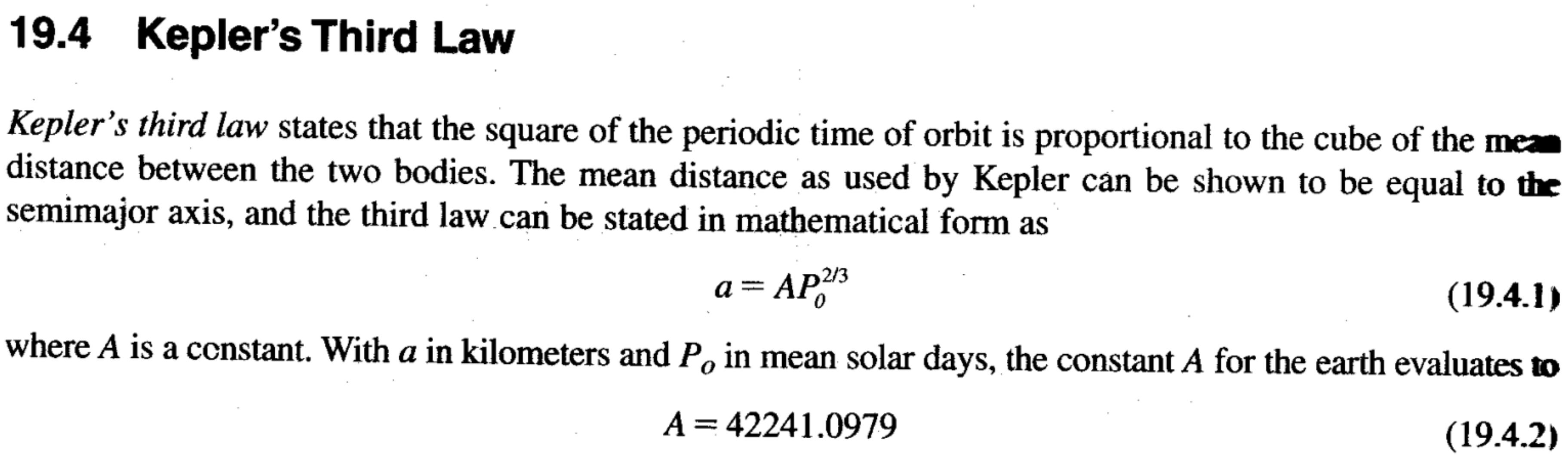
Orbits-Kepler’s law

19.3 Kepler’s Second Law

Kepler’s second law states that for equal time intervals the satellite sweeps out equal areas in the orbital plane, focused at the barycenter. Referring to Fig. 19.3.1, assuming that the satellite travels distances S_1 and S_2 meters in 1 s, the areas A_1 and A_2 will be equal. The average velocities are S_1 and S_2 m/s. Because of the equal area law, it is obvious that distance S_1 is greater than distance S_2 and hence the velocity S_1 is greater than velocity S_2.Generalizing, it can be said that the velocity will be greatest at the point of closest approach to the earth (termed the *perigee*) and will be least at the farthest point from the earth (termed the *apogee*). This also has fundamental significance in the selection of orbits for communication satellites, as will be shortly shown.



Orbits-Kepler's law



19.4 Kepler's Third Law

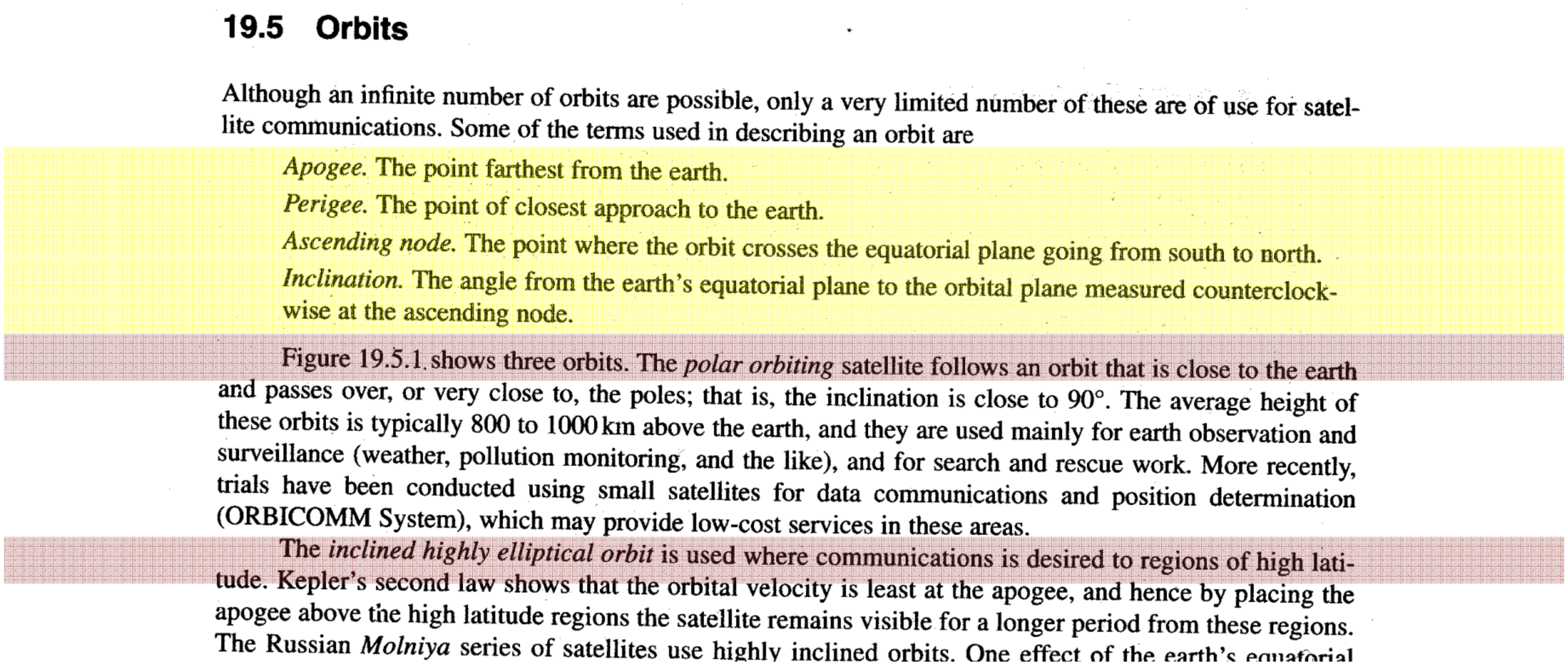
Kepler's third law states that the square of the periodic time of orbit is proportional to the cube of the mean distance between the two bodies. The mean distance as used by Kepler can be shown to be equal to the semimajor axis, and the third law can be stated in mathematical form as

$$a = AP_0^{2/3} \tag{19.4.1}$$

where A is a constant. With a in kilometers and P_o in mean solar days, the constant A for the earth evaluates to

$$A = 42241.0979 \tag{19.4.2}$$

Orbits



19.5 Orbits

Although an infinite number of orbits are possible, only a very limited number of these are of use for satellite communications. Some of the terms used in describing an orbit are

Apogee. The point farthest from the earth.

Perigee. The point of closest approach to the earth.

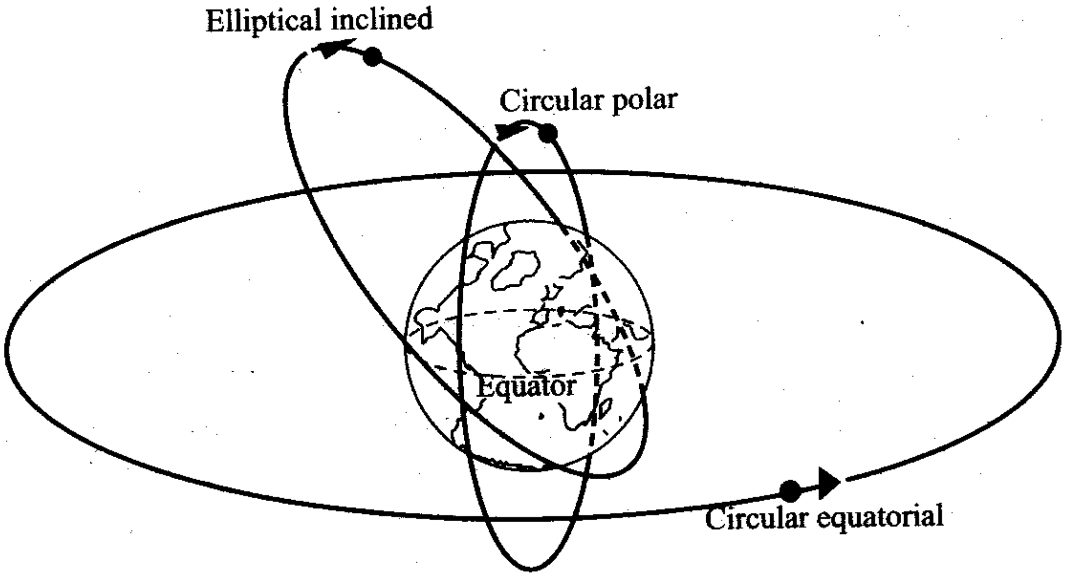
Ascending node. The point where the orbit crosses the equatorial plane going from south to north.

Inclination. The angle from the earth's equatorial plane to the orbital plane measured counterclockwise at the ascending node.

Figure 19.5.1 shows three orbits. The *polar orbiting* satellite follows an orbit that is close to the earth and passes over, or very close to, the poles; that is, the inclination is close to 90°. The average height of these orbits is typically 800 to 1000 km above the earth, and they are used mainly for earth observation and surveillance (weather, pollution monitoring, and the like), and for search and rescue work. More recently, trials have been conducted using small satellites for data communications and position determination (ORBICOMM System), which may provide low-cost services in these areas.

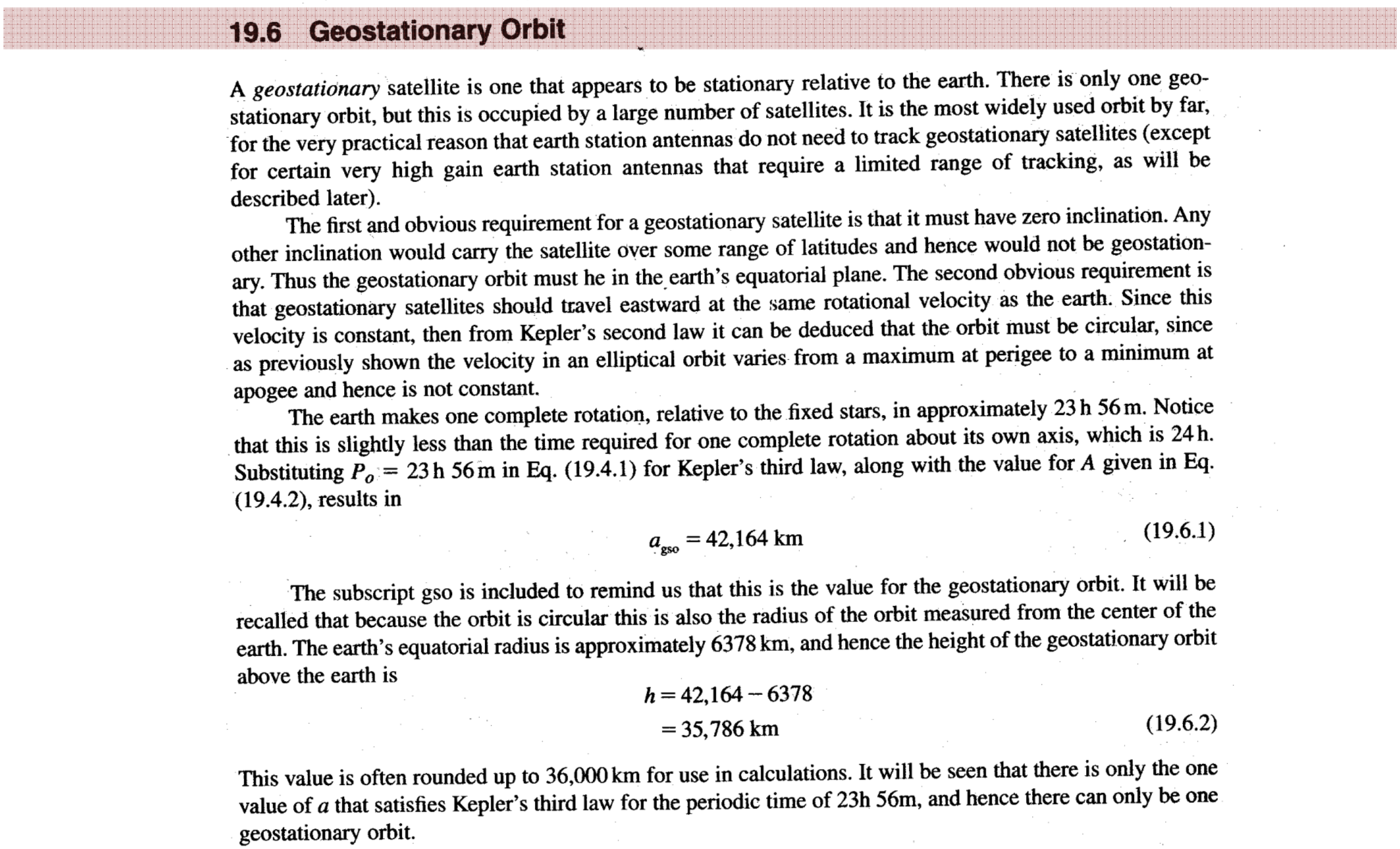
The *inclined highly elliptical orbit* is used where communications is desired to regions of high latitude. Kepler's second law shows that the orbital velocity is least at the apogee, and hence by placing the apogee above the high latitude regions the satellite remains visible for a longer period from these regions. The Russian *Molniya* series of satellites use highly inclined orbits. One effect of the earth's equatorial

Orbits



Three possible orbits. (From *Telecommunications Satellites,* Kenneth W. Gatland, Ed. Englewood
ntice Hall, 1984.)

Geostationary Orbit



19.6 Geostationary Orbit

A *geostationary* satellite is one that appears to be stationary relative to the earth. There is only one geostationary orbit, but this is occupied by a large number of satellites. It is the most widely used orbit by far, for the very practical reason that earth station antennas do not need to track geostationary satellites (except for certain very high gain earth station antennas that require a limited range of tracking, as will be described later).

The first and obvious requirement for a geostationary satellite is that it must have zero inclination. Any other inclination would carry the satellite over some range of latitudes and hence would not be geostationary. Thus the geostationary orbit must he in the earth's equatorial plane. The second obvious requirement is that geostationary satellites should travel eastward at the same rotational velocity as the earth. Since this velocity is constant, then from Kepler's second law it can be deduced that the orbit must be circular, since as previously shown the velocity in an elliptical orbit varies from a maximum at perigee to a minimum at apogee and hence is not constant.

The earth makes one complete rotation, relative to the fixed stars, in approximately 23 h 56 m. Notice that this is slightly less than the time required for one complete rotation about its own axis, which is 24 h. Substituting $P_o = 23\,\text{h}\ 56\,\text{m}$ in Eq. (19.4.1) for Kepler's third law, along with the value for A given in Eq. (19.4.2), results in

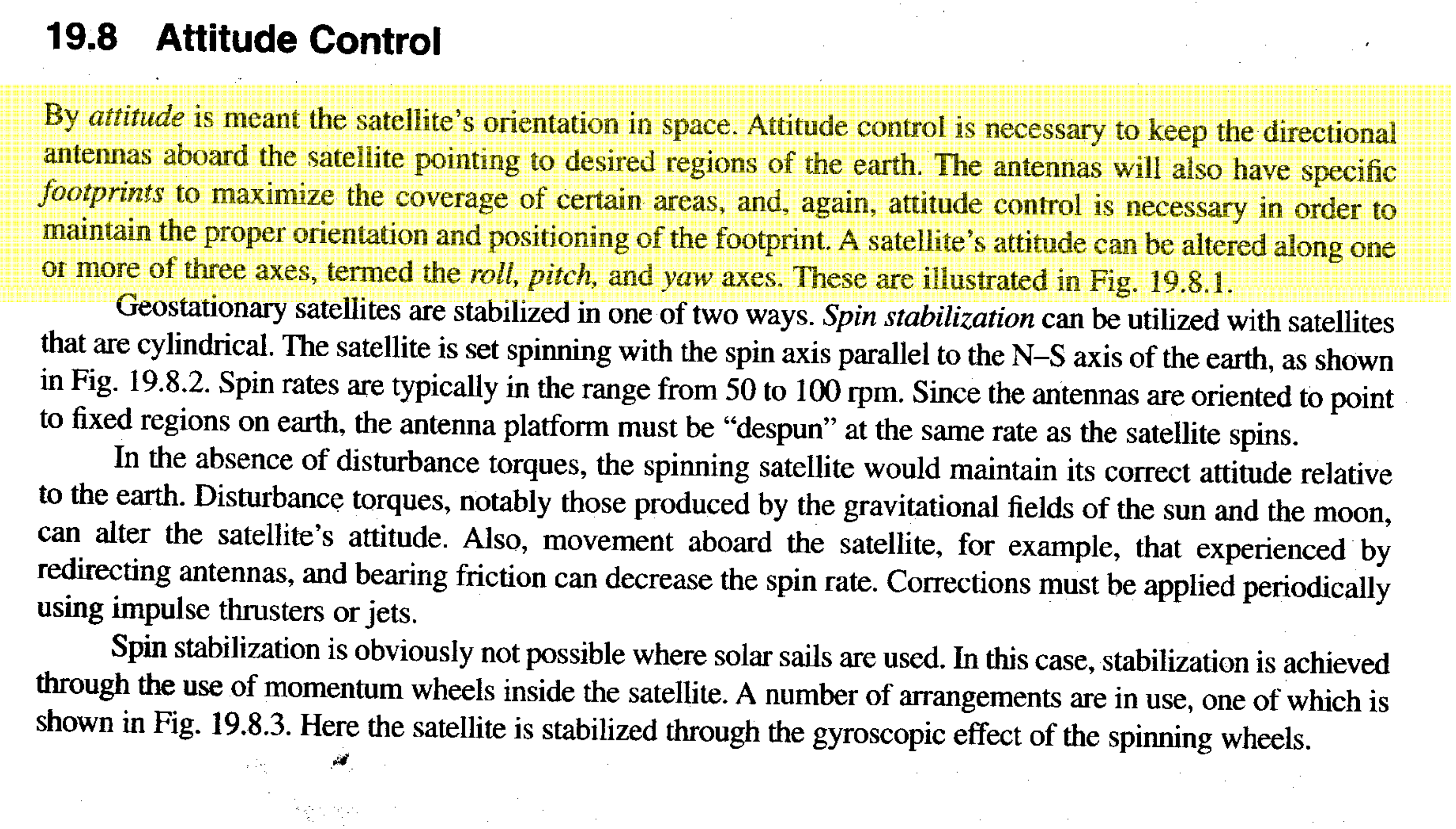
$$a_{\text{gso}} = 42{,}164\ \text{km} \tag{19.6.1}$$

The subscript gso is included to remind us that this is the value for the geostationary orbit. It will be recalled that because the orbit is circular this is also the radius of the orbit measured from the center of the earth. The earth's equatorial radius is approximately 6378 km, and hence the height of the geostationary orbit above the earth is

$$\begin{aligned} h &= 42{,}164 - 6378 \\ &= 35{,}786\ \text{km} \end{aligned} \tag{19.6.2}$$

This value is often rounded up to 36,000 km for use in calculations. It will be seen that there is only the one value of a that satisfies Kepler's third law for the periodic time of 23h 56m, and hence there can only be one geostationary orbit.

ALTITUDE



19.8 Attitude Control

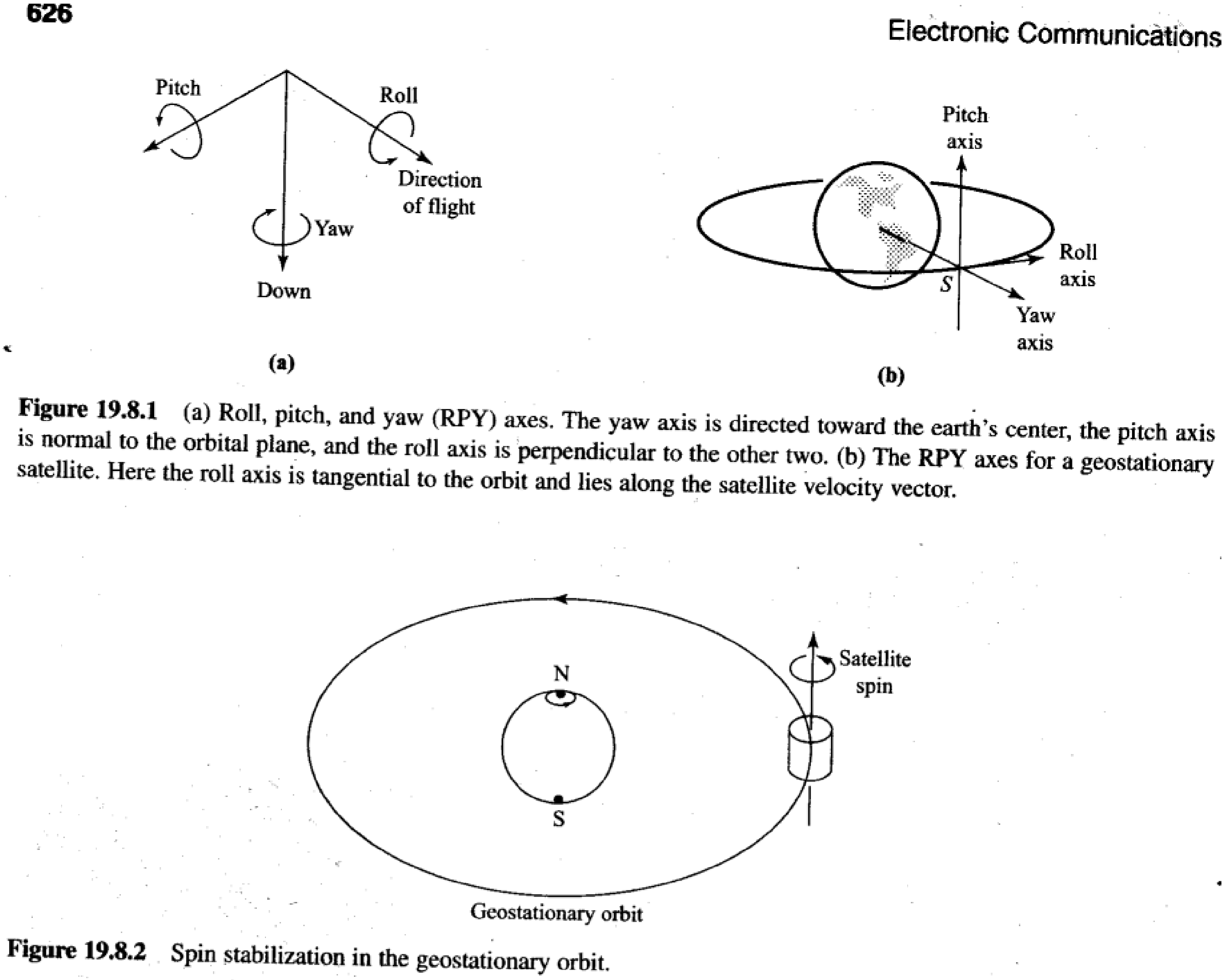
By *attitude* is meant the satellite's orientation in space. Attitude control is necessary to keep the directional antennas aboard the satellite pointing to desired regions of the earth. The antennas will also have specific *footprints* to maximize the coverage of certain areas, and, again, attitude control is necessary in order to maintain the proper orientation and positioning of the footprint. A satellite's attitude can be altered along one or more of three axes, termed the *roll, pitch,* and *yaw* axes. These are illustrated in Fig. 19.8.1.

Geostationary satellites are stabilized in one of two ways. *Spin stabilization* can be utilized with satellites that are cylindrical. The satellite is set spinning with the spin axis parallel to the N–S axis of the earth, as shown in Fig. 19.8.2. Spin rates are typically in the range from 50 to 100 rpm. Since the antennas are oriented to point to fixed regions on earth, the antenna platform must be "despun" at the same rate as the satellite spins.

In the absence of disturbance torques, the spinning satellite would maintain its correct attitude relative to the earth. Disturbance torques, notably those produced by the gravitational fields of the sun and the moon, can alter the satellite's attitude. Also, movement aboard the satellite, for example, that experienced by redirecting antennas, and bearing friction can decrease the spin rate. Corrections must be applied periodically using impulse thrusters or jets.

Spin stabilization is obviously not possible where solar sails are used. In this case, stabilization is achieved through the use of momentum wheels inside the satellite. A number of arrangements are in use, one of which is shown in Fig. 19.8.3. Here the satellite is stabilized through the gyroscopic effect of the spinning wheels.

ALTITUDE



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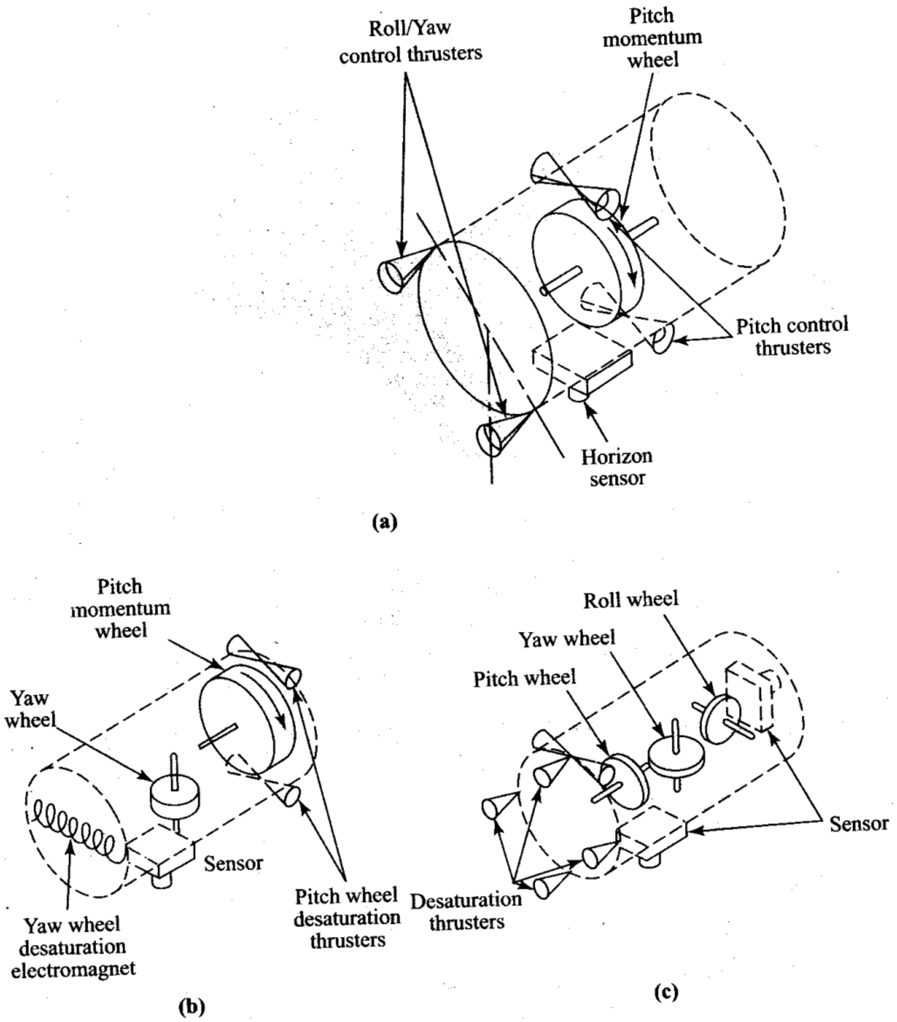
Electronic Communications

Figure 19.8.1 (a) Roll, pitch, and yaw (RPY) axes. The yaw axis is directed toward the earth's center, the pitch axis is normal to the orbital plane, and the roll axis is perpendicular to the other two. (b) The **RPY** axes for a geostationary satellite. Here the roll axis is tangential to the orbit and lies along the satellite velocity vector.

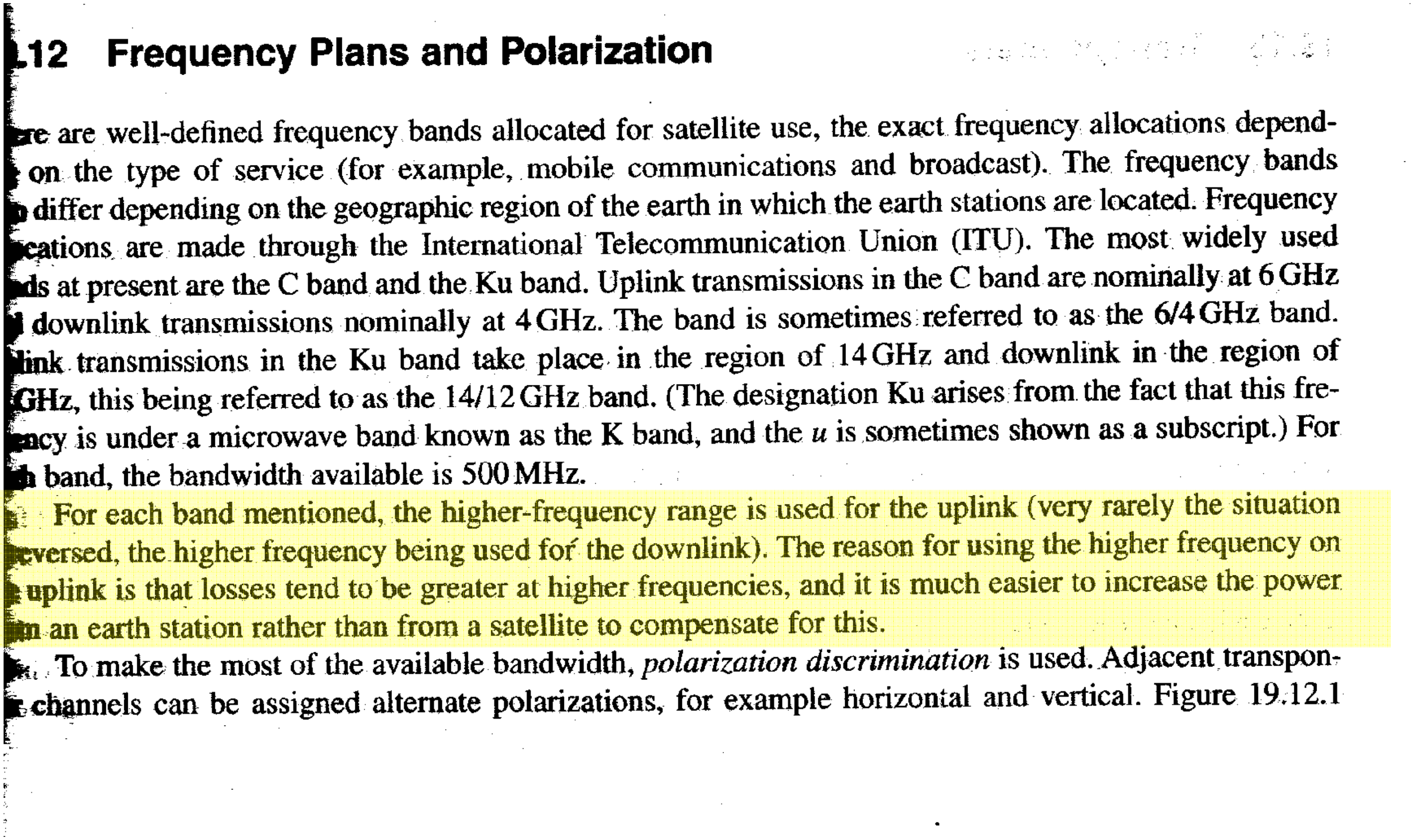
Figure 19.8.2 Spin stabilization in the geostationary orbit.

ALTITUDE



9.8.3 Momentum wheel stabilization. (Reprinted with permission from *Spacecraft Attitude Determination and* Edited by James A. Wertz. Copyright © 1984 by D. Reidel Publishing Company, Dordrecht, Holland).

Frequency plans & Polarisation



12 Frequency Plans and Polarization

re are well-defined frequency bands allocated for satellite use, the exact frequency allocations depend- on the type of service (for example, mobile communications and broadcast). The frequency bands differ depending on the geographic region of the earth in which the earth stations are located. Frequency cations are made through the International Telecommunication Union (ITU). The most widely used ds at present are the C band and the Ku band. Uplink transmissions in the C band are nominally at 6 GHz downlink transmissions nominally at 4 GHz. The band is sometimes referred to as the 6/4 GHz band. link transmissions in the Ku band take place in the region of 14 GHz and downlink in the region of GHz, this being referred to as the 14/12 GHz band. (The designation Ku arises from the fact that this fre- ncy is under a microwave band known as the K band, and the *u* is sometimes shown as a subscript.) For band, the bandwidth available is 500 MHz.

For each band mentioned, the higher-frequency range is used for the uplink (very rarely the situation versed, the higher frequency being used for the downlink). The reason for using the higher frequency on uplink is that losses tend to be greater at higher frequencies, and it is much easier to increase the power n an earth station rather than from a satellite to compensate for this.

To make the most of the available bandwidth, *polarization discrimination* is used. Adjacent transpon- channels can be assigned alternate polarizations, for example horizontal and vertical. Figure 19.12.1

Frequency plans & Polarisation

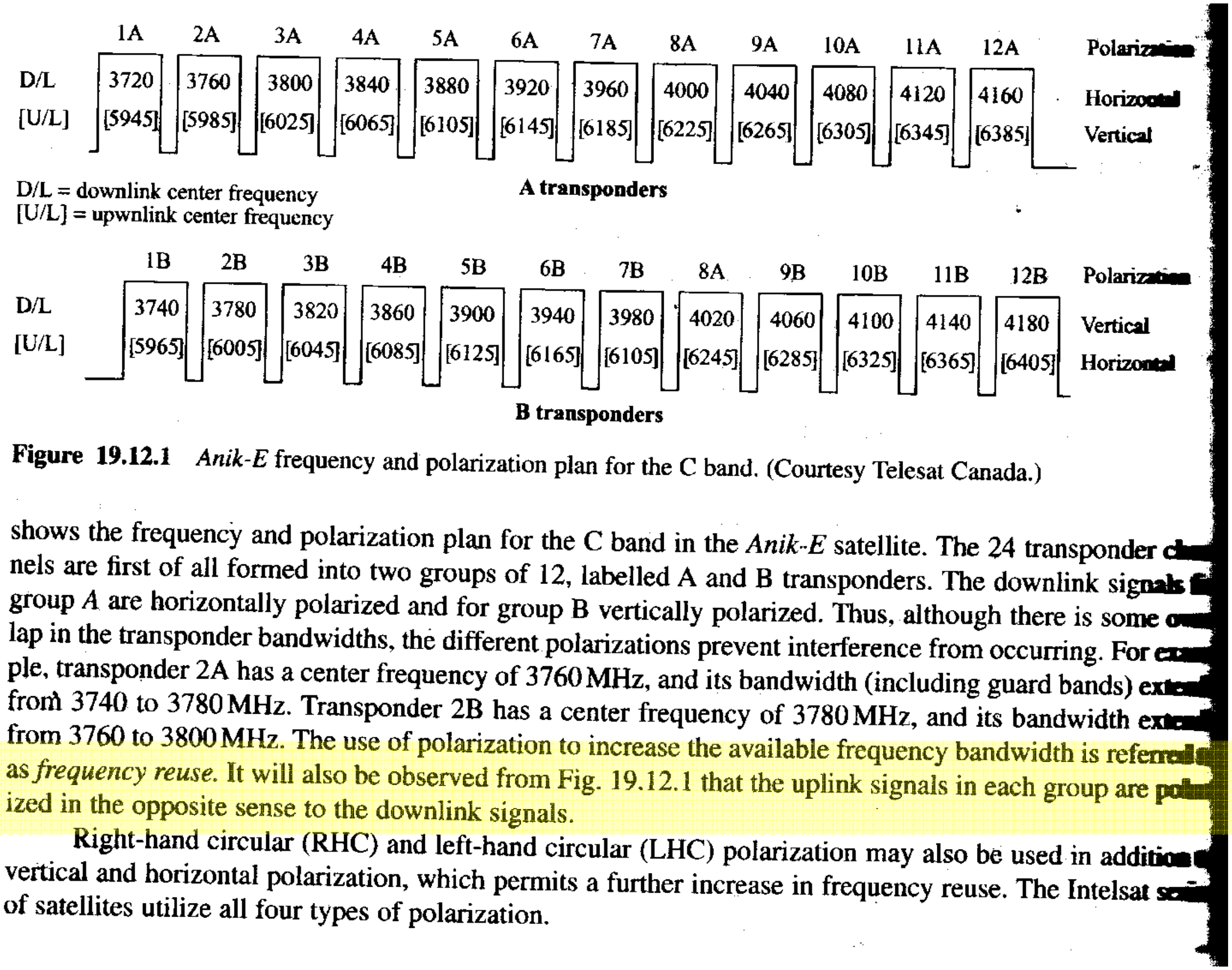
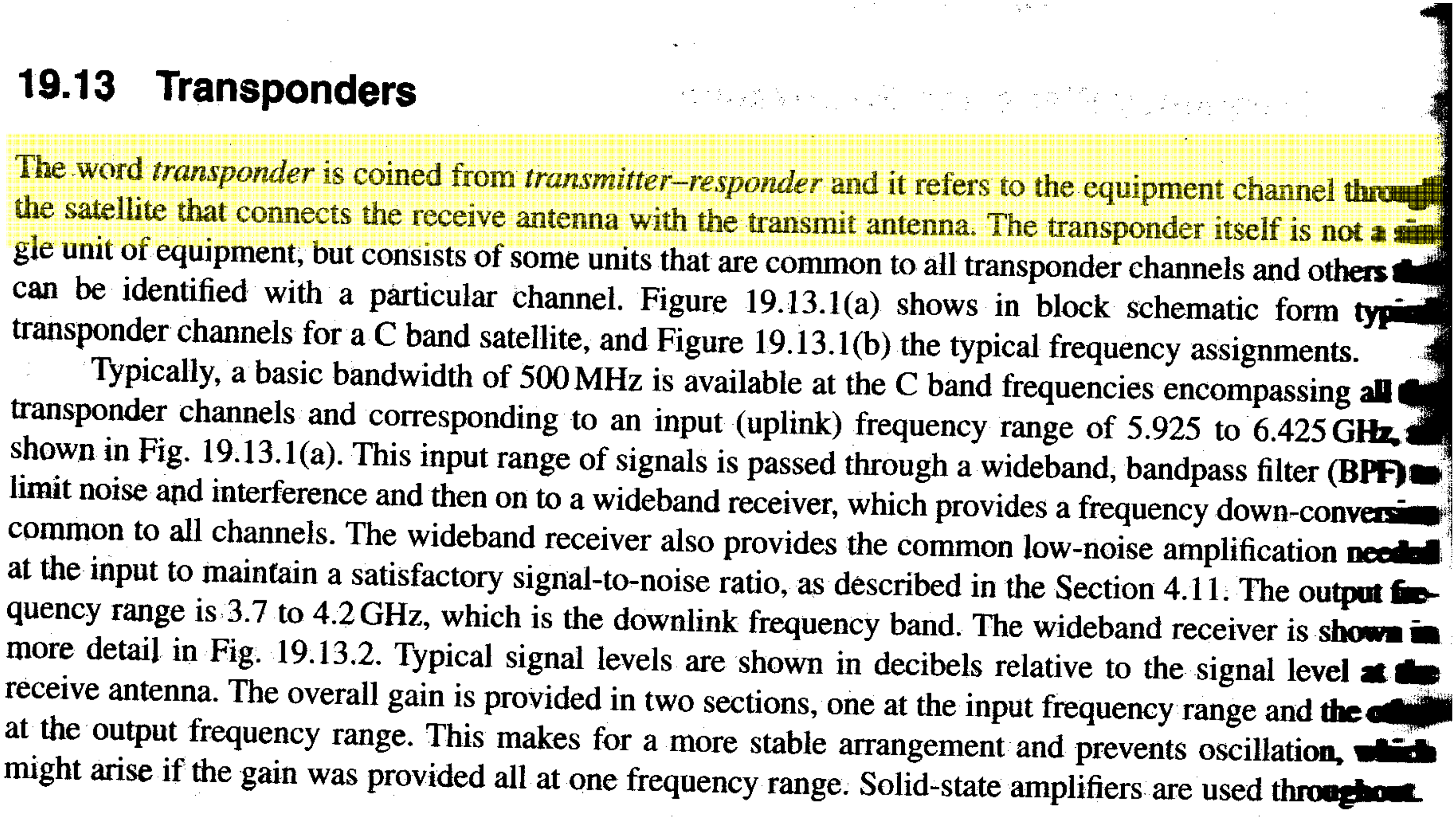


Figure 19.12.1 *Anik-E* frequency and polarization plan for the C band. (Courtesy Telesat Canada.)

shows the frequency and polarization plan for the C band in the *Anik-E* satellite. The 24 transponder ch nels are first of all formed into two groups of 12, labelled A and B transponders. The downlink signals f group *A* are horizontally polarized and for group B vertically polarized. Thus, although there is some o lap in the transponder bandwidths, the different polarizations prevent interference from occurring. For exa ple, transponder 2A has a center frequency of 3760 MHz, and its bandwidth (including guard bands) exte from 3740 to 3780 MHz. Transponder 2B has a center frequency of 3780 MHz, and its bandwidth exte from 3760 to 3800 MHz. The use of polarization to increase the available frequency bandwidth is referred as *frequency reuse*. It will also be observed from Fig. 19.12.1 that the uplink signals in each group are pol ized in the opposite sense to the downlink signals.

Right-hand circular (RHC) and left-hand circular (LHC) polarization may also be used in addition vertical and horizontal polarization, which permits a further increase in frequency reuse. The Intelsat se of satellites utilize all four types of polarization.

Transponders



19.13 Transponders

The word *transponder* is coined from *transmitter–responder* and it refers to the equipment channel through the satellite that connects the receive antenna with the transmit antenna. The transponder itself is not a single unit of equipment, but consists of some units that are common to all transponder channels and others [illegible] can be identified with a particular channel. Figure 19.13.1(a) shows in block schematic form typical transponder channels for a C band satellite, and Figure 19.13.1(b) the typical frequency assignments.

Typically, a basic bandwidth of 500 MHz is available at the C band frequencies encompassing all [illegible] transponder channels and corresponding to an input (uplink) frequency range of 5.925 to 6.425 GHz, [illegible] shown in Fig. 19.13.1(a). This input range of signals is passed through a wideband, bandpass filter (BPF) [illegible] limit noise and interference and then on to a wideband receiver, which provides a frequency down-conversion common to all channels. The wideband receiver also provides the common low-noise amplification needed at the input to maintain a satisfactory signal-to-noise ratio, as described in the Section 4.11. The output frequency range is 3.7 to 4.2 GHz, which is the downlink frequency band. The wideband receiver is shown in more detail in Fig. 19.13.2. Typical signal levels are shown in decibels relative to the signal level at the receive antenna. The overall gain is provided in two sections, one at the input frequency range and the [illegible] at the output frequency range. This makes for a more stable arrangement and prevents oscillation, which might arise if the gain was provided all at one frequency range. Solid-state amplifiers are used throughout.

Transponders

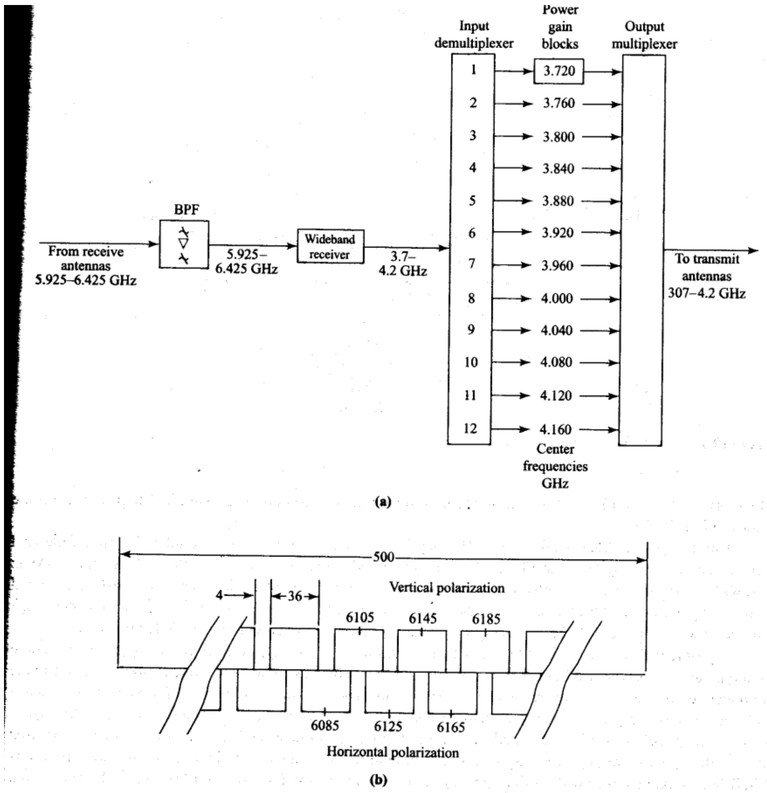


Figure 19.13.1 (a) C band satellite transponder channels. (b) Section of an uplink frequency and polarization plan.

Because the wideband receiver is critical to all transponders, a *redundant* receiver is provided. This is essentially a backup receiver that is switched in automatically if the other fails. An input *demultiplexer* following the wideband receiver is an arrangement of microwave circulators and filters that separates the 500-MHz band into the separate transponder channel bandwidths. A typical transponder bandwidth is 36 MHz, or 40 MHz including guard-bands, as shown in Fig. 19.13.1, although other values are commonly used. Following the demultiplexer, power amplifiers are provided for the individual transponder channels,

Transponders

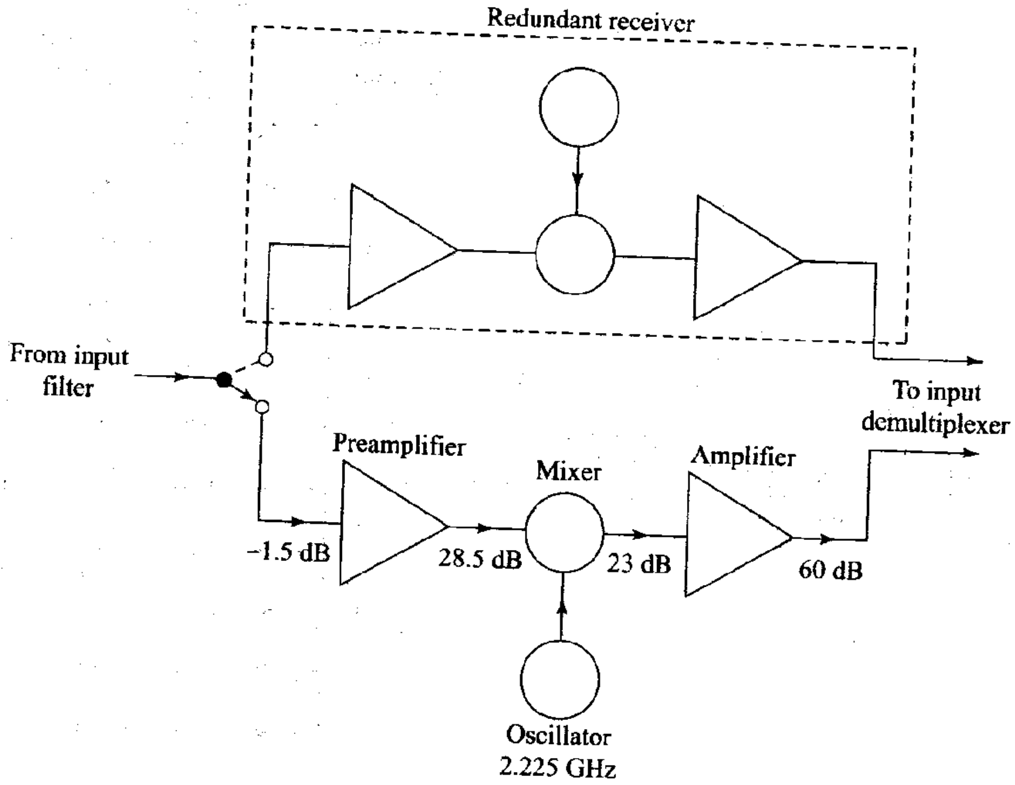
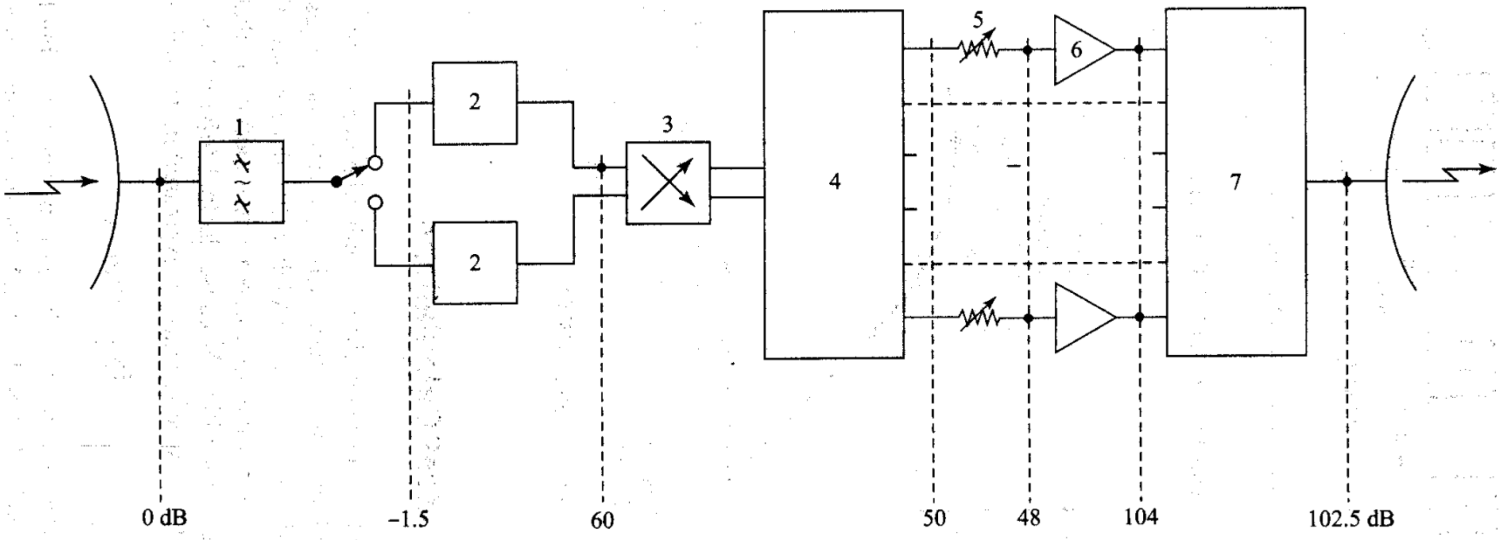


Figure 19.13.2 Satellite wideband receiver.

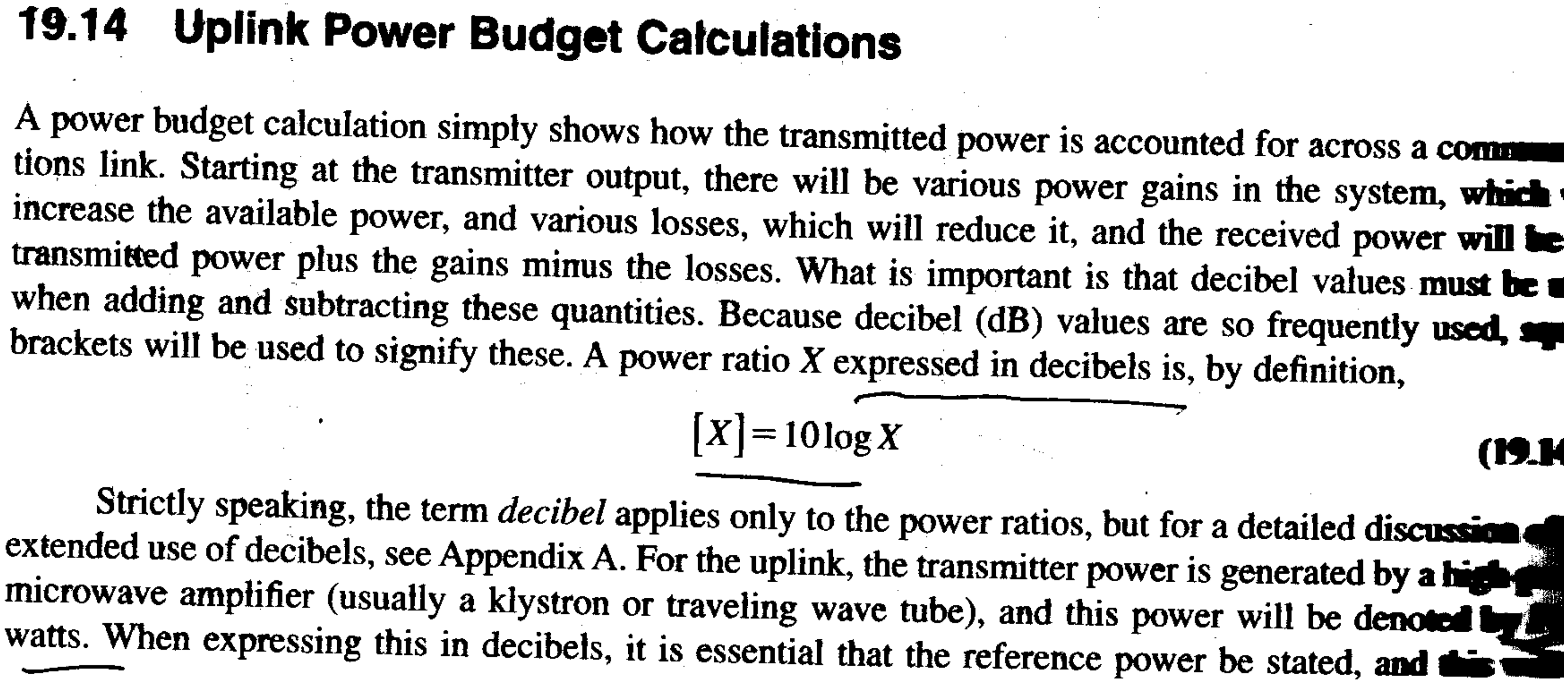
Transponders



0 dB	referecne level
1	input filter
2	wideband receiver
3	3 dB coupler
4	demultiplexer
5	attenuator (lower position)
6	amplifier
7	multiplexer

Figure 19.13.3 Typical relative power levels in a transponder. (Courtesy of CCIR. *CCIR Fixed Satellite Services Handbook*, p. 19, sect 4.2.2, final draft 1984).

Transmission path-Link budget



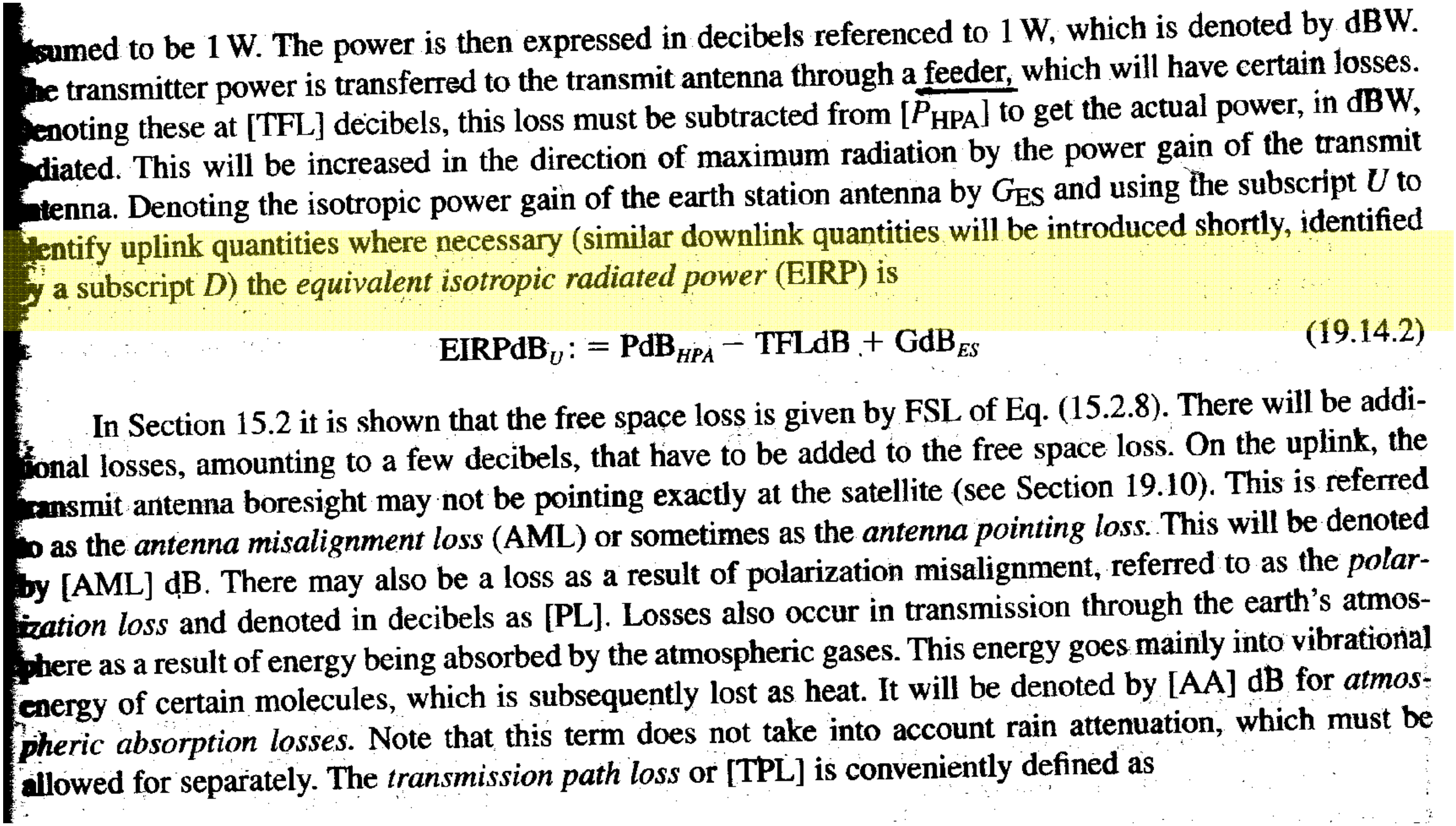
19.14 Uplink Power Budget Calculations

A power budget calculation simply shows how the transmitted power is accounted for across a comm tions link. Starting at the transmitter output, there will be various power gains in the system, which increase the available power, and various losses, which will reduce it, and the received power will be transmitted power plus the gains minus the losses. What is important is that decibel values must be when adding and subtracting these quantities. Because decibel (dB) values are so frequently used, brackets will be used to signify these. A power ratio X expressed in decibels is, by definition,

$$[X] = 10\log X \qquad (19.1$$

Strictly speaking, the term *decibel* applies only to the power ratios, but for a detailed discussion extended use of decibels, see Appendix A. For the uplink, the transmitter power is generated by a high microwave amplifier (usually a klystron or traveling wave tube), and this power will be denoted by watts. When expressing this in decibels, it is essential that the reference power be stated, and this

Transmission path-Link budget

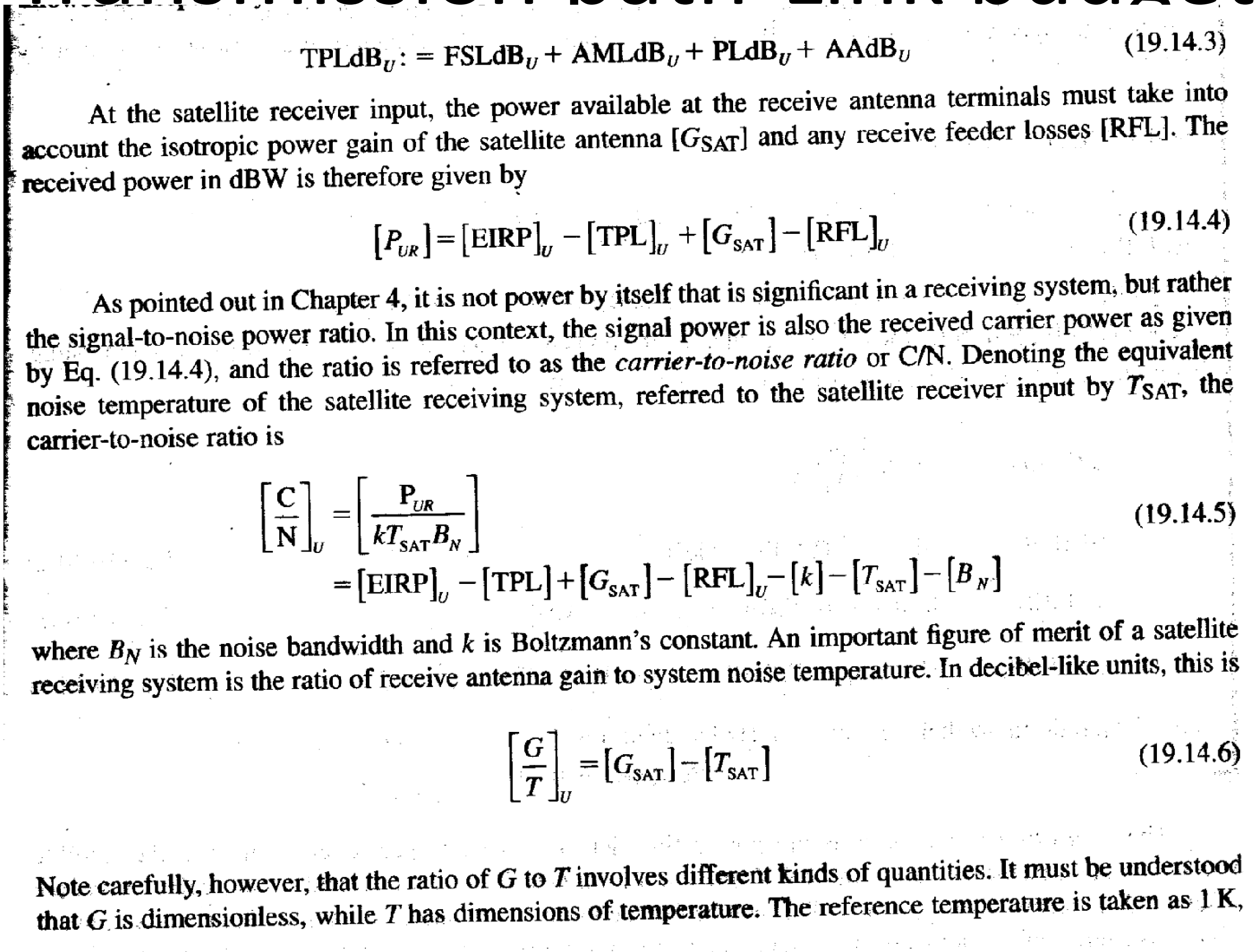


sumed to be 1 W. The power is then expressed in decibels referenced to 1 W, which is denoted by dBW.
he transmitter power is transferred to the transmit antenna through a feeder, which will have certain losses.
enoting these at [TFL] decibels, this loss must be subtracted from [P_{HPA}] to get the actual power, in dBW,
diated. This will be increased in the direction of maximum radiation by the power gain of the transmit
tenna. Denoting the isotropic power gain of the earth station antenna by G_{ES} and using the subscript U to
entify uplink quantities where necessary (similar downlink quantities will be introduced shortly, identified
y a subscript D) the *equivalent isotropic radiated power* (EIRP) is

$$\text{EIRPdB}_U := \text{PdB}_{HPA} - \text{TFLdB} + \text{GdB}_{ES} \qquad (19.14.2)$$

In Section 15.2 it is shown that the free space loss is given by FSL of Eq. (15.2.8). There will be addi-
ional losses, amounting to a few decibels, that have to be added to the free space loss. On the uplink, the
ansmit antenna boresight may not be pointing exactly at the satellite (see Section 19.10). This is referred
o as the *antenna misalignment loss* (AML) or sometimes as the *antenna pointing loss*. This will be denoted
by [AML] dB. There may also be a loss as a result of polarization misalignment, referred to as the *polar-*
ization loss and denoted in decibels as [PL]. Losses also occur in transmission through the earth's atmos-
phere as a result of energy being absorbed by the atmospheric gases. This energy goes mainly into vibrational
energy of certain molecules, which is subsequently lost as heat. It will be denoted by [AA] dB for *atmos-*
pheric absorption losses. Note that this term does not take into account rain attenuation, which must be
allowed for separately. The *transmission path loss* or [TPL] is conveniently defined as

Transmission path-Link budget



$$\text{TPLdB}_U := \text{FSLdB}_U + \text{AMLdB}_U + \text{PLdB}_U + \text{AAdB}_U \tag{19.14.3}$$

At the satellite receiver input, the power available at the receive antenna terminals must take into account the isotropic power gain of the satellite antenna $[G_{\text{SAT}}]$ and any receive feeder losses [RFL]. The received power in dBW is therefore given by

$$[P_{UR}] = [\text{EIRP}]_U - [\text{TPL}]_U + [G_{\text{SAT}}] - [\text{RFL}]_U \tag{19.14.4}$$

As pointed out in Chapter 4, it is not power by itself that is significant in a receiving system, but rather the signal-to-noise power ratio. In this context, the signal power is also the received carrier power as given by Eq. (19.14.4), and the ratio is referred to as the *carrier-to-noise ratio* or C/N. Denoting the equivalent noise temperature of the satellite receiving system, referred to the satellite receiver input by T_{SAT}, the carrier-to-noise ratio is

$$\left[\frac{\text{C}}{\text{N}}\right]_U = \left[\frac{\text{P}_{UR}}{kT_{\text{SAT}}B_N}\right] \tag{19.14.5}$$

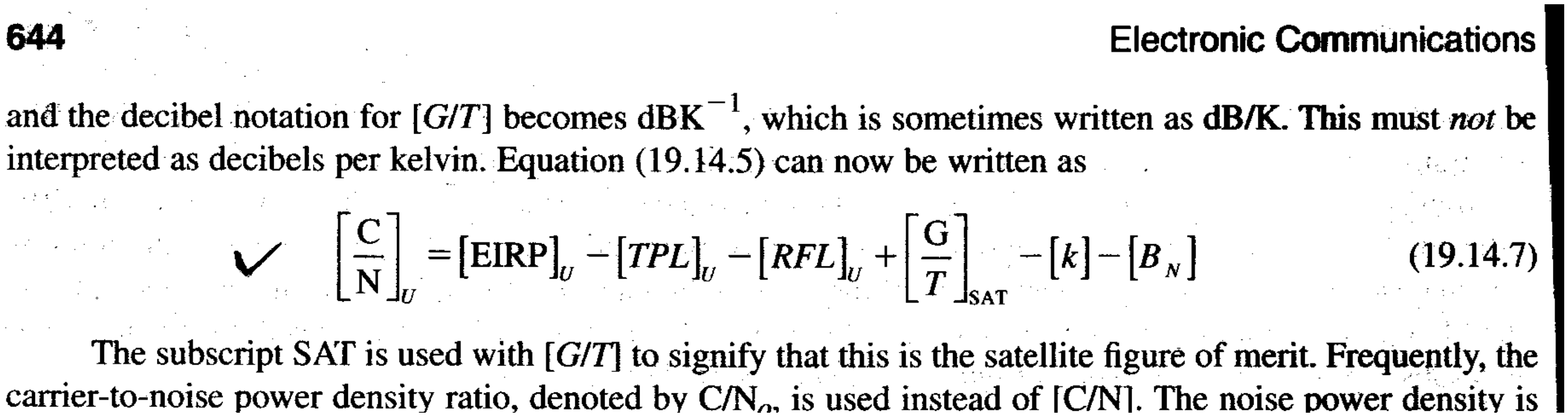
$$= [\text{EIRP}]_U - [\text{TPL}] + [G_{\text{SAT}}] - [\text{RFL}]_U - [k] - [T_{\text{SAT}}] - [B_N]$$

where B_N is the noise bandwidth and k is Boltzmann's constant. An important figure of merit of a satellite receiving system is the ratio of receive antenna gain to system noise temperature. In decibel-like units, this is

$$\left[\frac{G}{T}\right]_U = [G_{\text{SAT}}] - [T_{\text{SAT}}] \tag{19.14.6}$$

Note carefully, however, that the ratio of G to T involves different kinds of quantities. It must be understood that G is dimensionless, while T has dimensions of temperature. The reference temperature is taken as 1 K,

Transmission path-Link budget

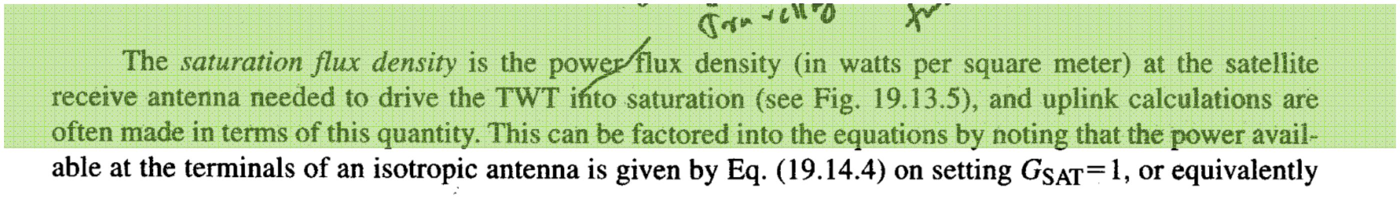


and the decibel notation for [*G*/*T*] becomes dBK^{-1}, which is sometimes written as **dB/K**. This must *not* be interpreted as decibels per kelvin. Equation (19.14.5) can now be written as

✓ $$\left[\frac{\mathrm{C}}{\mathrm{N}}\right]_U = [\mathrm{EIRP}]_U - [TPL]_U - [RFL]_U + \left[\frac{\mathrm{G}}{T}\right]_{\mathrm{SAT}} - [k] - [B_N] \qquad (19.14.7)$$

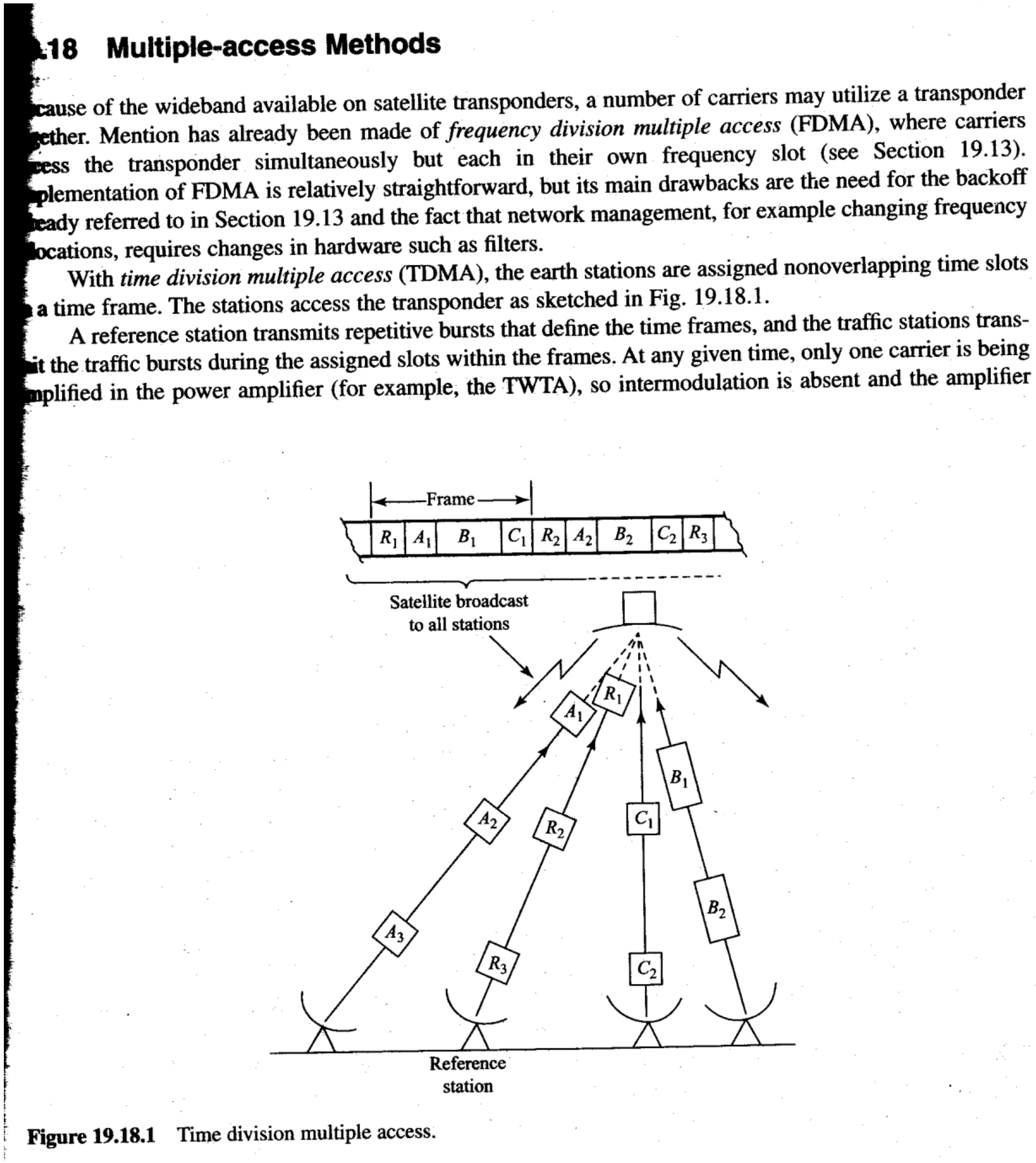
The subscript SAT is used with [*G*/*T*] to signify that this is the satellite figure of merit. Frequently, the carrier-to-noise power density ratio, denoted by C/N_0, is used instead of [C/N]. The noise power density is

Transmission path-Link budget



The *saturation flux density* is the power flux density (in watts per square meter) at the satellite receive antenna needed to drive the TWT into saturation (see Fig. 19.13.5), and uplink calculations are often made in terms of this quantity. This can be factored into the equations by noting that the power available at the terminals of an isotropic antenna is given by Eq. (19.14.4) on setting $G_{SAT} = 1$, or equivalently

ACCESS METHODS



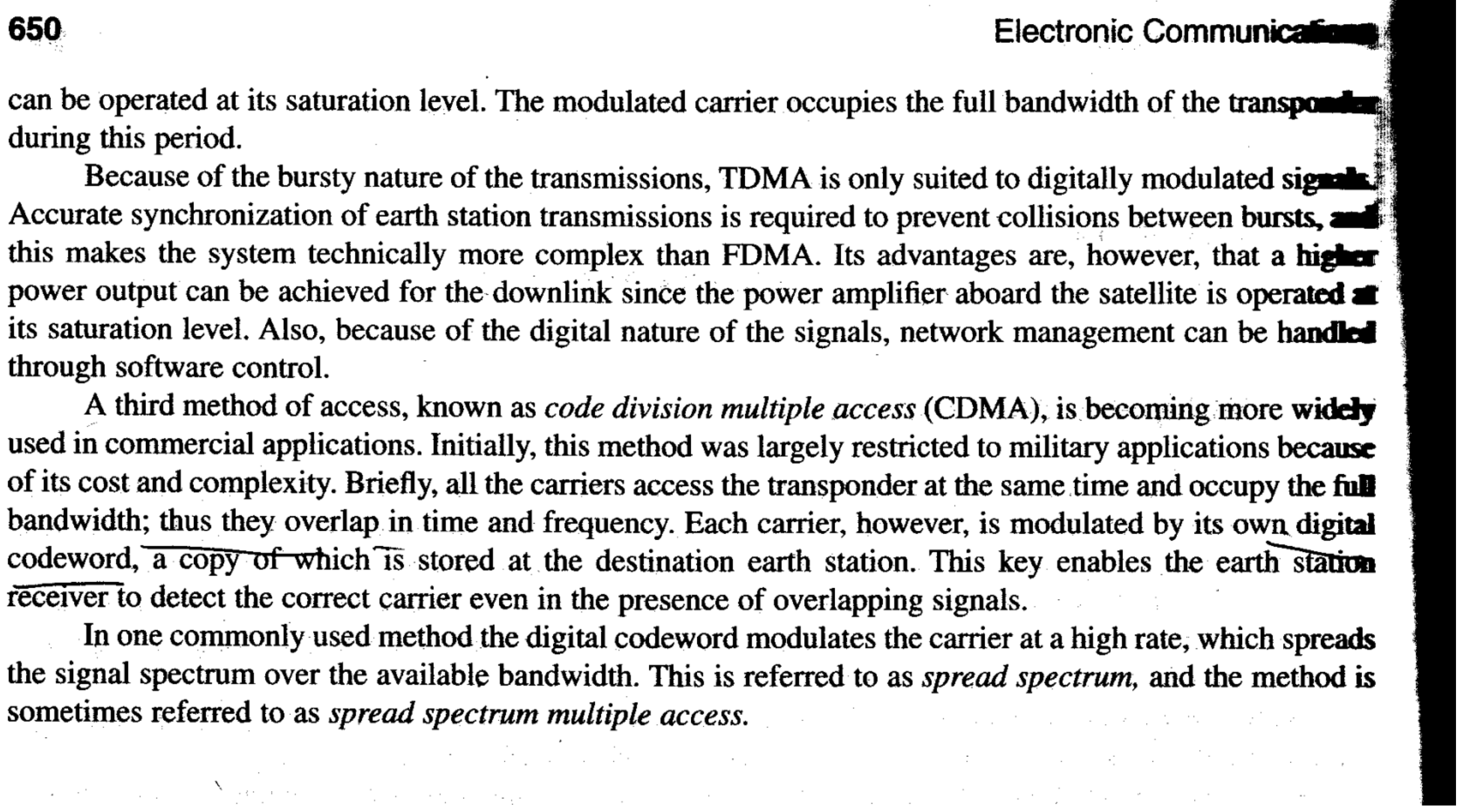
.18 Multiple-access Methods

cause of the wideband available on satellite transponders, a number of carriers may utilize a transponder ether. Mention has already been made of *frequency division multiple access* (FDMA), where carriers ess the transponder simultaneously but each in their own frequency slot (see Section 19.13). plementation of FDMA is relatively straightforward, but its main drawbacks are the need for the backoff eady referred to in Section 19.13 and the fact that network management, for example changing frequency ocations, requires changes in hardware such as filters.

With *time division multiple access* (TDMA), the earth stations are assigned nonoverlapping time slots a time frame. The stations access the transponder as sketched in Fig. 19.18.1.

A reference station transmits repetitive bursts that define the time frames, and the traffic stations transit the traffic bursts during the assigned slots within the frames. At any given time, only one carrier is being plified in the power amplifier (for example, the TWTA), so intermodulation is absent and the amplifier

Figure 19.18.1 Time division multiple access.



can be operated at its saturation level. The modulated carrier occupies the full bandwidth of the transponder during this period.

Because of the bursty nature of the transmissions, TDMA is only suited to digitally modulated signals. Accurate synchronization of earth station transmissions is required to prevent collisions between bursts, and this makes the system technically more complex than FDMA. Its advantages are, however, that a higher power output can be achieved for the downlink since the power amplifier aboard the satellite is operated at its saturation level. Also, because of the digital nature of the signals, network management can be handled through software control.

A third method of access, known as *code division multiple access* (CDMA), is becoming more widely used in commercial applications. Initially, this method was largely restricted to military applications because of its cost and complexity. Briefly, all the carriers access the transponder at the same time and occupy the full bandwidth; thus they overlap in time and frequency. Each carrier, however, is modulated by its own digital codeword, a copy of which is stored at the destination earth station. This key enables the earth station receiver to detect the correct carrier even in the presence of overlapping signals.

In one commonly used method the digital codeword modulates the carrier at a high rate, which spreads the signal spectrum over the available bandwidth. This is referred to as *spread spectrum,* and the method is sometimes referred to as *spread spectrum multiple access.*

C-Bad receiver

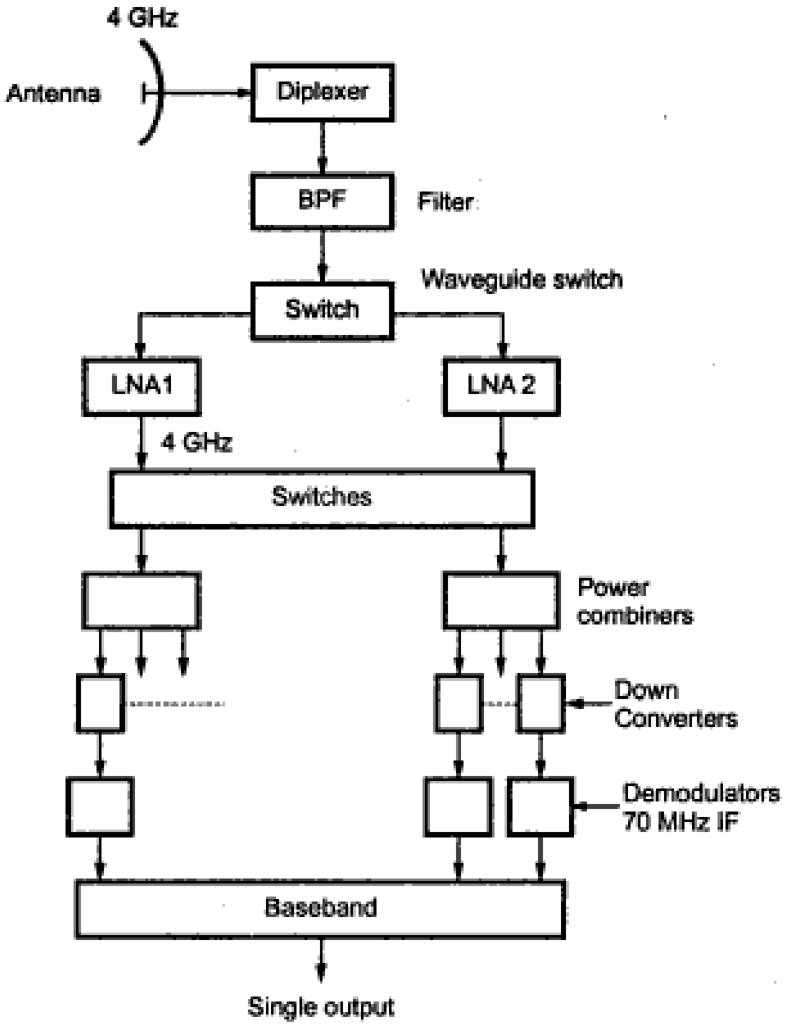
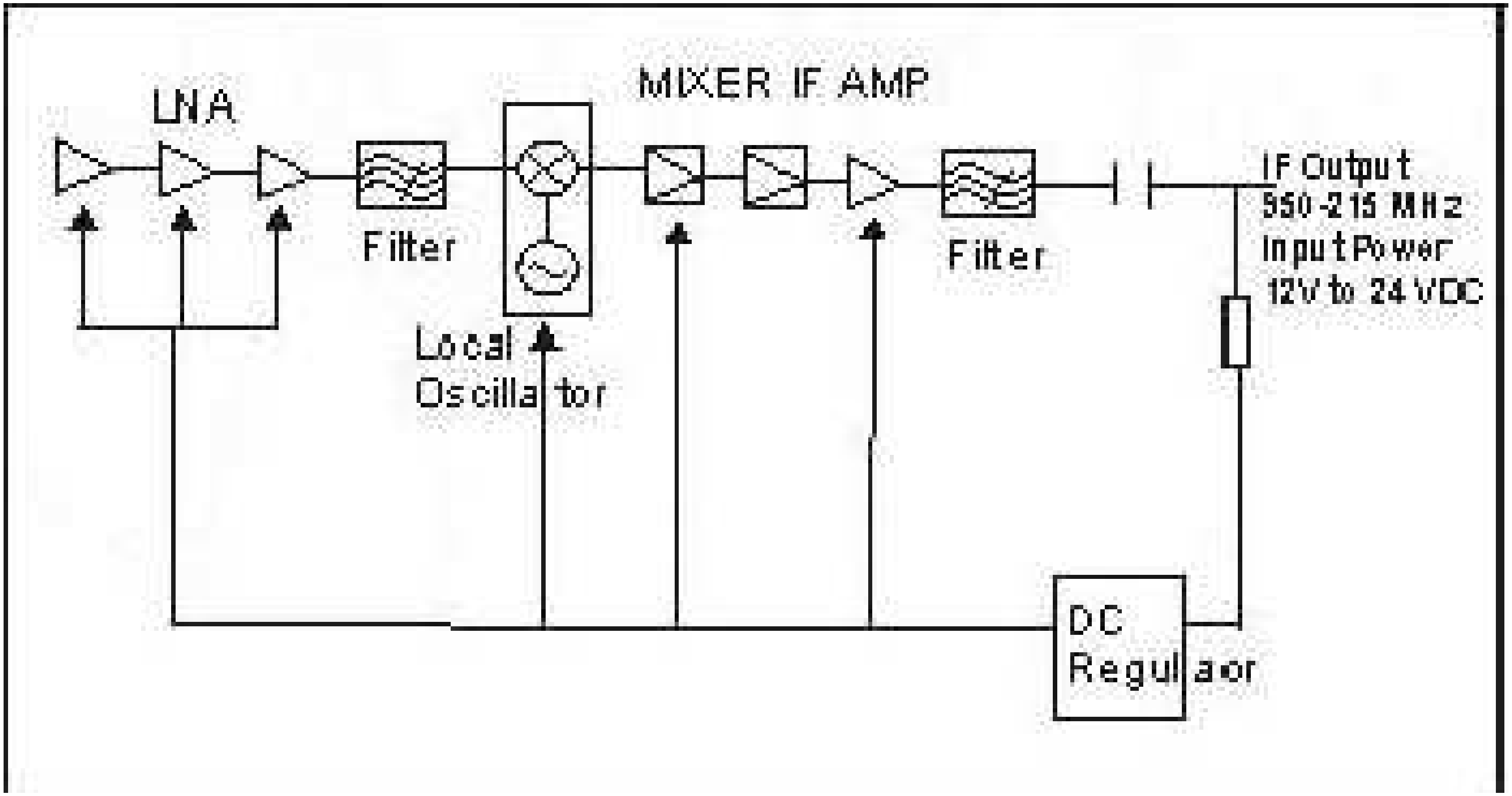


Fig. 5.10.3 Block diagram of receiver


LNA
MIXER IF AMP
Filter
Local Oscillator
Filter
IF Output
950-2150 MHz
Input Power
12V to 24 VDC
DC Regulator

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Power requirements:............110-120 VAC, 60 Hz, Single phase. UL listed. Operating frequency:...................3.7 to 4.2 Ghz and 11.7 to 12.2 Ghz. Antenna type:.......Perforated aluminum parabolic reflector with 180 degree horizon to horizon mount. All mounting frame hardware is of galvanized steel or non-corrosive metal. Parabolic reflector and its support structure is power coated to prevent corrosion. Mounting pole is the industry standard 3.5 inch diameter schedule 40 pipe. Unmounted weight:...190 lbs. Minimum mid-band gain:............Antenna size - 2.74 meter, C band gain is 39.6 dbi, KU band is 47.1 dbi. Minimum efficiency:...............................70% C band 43%, KU band. Input VSWR:...1.3: 1 Maximum.

Noise Temperature:...........C band 45 degrees Kelvin, KU band 180 degrees Kelvin, maximum, across full bandwidth. Gain:..C band 60 db, KU band 55 db. Gain Flatness:.................................+/- 1.5 db/500 Mhz Maximum. Power requirements:........15-28 VDC, fed thru coaxial cable from receiver. Input VSWR:...3.0:1, 50 ohm system. Cables from LNB to receiver:...........................RG6 and connectors. Receiver Capable of receiving scrambled signals with the addition of Video Cipher II Plus Descrambler. Antenna input impedance:............75 ohms, unbalanced, type F connector, return loss greater than 20 db. IF:

IF: Input level:..-65 to -25 dbm AGC range:..40 db minimum. IF frequency:...480 mhz IF bandwidth:....................................26 mhz/18 mhz switchable. Threshold(static):...................................less than 7.5 db C/N. Video: Tuning system:...................................PLL digital synthesizer. Deemphasis:...