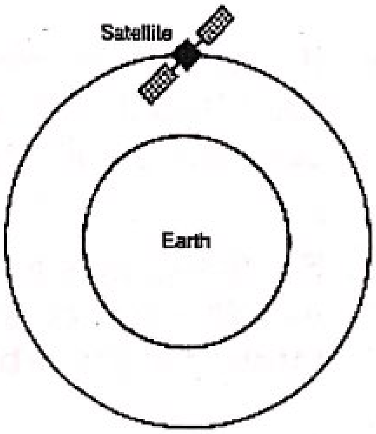
# Contents

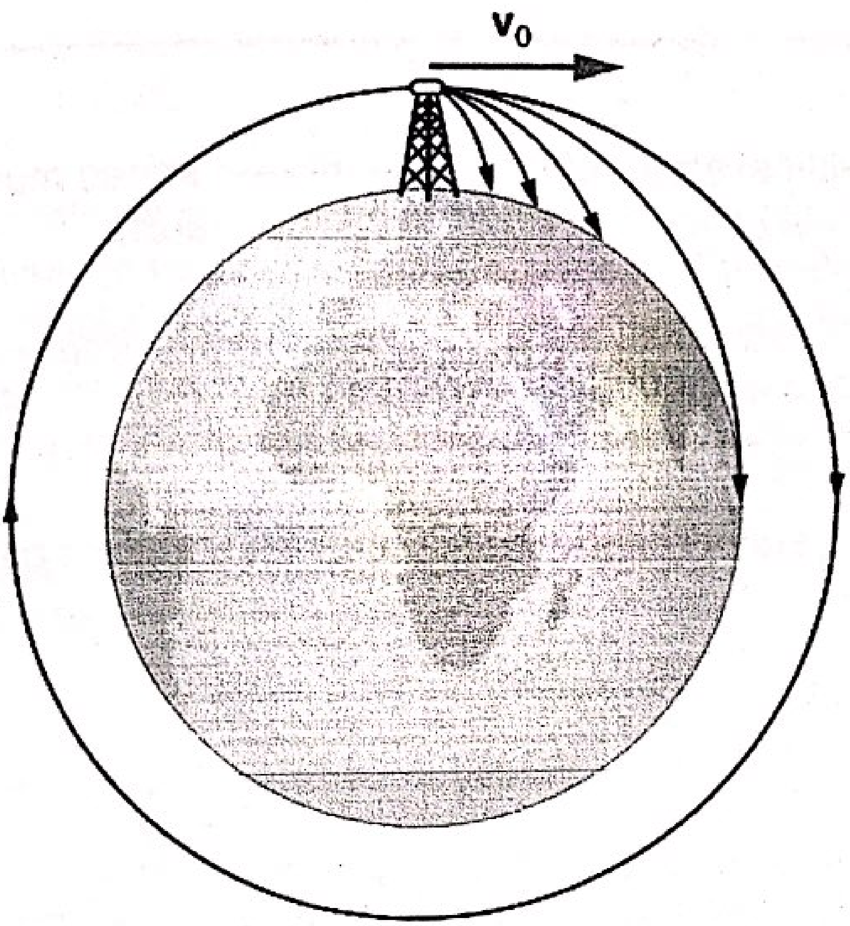
# Satellite

- A satellite is a physical object that orbits, or rotates about, some celestial body.
- Satellites occur in nature, and our own solar system is a perfect example.
- The moon is a satellite to the earth.
- A balance between the inertia of the rotating satellite at high speed and the gravitational pull of the orbited body keeps the satellite in place.



# Satellite Orbits (Principles)

- When it is launched, the satellite is given both vertical and forward motion.
- If a satellite's velocity is too high, the satellite will overcome the earth's pull and go out into space. At lower speeds, gravity constantly pulls the satellite toward the earth.
- So, the goal is to give the satellite *acceleration* and *speed* that will exactly balance the gravitational pull so we keep the satellite rotating in the orbit.
- The closer the satellite is to earth, the stronger the effect of the earth's gravitational pull. So in low orbits, the satellite must travel faster.

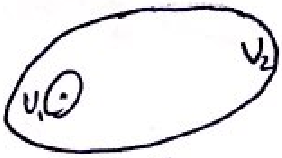

$v_0$

- The lowest practical earth orbit is ~100 mi ----> speed must be 17,500 mi/h to stay in orbit (1.5 hr to orbit the earth).

- Communication satellites are usually much farther from earth. A typical distance is 22,300 mi ----> speed must be 6800 mi/h to stay in orbit (24 hr to orbit the earth, which is the earth's own rotational time).
- Note, the earth radius is about 3960mi. Earth rotation speed is 1040 mi/h.

A satellite rotates about the earth in either a *circular* or an *elliptical* path (which can be accurately described mathematically). So, it is possible to calculate the position of a satellite at any given time.

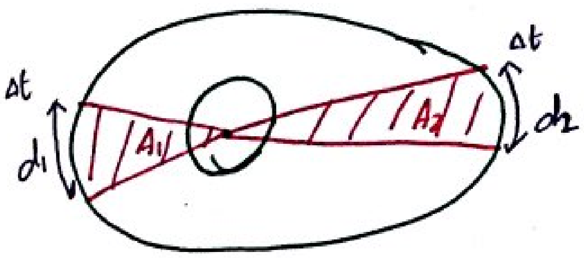
In a circular orbit, the speed of rotation is constant. However, in an elliptical orbit, the speed changes depending upon the height of the satellite above the earth. Naturally the speed of the satellite is greater when it is close to the ear than when it is far away (how is this related to 2nd Keplers's law??)




$v_1 > v_2$



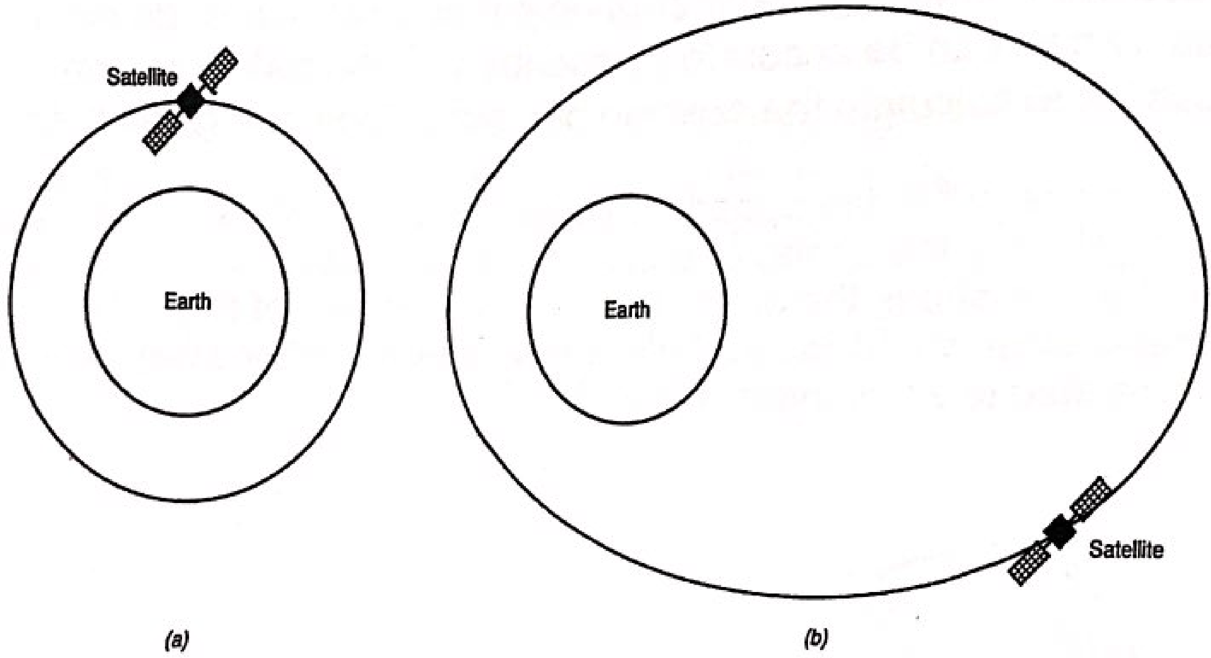
kepler's's law

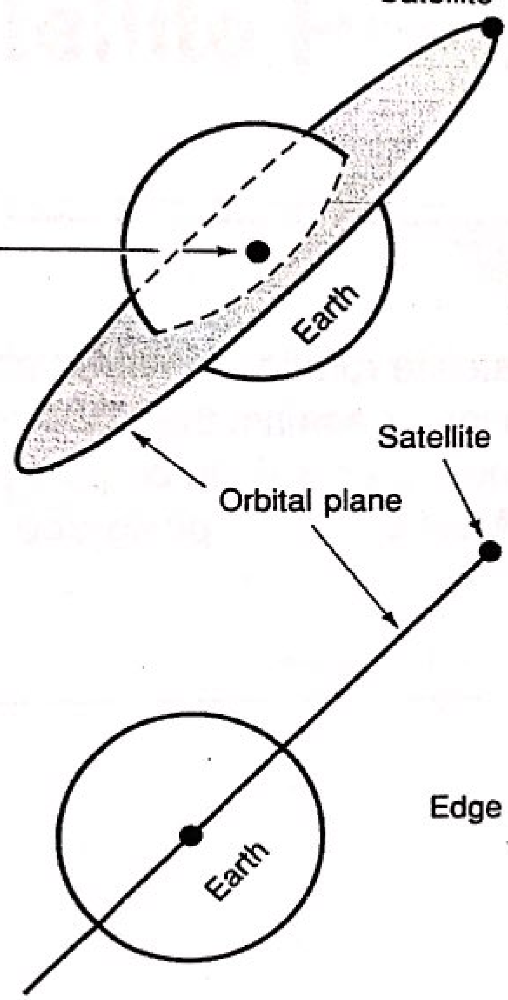



$A_1 = A_2$

$d_1 > d_2$

$v_1 > v_2$

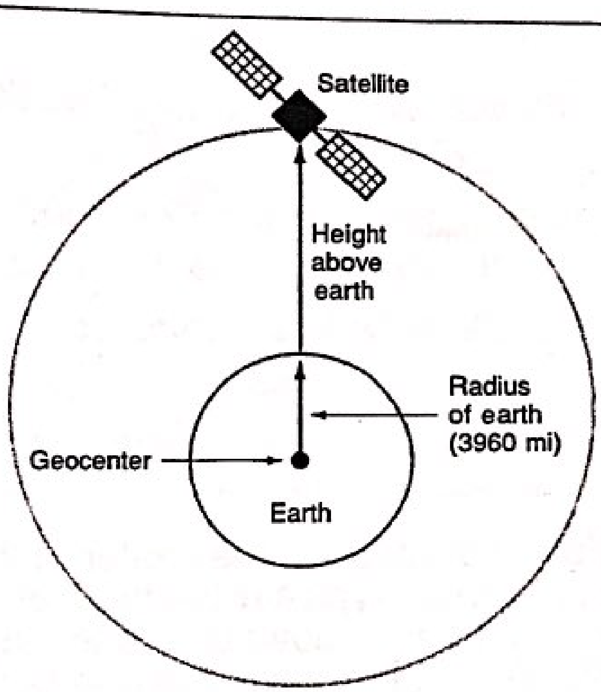

Satellite
Earth
(a)
Earth
Satellite
(b)


Satellite
Geocenter
Earth
Satellite
Orbital plane
Earth
Edge view

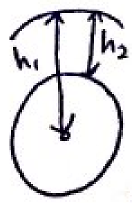
- The direction of satellite rotation may be either in the same direction as the earth's rotation or against the direction of earth's rotation. In the former case, the orbit is said to be posigrade, and in the latter case, retrograde. Most orbits are posigrade.

# Satellite Height

For circular orbit, the height is really the distance between the center of the earth and the satellite.

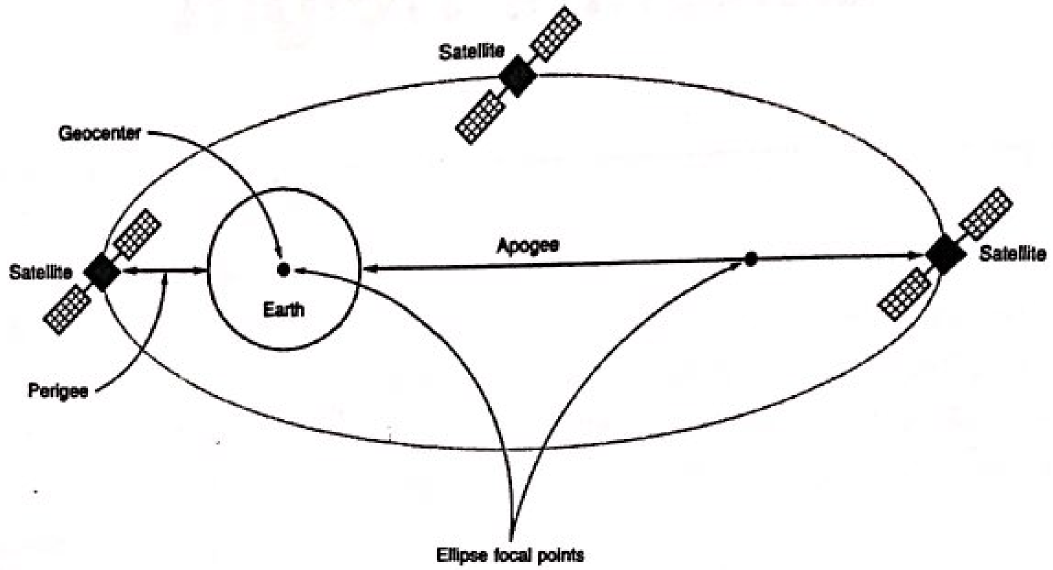




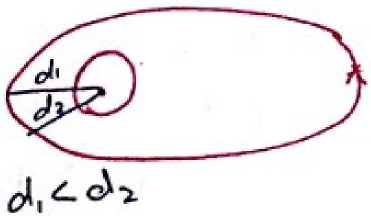

$h_1$ = hight from geocenter

$h_2$ = hight from surface.




- For elliptical orbit, the center of the earth is one of the focal points of the ellipse. Typically the two points of greatest interest are the highest point above the earth—the *apogee*—and the lowest point—the *perigee*. The apogee and perigee distances typically are measured from the geocenter of the earth.



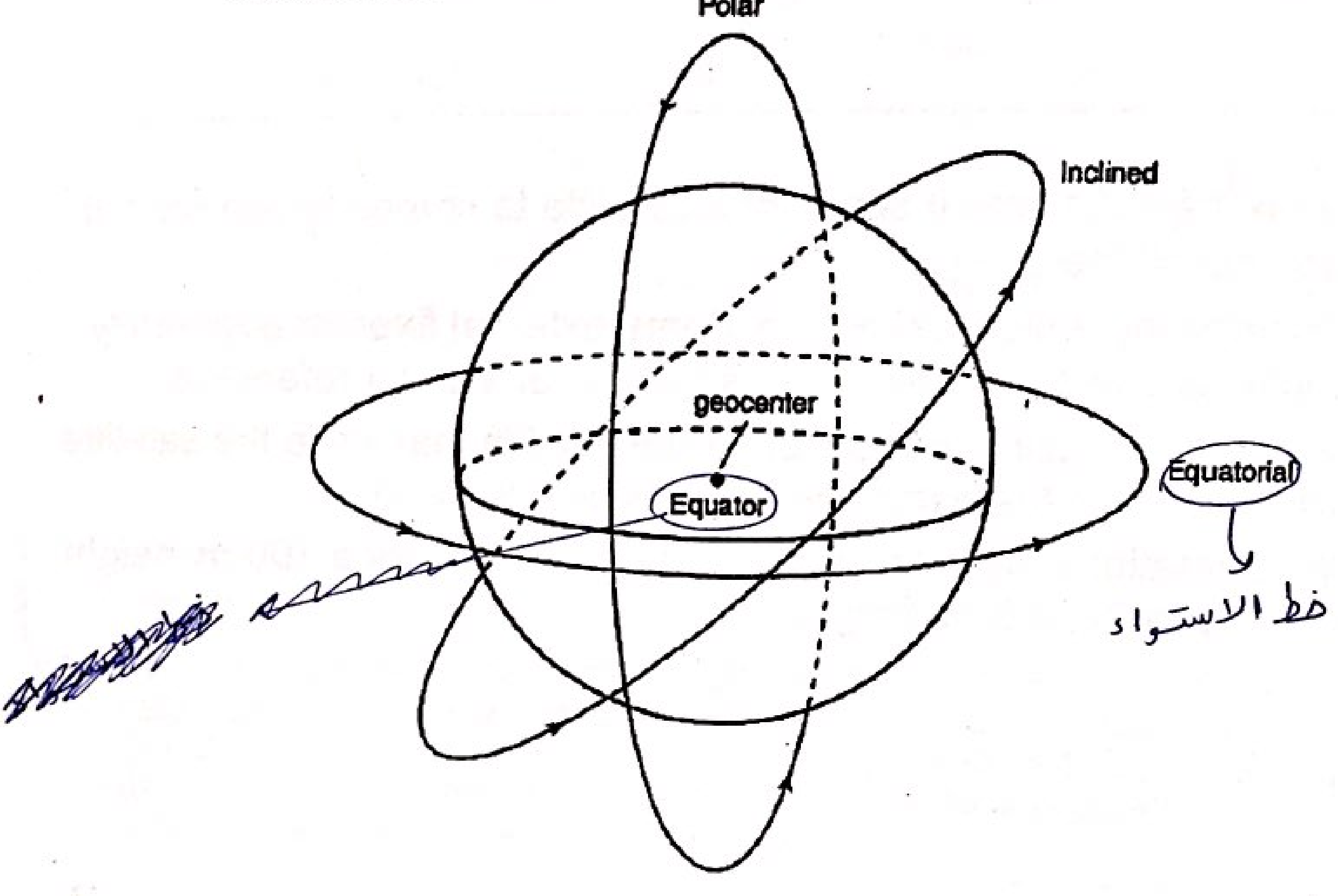



$d_1 < d_2$

# Satellite Period

- The *period* is the time it takes for a satellite to complete one orbit. It is also called the *sidereal*
- In determining a sidereal period. Some external fixed or apparently motionless object is used such as the sun or star for reference.
- The reason for using a fixed reference point is that while the satellite is rotating about the earth, the earth itself is rotating.
- Typical rotational periods range from about 1.5 h for a 100-mi height to 24 h for a 22,300-mi height.

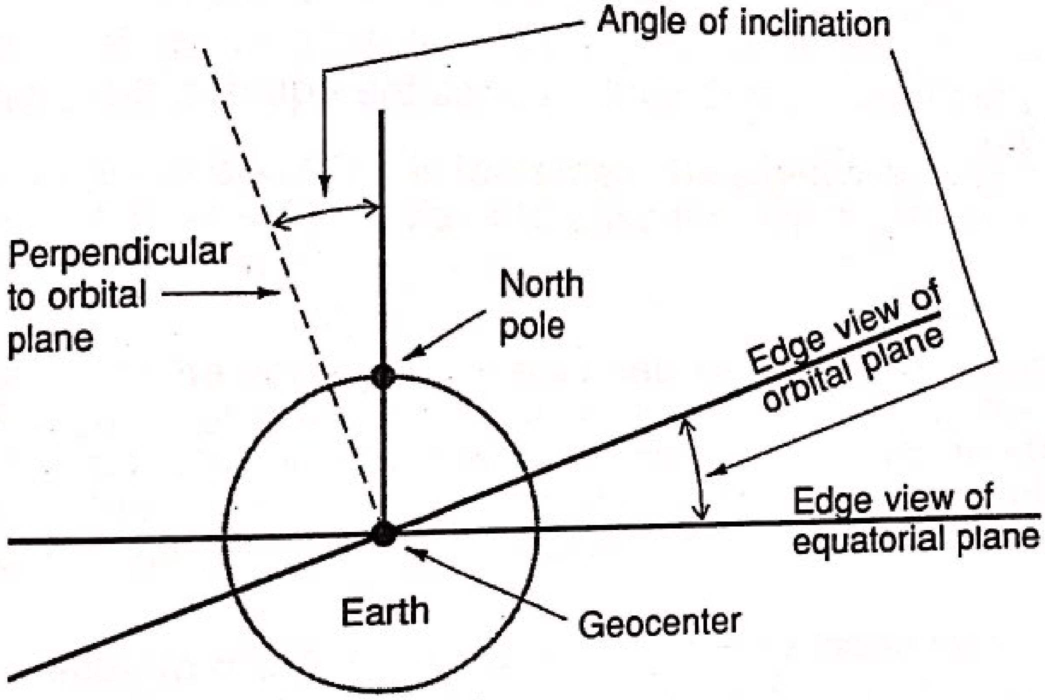
# Satellite Orbital Pattern






100 mi → 17,500 mi/h

# Angle of Inclination



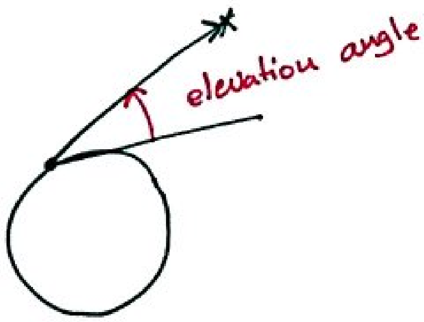

(*a*)

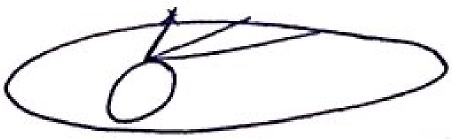
- Satellite orbits can have inclination angles of 0° through 90°.
- Orbits with 0° inclination are generally called *equatorial orbits,* and orbits with inclinations of 90° are referred to as *polar orbits.*
- When the satellite has an angle of inclination, the orbit is said to be either *ascending* or *descending.* As the satellite moves from south to north and crosses the equator, the orbit is ascending. When the satellite goes from north to south across the equator, the orbit is descending.

# Angle of Elevation

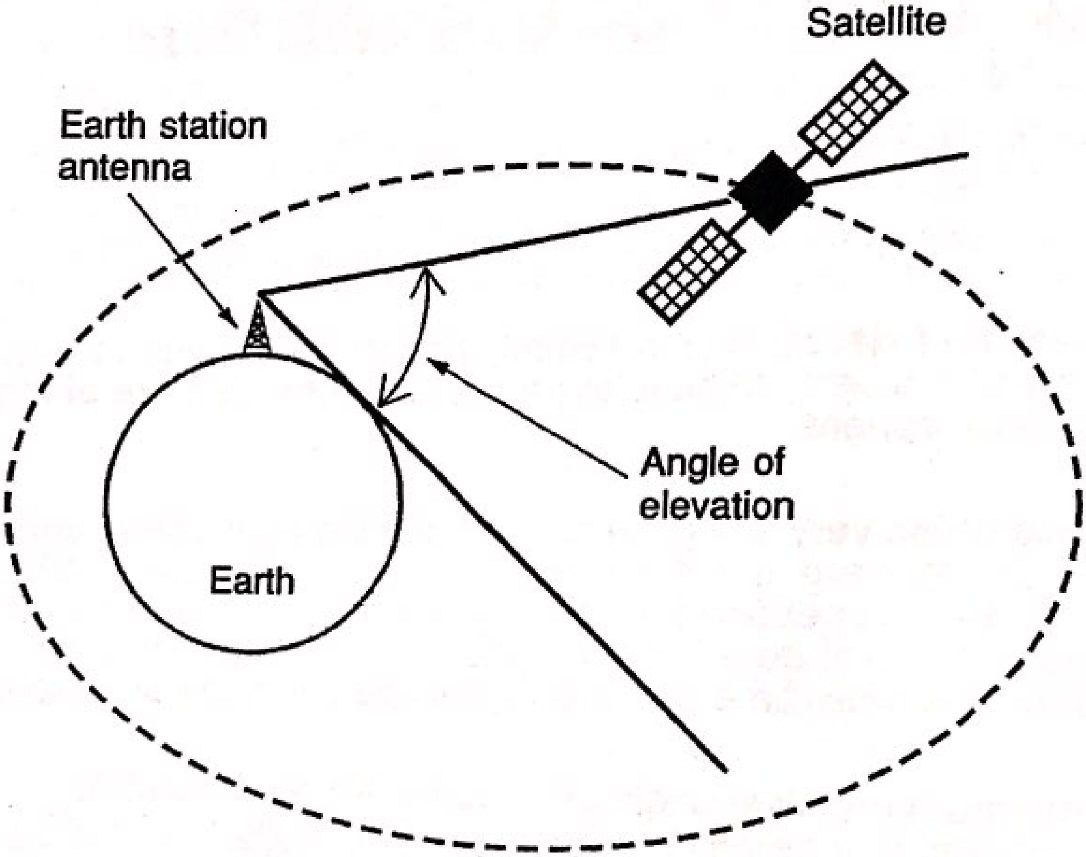
- The angle of elevation of a satellite is the angle that appears between the line from the earth station's antenna to the satellite and the line between the earth station's antenna and the earth's horizon.
- If the angle of elevation is too small, the signals between the earth station and the satellite have to pass through much more of the earth's atmosphere.
- Because of the very low powers used and the high absorption of the earth's atmosphere, it is desirable to minimize the amount of time that the signals spend in the atmosphere. Noise in the atmosphere also contributes to poor performance. The lower the angle of radiation, the more time that this signal spends in the atmosphere.
- The minimum practical angle of elevation for good satellite performance is generally 5°. <u>The higher the angle of elevation, the better.</u>

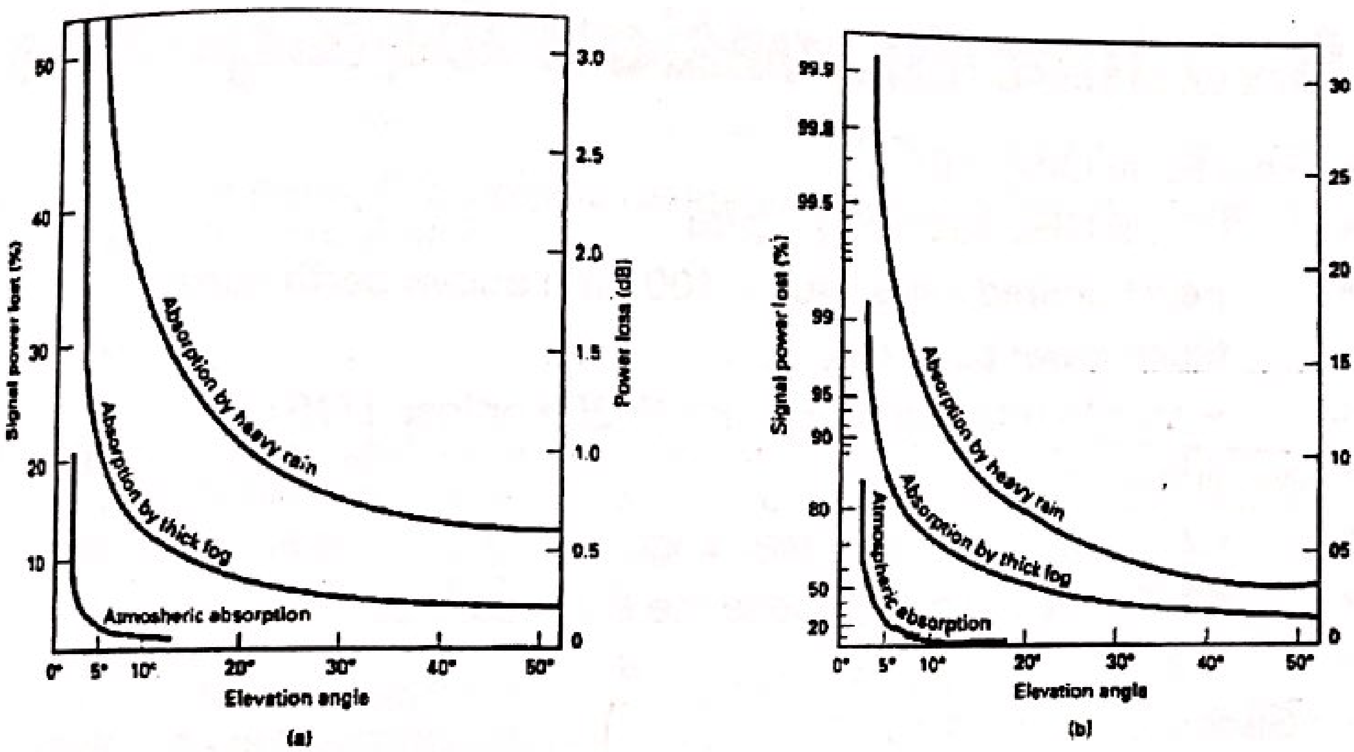




$d\uparrow$ , $\mathring{e}\downarrow$ → that's why the elevation angle should be minimized.


Satellite
Earth station antenna
Angle of elevation
Earth




Attenuation due to atmospheric absorption: (a) 6/4-GHz band; (b) 14/12-GHz band

# Satellite Elevation Categories

- Low Earth Orbit (LEO)
  - 1 – 2.5 GHz frequency range
  - Few hundred miles (400 – 1000 mi) above earth surface
  - Much lower path loss
  - ~ 1.5 h to rotate around earth (0.25h or loss LOS)
- Medium Earth Orbit (MEO)
  - 1.2 – 1.66 GHz frequency range
  - 6000 – 12000 miles above the earth surface
  - Period of 5 – 12 hrs (LOS 2 – 4 hr)
- Geosynchronous Earth Orbit (GEO) (most commercial satellites)
  - 2 – 18 GHz frequency range
  - 22,300 mi above the earth surface
  - Period of 24 hrs (LOS 24)
  - Equatorial orbit

# Geosynchronous Orbits

- At some point, the satellite disappears around the other side of the earth. Problem!!!

- Solutions:

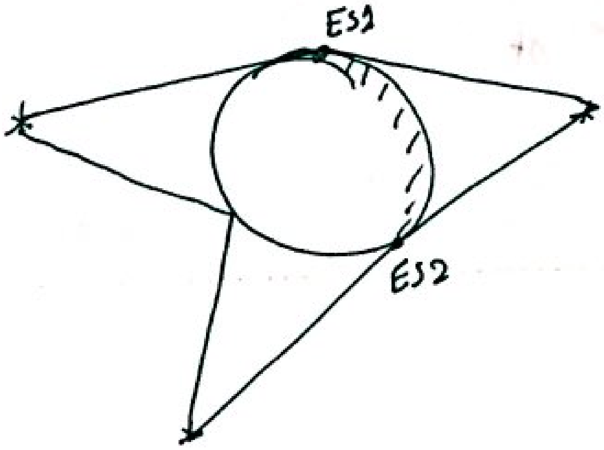
1. launching a satellite with a very long elliptical orbit so that the earth station can "see" the apogee. So for short time the satellite will disappear. This solution is undesirable in many communication applications.

losses ↑

$P_t$ ↑

2. Using Multiple satellite systems (more than one satellite). Typically three satellites can provide continuous communication at all times. However, multiple tracking stations and complex signal switching or "hand-off" systems between stations are required. These stations is expensive and inconvenient.



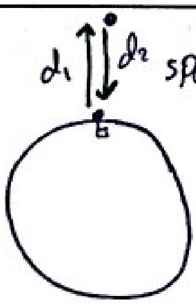


- Multiple satellite systems are used and usually located in two ranges above the earth: LEOs and MEOs.(The greater the height above the earth, the better the view but the higher power and delay)

- 3. The best solution is *geosynchronous earth orbit (GEO)*, where a synchronous or geostationary satellite is lunched. At a distance of 22,300 mi (or 35,888 km). So, it rotates about the earth in exactly 24 hour. So, it appears to be fixed or stationary.

- Disadvantage: Higher power is required for such a great distance, and the round-trip delay is about 260 ms (calculate??), which is very noticeable in voice communication.






speed = $3\times10^8$ m/s

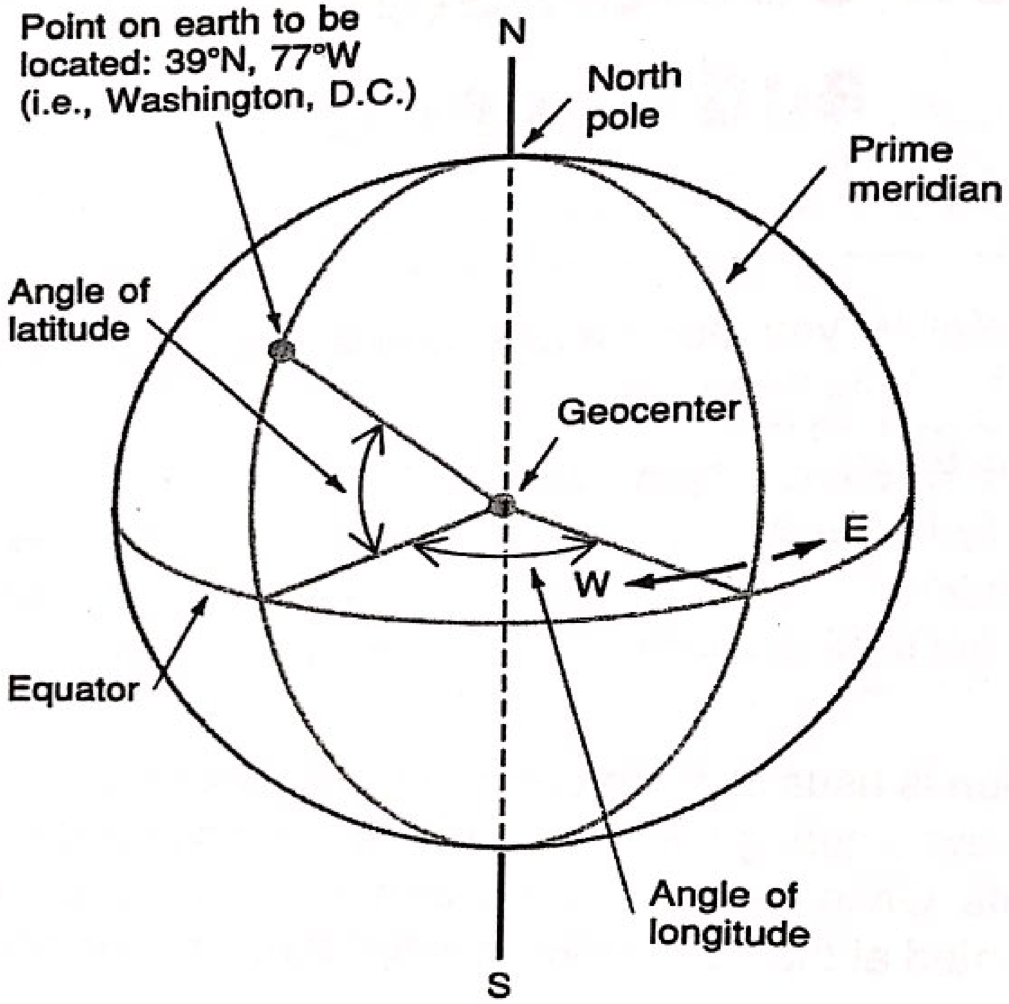
$\cancel{\text{Ease}} = \frac{d}{\Delta t} = \frac{d_1+d_2}{\Delta t}$

$\Delta t = \frac{(35000\times10^3)2}{3\times10^8} \approx 260ms$

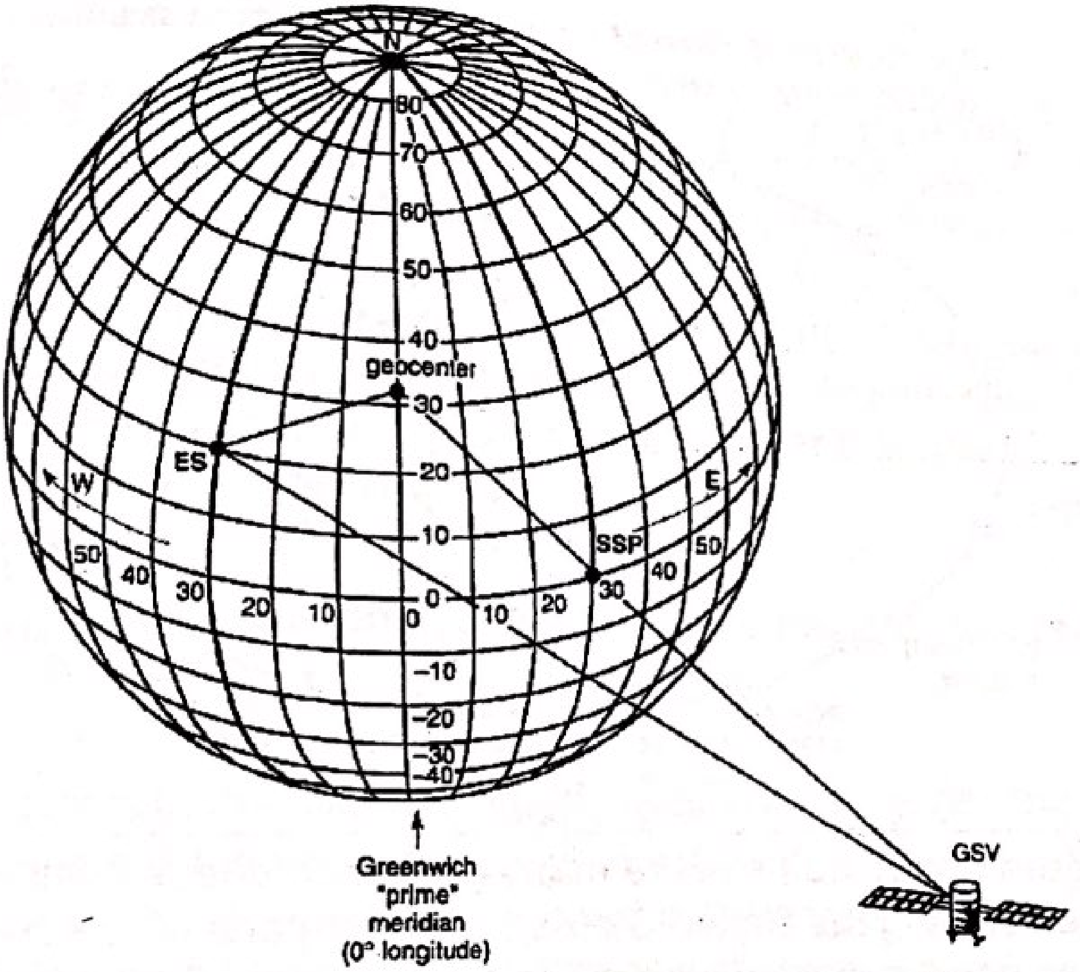
Scanned with CamScanner

# Position Coordinates in Latitude and Longitude

- To use a satellite, you must be able to locate its position in space.
- The satellite location is specified by a point on the surface of the earth directly below the satellite. This point is known as the *subsatellite point (SSP)*. The subsatellite point is then located by using conventional latitude and longitude designations.
- That position is usually predetermined by the design of the satellite and is achieved during the initial launch and subsequent position adjustments. Once the position is known, the earth station antenna can be pointed at the satellite for optimum transmission and reception.



Point on earth to be located: 39°N, 77°W (i.e., Washington, D.C.)
N
North pole
Prime meridian
Angle of latitude
Geocenter
E
W
Equator
Angle of longitude
S

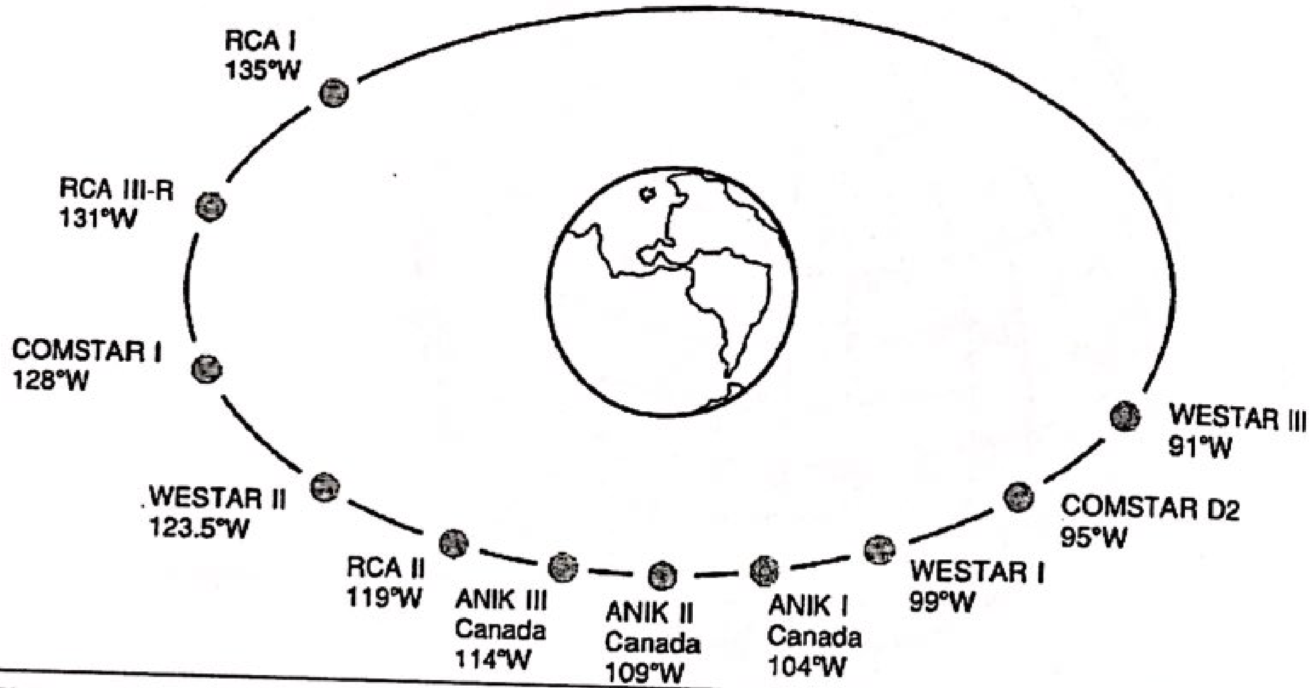



SSP of Geosynchnonos satellite



SSP| geosynchronous = ( .... ° ) W E

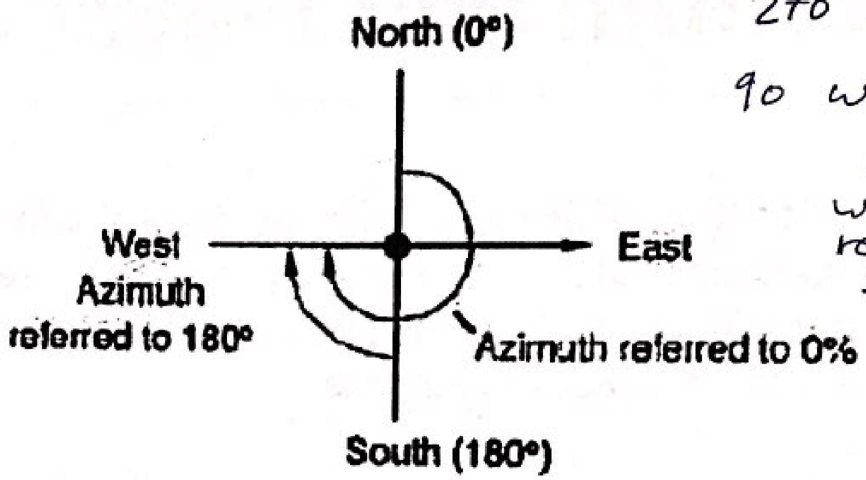
The location of some of the many communication satellites in geosynchronous orbit.




This figure shows some of the many geosynchronous communication satellites serving the United States and other parts of North America. Because geosynchronous satellites rotate about the equator, their subsatellite point is on the equator. For that reason, all geosynchronous satellites have a latitude of 0°.

# Azimuth and Elevation

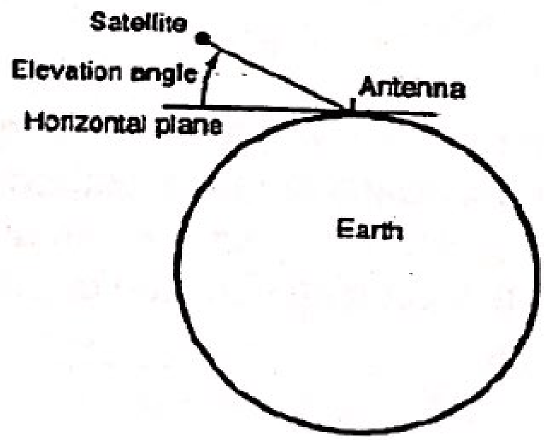
- Knowing the location of the satellite is insufficient information for most earth stations that must communicate with the satellite. The earth station really needs to know the azimuth and elevation settings of its antenna to intercept the satellite.
- The azimuth and elevation designations in degrees tell where to point the antenna.
- *Azimuth* refers to the direction where north is equal to 0°. The *azimuth angle* is the horizontal angle measured clockwise with respect to north. The *angle of elevation* is the angle between the horizontal plane and the pointing direction of the antenna.




270° w.r.t N

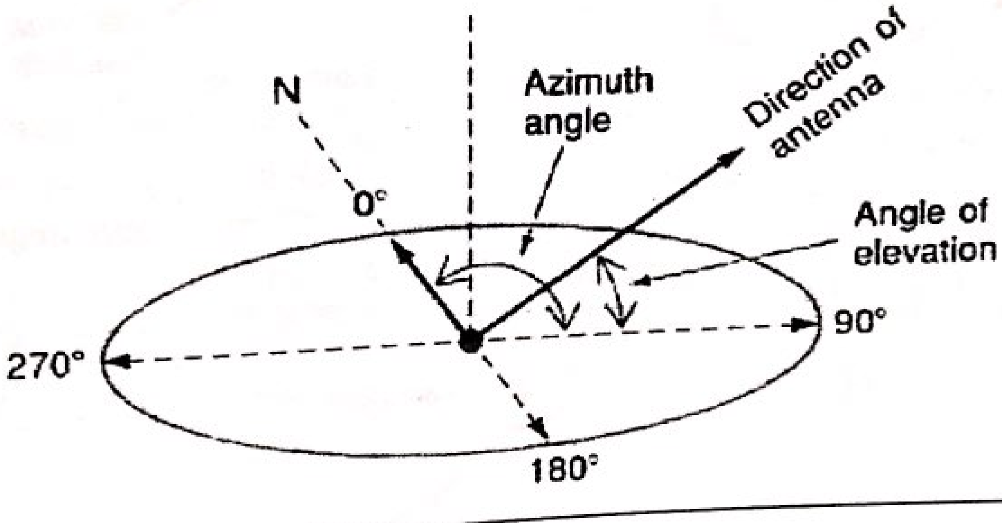
90 w.r.t S

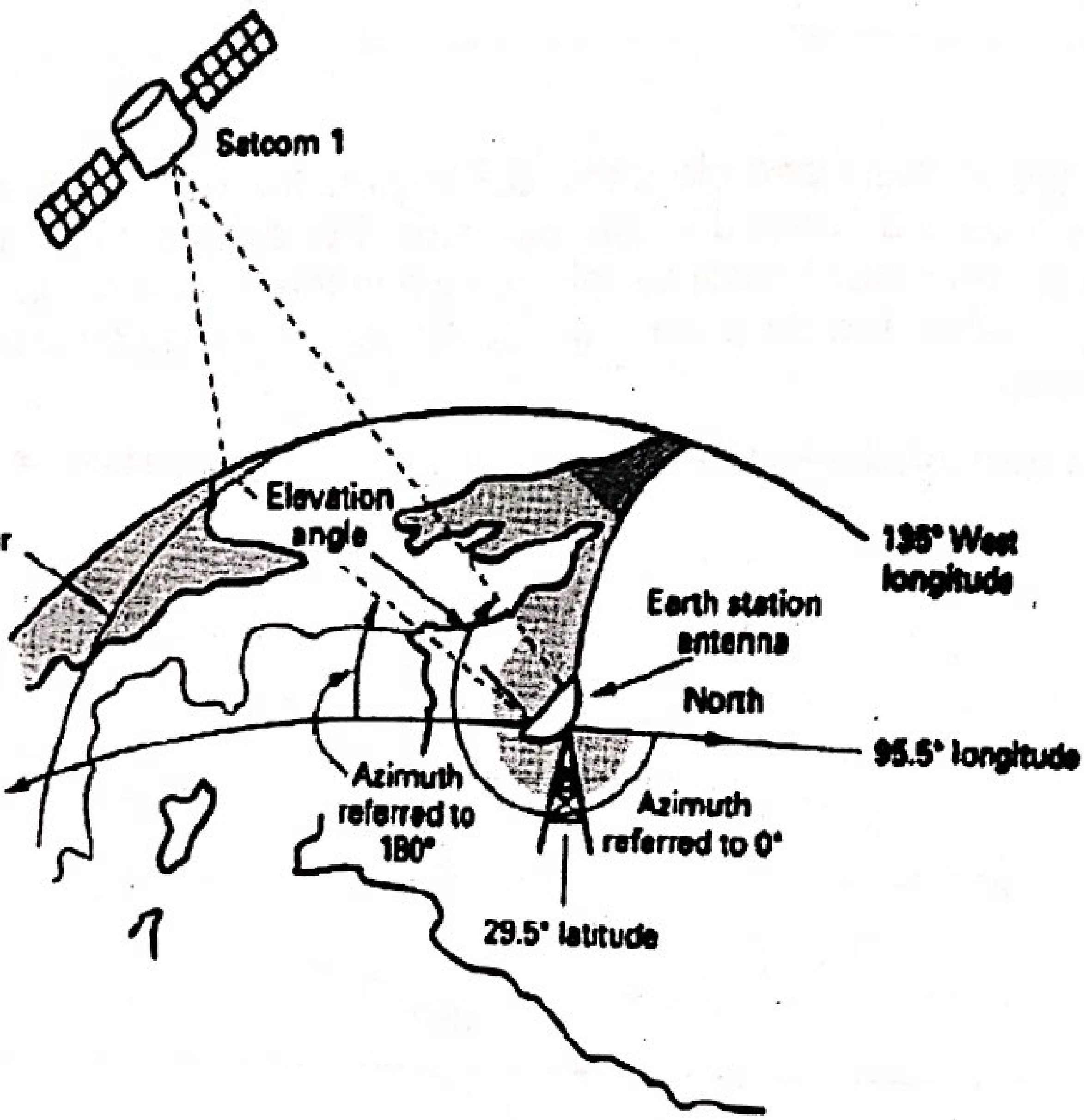
with respect to



- Once the azimuth and elevation are known, the earth station antenna can be pointed in that direction. For a geosynchronous satellite, the antenna will simply remain in that position. For any other satellite, the antenna must be moved as the satellite passes overhead.

Azimuth and elevation: Azimuth = 90°; elevation = 40°.





Satcom 1
Elevation angle
Equator
136° West longitude
Earth station antenna
North
95.5° longitude
South
Azimuth referred to 180°
Azimuth referred to 0°
29.5° latitude

## How to determine the azmiuth and elevation angles of GEOs?

1- Determine the longtitude and latitude of the earth station.

2- Table 8.1 gives the longtitude of the satellite of interest.

3- Calculate the difference in degrees between the longtitude of the satellite and the earth station.

4- Use Figure 8-12 to determine the azimuth and use figure 8-13 to determine the elevation.

**Table 14-1 Longitudinal Position of Several Current Synchronous Satellites Parked in an Equatorial Arc[a]**

| Satellite | Longitude (°W) |
|---|---|
| *Satcom I* | 135 |
| *Satcom II* | 119 |
| *Satcom V* | 143 |
| *Satcom C1* | 137 |
| *Satcom C3* | 131 |
| *Anik 1* | 104 |
| *Anik 2* | 109 |
| *Anik 3* | 114 |
| *Anik C1* | 109.25 |
| *Anik C2* | 109.15 |
| *Anik C3* | 114.9 |
| *Anik E1* | 111.1 |
| *Anik E2* | 107.3 |
| *Westar I* | 99 |
| *Westar II* | 123.5 |
| *Westar III* | 91 |
| *Westar IV* | 98.5 |
| *Westar V* | 119.5 |
| *Mexico* | 116.5 |
| *Galaxy III* | 93.5 |
| *Galaxy IV* | 99 |
| *Galaxy V* | 125 |
| *Galaxy VI* | 74 |
| *Telstar* | 96 |
| *Comstar I* | 128 |
| *Comstar II* | 95 |
| *Comstar D2* | 76.6 |
| *Comstar D4* | 75.4 |
| *Intelsat 501* | 268.5 |
| *Intelsat 601* | 27.5 |
| *Intelsat 701* | 186 |

[a]0° latitude.

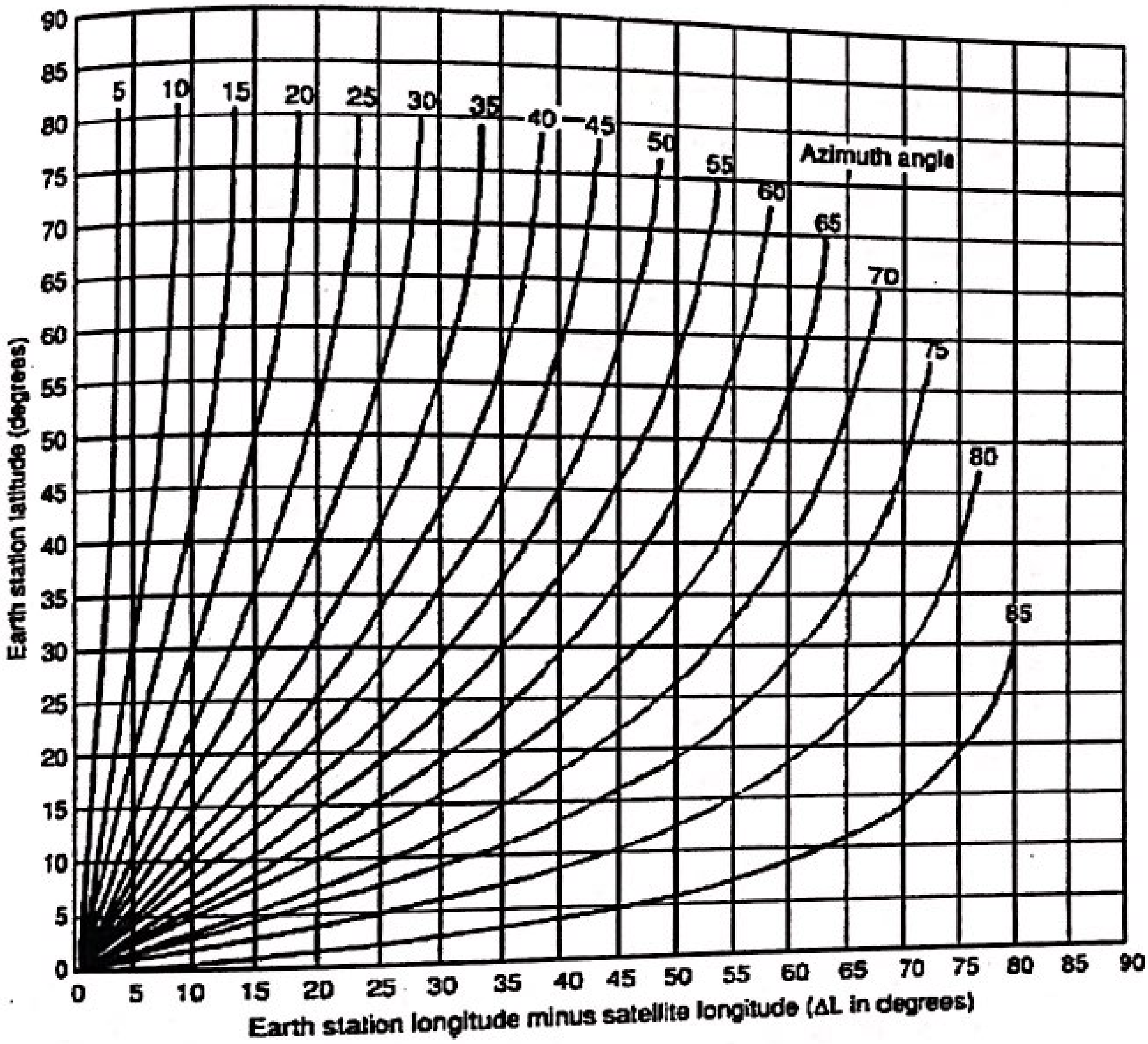



FIGURE 14-12 Azimuth angles for earth stations located in the northern hemisphere referenced to 180 degrees

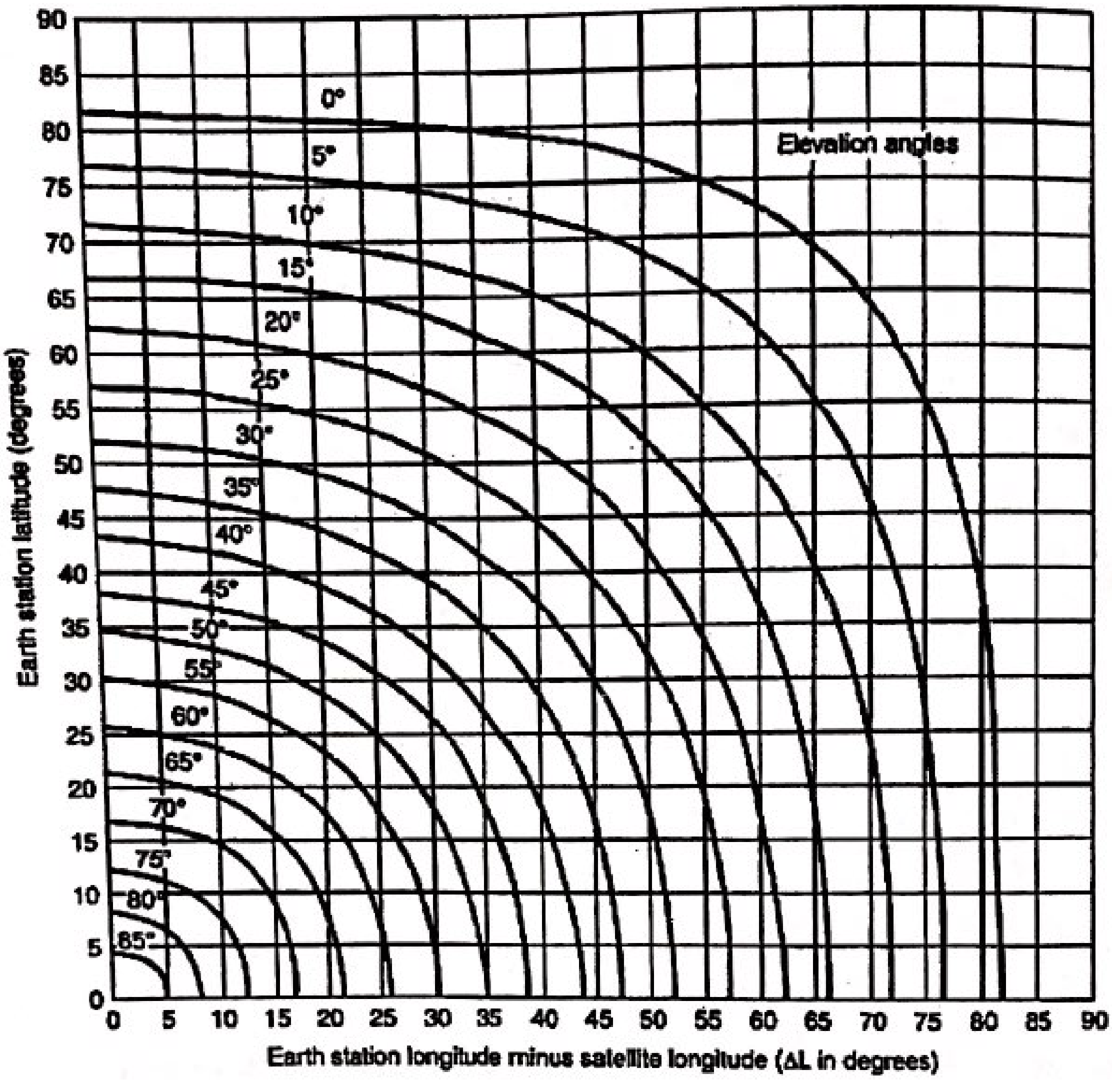



FIGURE 14-13 Elevation angles for earth stations located in the Northern Hemisphere

# Example:

For Satcom I satellite, find the azimuth and elevation angles required for an earth station located at 95.5 W longtitude and 29.5 N latitude.

Solution: Azimuth 59 w, elevation 35

SSP : $135^\circ$ w

ES : $29.5^\circ$ N, $95.5^\circ$ w

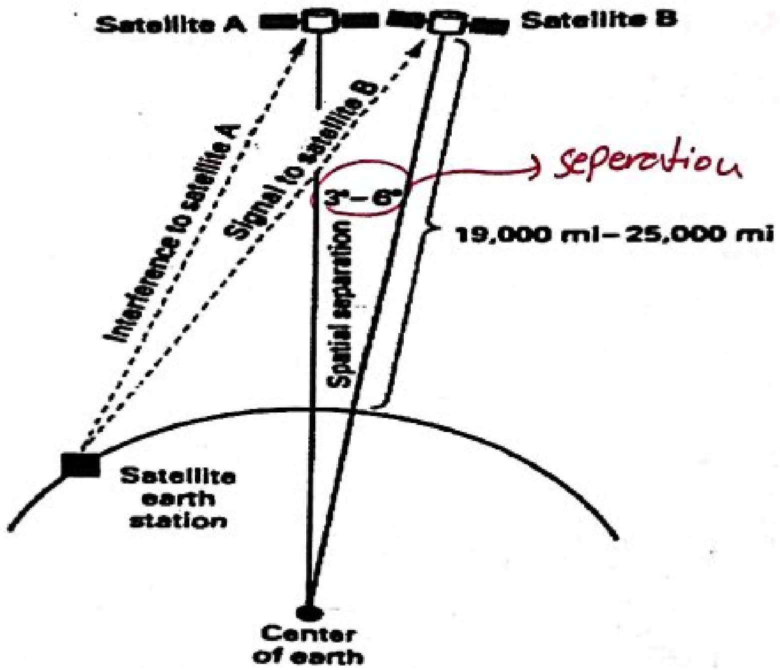
Y-axis

$\Delta L = 135^\circ - 95.5^\circ = 39.5^\circ$

X-axis

# Spatial Separation of Satellite in GEO

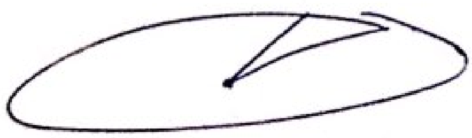
- Satellites operating at or near the same frequency must be sufficiently separated in space to avoid interfering with each other.




→ seperation 1 ~ 6° (not less than 1)



$$SINR = \frac{S}{N+I}$$



22,300 + 4000

26,300 mile

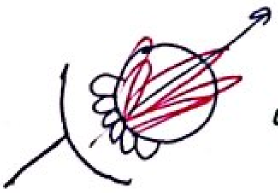
# Spatial Separation of Satellite in GEO

- The required spatial separation is dependent on the following variables:

1. Beamwidths and side lobe radiation of both the earth station and satellite antennas
2. RF carrier frequency
3. Encoding or modulation technique used (related to BW)
4. Acceptable limits of interference (related to Rx sensitivity)
5. Transmit carrier power

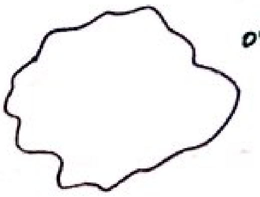
- Generally, 1 to 4 degrees of spatial separation is required, depending on the variables stated previously.

Bandwidth → narrow
Bandwidth → wide



directional

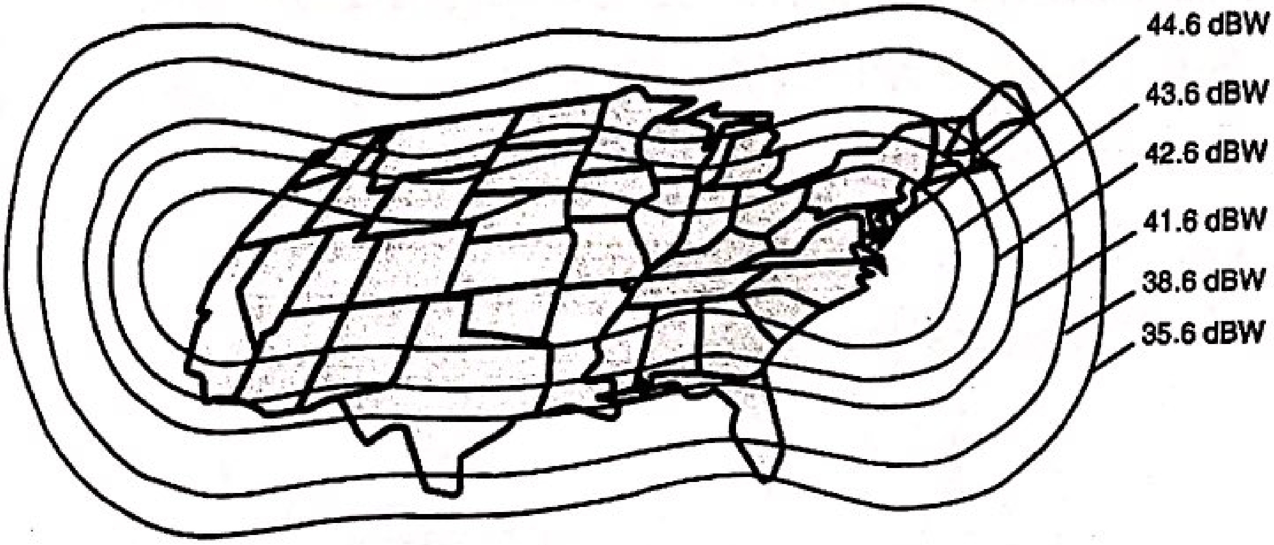
omni-directional



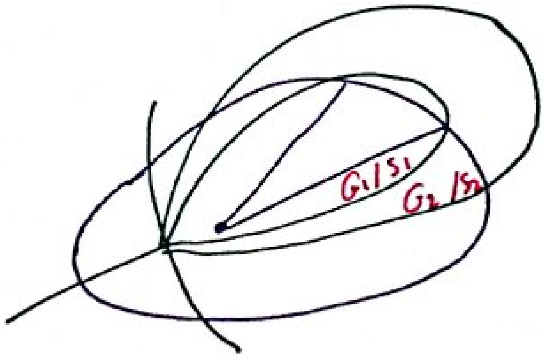
# Satellite Antenna Radiation Pattern: Footprints

- The geographical representation of a satellite antenna's radiation pattern is called a footprint or sometimes a footprint map.
- Footprint of a satellite is the area on earth's surface that the satellite can receive from or transmit to.
- The satellite footprint map depends on the location of the satellite in its orbit, its carrier frequency, and the gain of its antenna.
- A footprint map is constructed by drawing continuous lines between all points on a map with equal EIRPs

# Satellite Antenna Radiation Pattern: Footprints




$EIRP = P_t G_t$



## Satellite Antenna Radiation Pattern: Footprints

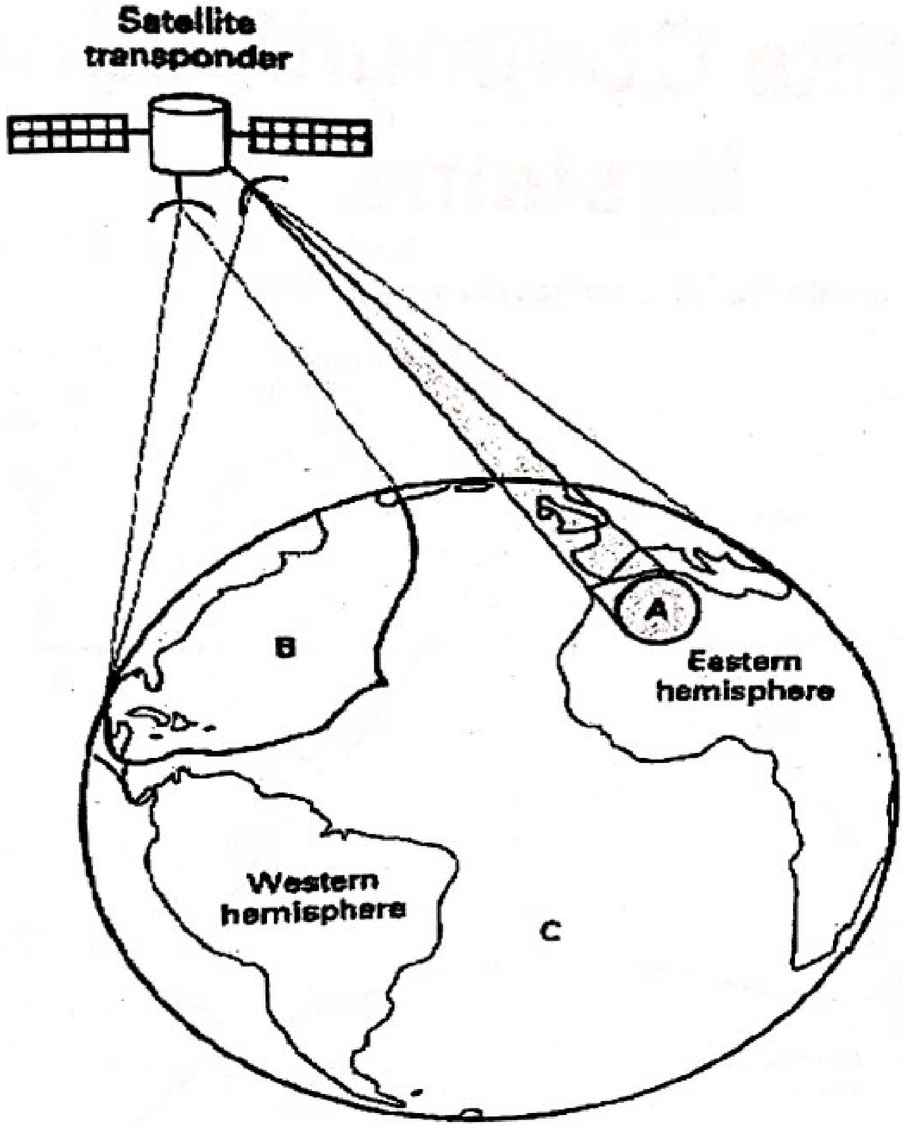
- Radiation patterns is categorized as:

a) Spot: less than 10% of earth surface (higher EIRPs)

b) Zonal: less than 10%

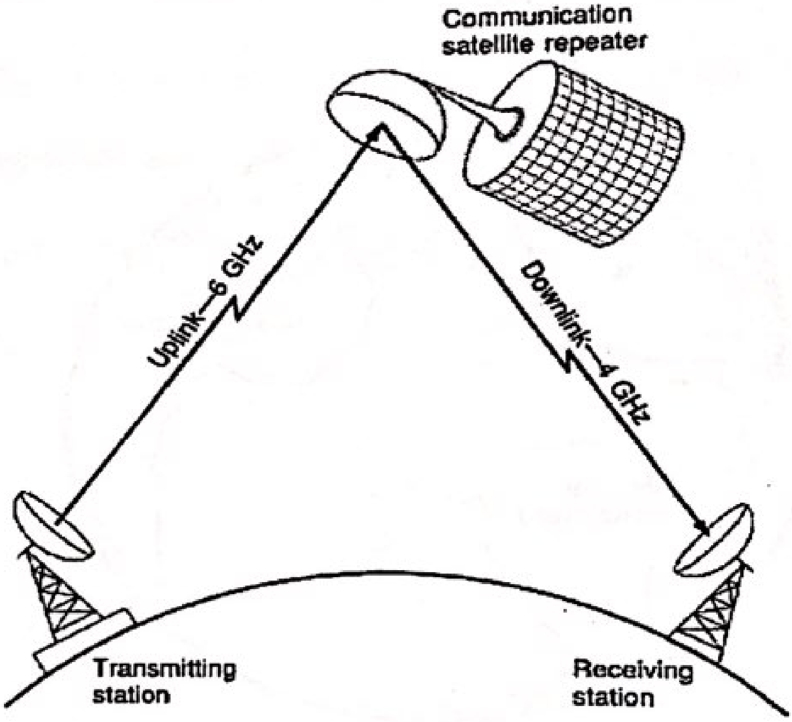
c) Hemispherical: up to 20%

d) Earth (global): ~ 42%

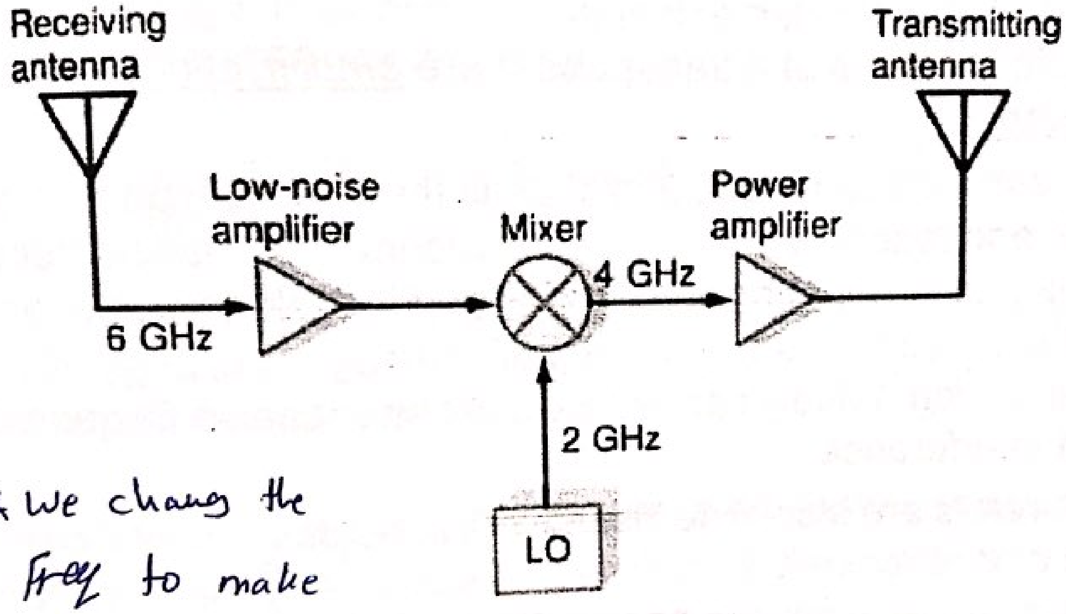

Satellite
transponder
A
B
Eastern
hemisphere
Western
hemisphere
C

# Satellite Communication Systems

Using a satellite as a microwave relay link.



A satellite transponder.




* We chang the freq to make sure no interference will occur.

- The transmitter-receiver combination in the satellite is known as a *transponder.*
- A typical uplink frequency is 6 GHz, and a common downlink frequency is 4 GHz.
- The basic functions of a transponder are *amplification* and *frequency translation.*
- The reason for frequency translation is that the transponder cannot transmit and receive on the same frequency. The transmitter's strong signal would overload, or "desensitize," the receiver and block out the very small uplink signal, thereby prohibiting any communication. Widely spaced transmit and receive frequencies prevent interference.
- Transponders are also wide-bandwidth units so that they can receive and retransmit more than one signal. Any earth station signal within the receiver's bandwidth will be amplified, translated, and retransmitted on a different frequency.

- Although the typical transponder has a wide bandwidth, it is used with only one uplink or downlink signal to minimize interference and improve communication reliability.
- To be economically feasible, a satellite must be capable of handling several channels.
- As a result, most satellites contain multiple transponders, each operating at a different frequency. Each transponder represents an individual communication channel.
- Various multiple-access schemes are used so that each channel can carry multiple information transmissions.

# Frequency Allocations

- Most communication satellites operate in the microwave frequency spectrum.
- However, there are some exceptions. For example, many military satellites operate in the 200- to 400-VHF/UHF range.
- VHF, UHF, and microwave signals penetrate the ionosphere with little or no attenuation and are not refracted to earth, as are lower frequency signals in the 3- to 30-MHz range.
- The microwave spectrum is divided up into frequency bands that have been allocated to satellites as well as other communication services such as radar.
- These frequency bands are generally designated by a letter of the alphabet.

Frequency bands used in satellite communication.

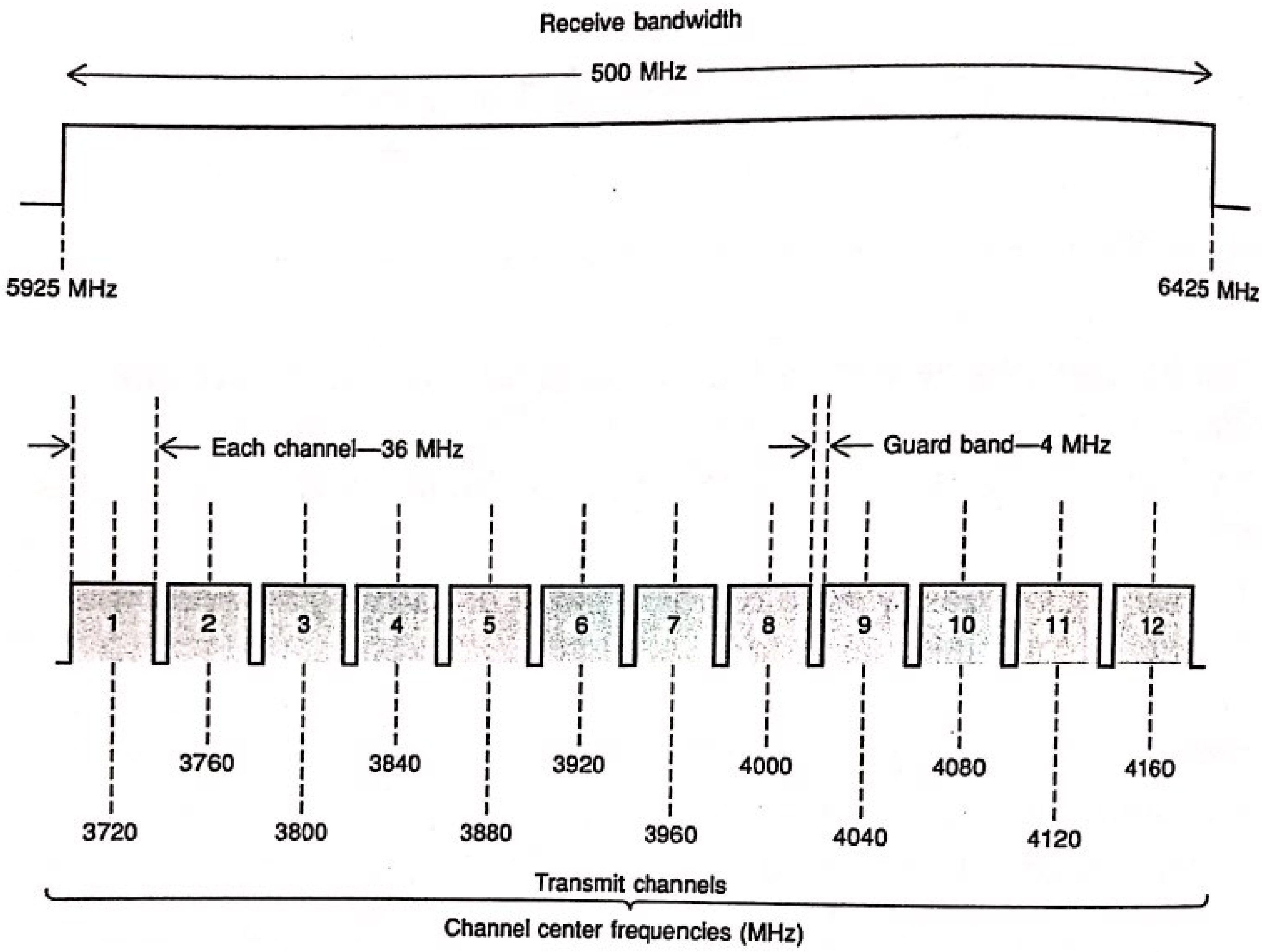
| Band | Frequency |
|---|---|
| P | 225–390 MHz |
| J | 350–530 MHz |
| L | 1530–2700 MHz |
| S | 2500–2700 MHz |
| C | 3400–6425 MHz |
| X | 7250–8400 MHz |
| Ku | 10.95–14.5 GHz |
| Ka | 17.7–31 GHz |
| Q | 36–46 GHz |
| V | 46–56 GHz |
| W | 56–100 GHz |

# C, Ku, X, and L bands

- One of the most widely used satellite communication bands is the C band.
- The C band is referred to by the designation 6/4 GHz, where the uplink frequency is given first.
- Most new communication satellites will operate in the Ku band. This upward shift in frequency is happening because the *C band* is overcrowded.
- Naturally, the electronic equipment that can achieve these higher frequencies is more complex and expensive.
- For a given antenna size, the gain is higher in the Ku band than in the C band. This can improve communication reliability while decreasing antenna size and cost.
- The military uses the X band for its satellites and radar. The L band is used for navigation as well as marine and aeronautical communication and radar.

# Spectrum Usage

- The frequencies designated for the C band uplink and downlink. These are 5925 to 6425 and 3700 to 4200 MHz, respectively.
- You can see that the bandwidth between the upper and lower limits is 500 MHz.
- This is an incredibly wide band, capable of carrying an enormous number of signals.
- The 500-MHz bandwidth is typically divided into 12 separate transmit channels, each 36 MHz wide.
- A separate transponder is allocated to each of the 12 channels.
- 36 MHz channel: can handle up to 1000 one-way analog telephone conversations as well as one full-color TV channel


Receive bandwidth
500 MHz
5925 MHz
6425 MHz
Each channel—36 MHz
Guard band—4 MHz
1
2
3
4
5
6
7
8
9
10
11
12
3720
3760
3800
3840
3880
3920
3960
4000
4040
4080
4120
4160
Transmit channels
Channel center frequencies (MHz)

## Example

A satellite transponder operates in the C band. Assume a local-oscillator frequency of 2 GHz.

a. What is the uplink receiver frequency if the downlink transmitter is on channel 4? The downlink frequency of channel 4 is 3840 MHz . The downlink frequency is the difference between the uplink frequency $f_u$ and the local-oscillator frequency $f_{LO}$:

$$f_d = f_u - f_{LO}$$

Therefore,

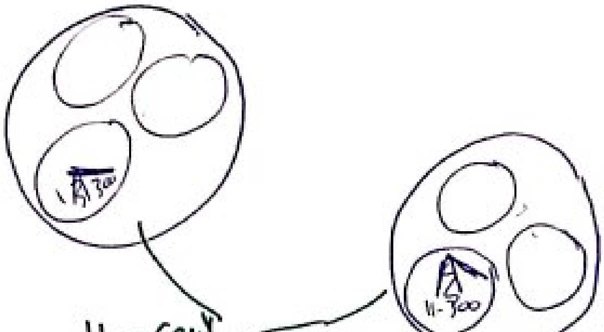
$$f_u = f_d + f_{LO}$$

$$= 3840 + 2000 = 5840 \text{ MHz} = 5.84 \text{ GHz}$$

b. What is the maximum theoretical data rate if one transponder is used for binary transmission?
The bandwidth of one transponder channel is 36 MHz. For binary transmission, the maximum theoretical data rate or channel capacity $C$ for a given bandwidth $B$ is

$$C = 2B$$

$$= 2(36) = 72 \text{ Mbps}$$



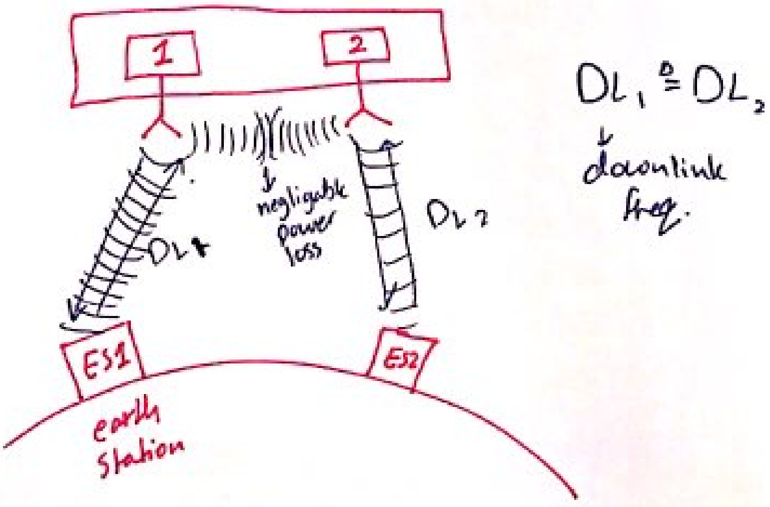
They can use same channel at the same time

# Frequency Reuse

- One system for effectively doubling the bandwidth and information carrying capacity of a satellite is known as frequency reuse.
- In this system, a communication satellite is provided with two identical sets of 12 transponders that use the same channels. But to eliminate the interference:

1. They use different antenna polarizations ( vertical/ horizontal, or left-hand circularly polarized (LHCP) antenna/ right-hand circularly polarized (RHCP) antenna) .
2. They use narrow beam or spot beam antennas, the area on the earth covered by the satellite can be divided up into smaller segments. This technique is referred to a spatial-division multiple access (SDMA)

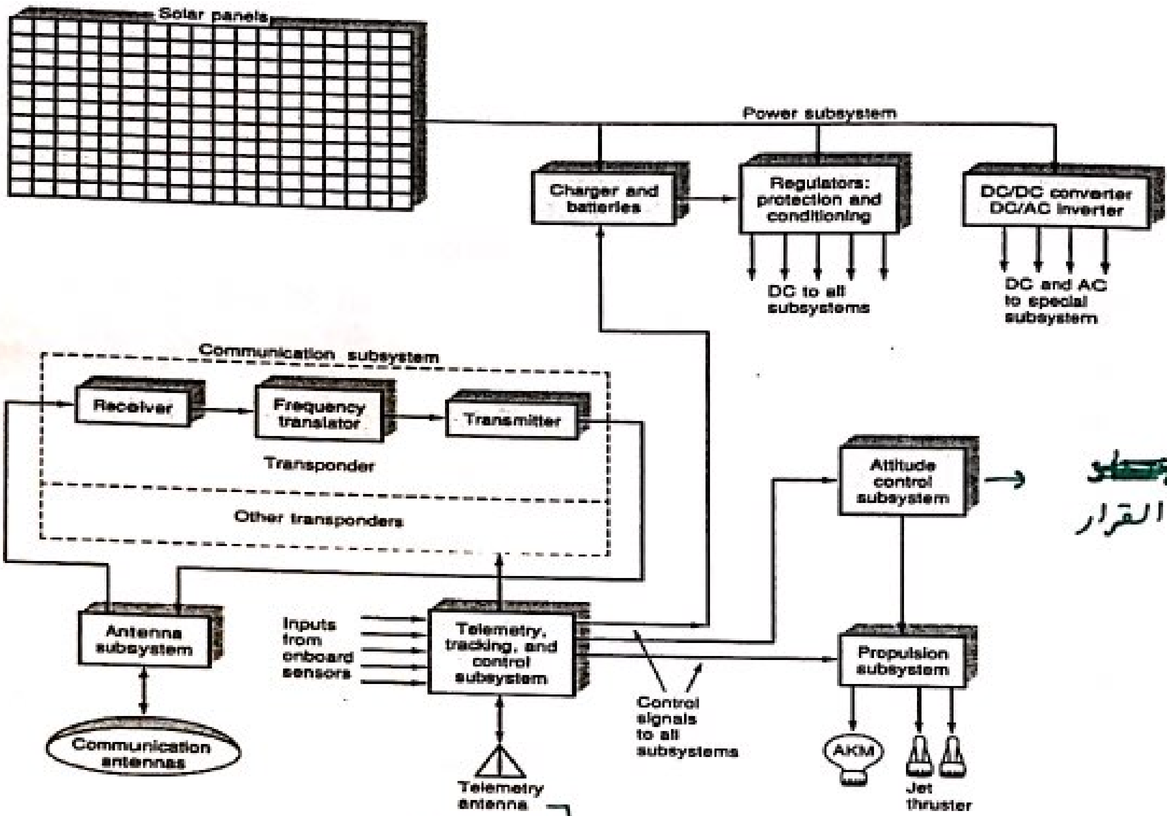
52



# Access Methods

1. FDMA was widely used in early satellites.
2. Today, TDMA is more prevalent.
3. In some of the newer satellites, CDMA is used. CDMA provides the security so important in today's wireless systems.
4. Today, more and more satellites use SDMA.

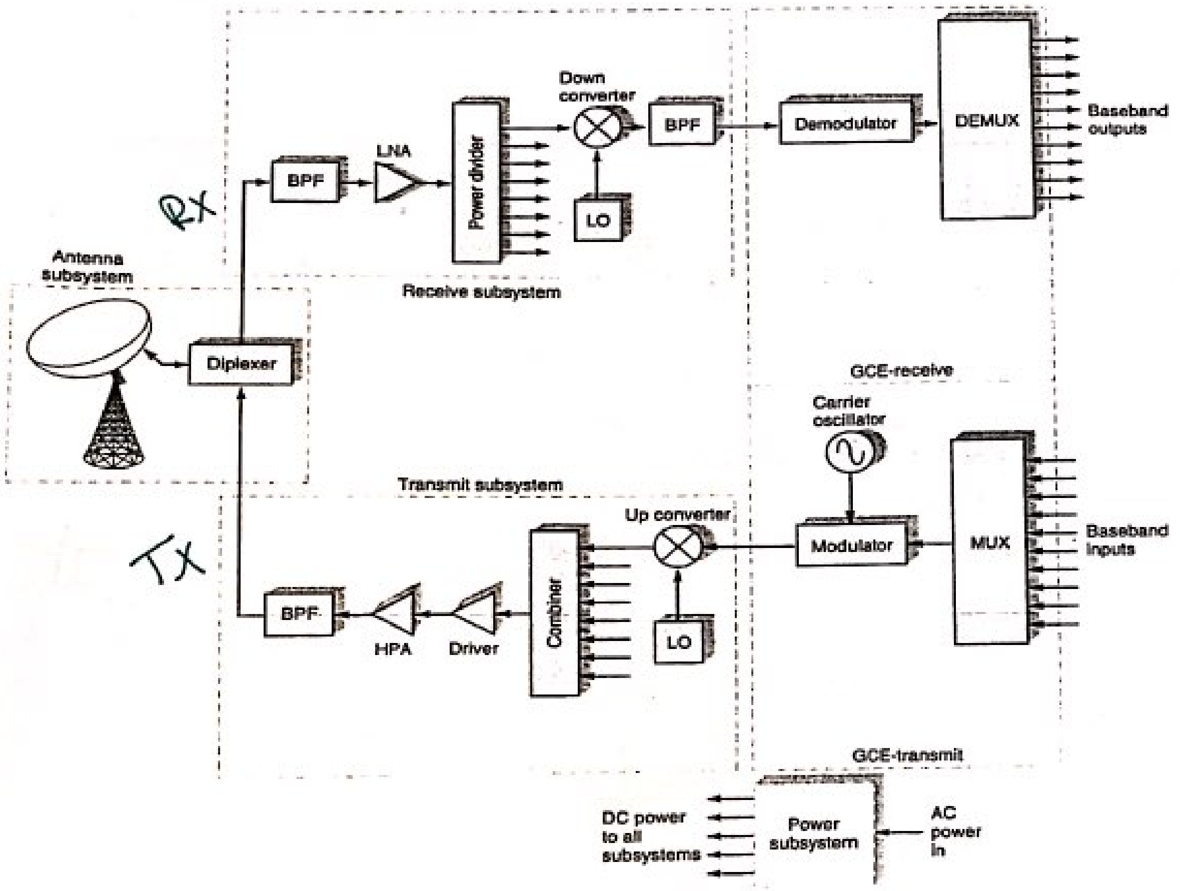
# General Block Diagram of a Communication Satellite




~~[illegible]~~ لاتخاذ القرار

للمراقبة والملاحظة

# Ground Station



# Satellite Applications

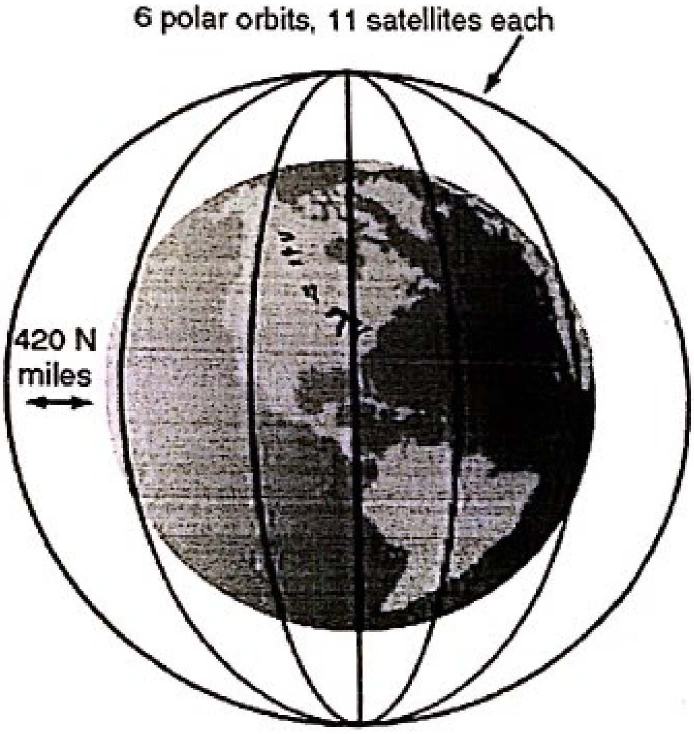
1. **Communication Satellites**

- Long-distance telephone service
- TV transmission

2. **Satellite Cell Phones**

- One of the oldest and most widely used is the Iridium system.
- The system provides truly global coverage between any two handheld cellular telephones or between one of the cellular telephones and any other telephone on earth.

The Iridium satellite cellular telephone system.



- In addition to voice communication, Iridium (L-band) will be able to provide a whole spectrum of other communication services including
  **a)** ***Data communication*** E-mail and other computer communication.
  **b)** ***Fax*** Two-way facsimile.
  **c)** ***Paging*** Global paging to receivers with a two-line alphanumeric display.
  **d)** ***Radio Determination Services (RDSs)*** A subsystem that permits satellites to locate transceivers on earth. Accuracy is expected to be within 3 mi.

- Other systems: Globalstar, INMARSAT.
- Satellite phones are expensive because they require higher power to reach the satellites hundreds or thousands of miles away. Higher power also calls for larger batteries.
- All satellite phones also have a large antenna that must be fully extended. And all calls must be made outside so the phone can "see" the satellite. Indoor calls do not work.

3. **Digital satellite radio or digital audio radio service (DARS)**

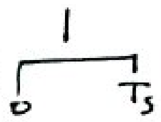
This service provides hundreds of channels of music, news, sports, and talk radio primarily to car portable and home radios. Conventional AM and FM radio stations cover only short distances and are subject to local and even national radio propagation effects.

4. **Surveillance Satellites.**

Satellites can look at the earth and transmit what they see to ground stations for a wide variety of purposes:

- TV cameras can take pictures and send them back to earth as electric signals.
- Infrared sensors detect heat sources.
- Small radars can profile earth features.
- Intelligence satellites collect information about enemies and potential enemies.
- Satellites photograph cloud cover and send back to earth pictures that are used for determining and predicting the weather.
- Creating more accurate and more detailed maps.
- GPS

Bpsk  101...1 → $\boxed{\text{modulator}}$ →

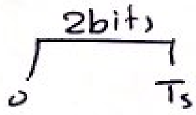



M-QAM

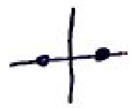
spectral efficiency = $R_b/B$  bit/sec/Hz

bit/channel-use

4-QAM

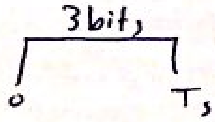


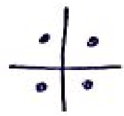

⇒ performance is worst than Bpsk



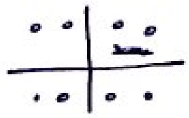
Bpsk

8-QAM



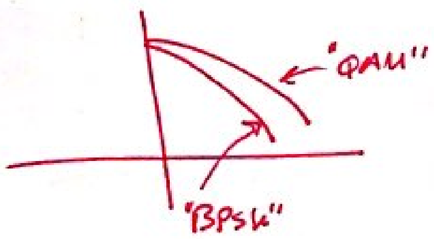



4-QAM



8-QAM

$P_e$ = BER



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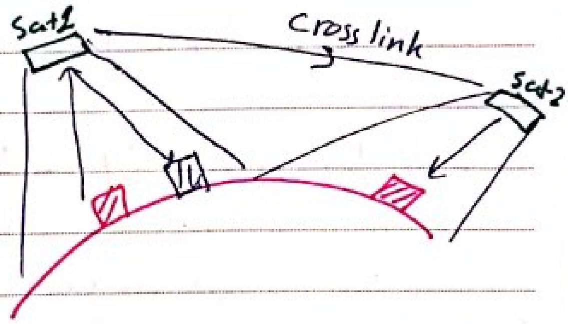
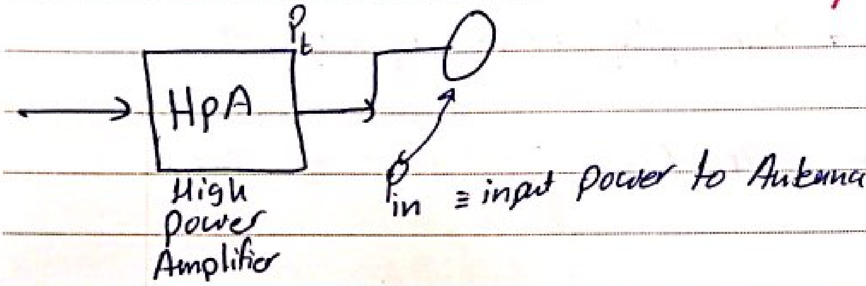
## ① Satellite System link model :-

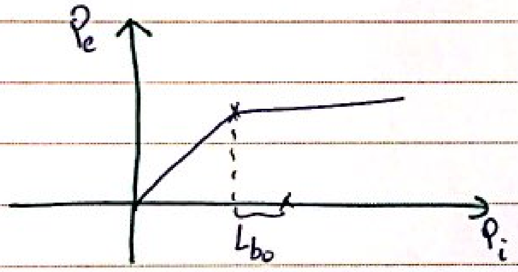



* Satellite system parameters.

① Back-off loss ( $L_{bo}$ )




$$P_{in} = P_t - L_{bo}$$




② Transmit power : $P_t$

$$P_t^{sat} \gg P_t^{Microwave}$$

dBw dBm

③ Effective Isotropic Radiated power (EIRP)

branching and coupling losses

$$\underset{dBW}{EIRP} = \underset{dBW}{P_t} - \underset{dB}{L_{bo}} - \underset{dB}{L_{bf}} + \underset{dB}{A_t}$$

Ex :- $P_t = \overset{10{,}000 \text{ watts}}{40 \, dBW}$ , $L_{bo} = 3dB$ , $L_{bf} = 3dB$ , $A_t = 40 dB$

$$EIRP = 40 - 3 - 3 + 40 = 74 \, dBW$$

④ Bit Energy ($E_b$) (at the transmitter)

$$\boxed{E_b = P_t T_b}$$

J/bit watt sec

$$E_b = \frac{P_t}{f_b}$$

data rate

$$\underset{dBJ}{E_b} = 10 \log (E_b)$$

Ex:- $P_t = 1000 W$, transmission rate is 50 Mbps.

$$E_b = \frac{P_t}{F_b} = \frac{10^3}{50 \times 10^6} = 20 \, \mu J$$

$$E_{b_{dBJ}} = -47 \, dBJ$$

No.

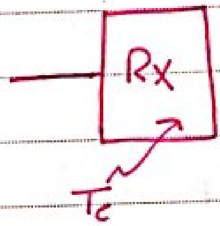
## [5] Equivalent Noise Temprature : "Te"

$NF = 10\log(F)$

$T_e$ : noise exist

$F = 1 + \frac{T_e}{T}$ ← $290°k$

noise factor




$N = kT_eB$ (noise added by a device)

Typically : Satellite $T_e \sim 1000$ kelvin

$E_s$ : $T_e \sim 200-1000$ kelvin

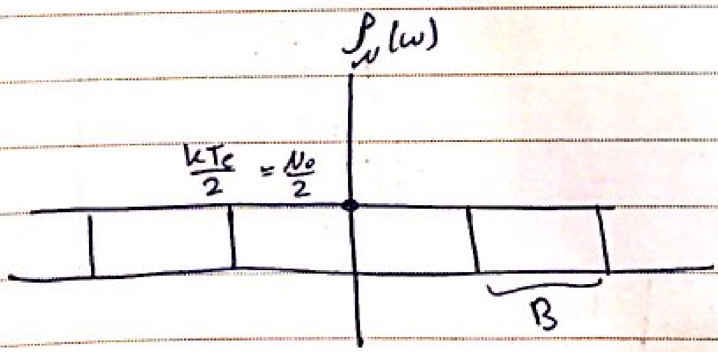
## [6] Noise Density "$N_o$"

$N = kT_eB$

$$\boxed{N_o = \frac{N}{B} = kT_e}$$

$N_o\ dBw/Hz = N_{dBw} - B_{dBHz}$

$= 10\log_{10}(k) + T_{e\,dB\,kelvin}$




$N = \frac{kT_e}{2} . B . 2$

$= kT_eB$

Ex:- For an equivalent noise Bw of 10 MHz and total noise power of 0.0276 pW. Find $N_o$, $T_e$.

$$T_e = \frac{N}{kB}$$

$B = 10$ MHz

$N = 0.0276$ pW, $1p = 10^{-12}$

$B\uparrow$, $N\uparrow$

$$N_o = \frac{N}{B} = \frac{0.0276 \times 10^{-12}}{10 \cdot 10^{6}} = 276 \times 10^{-23} \text{ W/Hz}$$

$$T_e = \frac{N_o}{k} = \frac{276 \times 10^{-23}}{1.38 \times 10^{-23}} = 200 \text{ kelvin}$$

$$\triangleq 23 \text{ dB/kelvin}$$

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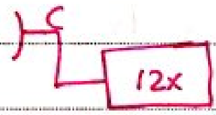
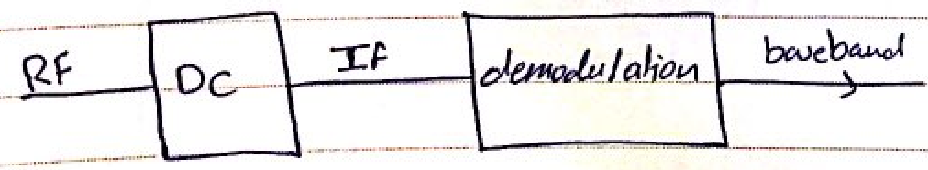
$\boxed{7}$ Carrier-to-noise-density ratio

$$\frac{C}{N_o} = \frac{C}{kT_e}$$ ← wideband carrier power




unit $\frac{W}{W/Hz} = [Hz]$

$$\left(\frac{C}{N_o}\right)_{dBHz} = C_{dBW} - N_{o\,dBW/Hz}$$



## 8 Energy-of-bit to noise-density ratio

received bit energy $\rightarrow \dfrac{E_b}{N_o} = \dfrac{C T_b}{N/B} = \dfrac{C/f_b}{N/B}$

$$\boxed{\frac{E_b}{N_o} = \left(\frac{C}{N}\right)\left(\frac{B}{f_b}\right)} \qquad \boxed{B = \frac{f_b}{\log_2(M)}}$$

$\Rightarrow$ BPSK

$B = \dfrac{R_b}{2}$

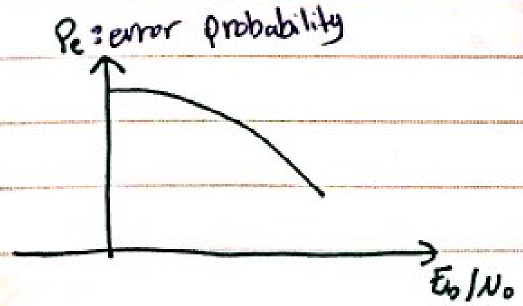
PSK

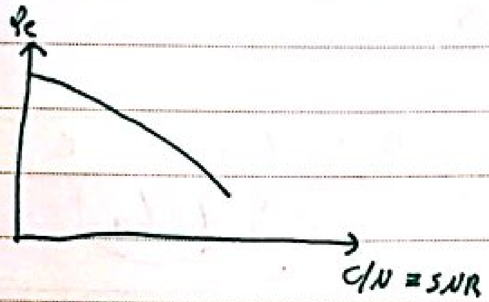
$B = \dfrac{R_b}{4}$

$\Rightarrow M$ : modulation order

BPSK : $M=2$ , QPSK : $M=4$ , 16-QAM : $M=16$

$$\left(\frac{E_b}{N_o}\right)_{dB} = \left(\frac{C}{N}\right)_{dB} + \left(\frac{B}{f_b}\right)_{dB}$$

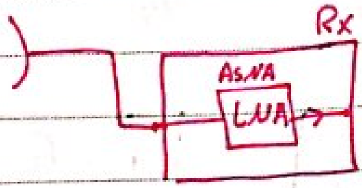



BPSK $\Rightarrow P_e = Q\left(\sqrt{2\dfrac{E_b}{N_o}}\right)$ (not required in the exam)

9 Gain-to-equivalent noise temprature ratio

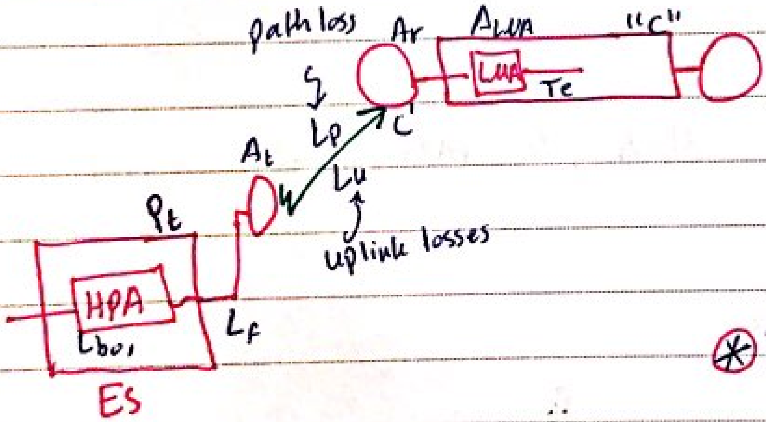
$$\frac{G}{T_e} = \frac{A_r A_{LNA}}{T_e}$$




$$\left(\frac{G}{T_e}\right)_{dB\,kelvin^{-1}} = A_{r_{dB}} + A_{LNA_{dB}} - (T_e)_{dB\,kelvin}$$

10 Satellite link Equations:-

uplink Equation:




(*) $P_{in} = P_{t\,dBw} - L_{bo\,dB} - L_{b\,dB} - L_{f\,dB}$

$$\boxed{\frac{C}{N_o} = \frac{\overbrace{P_{in} A_t A_r A_{LNA}}^{C}}{\underbrace{k T_e}_{N_o} L_p L_u}}$$

(*) $P_{in} = \frac{P_t}{L_{bo} * L_b * L_f}$

No.

$$\frac{C}{N_o} = \frac{EIRP}{k\,L_p\,L_u} \cdot \frac{G}{T_e} \quad , \text{ where } G = A_r\,A_{LNA}$$

$$\boxed{\left(\frac{C}{N_o}\right)_{dB} = EIRP_{dBw} - L_{p_{dB}} - L_{u_{dB}} - 10\log(k) + \left(\frac{G}{T_e}\right)_{dB\ kelvin^{-1}}}$$

- $EIRP_{dBw} = P_{t_{dBw}} - L_{bo_{dB}} - L_{b_{dB}} - L_{f_{dB}} + A_{b_{dB}}$

- $L_{p_{dB}} = 20\log\left(\frac{4\pi D}{\lambda}\right)$

* Example 14-8 : page 598

$$\frac{E_b}{N_o} = \frac{C}{f_b\,N_o}$$

$$\left(\frac{E_b}{N_o}\right)_{dB} = \left(\frac{C}{N_o}\right)_{dB} - 10\log(f_b)$$

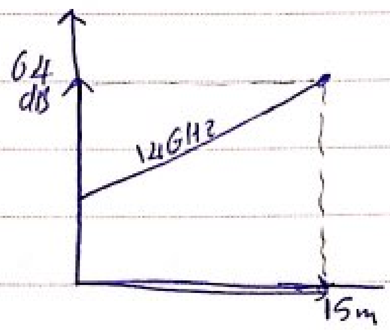
Find $(C/N_o)_{dB}$ , $(E_b/N_o)_{dB}$

① $P_t = 2000\,W = 33\,dBw$

② $L_{bo} = 3\,dB$

③ $L_{bf} = L_b + L_f = 4\,dB$

④ $A_t = 64\,dB$ / $f = 14\,GHz$
Diameter = 15m



No.

⑤ $L_u = 0.6$ dB

⑥ $L_p = 206.5$ dB

⑦ $G/T_e = -5.3$ dB kelvin$^{-1}$

⑧ $L_{bf} = 0$ dB

⑨ $f_b = 120$ Mbps

⑩ 8-psk

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Sol:- $\left(\frac{C}{N_o}\right) = EIRP_{dBw} - L_{p_{dB}} - L_{u_{dB}} + \left(\frac{G}{T_e}\right) - 10\log(k)_{dBk^{-1}}$

$EIRP = P_t - L_{bo} - L_b - L_f + A_t$

$= 33_{dBw} - 3dB - 4dB + 64dB = 90$ dBw

$\left(\frac{C}{N_o}\right) = 90\ dB_w - 206.5_{dB} - 0.6_{dB} + (-5.3dBk^{-1}) - 10\log(1.38\times10^{-23})$

$= 106.2$ dB

$(C/N) = \left(\frac{C}{N_o B}\right)$

$(C/N) = \left(\frac{C}{N_o}\right) - 10\log(B)$

$= 106.2\,dB - 10\log(\quad)$

smile

No.

* $f_b = \log_2(M)B$

$$B = \frac{f_b}{\log_2(M)} = \frac{120\ Mbps}{3} = 40\ MHz$$

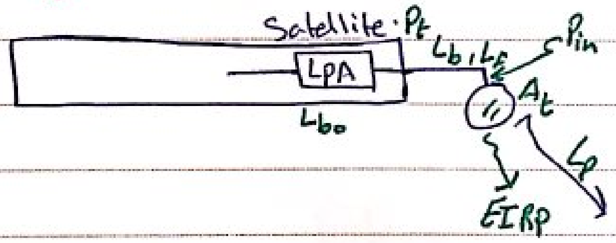
$\Rightarrow$ $106.2\,dB - 10\log(40\times10^6) = 30.2\ dB$

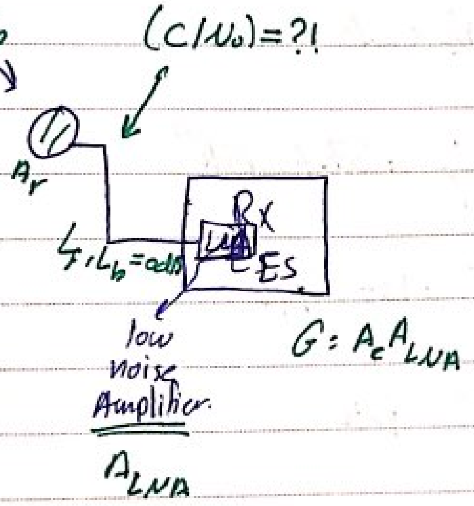
$$\frac{E_b}{N_b} = \frac{CB}{f_b N} = \left(\frac{C}{N}\right)\left(\frac{B}{f_b}\right)$$

$$\frac{E_b}{N_0} = \left(\frac{C}{N}\right) + 10\log\left(\frac{B}{f_b}\right) = 30.2\,dB + 10\log(1/3) = 25.4\ dB$$

$$F_m = C - C_{min}$$

$\Rightarrow$ Downlink equation :-




$$\left(\frac{C}{N_0}\right) = EIRP^{(sat)}_{dB} - L_{p_{dB}} - L_d + \left(\frac{G}{T_e}\right)^{(E_s)}_{dBk^{-1}} - 10\log(k)$$

smile

No.

Ex:- Compute the link budget from the following DL system: page 597 to find parameters

① $P_t = 10 W \cong 10\ dBW$

② $L_{b_o} = 0.1\ dB$

③ $L_{bf} = 0.5\ dB$

④ $A_t = 30.8\ dB$ $(D = 0.37\ m)$
$(f = 12 GHz)$

⑤ $L_d = 0.4\ dB$

⑥ $L_p = 205.6\ dB$ $\left( \begin{array}{l} f = 12 GHz \\ d = 35{,}930\ km \end{array} \right)$

⑦ $A_r = 62\ dB$ $\left( \begin{array}{l} D = 15 m \\ f = 12 GHz \end{array} \right)$

⑧ $L_{bf} = 0\ dB$

⑨ $T_e = 270\ k$

⑩ $\frac{G}{T_e} = 37.7\ dBk^{-1}$

⑪ $f_b = 120\ Mbps$

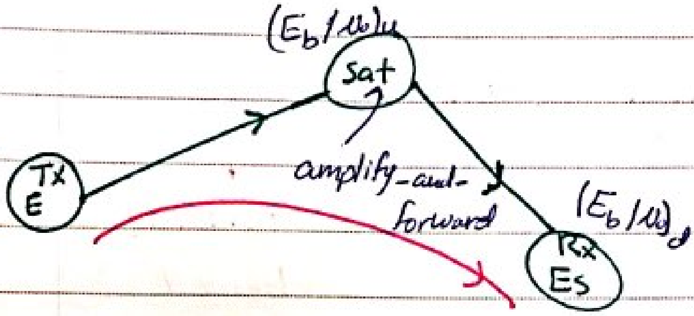
⑫ 8 - psk

No.

$(C/N_0) = 100.5 \text{ dB}$

$(C/N) = 24.47 \text{ dB}$

$E_b/N_0 = 19.7 \text{ dB}$




$$\boxed{\text{overall}\left(\frac{E_b}{N_0}\right)_o = \frac{(E_b/N_0)_u (E_b/N_0)_d}{(E_b/N_0)_u + (E_b/N_0)_d}}$$

$$\left(\frac{E_b}{N_0}\right)_o = \frac{10^{2.54} \cdot 10^{1.98}}{10^{2.54} + 10^{1.98}} = 73.5 \triangleq 18.7 \text{ dB}$$