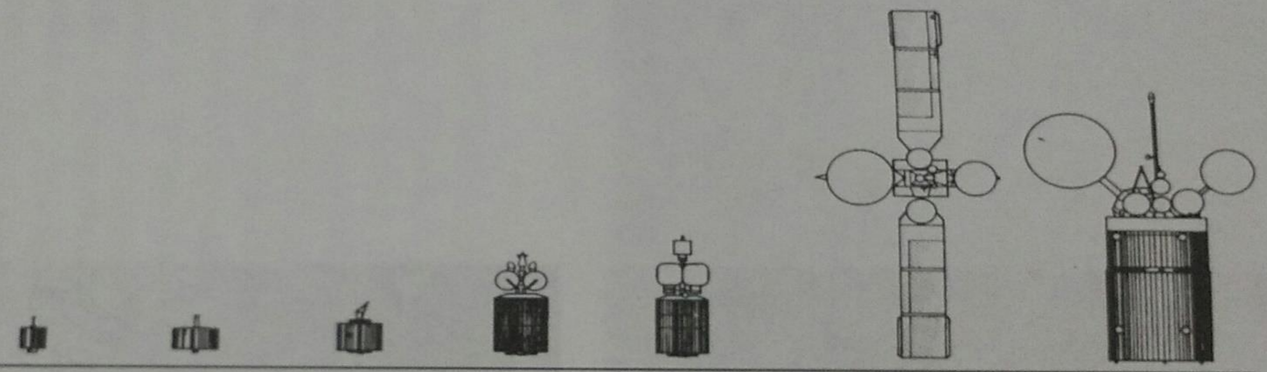
Satellite Communication and GPS

MODULE 1

INTELSAT , Evolution



Designation: Intelsat	I	II	III	IV	IV A	V	V A/V B	VI
Year of first launch	1965	1966	1968	1971	1975	1980	1984/85	1986/87
Prime contractor	Hughes	Hughes	TRW	Hughes	Hughes	Ford Aerospace	Ford Aerospace	Hughes
Width (m)	0.7	1.4	1.4	2.4	2.4	2.0	2.0	3.6
Height (m)	0.6	0.7	1.0	5.3	6.8	6.4	6.4	6.4
Launch vehicles		Thor Delta		Atlas-Centaur		Atlas-Centaur and Ariane	Atlas-Centaur and Ariane	STS and Ariane
Spacecraft mass in transfer orbit (kg)	68	182	293	1385	1489	1946	2140	12,100/3720
Communications payload mass (kg)	13	36	56	185	190	235	280	800
End-of-life (EOL) power of equinox (W)	40	75	134	480	800	1270	1270	2200
Design lifetime (years)	1.5	3	5	7	7	7	7	10
Capacity (number of voice channels)	480	480	2400	8000	12,000	25,000	30,000	80,000
Bandwidth (MHz)	50	130	300	500	800	2137	2480	3520

Figure 1.1 Evolution of INTELSAT satellites. (*From Colino 1985; courtesy of ITU Telecommunications Journal.*)

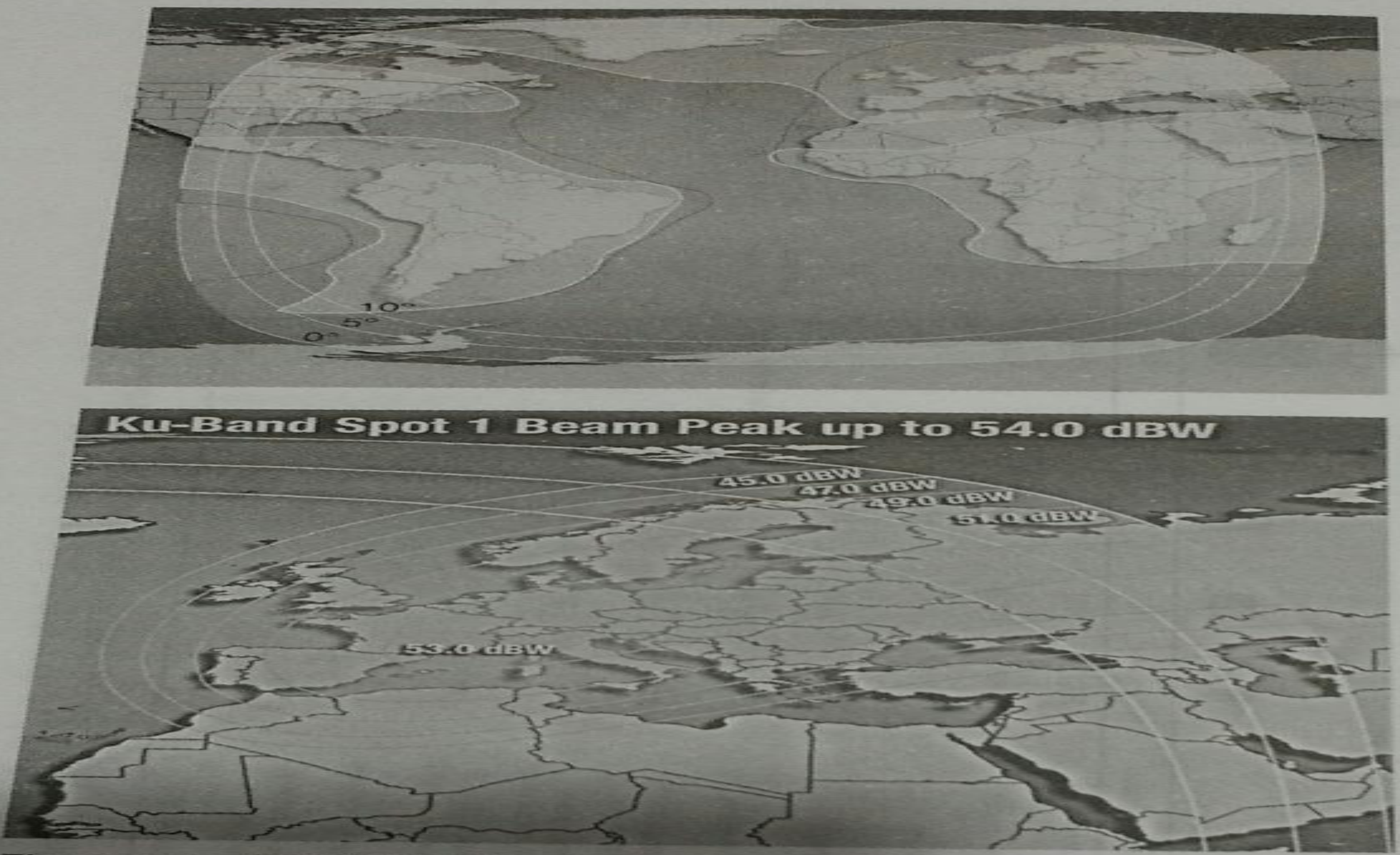


Figure 1.2 INTELSAT satellite 905 is positioned at 335.5° E longitude. (*a*) The footprints for the C-band antennas; (*b*) the Ku-band spot 1 beam antennas; and (*c*) the Ku-band spot 2 beam antennas.

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*In addition to transoceanic route services, INTELSAT – used for domestic services within any given country and regional services between countries. Vista- for telephone and Intelnet for data exchange.

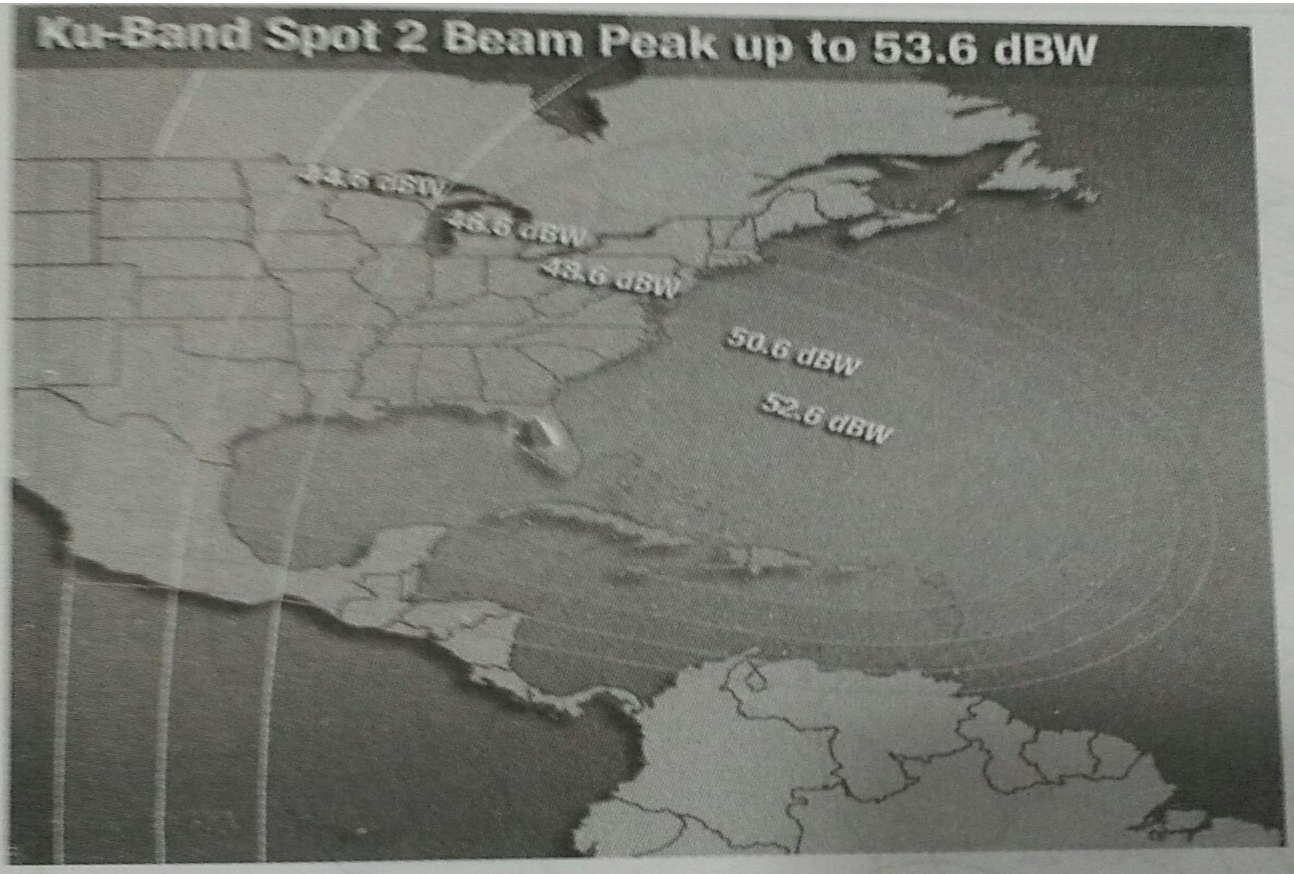

Figure 1.2 *(Continued)*.

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US Domsat

*Domestic Satellite, for various telecommunications services, voice, data and video transmissions within the country. In USA all Domsats are in geostationary orbit (wide selection of TV channels and commercial telecommunication traffic).

* US Domsats providing a DTH television service- classified (broad) as high power, medium power,low power (Reinhart, 1990). Defining characteristics are as in table 1.4.

*Equivalent Isotropic Radiated Power (EIRP) in dBW, -with Tx antenna gain G, Ps is radiated power, isotropic means equally in all directions (hypothetical). Upper limit of EIRP is 60dBW for the high power category of 37dBW for low power category (23dB difference)- represent an increase in received power of 10e2.3 or about 200:1 in high power category (allow much smaller antenna for Rx).

*Table 1.4 shows DBS service is provided by high power category.

* Medium power category- point to point services, but space may be leased on these satellites for DBS.

* Low power category, no official DBS service.

Contd.

* Home experimenters discovered a wide range of radio and TV programming could be received in this band and now it is defacto DBS service provided in this band, large no of TV Receive only (TVRO) dishes appeared in the yards and rooftops (USA), TVRO C-band reception prohibited in several parts of world (Reason- aesthetic , large dish antenna needed, partly commercial).

*Many NA C band TV broadcasts for now encrypted or scrambled (fear of theft).

* True DBS is in Ku band , fig.1.5 for DBS service (Canada govt. 1983). TV signal may be relayed over a terrestrial link to uplink station 14GHz band narrow beam signal. Down link 12GHz band from satellite to ground – signal in wide beam . Individual RX in beam coverage area receives satellite signal.

* Table 1.5 summarizes orbital assignments for domestic fixed satellites for US (FCC 1996), in geostationary orbit.

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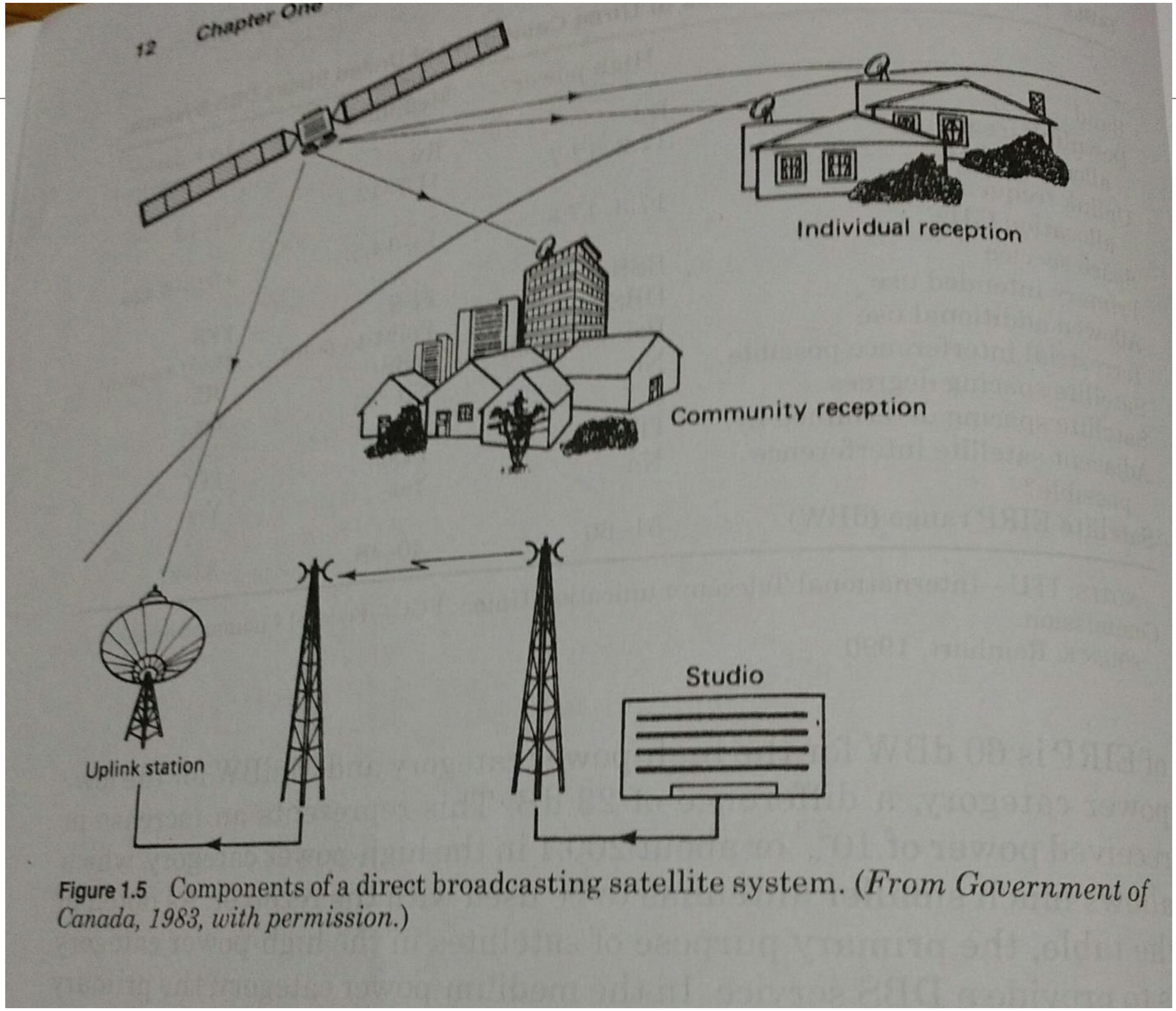

Figure 1.5 Components of a direct broadcasting satellite system. (*From Government of Canada, 1983, with permission.*)

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TABLE 1.5 FCC Orbital Assignment Plan (May 7, 1996)

Location, degrees west longitude	Satellite	Band/polarization
139	Aurora II/Satcom C-5	4/6 GHz (vertical)
139	ACS-3K (AMSC)	12/14 GHz
137	Satcom C-1	4/6 GHz (horizontal)
137	Unassigned	12/14 GHz
135	Satcom C-4	4/6 GHz (vertical)
135	Orion O-F4	12/14 GHz
133	Galaxy 1-R(S)	4/6 GHz (horizontal)
133	Unassigned	12/14 GHz
131	Satcom C-3	4/6 GHz (vertical)
131	Unassigned	12/14 GHz
129	Loral 1	4/6 GHz (horizontal)/12/14 GHz
127	Galaxy IX	4/6 GHz (vertical)
127	Unassigned	12/14 GHz
125	Galaxy 5-W	4/6 GHz (horizontal)
125	GSTAR II/unassigned	12/14 GHz
123	Galaxy X	4/6 GHz (vertical)/12/14 GHz
121	EchoStar FSS-2	12/14 GHz
105	GSTAR IV	12/14 GHz
103	GE-1	4/6 GHz (horizontal)
103	GSTAR 1/GE-1	12/14 GHz
101	Satcom SN-4 (formerly Spacenet IV-n)	4/6 GHz (vertical)/ 12/14 GHz
99	Galaxy IV(H)	4/6 GHz (horizontal)/12/14 GHz
97	Telstar 401	4/6 GHz (vertical)/12/14 GHz
95	Galaxy III(H)	4/6 GHz (horizontal)/12/14 GHz
93	Telstar 5	4/6 GHz (vertical)
93	GSTAR III/Telstar 5	12/14 GHz
91	Galaxy VII(H)	4/6 GHz (horizontal)/12/14 GHz
89	Telestar 402R	4/6 GHz (vertical)/12/14 GHz
87	Satcom SN-3 (formerly Spacenet III-)/GE-4	4/6 GHz (horizontal)/12/14 GHz
85	Telstar 302/GE-2	4/6 GHz (vertical)
85	Satcom Ku-1/GE-2	12/14 GHz
83	Unassigned	4/6 GHz (horizontal)
83	EchoStar FSS-1	12/14 GHz
81	Unassigned	4/6 GHz (vertical)
81	Satcom Ku-2/unassigned	12/14 GHz
79	GE-5	4/6 GHz (horizontal)/12/14 GHz
77	Loral 2	4/6 GHz (vertical)/12/14 GHz
76	Comstar D-4	4/6 GHz (vertical)
74	Galaxy VI	4/6 GHz (horizontal)
74	SBS-6	12/14 GHz
72	Unassigned	4/6 GHz (vertical)
71	SBS-2	12/14 GHz
69	Satcom SN-2/Telstar 6	4/6 GHz (horizontal)/12/14 GHz
67	GE-3	4/6 GHz (vertical)/12/14 GHz
64	Unassigned	4/6 GHz (horizontal)
64	Unassigned	12/14 GHz
62	Unassigned	4/6 GHz (vertical)
62	ACS-2K (AMSC)	12/14 GHz
60	Unassigned	4/6 GHz
60	Unassigned	12/14 GHz

Contd.

* US Ka band assignments are for broadband services- Internet. US FCC specifies (1983), 2deg as minimum orbital spacing for satellites in 6/4 GHz band (6GHz for earth to satellite – uplink and 4GHz for satellite to earth station down link.

* These are frequently employed for geostationary satellites. Reason- less attenuation of signal due to rain.

* 1.5 deg orbital spacing for 14/12GHz band (FCC 1983). Interference between satellite circuits is increasing as satellites are positioned closer together. For each band these spacings - based on acceptable interference levels. With 2deg spacing in 6/4GHz band excessive interference is expected as the no. of satellites in this band are increasing.

Polar Orbiting Satellites

*Orbit earth so as to cover the north and south polar regions. Not orbiting around poles or pole. Fig.1.6 shows a polar orbit in relation to the geostationary orbit. There is only one geostationary orbit and theoretically any number of polar orbits are possible.

* US weather satellites (by experience) are relatively low orbiting, altitude ranging from 800 to 900km. Geostationary orbiting at 36000km. Low Earth Orbiting types- LEOSATS.

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*US National Polar Orbiting Operational Environmental Satellite System (NPOESS 1994) consolidates polar satellite operations of Air Force, NASA and NOAA (National Oceanic and Atmospheric Administration). NPOESS manages Integrated Program Office (IPO).

*By 2005 a four orbit system consists of 2 Military orbits, one US Civilian orbit and one European Organisation for the exploration of the METSAT program, Meteorological Satellite, EUMETSAT/METOP Meteorological Operations orbit . These are Sun synchronous , they cross the equator at the same local time each day. Eg. NPOESS (civilian) orbit crosses equator going from S to N at 1.30PM, 5.30PM, 9.30PM.

*Orbital pass from N to S is called descending pass, S to N as ascending pass. Polar orbits almost circular at heights of 800- 900km above Earth.

*Polar orbits track weather conditions over entire earth, provide wide range of data, visible and IR radiometer data for imaging purposes, radiation measurements and temperature profiles, carry UV sensors, measure ozone levels, ozone hole over Antarctica.

*Most polar orbiting satellites used in weather and environmental studies, monitoring and search and rescue operation have footprint about 6000km in diameter . This is the antenna spot beam on the surface of earth. While orbiting, the spot beam sweeps out a swath on the surface of earth~ 6000km wide passing over N and S poles. Orbital period of satellites ~102min.

Contd.

TABLE 1.7 NOAA KLM Satellites

Launch date	NOAA-K (NOAA-15): May 13, 1998 NOAA-L: September 21, 2000 NOAA-M: June 24, 2000 NOAA-N: March 19, 2005 (tentative) NOAA-N': July 2007
Mission life	2 years minimum
Orbit	Sun synchronous, 833 ± 19 km or 870 ± 19 km
Mass	1478.9 kg on orbit; 2231.7 kg on launch
Length/Diameter	4.18 m/1.88 m
Sensors	Advanced very high resolution radiometer (AVHRR/3) Advanced microwave sounding unit-A (AMSU-A) Advanced microwave sounding unit-B (AMSU-B) High resolution infrared radiation sounder (HIRS/3) Space environment monitor (SEM/2) Search and rescue (SAR) repeater and processor Data collection system (DCS/2)

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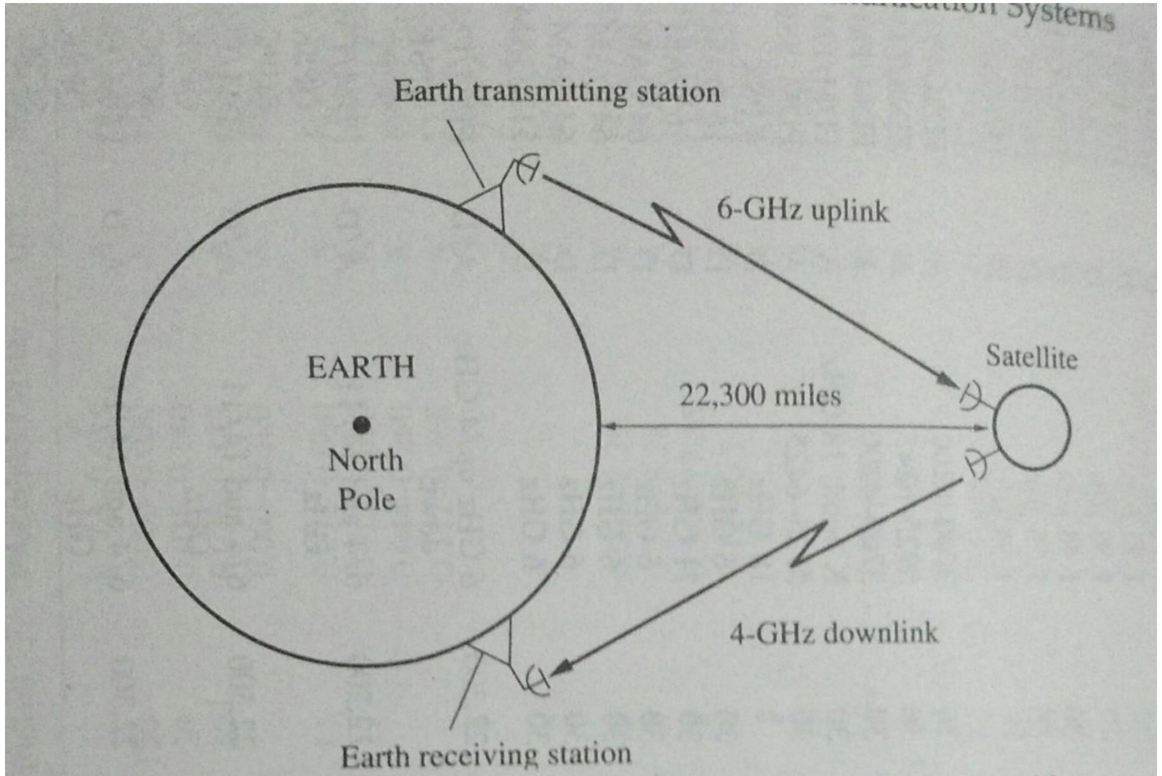

Figure 8–8 Communications satellite in geosynchronous orbit.

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The following figures give various aspects of satellite in picture.

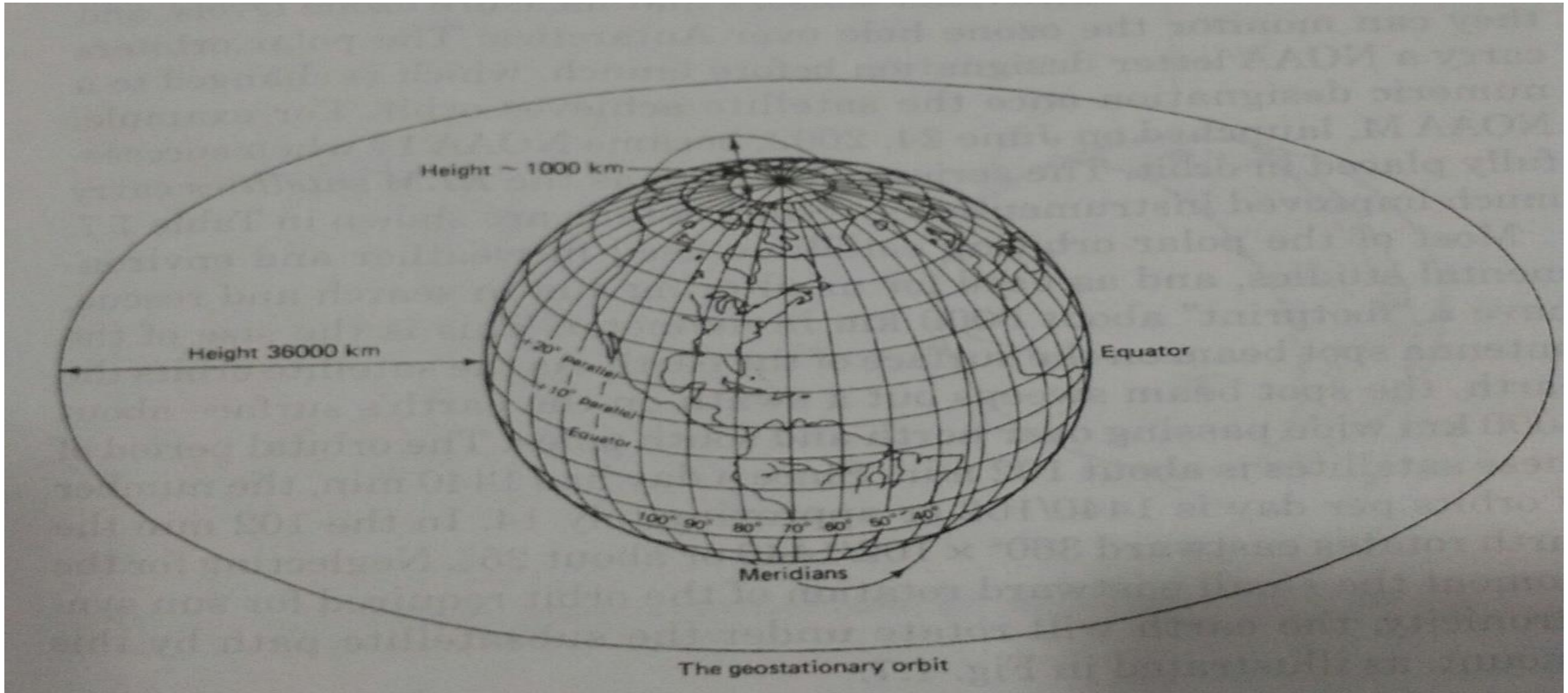

Figure 1.6 Geostationary orbit and one possible polar orbit.

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A day has 1440min, no. of orbits/day

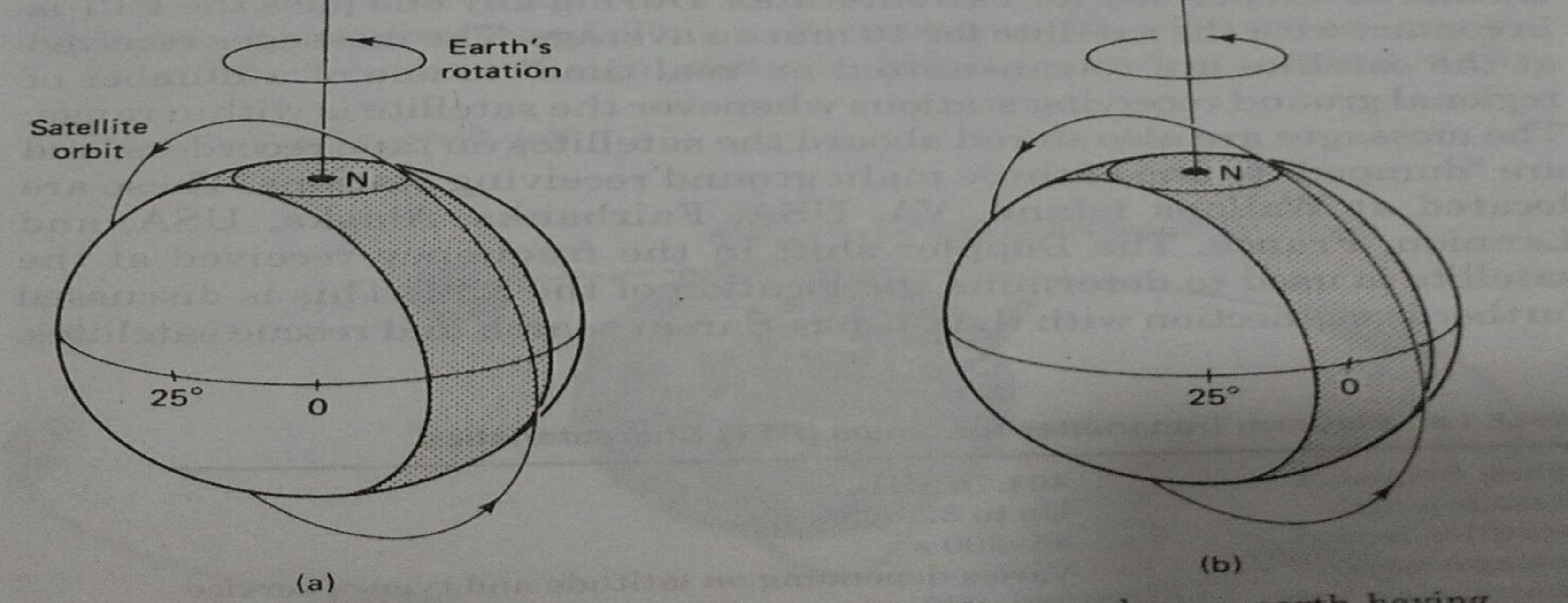

Figure 1.7 Polar orbiting satellite: (*a*) first pass; (*b*) second pass, earth having rotated 25°. Satellite period is 102 min.

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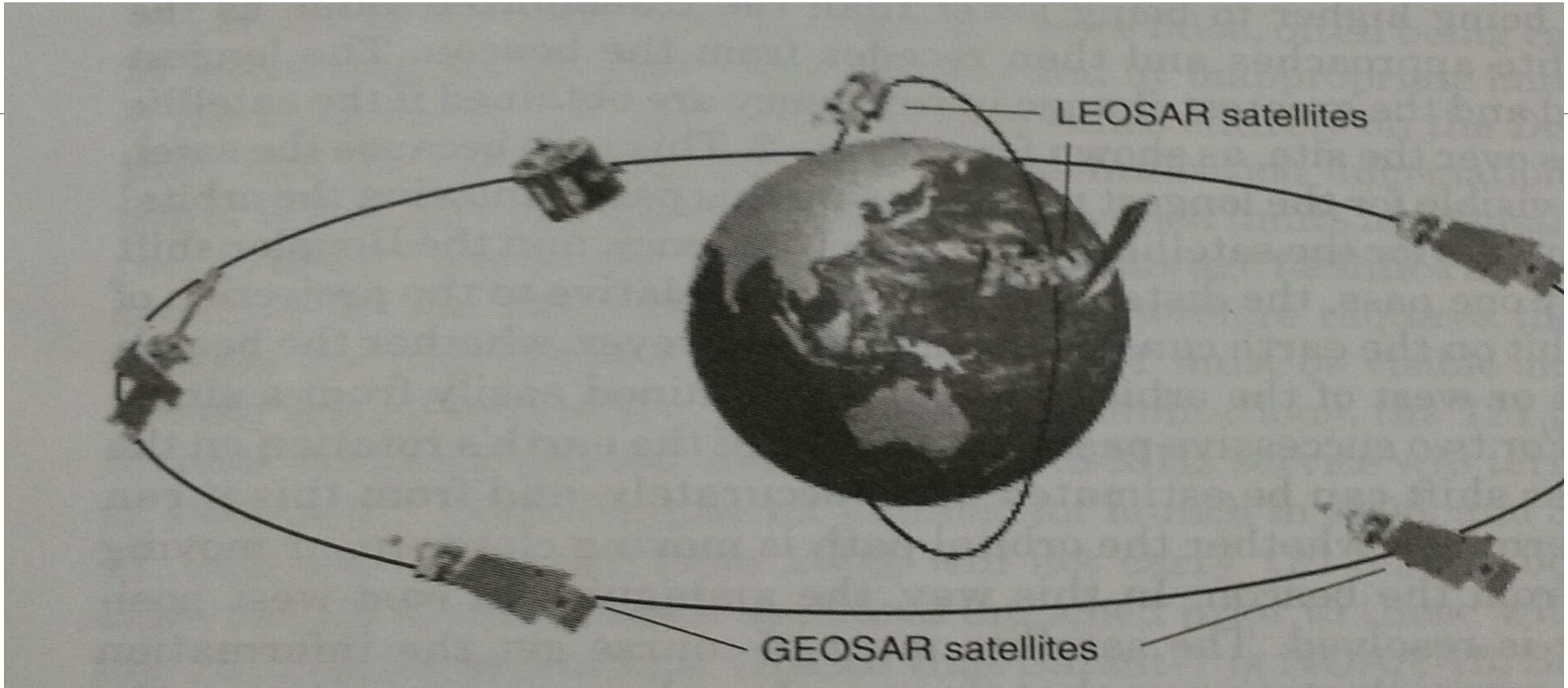

Figure 1.8 Geostationary orbit search and rescue (GEOSAR) and low earth orbit s and rescue (LEOSAR) satellites. (*Courtesy of Cospas-Sarsat Secretariat.*)

Kepler’s Laws

Fig.2.1 The foci F1 and F2 , the semimajor axis a and semiminor axis b of an ellipse.

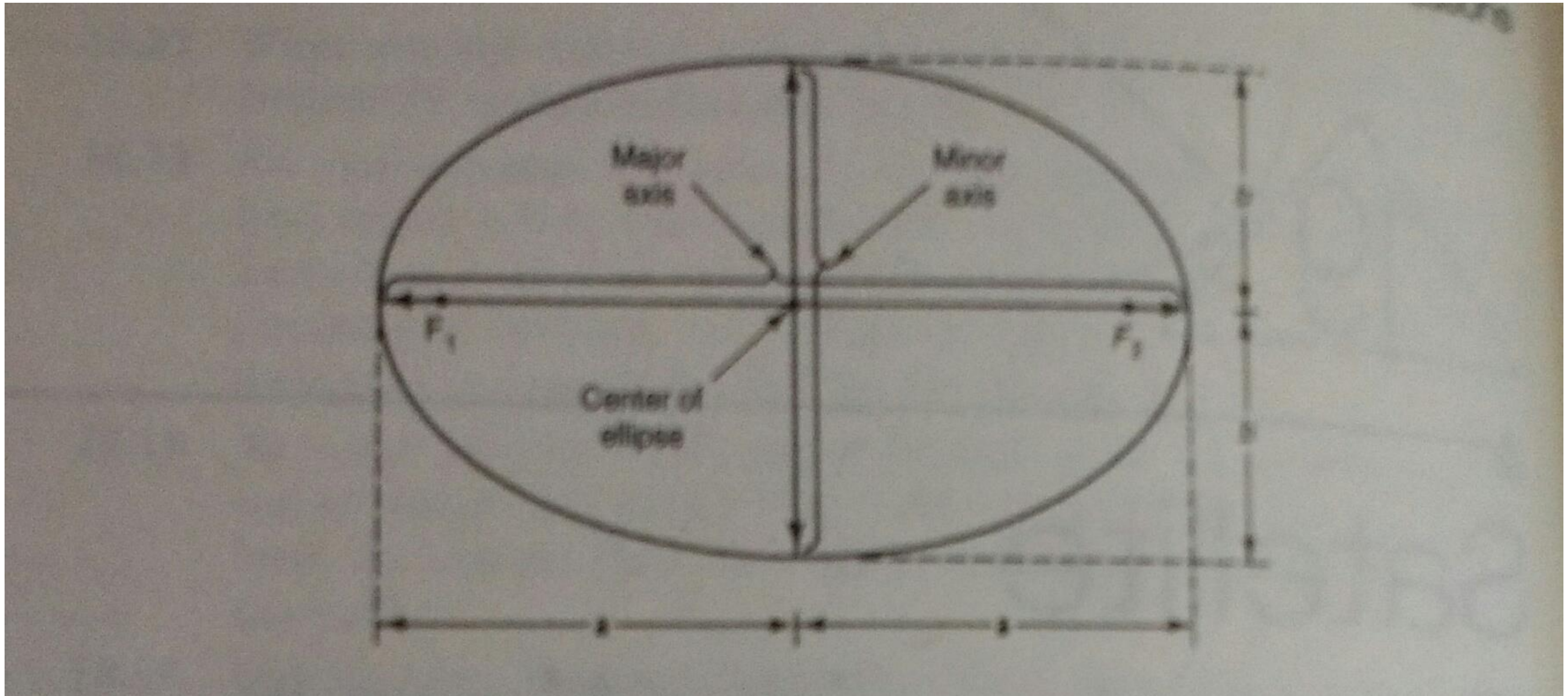

Figure 19.2.1 Foci F_1 and F_2, the semimajor axis *a* and the semiminor axis *b* of an ellipse.

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Kepler's First Law states that the path followed by a satellite around a primary is ellipse. See fig. in the previous slide. Centre of mass of two body system- called barycenter is always centered on one of the foci. Mass of earth>> mass of satellite. Centre of mass therefore coincides with the center of the earth, always at one of the foci.

a= semimajor axis of ellipse

b= seminor axis

Eccentricty e= sqrt (a*2-b*2)/a

By knowing a and e of the spacecraft (specified) , b can be calculated.

For an elliptical orbit 0<e<1. For e=0, orbit is circular.

Kepler's Second law: States that for equal time intervals, the satellite will cover equal areas in its orbital plane. From fig.2.2, if satellite travels distance S1 in 1s and S2 in the same duration, then the areas A1 and A2 are equal.

Average velocities are s1 and S2 m/s, hence s1>S2. Satellite takes longer time to travel a given distance when it is farther away from earth. Significance of this is that the length of time satellite can be seen from a place can be increased.

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Kepler's Third Law: States that the square of the periodic time of orbit is proportional to the cube of the mean distance a between the two bodies.

a*3= μ/ n*2   n is the mean motion of the satellite in radians/s and μ is earth's geocentric gravitational constant. This is for ideal case, earth is perfectly spherical and no perturbing forces.

μ= 3.986005 x 10*14 m*3/s*2

Mean motion n in radians/s, gives orbital period in seconds

P= 2л/ n

Importance of Kepler's third law is that it shows there is a fixed relationship between P and a. In particular ie., geostationary orbit is determined by rotational period of earth.

Ex.1: Calculate the radius of a circular orbit, for P=1day.

One day= 86400s, hence mean motion is n= 2л/86400= 7.272 x 10*-5rad/s

From Kepler's third law, a= [3.986005 x 10*14/ (7.272 x 10*-5)*2]*1/3 = 42241km

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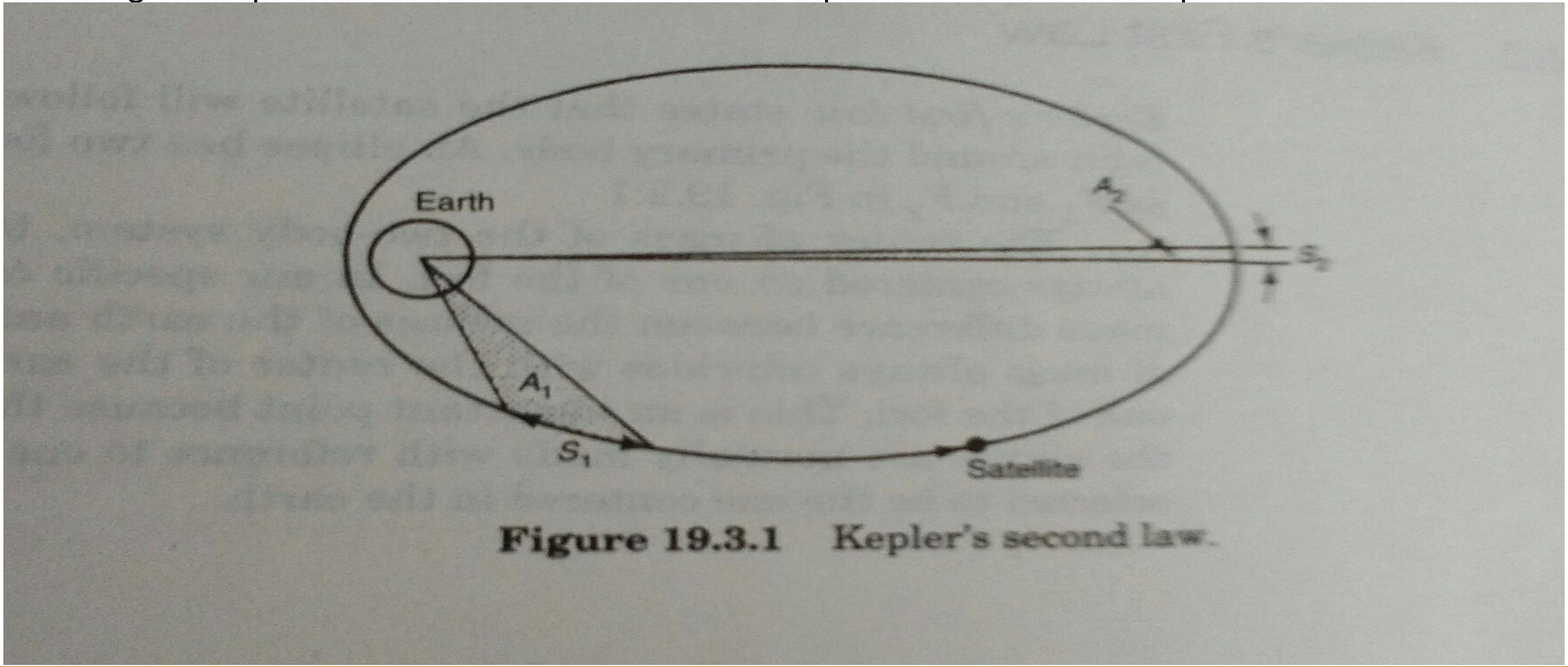
Fig. 2.2 Kepler's second law. Areas A1 and A2 swept out in unit time are equal.



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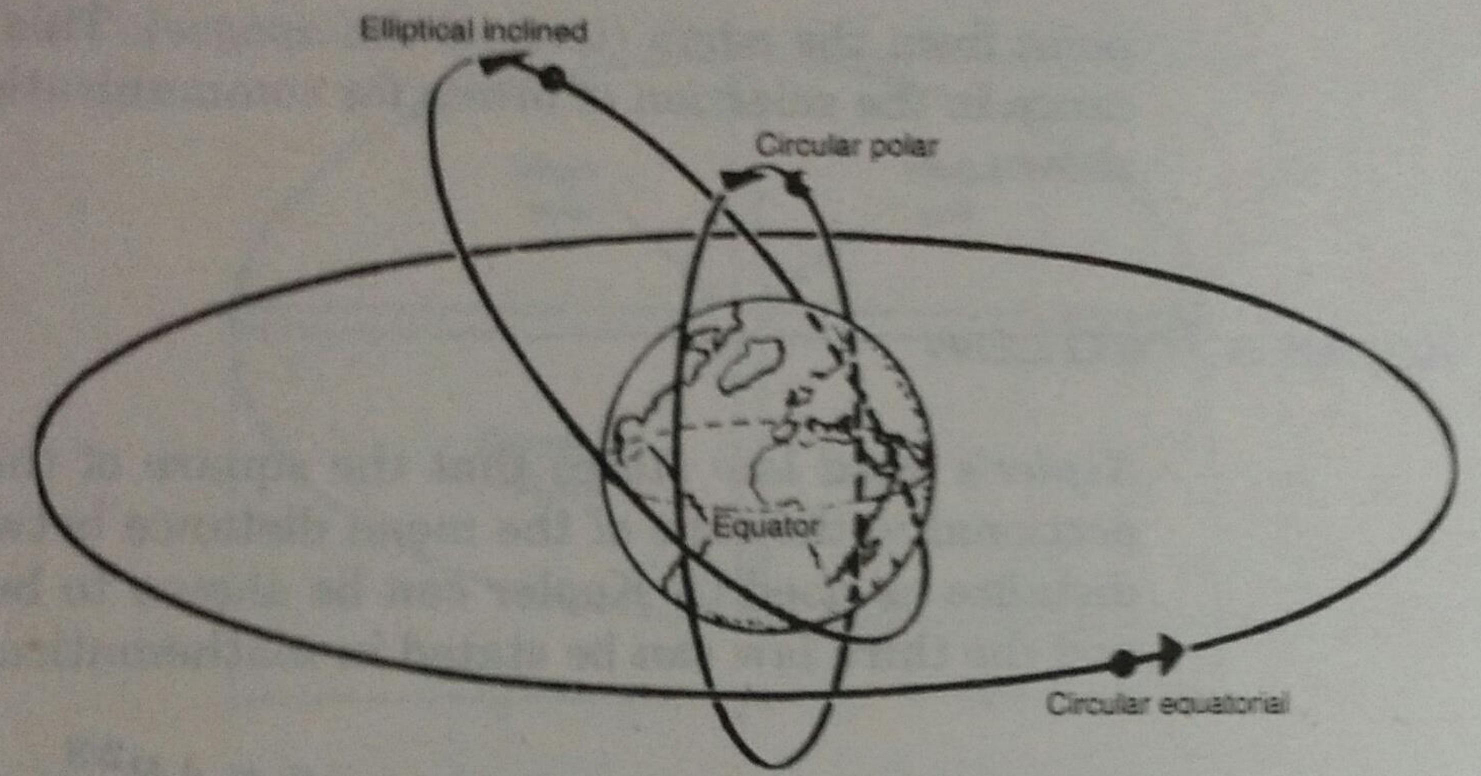

Figure 19.5.1 Three possible orbits. (From *Telecommunications Satellites,* Kenneth W. Gatland, Ed. Englewood Cliffs, NJ: Prentice Hall, 1984.)

*Above fig.1.1 shows three orbits. Polar orbiting satellite orbits close to earth, passes over or very close to poles. Inclination is close to 90deg. Altitude ~800km to 1000km. Low cost services.

*Inclined highly elliptical orbit is used where communication to high latitude is desired. The orbital velocity is least at apogee (Kepler's 2nd law), by placing apogee above high latitude regions satellite remains visible for a longer period from these regions. At an inclination of i=63.4deg, the rotation of the line of apsides is zero, apogee of satellites remain fixed over a particular region are launched in this inclination. Called 63deg slot. Russian Molniya series use highly inclined orbit.

* Circular equatorial.

Ex: Find the semimajor axis for the satellite parameters given in Table 2.1.

Mean motion as in table 2.1 , NN= 14.23304826/day

In radians, n_o= 2лx NN= 0.001.4/s. From Kepler's 3rd law, a= $[\mu \frac{1}{no^2}]^{1/3}$

= 7192.335km

Contd.

Ex: Calculate apogee and perigee heights . Orbital parameters are as in table 2.1. Mean earth radius is R=6371km.

From table 2.1: e= 0.0011501 and for a= 7192.335km,

$r_{a} =$ 7192.335(1+0.0011501) = 7200.607km , r_{p} = 7192.335 (1- 0.0011501)= 7184.063

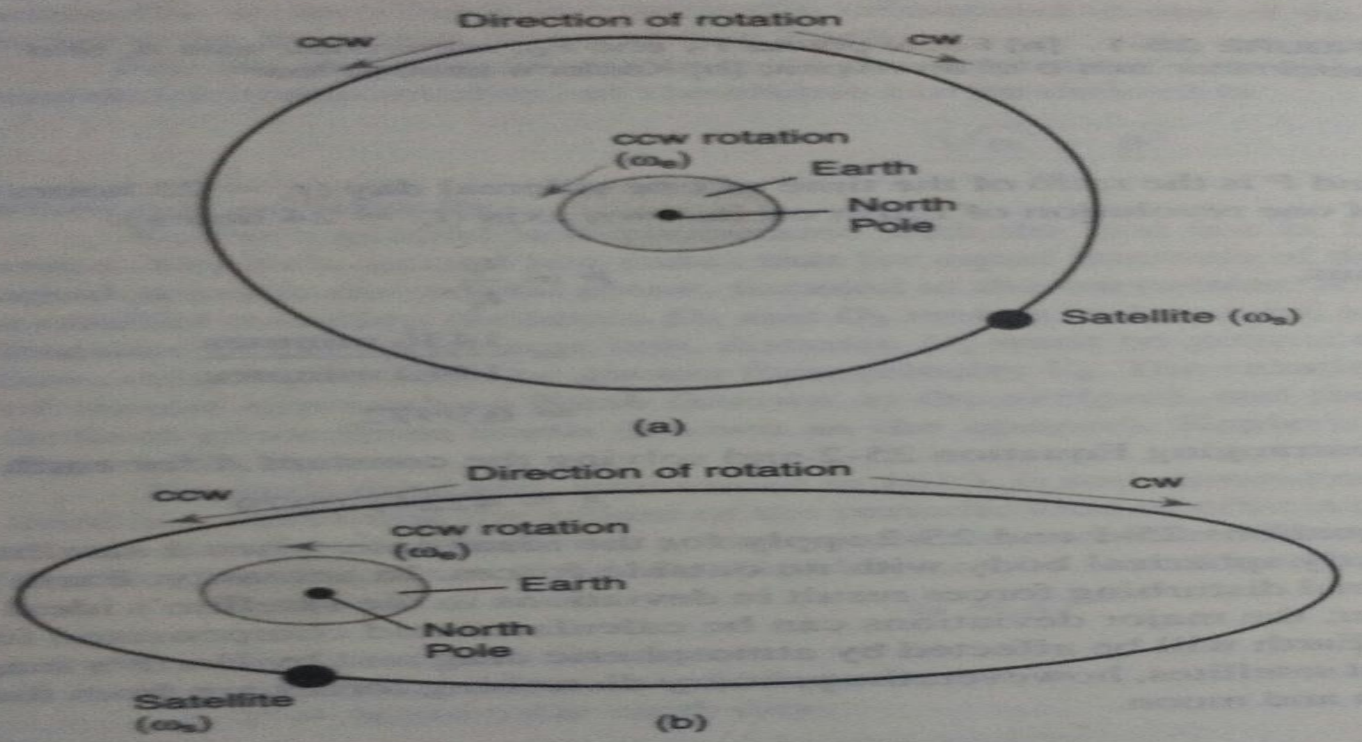

FIGURE 25-2 Satellite orbits: [a] circular; [b] elliptical

Chapter 25

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Definitions of orbiting satellites: Refer fig.2.3 and 2.4 text book.

Subsaellite path: Path traced out on the earth's surface directly below the satellite.

Apogee: Point farthest from earth, height ha.

Perigee: Point of closest approach to earth hp.

Line of apsides: Line joining the perigee and apogee through the center of earth.

Ascending Node: The point where the orbit crosses the equatorial plane going from S to N.

Descending Node: The point where the orbit crosses the equatorial plane going from N to S.

Line of nodes: The line joining the ascending and descending nodes through the center of earth.

Inclination: The angle between the orbital plane and earth's equatorial plane. Measured at the ascending node from the equator to the orbit going from east to north. Inclination is I in fig. 2.3. Greatest latitude north or south reached by orbiting path is i.

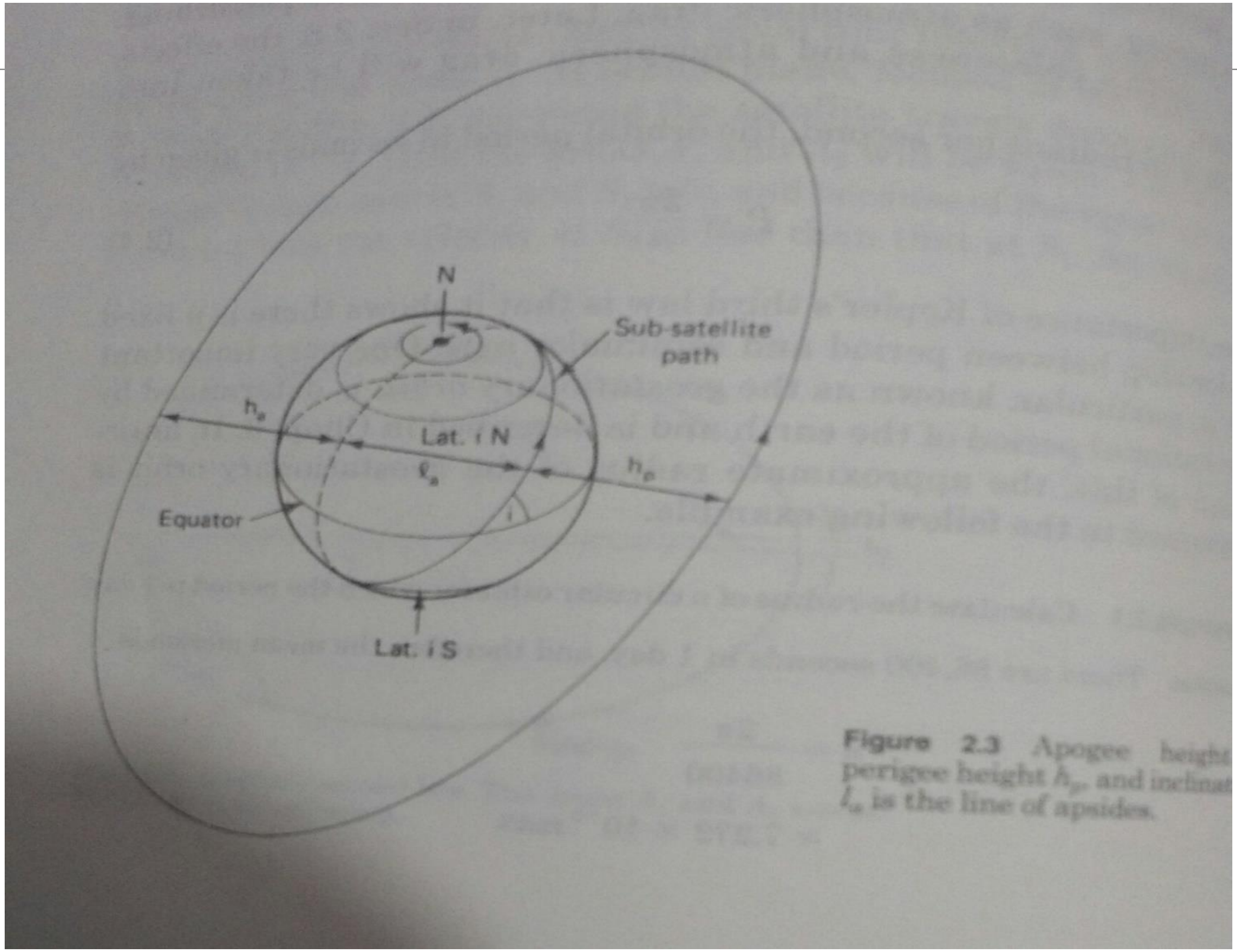

Figure 2.3 Apogee height perigee height h_p, and inclinat l_a is the line of apsides.

Fig.2.4 Prograde and retrograde orbits

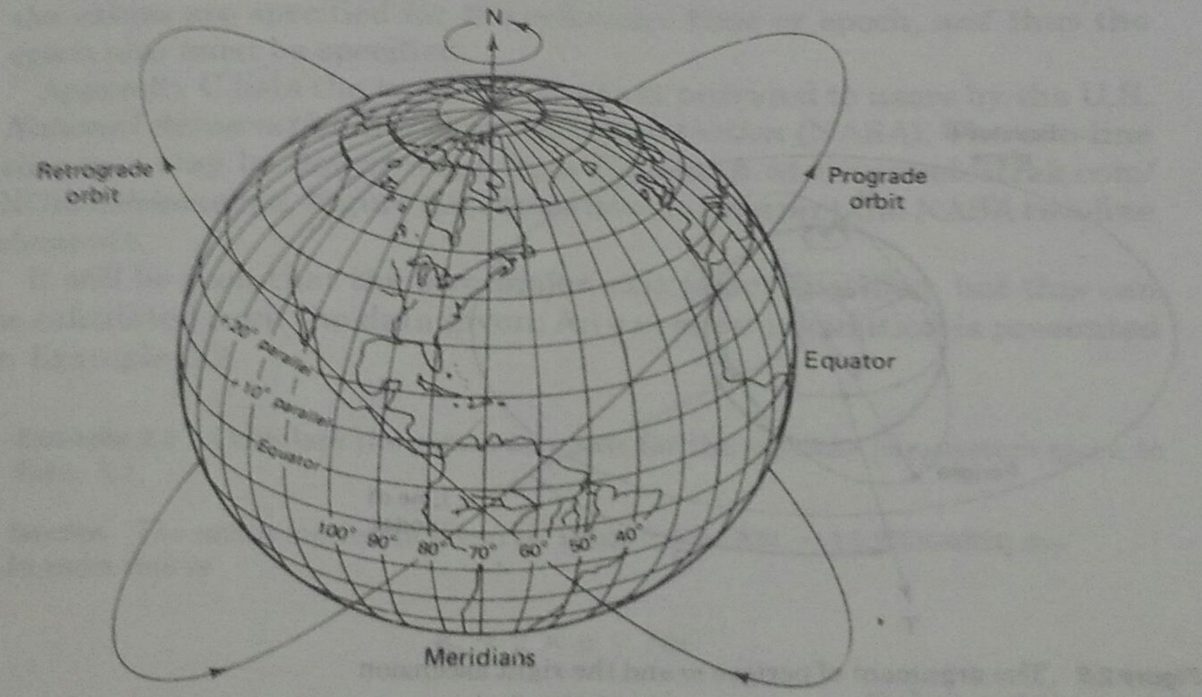

Figure 2.4 Prograde and retrograde orbits.

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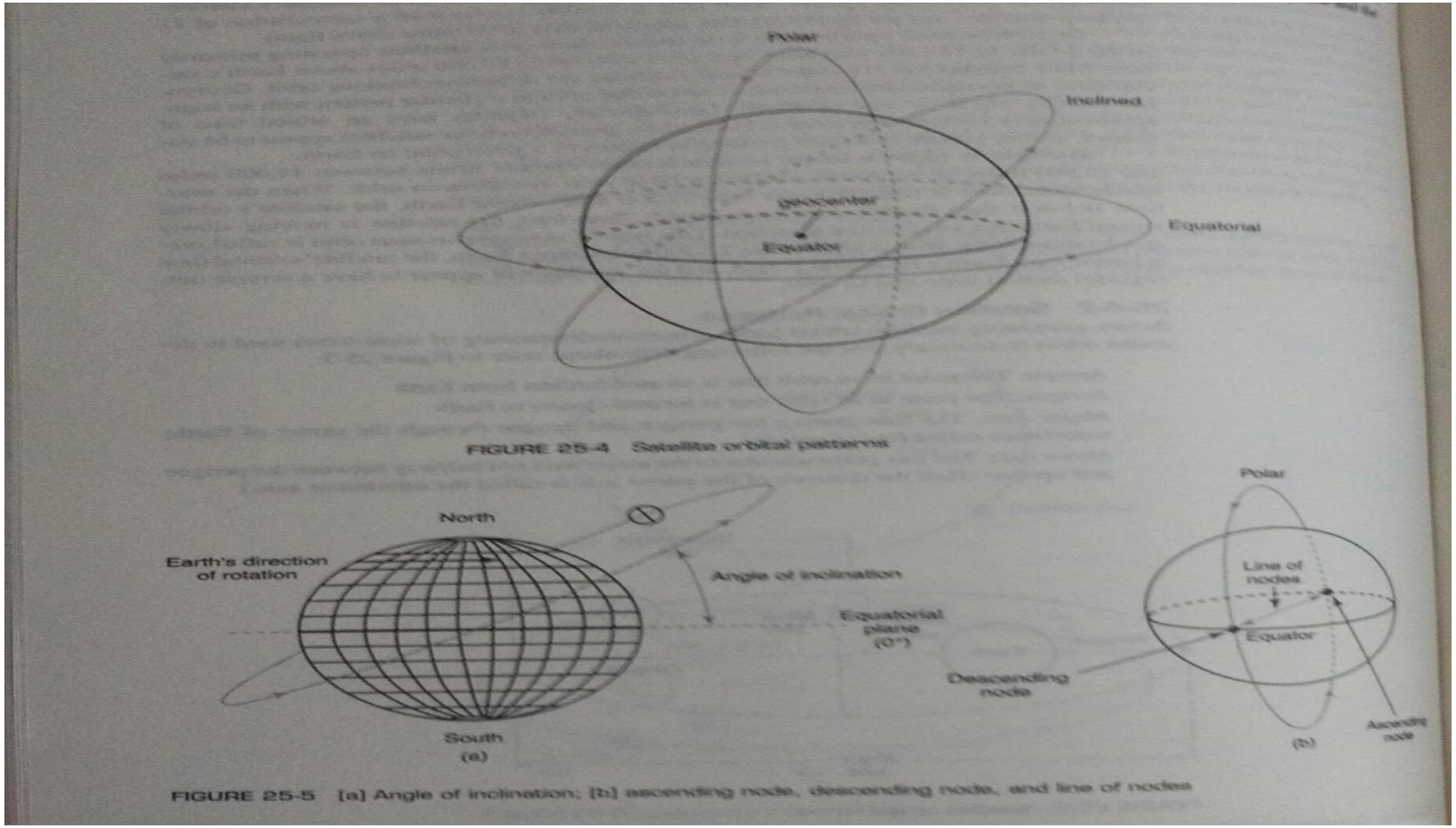

FIGURE 25-4 Satellite orbital patterns

FIGURE 25-5 [a] Angle of inclination; [b] ascending node, descending node, and line of nodes

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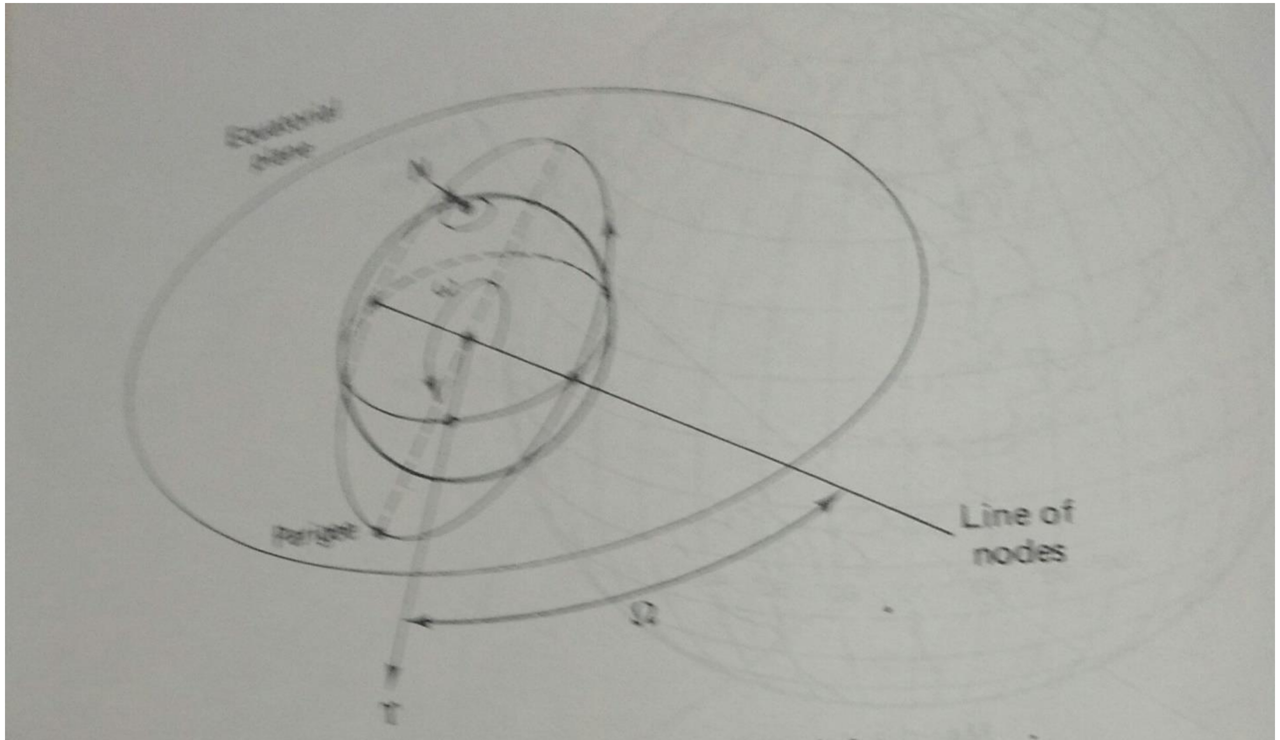

Figure 2.5 The argument of perigee ω and the right ascension of the ascending node Ω.

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* Nonsynchronous satellites rotate around earth in an elliptical or circular pattern. In circular orbit, the speed or rotation is constant. In elliptical orbit, the speed depends on the height of the satellite above earth, speed is higher when closer to earth and lesser when farther from earth.

Prograde and Retrograde Orbits: Satellite orbiting in the same direction as earth's rotation (CCW) and angular velocity > earth's ($\omega s > \omega e$), orbit is called as prograde or posigrade or direct orbit. If satellite is orbiting in opposite direction as that of earth, CW or in the CCW with $\omega s < \omega e$, orbit is called retrograde orbit. Most nonsynchronous satellites rotate around earth in in prograde orbit.

*Inclination of prograde orbit is always 0deg to 90deg. Most satellites are launched in prograde orbit as earth's rotational velocity aids the orbital velocity, saves launch energy.

* Inclination of retrograde orbit is always within 90deg to 180deg.

*Position of nonsynchronous satellites is continuously changing wrt a fixed point on earth and therefore are useful when they are available ie., as small as 15min/ orbit for a fixed position on

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earth. Need expensive and complicated tracking system at earth stations to locate the satellite as it comes into view on each orbit and lock its antenna onto satellite and track it as it passes overhead.

* Major advantage of nonsynchronous orbiting satellites, propulsion rockets are not needed on board to keep them in their respective orbits.

* Most commercial communication satellites are geosynchronous or geostationary satellites, orbit around earth with angular velocity $\omega s = \omega e$. Have an orbital time of ~ 24hours (same as earth's) , appear to be stationary as they appear to be fixed wrt to a position on earth.

Argument of Perigee: From fig.2.5, argument of perigee is shown as ω.

Right Ascention of Ascending Node: Position of ascending node is specified to define completely the position of orbit in space. As the earth spins and the orbital plane remains stationary, longitude of ascending node is not fixed, not useful as reference. Longitude and time of crossing of the ascending node are useful for practical determination of orbit. For absolute measurement a fixed reference in space is needed. First point of Aries is the reference chosen (or vernal, spring, equinox). Line of Aries is shown as ϒ , right ascension of ascending node is shown as Ω in fig.2.5.

Contd.

Mean anomaly: Gives an average value of the angular position of the satellite with reference to the perigee. For circular orbit, M gives the angular position of the satellite in the orbit. Difficult to calculate for elliptical orbit, hence M is used as an intermediate step in the calculation.

True anomaly: It is the angle from perigee to satellite position measured at the earth's center. Gives the true angular position of the satellite in the orbit as a function of time.

Apogee and Perigee Heights:

Not specified as orbital elements. From the geometry of ellipse

Length of radius vector at apogee = $r_a = a(1+e)$

Length of radius vector at perigee $r_p = a(1-e)$

To find apogee and perigee heights, radius of earth must be subtracted from radii lengths.

Ex: Find apogee and perigee heights for the orbital parameters of table 2.1. R=6371 km, mean radius of earth.

From table 2.1, e= 0.0011501 and if a= 7192.335km

Contd.

From expression of $r_a = a(1+e) = 7192.335(1+0.0011501) = 7200.607$km

$r_p = a(1-e) = 7192.335(1-0.0011501) = 7184.603$km

Height $h_a = ra - R = 7200.607 - 6371 = 829.6$km

Height $hp = rp - R = 7184.603 - 6371 = 813.1$km

Orbit Perturbations:

Keplerian orbit described so far assumes ideal conditions, ie earth is a perfect sphere, only force acting is centrifugal force resulting from satellite motion balancing the earth's gravitational force. Practically, significant forces are gravitational forces of sun and moon on satellites above >>1000km height (least effect polar)on and earth's atmospheric drag on polar satellites (least effect on geostationary orbits).

Ex: Find the average length of civil year in the Gregorian calender.

Nominal no. of days in 400 years = 400 x 365= 146000. Number of leap years in 400 years= 400/4= 100, but must be reduced by 3. No. of days in 400 years in Gregorian calendar is

Contd.

= 146000+100-3= 146097. On an average of 146097/400= 365.2425 days.

Ex: Of these which are leap years? (a) 1987 (b) 1988 (c) 2000 (d) 2100

(a) 1987/4= 496.75 (hence not a leap year)

(b) 1988/4 = 497 (hence 1988 is a leap year)

(c) 2000/400 =5 (hence 2000 is a leap year)

(d) 2100/ 400 = 5.25 (hence 2100 is not a leap year)

Ex: Find the time in days , hours and minutes and seconds for the epoch day 324.95616765

This day is 324 th day of year plus 0.95616765 mean solar day. For the fraction in hours are 24x 0.95616765= 22.9480236, its decimal fraction in minutes is 60x 0.9480236= 56.881416, its decimal fraction in seconds= 0.881416 x60= 52.88496. The epoch is day 324, at 22h, 58m, 52.88s.

Ex: Find the Julian day for 13 h UT on 18 December 2000.

Find the time in Julian centuries from the reference time January 0.5, 1900 to 13h UT on 18 December 2000.

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Year 2000 is a leap year, from table 2.3 December 18 is has day no. 335+18= 353 for the midnight December 17/18. UT= 13h , expressed as fraction 13/24= 0.5416667. From table 2.2, Julian date for January 0.0, 2000 is 2451543.5. The required Julian date is 2451543.5+ 353+ 0.5416667= 2451897.0417.

JD ref= 2415020 days (correspond to Jan 0.5 1900), JC= 36525 days (Julian century consists of).

From above example JD= 2451897.0417 days.

T= (JD- JDref)/JC= (2451897.0417- 2415020)/ 36525= 1.00963838

T is dimensinless.

As given by Bate,

1 mean solar day= 1.0027379093 a sidereal days= 24h 3min 56.55536s sidereal time

= 86636.55536 mean sidereal seconds.

1 mean sidereal day= 0.9972695664 mean solar days= 23h 56min 0.4.09054 mean solar time

= 86164.09054 mean solar seconds.   23 h 56 min is approximation for mean sidereal day.

Contd.

Ex: Find the time of perigee passage for the NASA elements in table 2.1

Specified values at epoch, n= 14.23304826 rev/day, mean anomaly Mo= 246.6853 deg and to= 223.79688452 days. Converting mean motion to deg/day ie. 360n.

Tp= to- Mo/n= 223.7968452- (246.6853/14.23304826x 360)= 223.74874044 days.

Also practice worked examples 2.14 , 2.15 in text book to grasp concepts.

Geostationary Orbit

*Conditions for the orbit to appear to be geostationary:

1. Satellite must travel eastward at the same rotational speed as earth.

2. Orbit must be circular.

3. Inclination of orbit must be zero.

Second condition proceeds from first and Kepler’s second law. Equal areas to be swept out in equal time means same speed and circular orbit.

Third condition means if inclination is there, it will make the satellite moving north and south. Zero inclination means orbit lies in the earth’s equatorial plane.

Radius of the orbit (circular) can be found from Kepler’s 3rd law. Radius be α_{GSO} = (μP/4∏*2)*1/3

P= 23h, 56min, 4s for geostationary mean solar time (ordinary clock time), time taken for earth to complete one revolution about N-S axis measured relative to the fixed stars. Using these values and eq.(2.3). α_{GSO} = 42164km, equatorial radius is α_E= 6378km

Hence, geostationary height is $\alpha_{GSO} - \alpha_E$ = 41264- 6378= 35786 ~ 360000

Precise geostationary orbit cannot be attained as disturbance forces in space and the effects of earth's equatorial bulge.

Gravitational fields of sun and moon produce a shift of 0.85deg/year in inclination. Earth's equatorial ellipticity causes satellite to drift eastward along the orbit. Station keeping maneuvers have to be periodically performed to correct for these shifts.

Antenna Look Angles (fig.3.1)

Antenna Look Angle: To maximize transmission and reception, the direction of maximum gain of earth station antenna called antenna boresight must point directly at satellite. Two information- angles azimuth or angle measured from the true north and the elevation or the angle measured up from the local horizontal plane are needed.

To point directly at the satellite, look angles for ground station antenna, azimuth and elevation angles required.

With geostationary orbit, no tracking is necessary but with large earth stations as the antenna beamwidth is very narrow, a tracking mechanism is needed to compensate for the variation about the nominal geostationary position.

Home reception antennas have broad beamwidth, no need to track, fixed position for antenna. Information on 1. earth station latitude λ_E, earth station longitude ϕ_E and longitude of subsatellite point ϕ_{SS} (satellite longitude) are needed for geostationary orbit.

Latitudes north are taken as +ve angles , latitude south are –ve angles (latitude 40deg S is -40deg). Longitudes east of Greenwich meridian are taken +ve angles, longitude west as –ve angles (longitude 35deg W is -35deg).

For LEO satellites, to find look angles, variation in earth's radius needed. For geostationary orbit, it has negligible effect on look angle and average radius of earth is considered R= 6371km. The geometry is in fig.3.1. ES position of earth station, SS subsatellite point, S satellite and d is range from earth station to satellite. Angle σ can be determined.

In fig.3.1 two types of triangles are there in geometry as shown in fig. 3.2a and 3.2b. With spherical triangle, sides are all arcs of great circles. Side a=90deg, a spherical triangle in which one side is 90deg is called quadrantal triangle. C= 90deg- λ_E, B=ϕ_E-ϕ_{ss}.

When earth station is west of subsatellite point, B is –ve, when east +ve. When earth station latitude is north, c< 90deg. When south, c >90deg. Napeir's rules (special rules) are used to solve the spherical triangle, have been modified here to take into account signed angles B and λ_E.

b= arccos(cosB cos λ_E), A= arcsin (sin|B|/ sinb), for which A and 180deg- A will satisfy, determined by inspection as in fig.3.3. Fig.3.3a, angle is acute(<90deg), by inspection azimuth angle is Az= A.

Fig.3.1 Geometry used in determining look angles for a geostationary satellite.

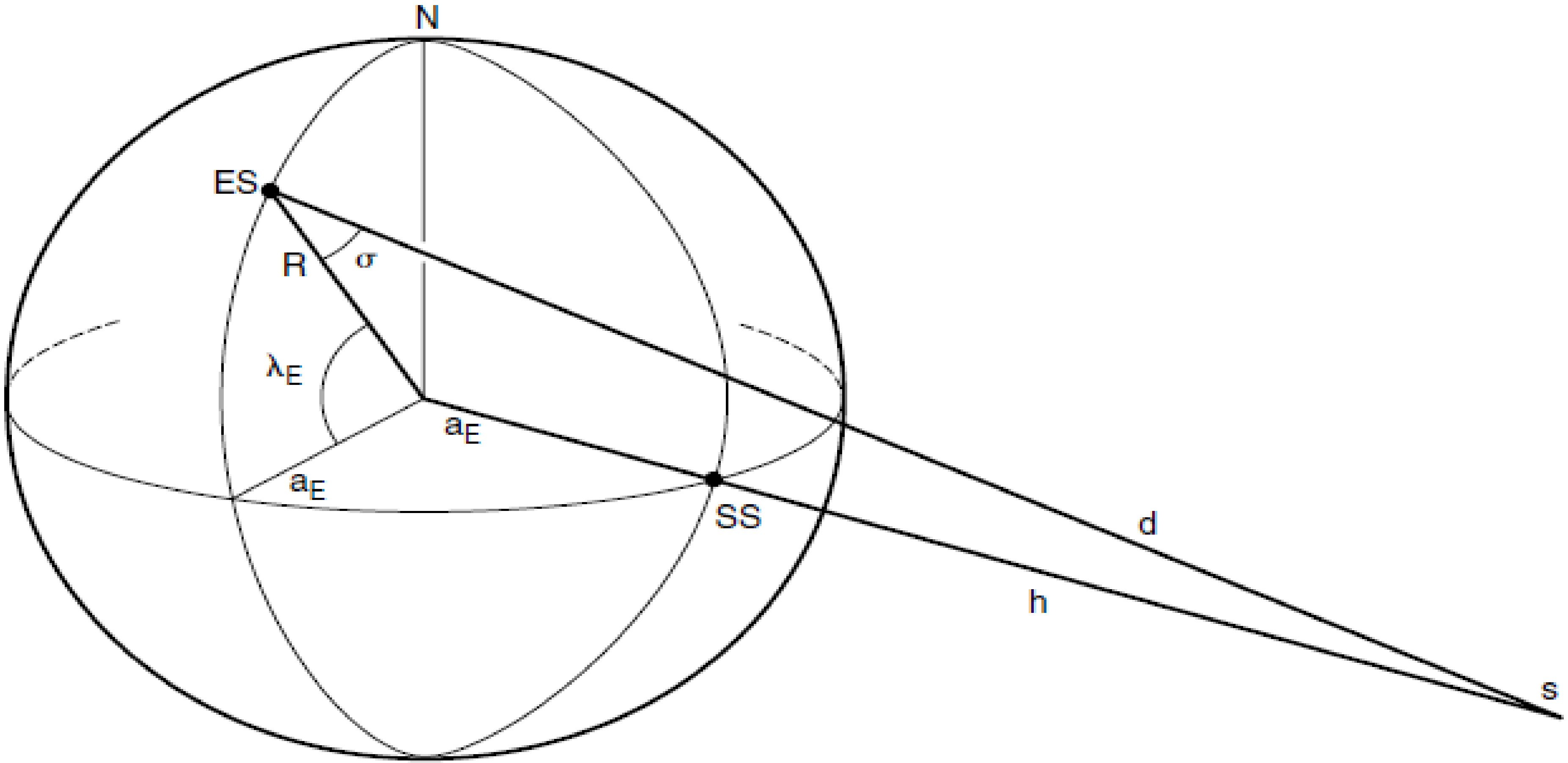
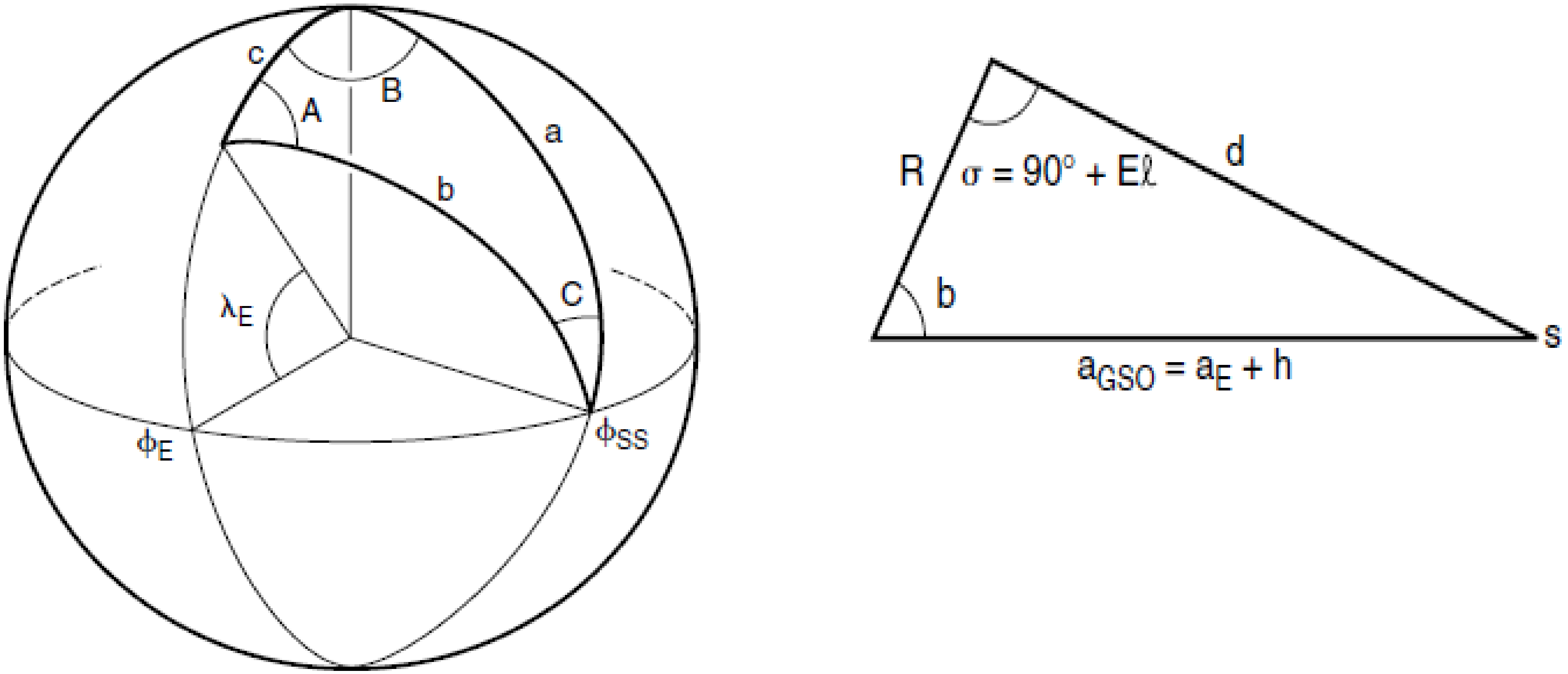


Fig.3.2 (a) Spherical geometry related to fig. 3.1. (b) plane triangle obtained from fig.3.1.



In fig.3.3b, angle A is acute, azimuth Az= 360deg- A. In fig.3.3c, Ac is obtuse, Ac=180-A, A is acute obtained from equation above. By inspection Az=Ac-180deg-A. In fig.3.3d, Ad is obtuse, Ad= 180-A, by inspection, Az= 360-Ad= 180+A. In all above cases, A is acute.

Applying the cosine rule for plane triangle the range d is found to a close approximation:

$$d = \sqrt{R^2 + a_{GSO}{}^2 - 2Ra_{GSO}\cos b}$$

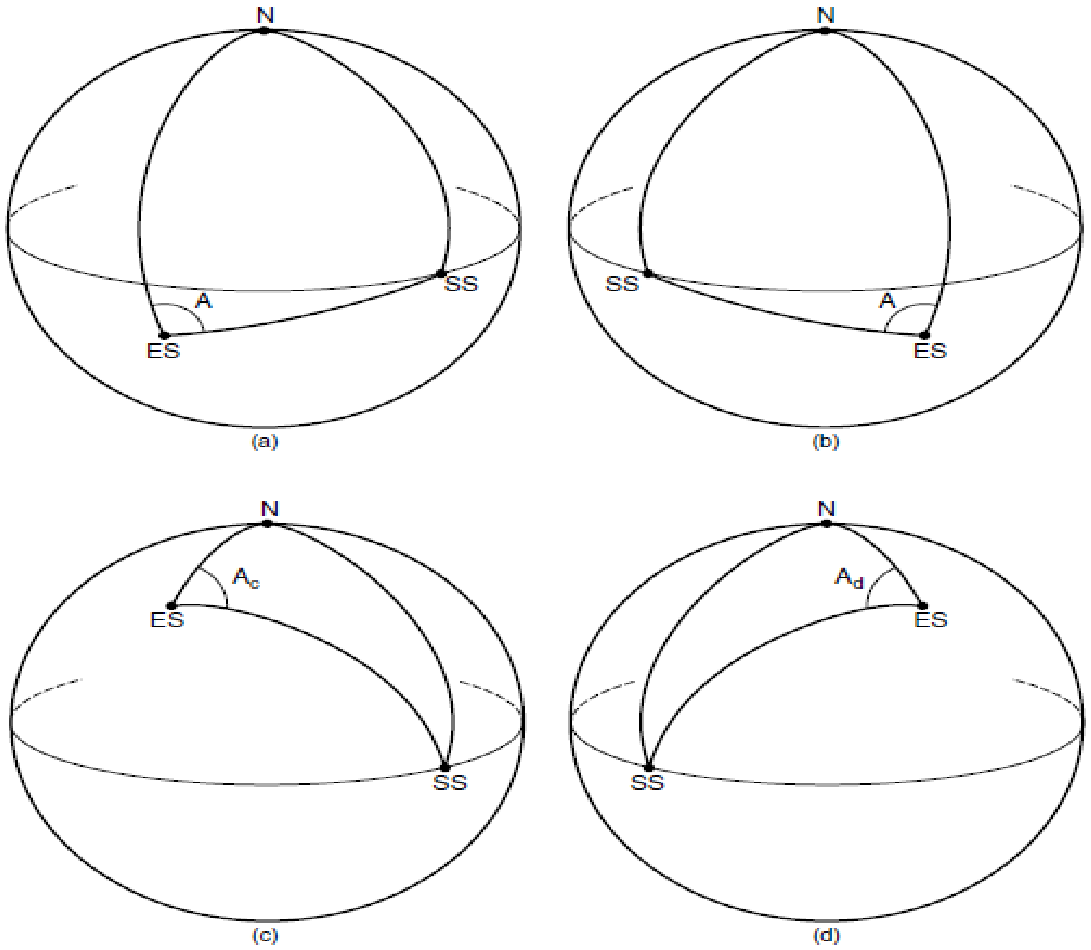
Applying the sine rule for plane triangle the angle of elevation El is found

$$El = \arccos\left(\frac{a_{GSO}}{d}\sin b\right)$$

TABLE 3.1 Azimuth Angles A_z from Fig. 3.3

Fig. 3.3	λ_E	B	A_z, degrees
a	<0	<0	A
b	<0	>0	$360° - A$
c	>0	<0	$180° - A$
d	>0	>0	$180° + A$

Fig.3.3 Azimuth angles related to angle A



Contd.

Fig.3.4 shows the look angles for Ku- band satellites from earth station Thunder Bay, Ontario, Canada.

The discussions made do not take into account the situation when earth is on equatorial plane. Earth station, directly under the satellite, elevation is 90deg and azimuth is irrelavent. For, B<0, subsatellite point is east of equatorial earth station azimuth is 90deg, for B>0 , when west , azimuth is 270deg.

For typical home installation, to maximize signal from satellite, antenna is aligned, precise look angle calculation not needed. In DBS (direct broadcast satellites), home antenna is aligned to one particular cluster of satellites.

Polar Mount Antenna:

For steerable home antenna, expense usually separate azimuth and elevation actuators not used. A single actuator that moves the antenna in a circular arc is used- called polar mount antenna. This is accurate for only one satellite, some pointing errors to be accepted for satellites on either side of this. Polar mount- the dish is mounted on an axis called polar axis so that the antenna boresight is normal to this axis , fig.3.5a. Fig 3.5 shows polar mount aligned along true

Contd.

North line, with boresight pointing due south. Term δ is used for angle of tilt, often referred to as declination. Angle between the polar mount and the local horizontal plane set equal to earth station latitude λE. This makes antenna boresight lie parallel to the equatorial plane. The dish is tilted at an angle δ relative to polar mount until the boresight is pointing at a satellite position due south the earth station. (There need bot be a satellite at this position).

From the geometry of fig. 3.5b $\delta = 90 - Elo - \lambda E$

Elo is angle of elevation required for the satellite position due south of earth station. For due south situation angle B, as per $B = øE - øss$ is $= 0$ or $b = \lambda E$. From fig.3.5c,

$\cos Elo = (\alpha GSO/d) \sin \lambda E$. From above equations,

$\delta = 90deg - \arccos (\alpha GSO/d) \sin \lambda E - \lambda E$. For calculations of d , a spherical earth of mean radius 6371km is assumed and earth station elevation ignored. The value of δ is quite accurate for initial adjustments leading to final adjustment if necessary.

Exercise: Practice worked examples 2.1, 2.2, 2.3, 2.4, 2.5, 2.10 , 2.12, 2.14, 2.15 in the text book to grasp the concepts.