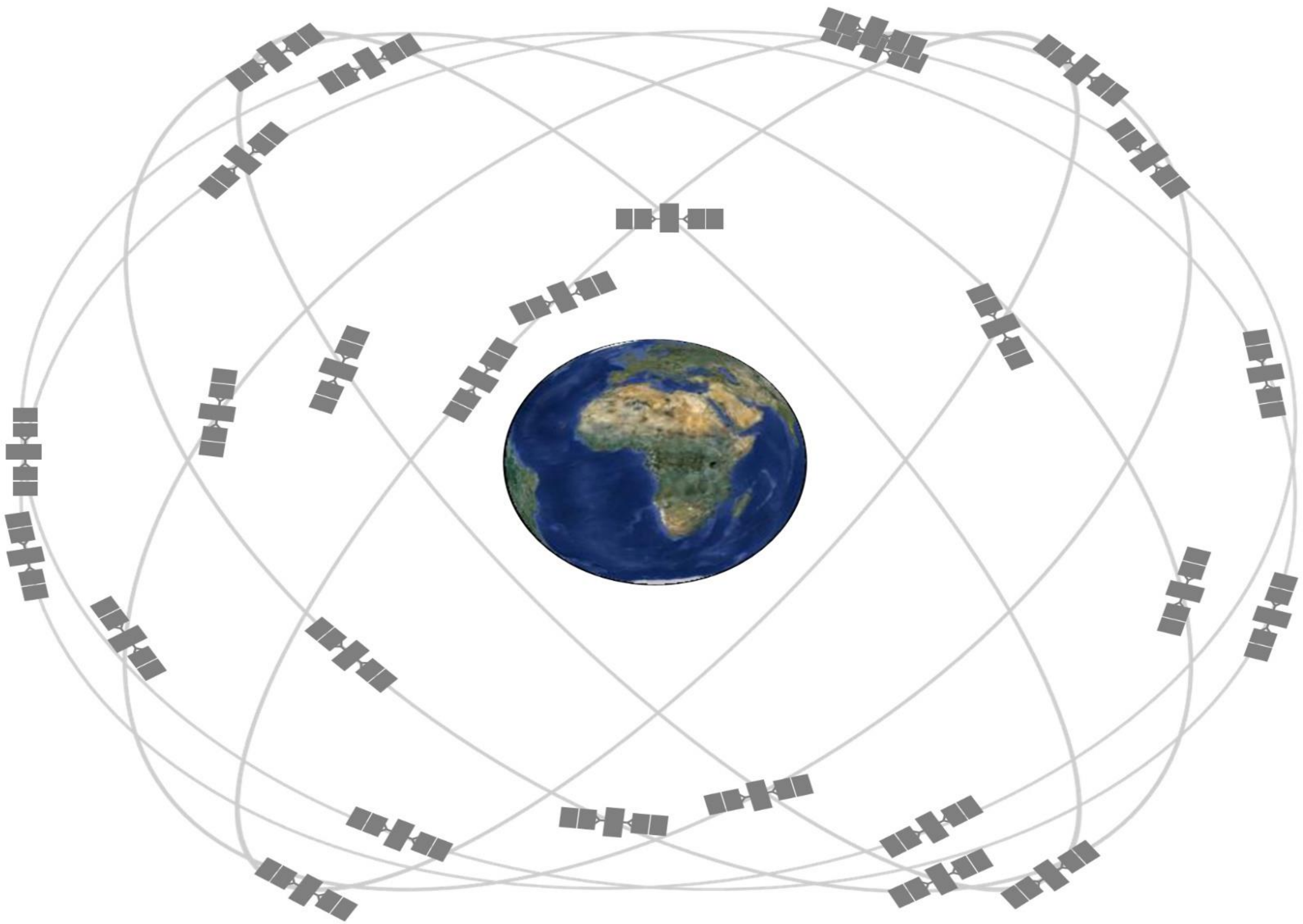
Chapter 4
Positioning by Global Positioning System



GPS System

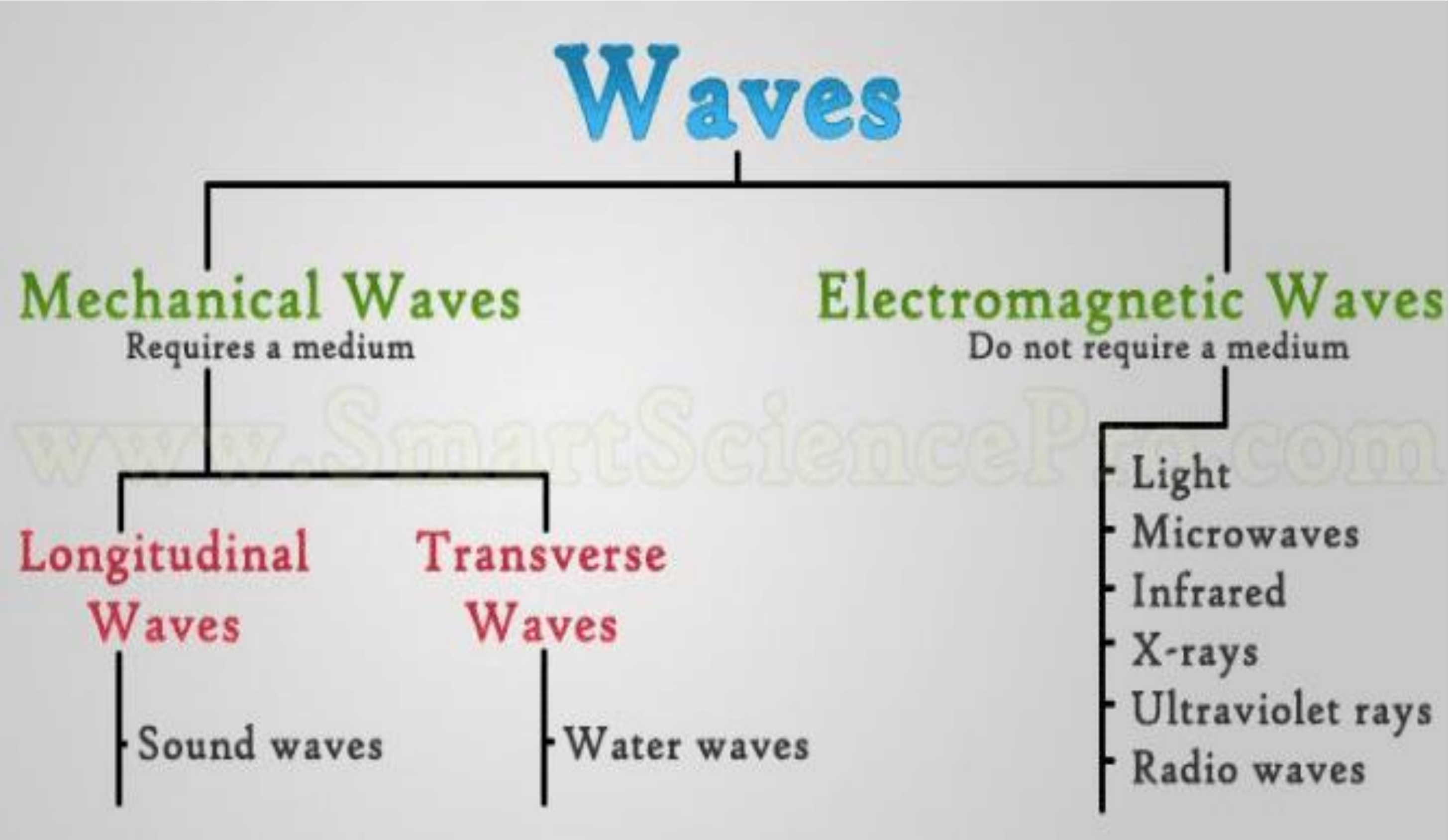
- The Global Positioning System (GPS) is a satellite-based radio-based navigation system that was developed by the U.S. Department of Defense (DoD) in the early 1970s.
- Initially, GPS was developed as a military system to fulfill U.S. military needs.
- However, it was later made available to civilians, and is now a dual-use system that can be accessed by both military and civilian users.
- GPS system is currently operated by United States Air Force

Cont..

Note: Radio waves have frequencies as high as 300 gigahertz (GHz) to *as low as 30 hertz (hz)*

At 300 GHz, the corresponding wavelength is 1 mm, and at 30 Hz is 10,000 km

- ✓ *Radio waves*
- ➢ *Communication (radio, TV)*
- ➢ *GPS*
- ➢ *Lowest frequency*



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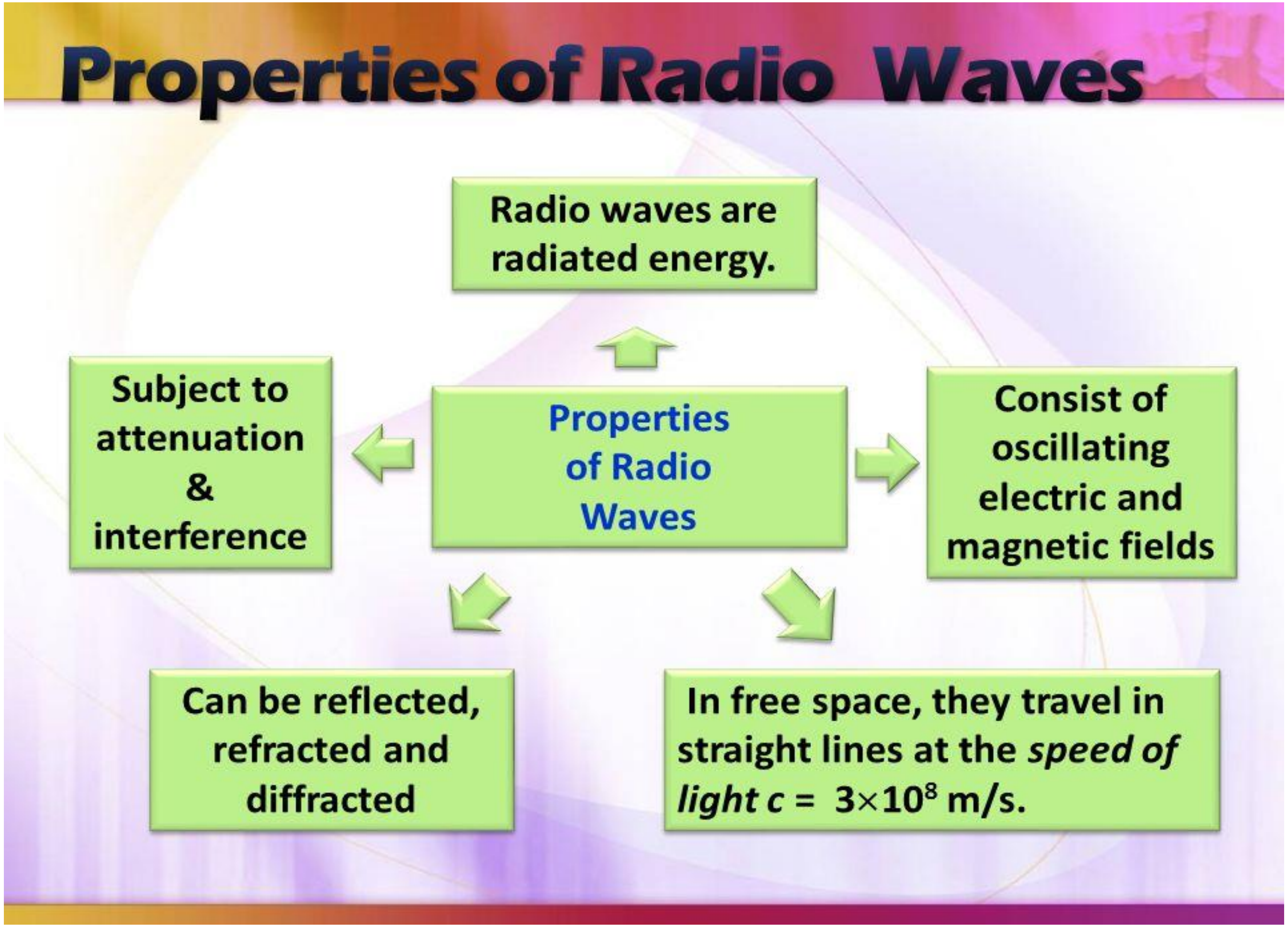


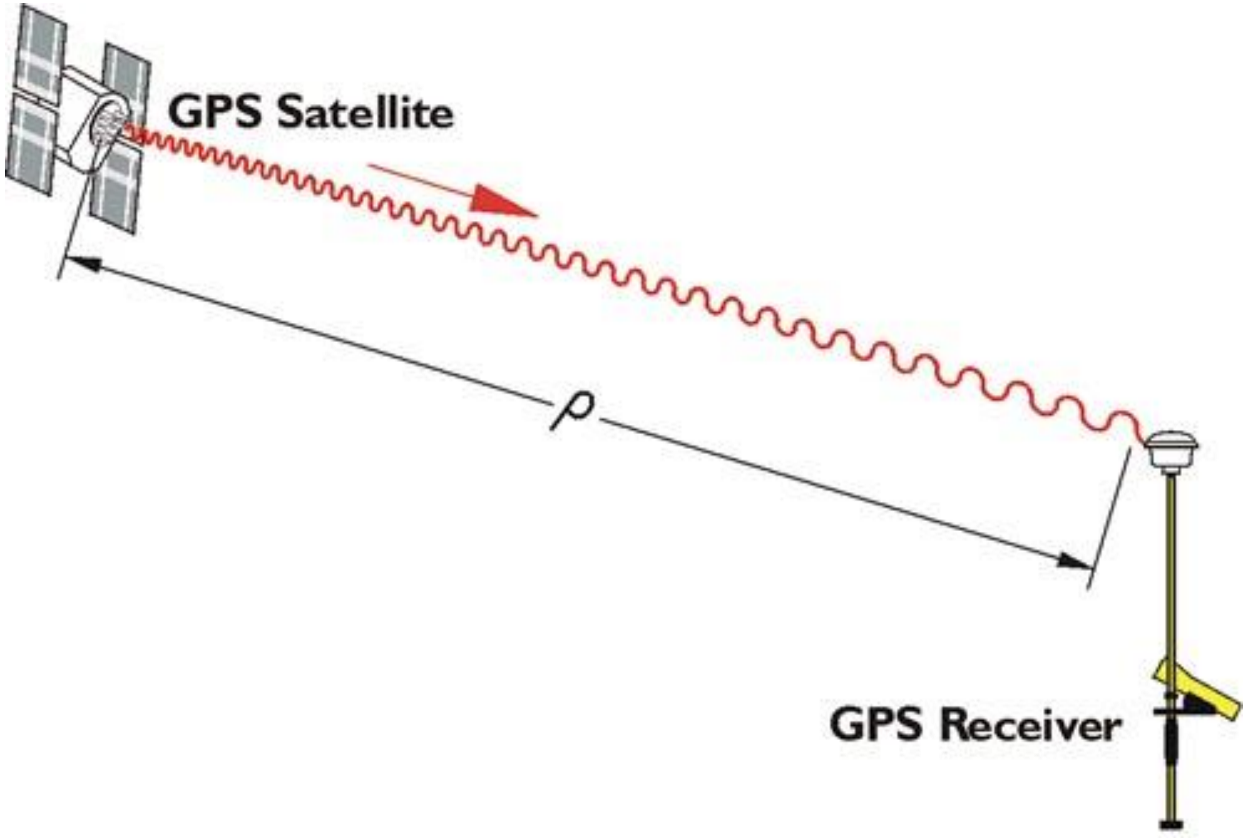
Attenuation = reduction of force

Contd…

- GPS provides continuous positioning and timing information, anywhere in the world under any weather conditions.
- GPS satellites also called NAVSTAR (Navigation Satellite Timing and Ranging), the official U.S. DOD name for GPS

Cont..

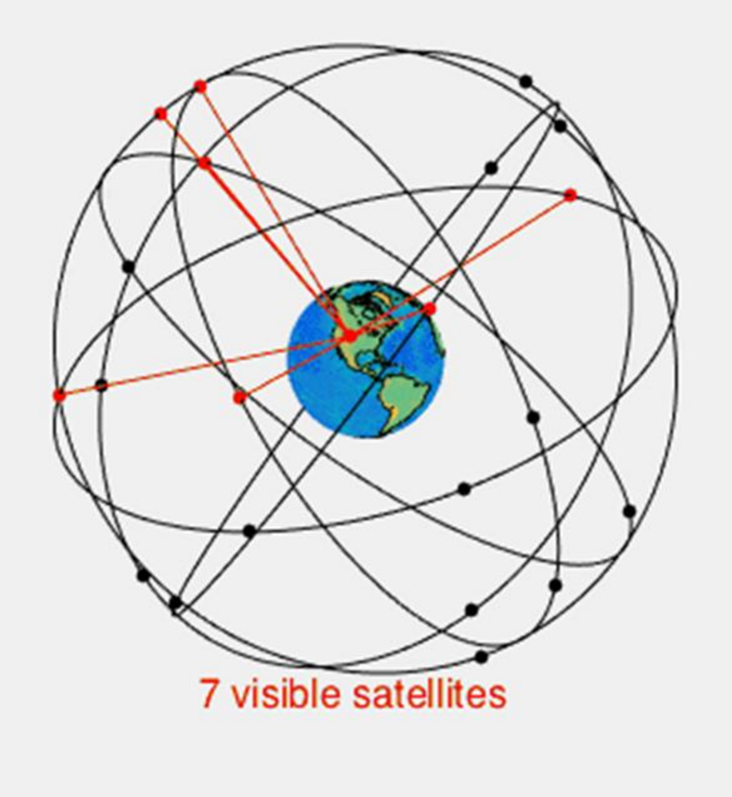
- As GPS serves an unlimited number of users as well as being used for security reasons, it is a one-way-ranging (passive) system i.e. user can only receive satellite signals



One-Way Ranging

Cont..

- Satellites = 24 plus (24 Operational satellite and till date extra 8 extra satellite)
- Orbits = inclination of about 55°(approx.) to the equator
  = separated by 60° right ascension of the ascending node
  = nearly circular (an elliptical shape with a maximum eccentricity is about 0.01)
- Altitude = 20200 Km (MEO-Medium earth orbit)
- semi-major axis = 26560 km
- orbital period of GPS satellite = 11 hrs 58 min (half sidereal day)
- four satellites are placed in each of six orbital planes



Cont…

- four to ten GPS satellites will be visible anywhere in the world, if an elevation angle of 10° is considered.

- This constellation, known as the initial operational capability (IOC), was completed in July 1993.

- Achieved full operational capabilities (FOC) on July 17, 1995

  *Note : Visit **astronauticsnow.com***

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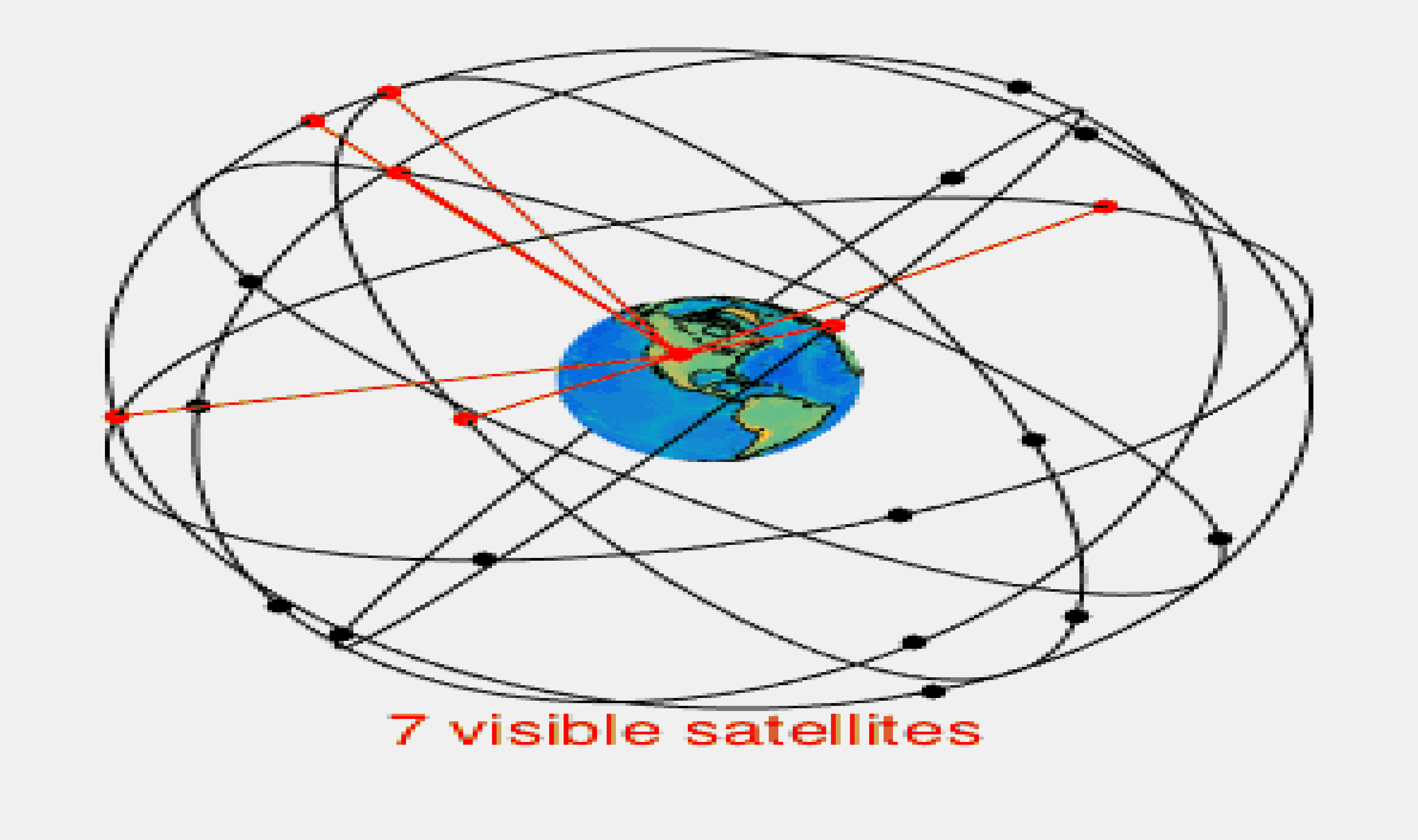


Contd…

•Components of GPS

3 segments:

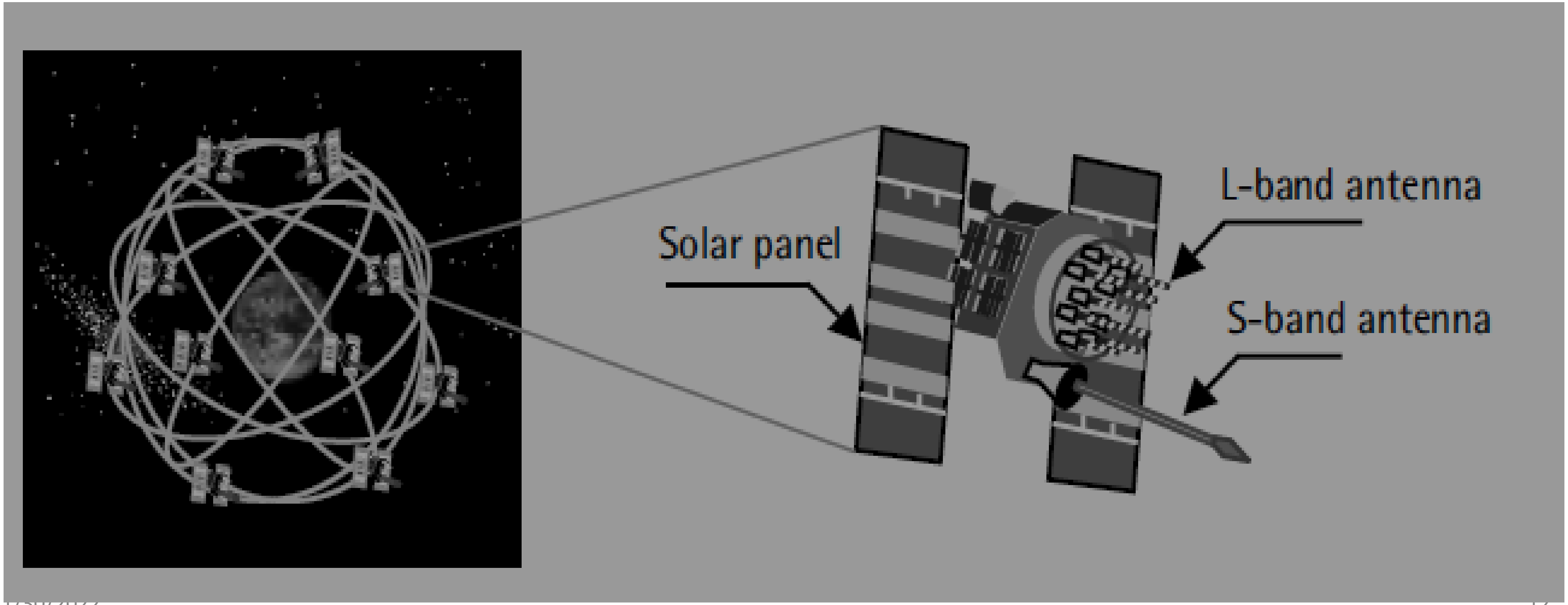
- Space segment
- Control segment
- User segment

Space Segment

- The space segment consists of the 24-satellite constellation, orbiting in six orbit with four satellite in each orbit.
- A minimum of 4 satellite must be viewed by the receiver (user) for accurate 3D coordinate.
- Each GPS satellite transmits a signal, which has a number of components:
  - two sine waves (also known as carrier frequencies),
  - two digital codes and a navigation message

Contd…

- The codes and the navigation message are added to the carriers
- The carriers and the codes are used mainly to determine the distance from the user's receiver to the GPS satellites.



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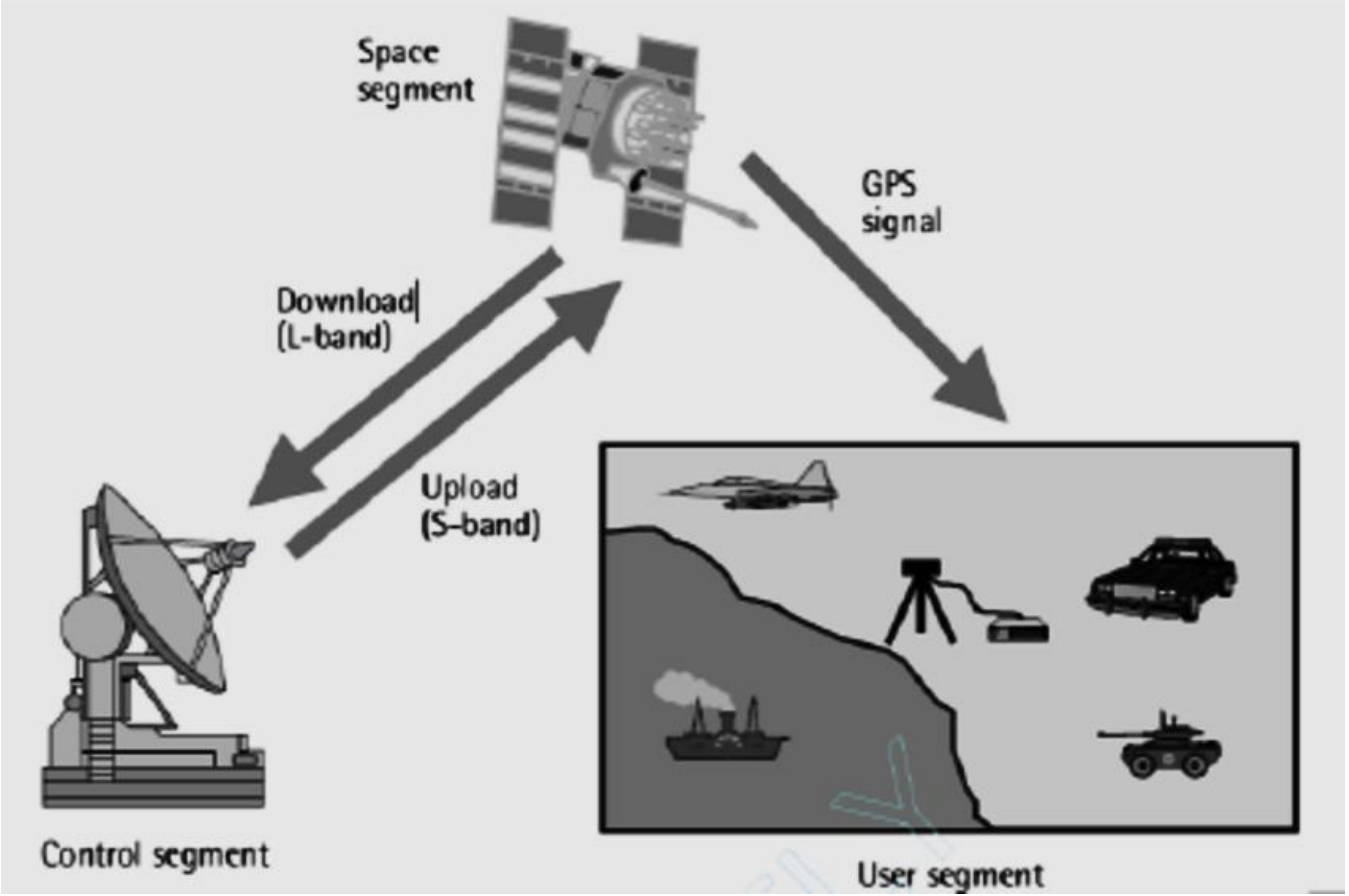
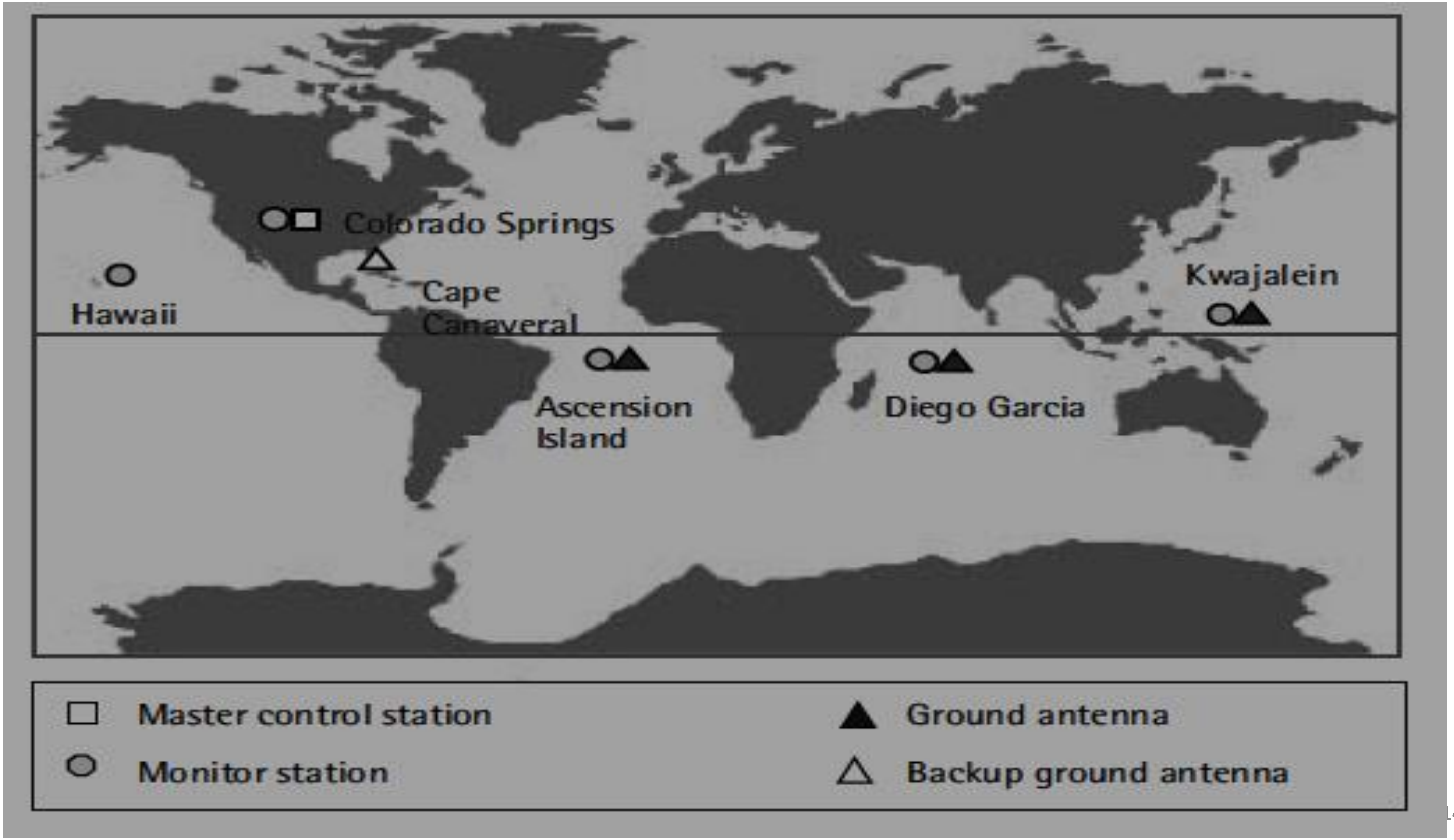

Space
segment
GPS
signal
Download
(L-band)
Upload
(S-band)
Control segment
User segment

Control Segment



Contd…

- The control segment of the GPS system consists of a

➢ worldwide network of tracking stations,

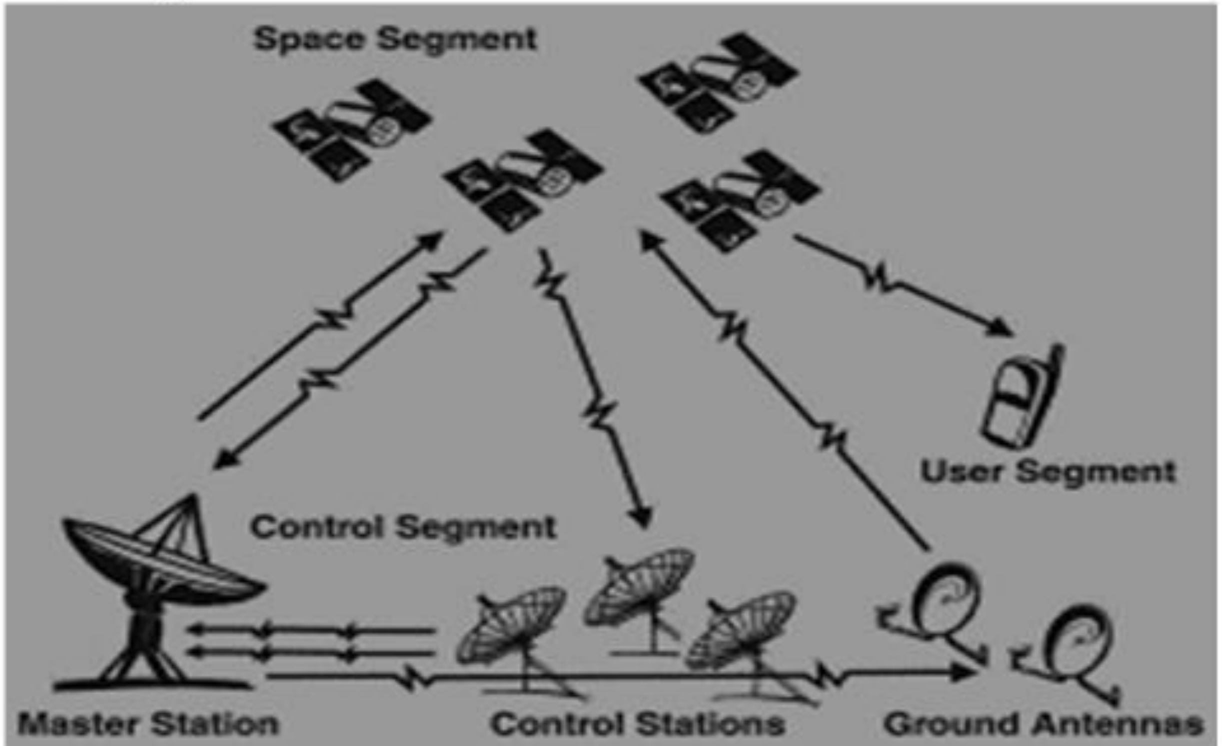
➢ with a master control station (MCS) located in the United States at Colorado Springs, Colorado, Monitor Station and ground antenna.

- The primary task of the operational control segment is tracking the GPS satellites in order to
  - determine and predict satellite locations
  - system integrity
  - behavior of the satellite atomic clocks
  - atmospheric data
  - the satellite almanac

Control Segment

- The monitor stations (Control station) receive all satellite signals, from which they determine the pseudo ranges to all visible satellites, and transmit the range data along with local meteorological data (air temperatures, humidity and wind speeds.) via data link to the Master Control Station.
- From these data the MCS computes satellite ephemeride and the behavior of the satellite clocks and formulates the navigation data (message).

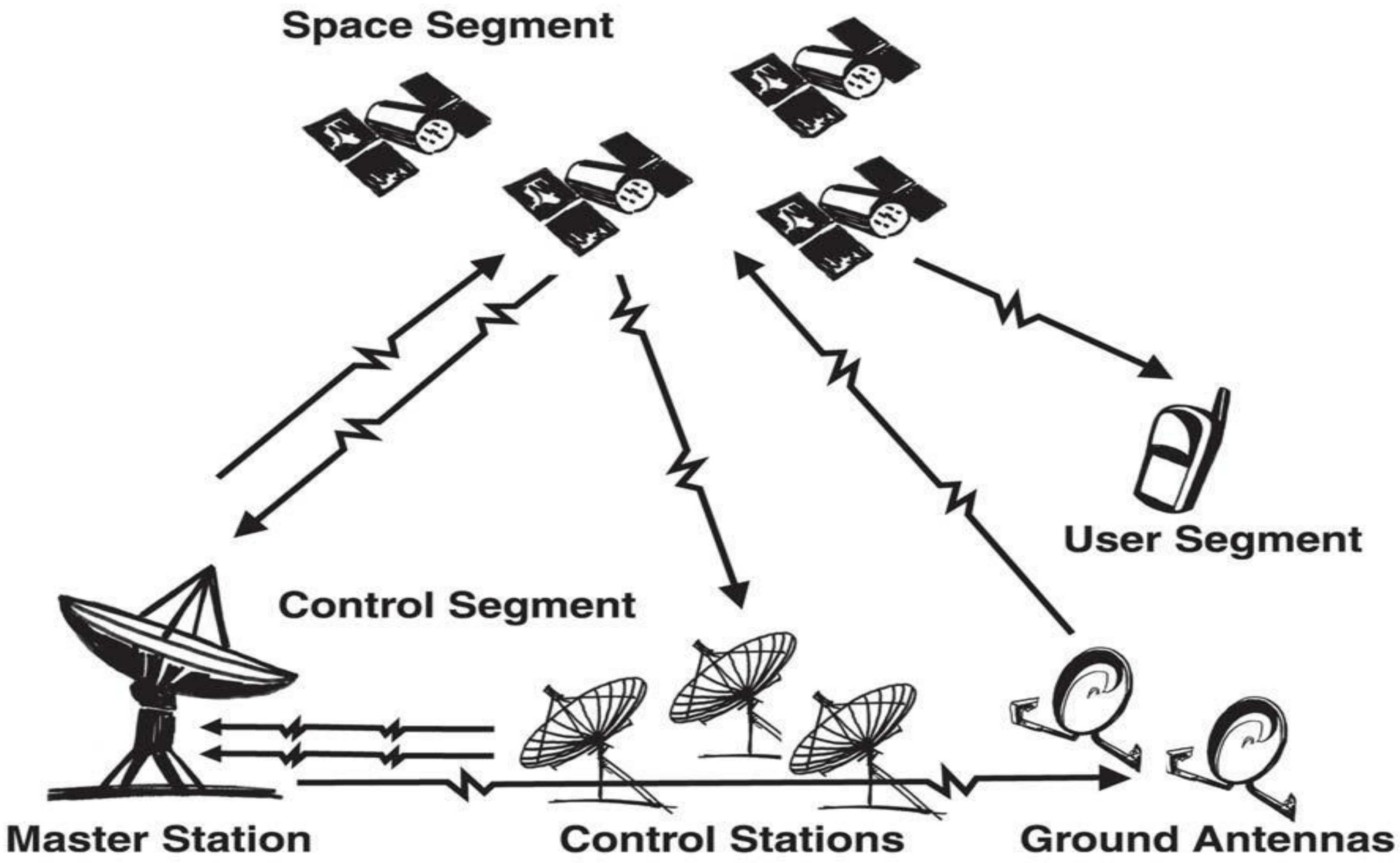
GPS segment



Cont..

- The message data are transmitted to the ground antennas and uplinked to the satellites in view.
- Because of the global distribution of the upload antennas (ground antenna) at least three contacts per day can be realized between the control segment and each particular satellite.

Cont…


Space Segment
User Segment
Control Segment
Master Station
Control Stations
Ground Antennas

Cont...

- Till date an operational control segment includes:
  - a Master Control Station
  - An alternative Master Control Station
  - 11 ground antenna
  - 16 monitoring station
- NOTE : four dedicated ground antennas, and
  six dedicated monitor stations (Control Station)

Contd…

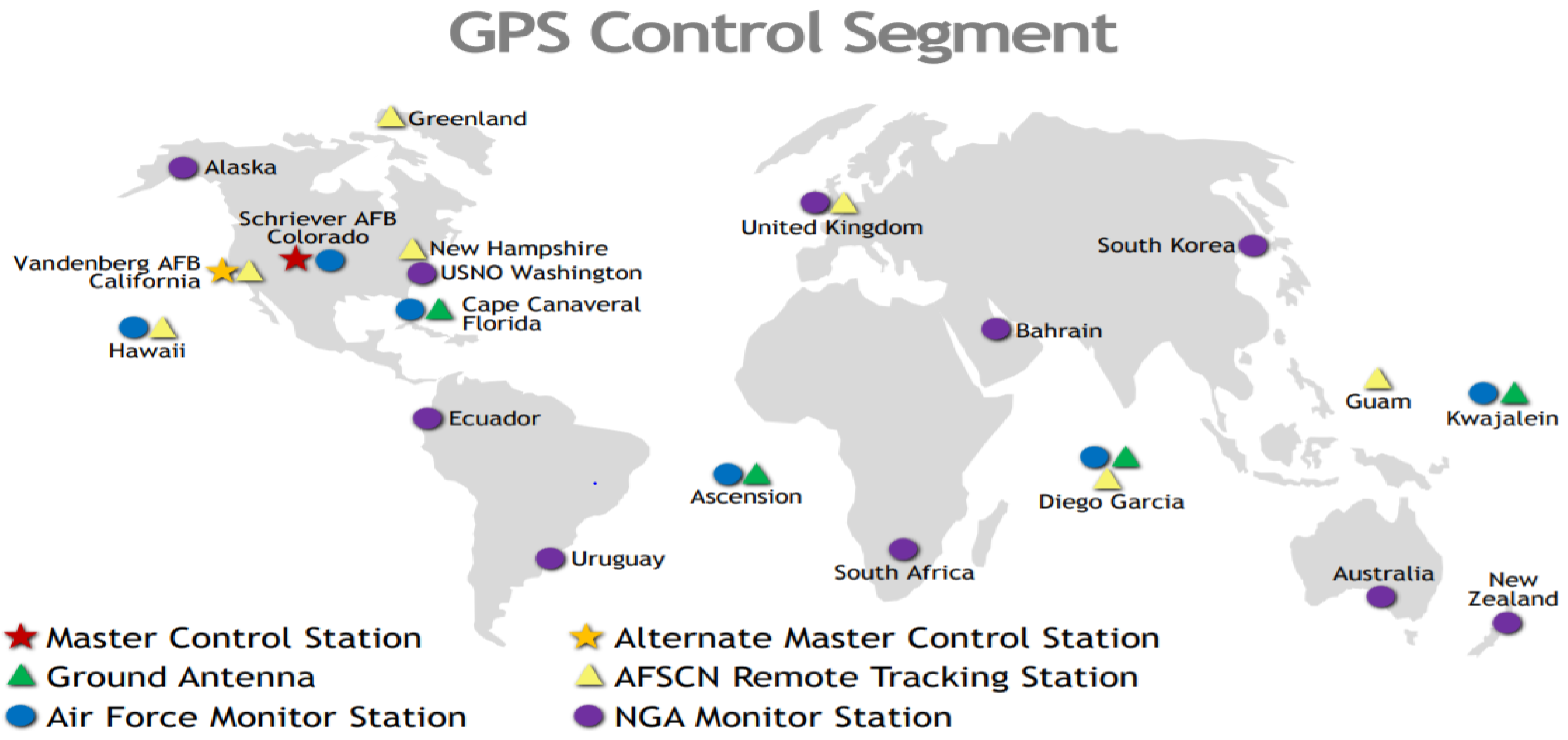


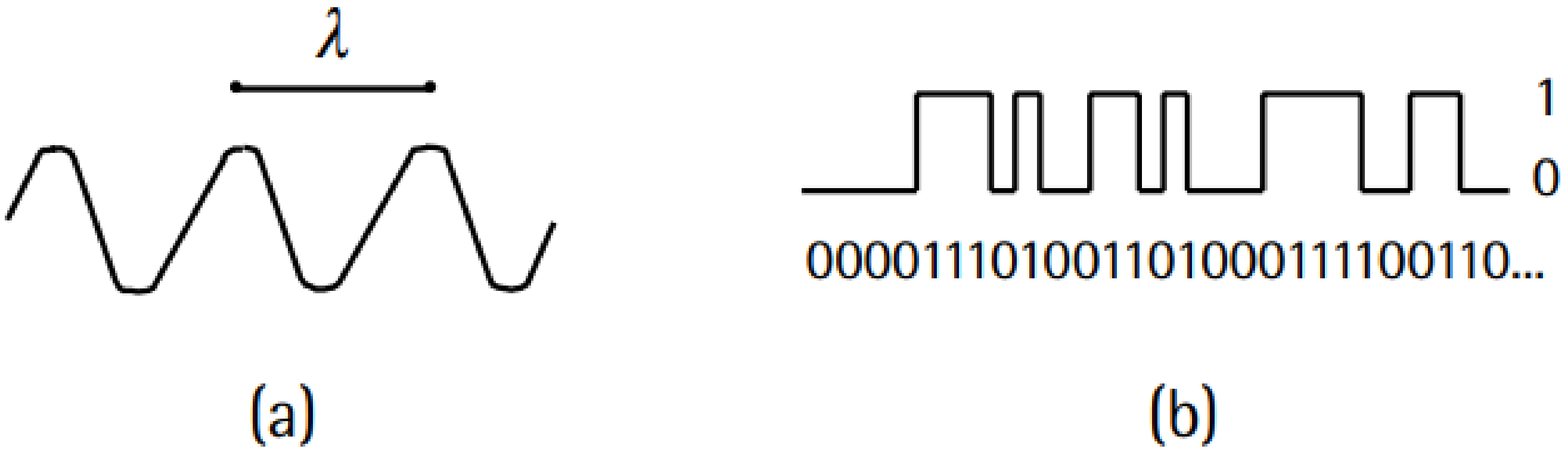
Fig : Control Segment

User Segment

- The user segment includes all military and civilian users.
- With a GPS receiver connected to a GPS antenna, a user can receive the GPS signals, which can be used to determine his or her position anywhere in the world.
- GPS is currently available to all users worldwide at no direct charge.

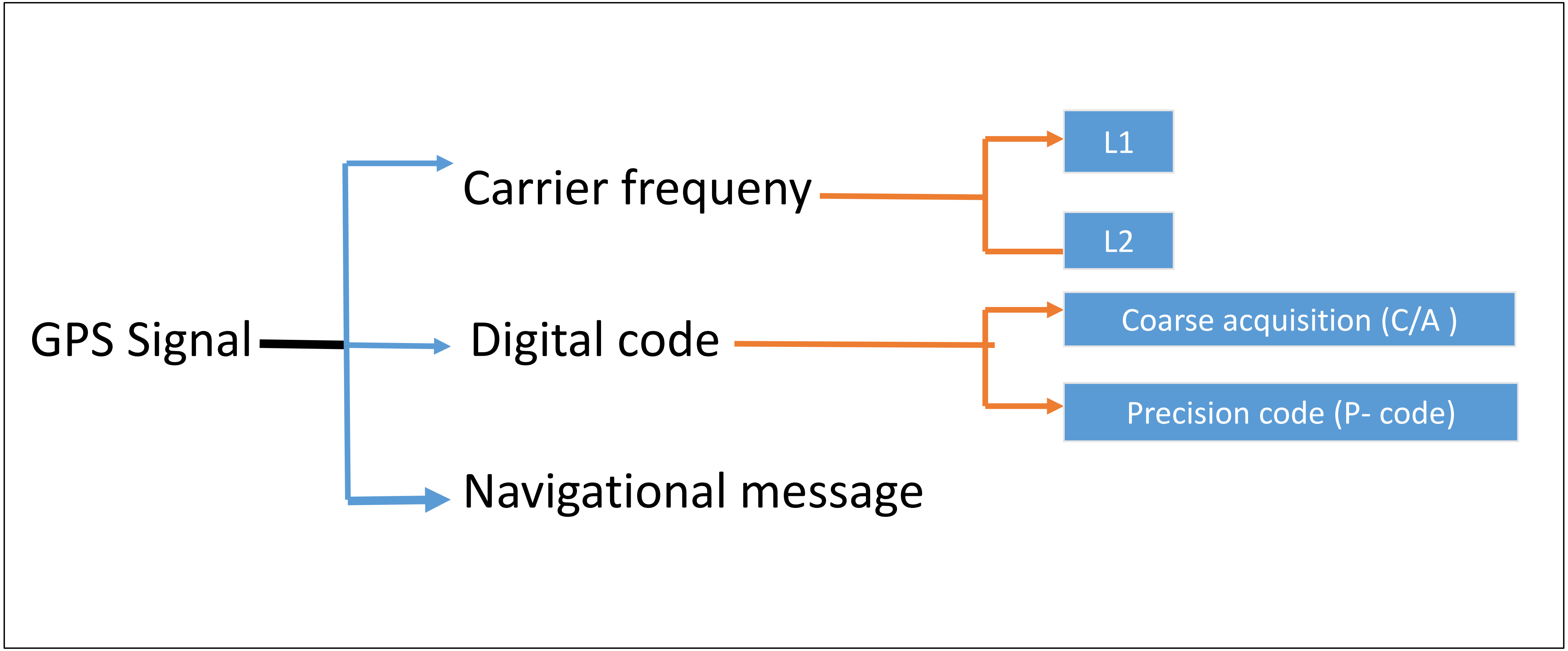
GPS Signals

- Each GPS satellite transmits a microwave radio signal composed of two carrier frequencies (or sine waves) modulated by two digital codes and a navigation message.



(a) A sinusoidal wave; and (b) a digital code.

Cont…


GPS Signal
Carrier frequeny
Digital code
Navigational message
L1
L2
Coarse acquisition (C/A)
Precision code (P- code)

2 carrier frequencies (L1 vs L2)

L1 Carrier	L2 Carrier
• Frequency = 1575.42 MHz	Frequency = 1227.60MHz
• Wavelength = 19 cm	Wavelength = 24.4 cm

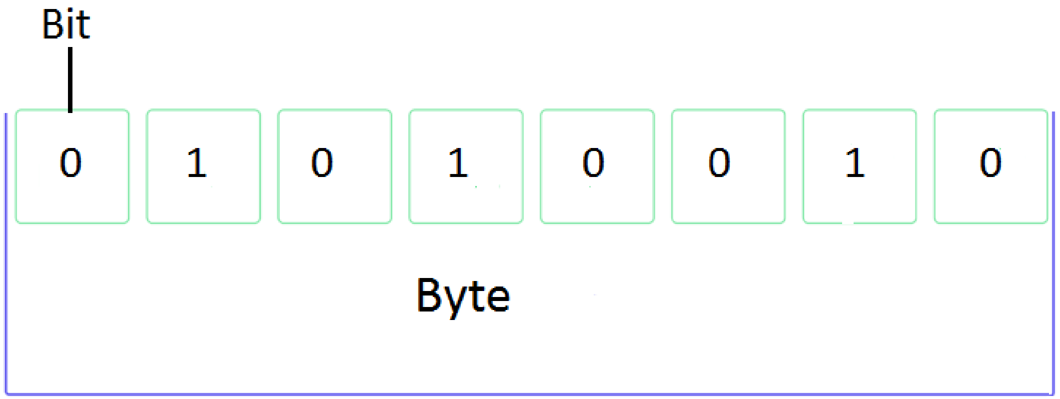
All satellite transmit same L1 and L2 Carrier frequencies

2 digital code (C/A code and P-code)

Coarse acquisition (c/a code)	Precision code (P-code)
• **Is a stream of 1023 binary digits (i.e., 1,023 zeros and ones), repeats itself every 1 millisec** • Chipping rate = 1.023 Mbps (i.e number of bits per second (chips per second)) • Duration of 1 bits =1ms (approx.), this equivalent to 300m long • Less precise than p-code • Widely used by civilians • Unique C/A code is assigned to identify satellite • Note = 1 mbps =1000000 bits = 1 second = 1000 millisecond	• **10 times faster than C/A code i.e chipping rate = 10.23Mbps, which repeats itself after 266 days** • **It has a stream of 2.35*10 power 14** **$10.23*10^6*266*86400$ = 2.35*10 power 14** • **266 long day code is divided into** **i. 32 segment = each segment 1 week long** **i.e each satellite transmit a unique 1-week segment of p- code initialized every Saturday/Sunday midnight crossing** **ii. 6 segment = reserved for other uses** **Note = 32 week + 6 week = 266 days** • **Mainly used for military purpose**

Contd…

- The P-code is designed primarily for military purposes. It was available to all users until January 3l, l994.
- At that time, the P-code was encrypted by adding to it an unknown W– code.
- This encryption is known as the anti-spoofing (AS).



8 bits = 1 Byte

Contd…

- **Navigational message**
- The GPS navigation message is a data stream added to both the Ll and the L2 carriers as binary biphase modulation at a low rate of 50 kbps.
- It consists of 25 frames of 1,500 bits each, or 37,500 bits in total
- This means that the transmission of the complete navigation message takes 750 seconds, or l2.5 minutes
- The navigation message contains, along with other information :

➢ the coordinates of the GPS satellites as a function of time

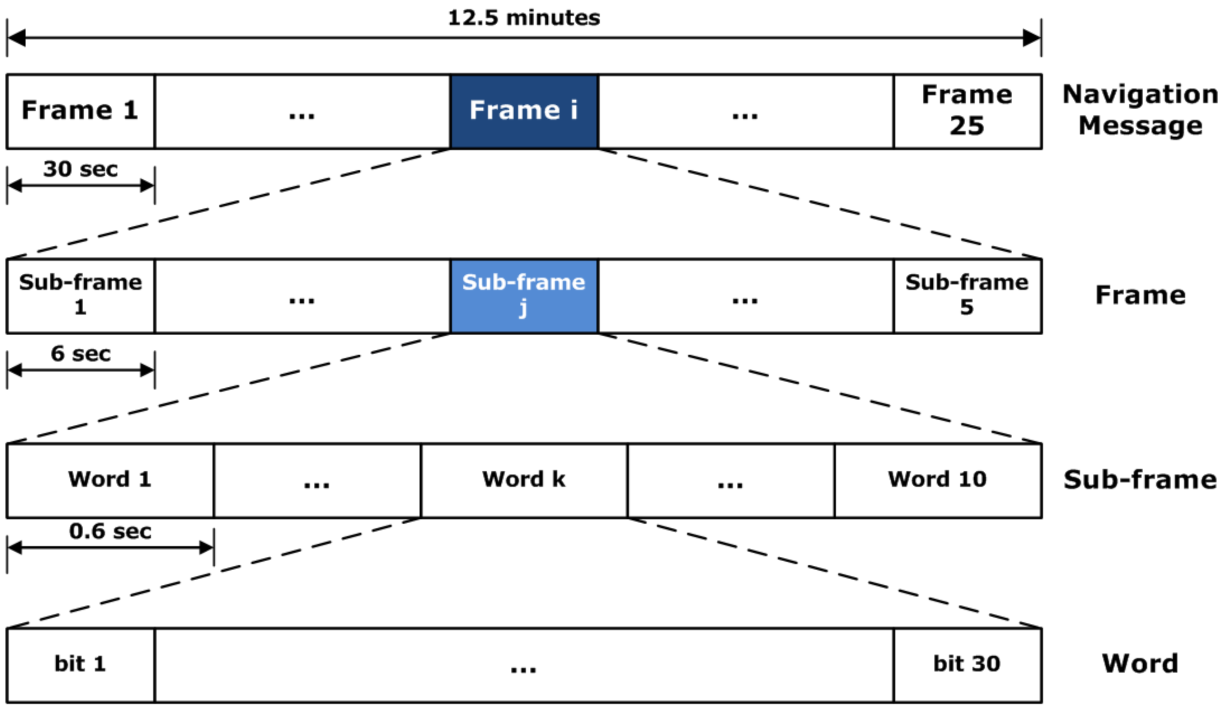
➢ the satellite health status

➢ the satellite clock correction

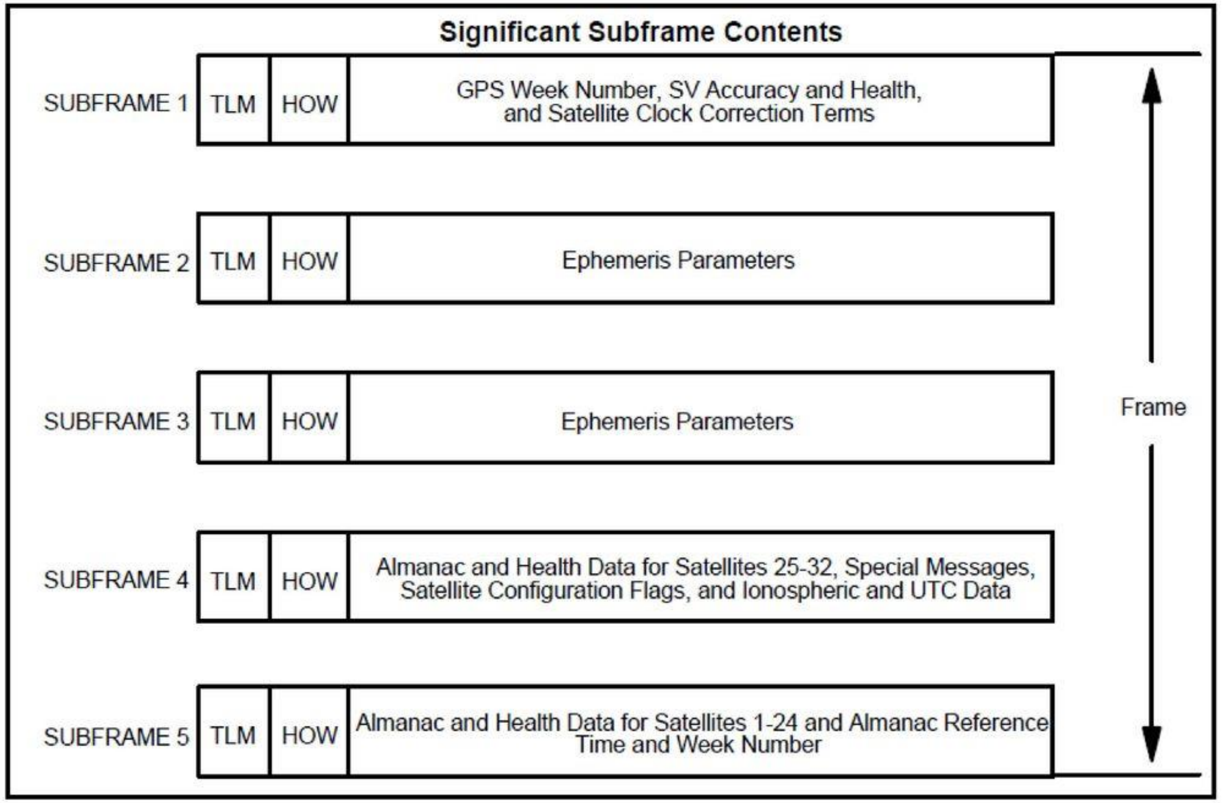
➢ the satellite almanac, and

atmospheric data.

Cont…



GPS Navigation Message



Contd…

- The navigation message contains, along with other information, the coordinates (the location) of the satellites as a function of time.
- The transmitted signals are controlled by highly accurate atomic clocks onboard the satellites.

Pseudorange measurement

- Pseudo-range = distance between the GPS receiver's antenna and the GPS satellite's antenna.
- Either the P-code or the C/A-code can be used for measuring the pseudorange.

i. Let us assume for a moment that both the satellite and the receiver clocks, which control the signal generation, are perfectly synchronized with each other.

ii. When the PRN(Pseudo random noise)code is transmitted from the satellite, the receiver generates an exact replica of that code.

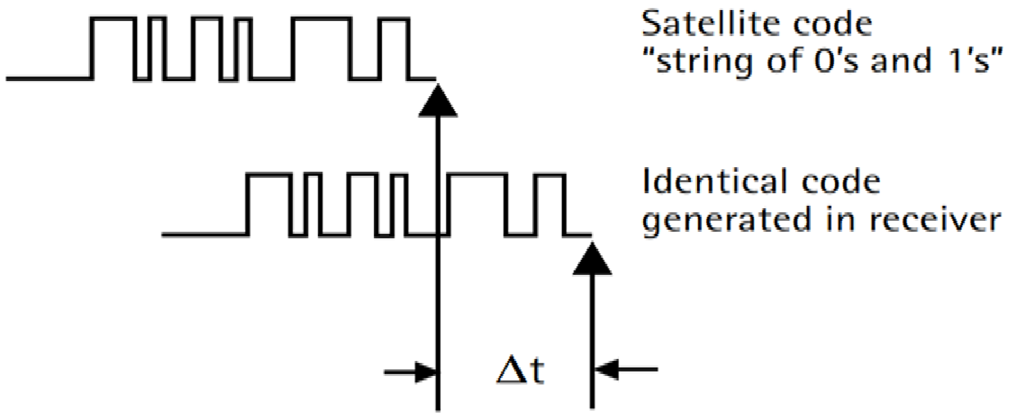


Figure 2.3 Pseudorange measurements.

Cont…

iii. After some times receiver picked the satellite signal

iv. Comparing transmitted and replicated code, receiver compute signal travel time

But Clocks are not perfectly synchronized

- ❖ So measured range contains error thus are referred as Pseudo range

Contd…

- But in reality receiver and satellite clocks synchronization is not exactly perfect.
- For this reason, this quantity is referred to as the pseudorange, not the exact range.

Carrier-phase measurement

- Another way of measuring the ranges to the satellites can be obtained through the carrier phases.
- $Range = (tot.no.of\ full\ carrier\ cycle + fractional\ cycle\ at\ receiver\ and\ satellite) * Carrier\ wavelength$

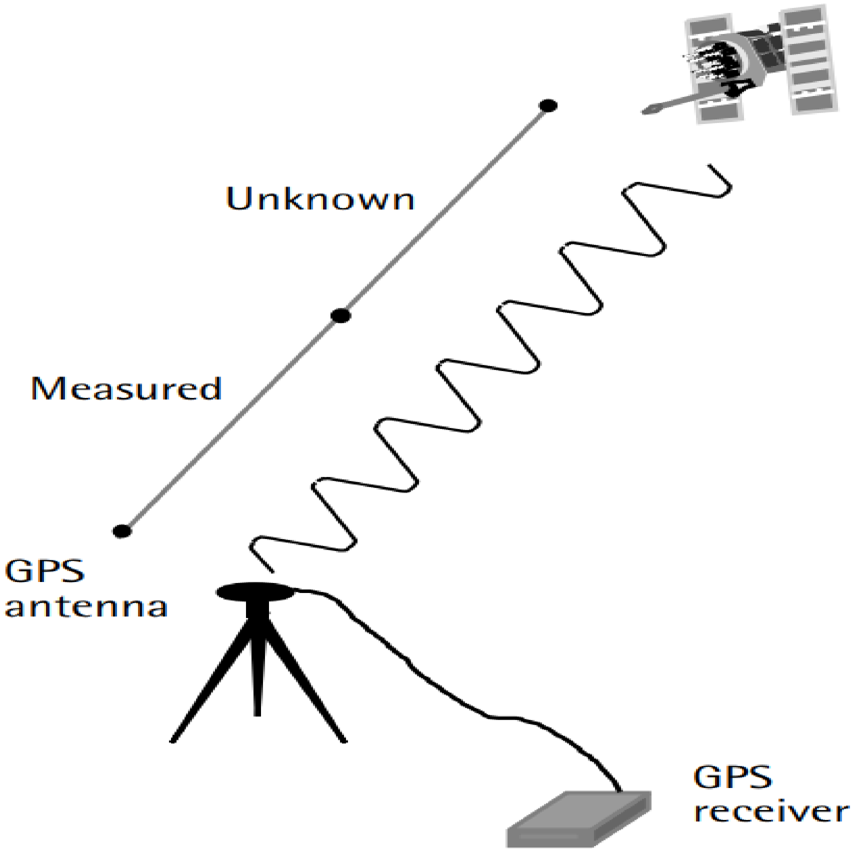


Figure 2.4 Carrier-phase measurements.

Contd…

- Carrier wave = pure sinusoidal waves, which means that all cycles look the same.
- Therefore, a GPS receiver has no means to differentiate one cycle from another.

✓In other words, the receiver, when it is switched on, cannot determine the total number of the complete cycles between the satellite and the receiver.

- initial number of complete cycles remains unknown, or ambiguous.
- This is commonly known as the initial cycle ambiguity, or the ambigu-ity bias.

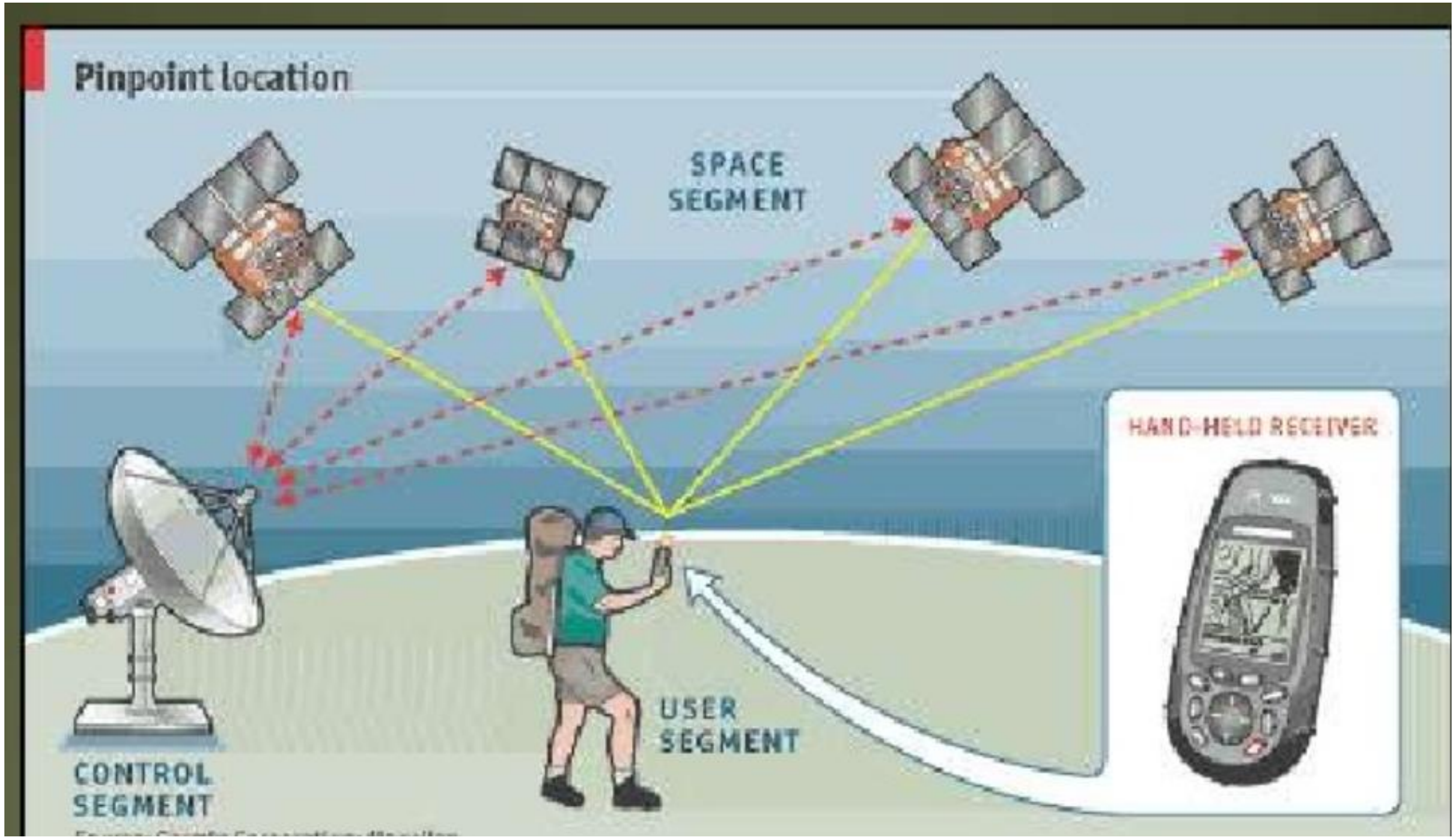
Contd…

- Fortunately

i. GPS receiver can track the phase change after being switched on.
ii. So that initial cycle ambiguity parameter is resolved

Working Principle of GPS

- The working/operation of Global positioning system is based on the ‘trilateration’ mathematical principle.



Contd…

- Things which is need to be determined before the receiver determines its position

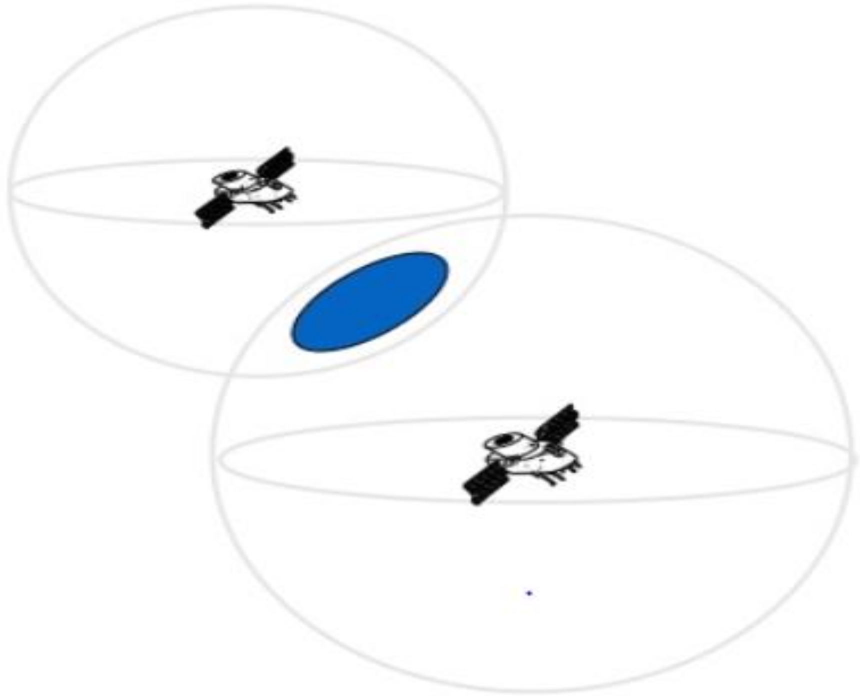
➢ Current locations of GPS satellite

➢ Range between satellite and receiver

- The orbit and the location of the satellites, are known in advances
- When the receiver receives the signal the ranges are computed by multiplying the time it take to reach the receiver with the velocity of radio wave (i.e speed of light).

Contd…

- Finally the receiver’s position is found out using the principle of Trilateration



•Distance measurements from two satellites limits our location to the intersection of two spheres, which is a circle.

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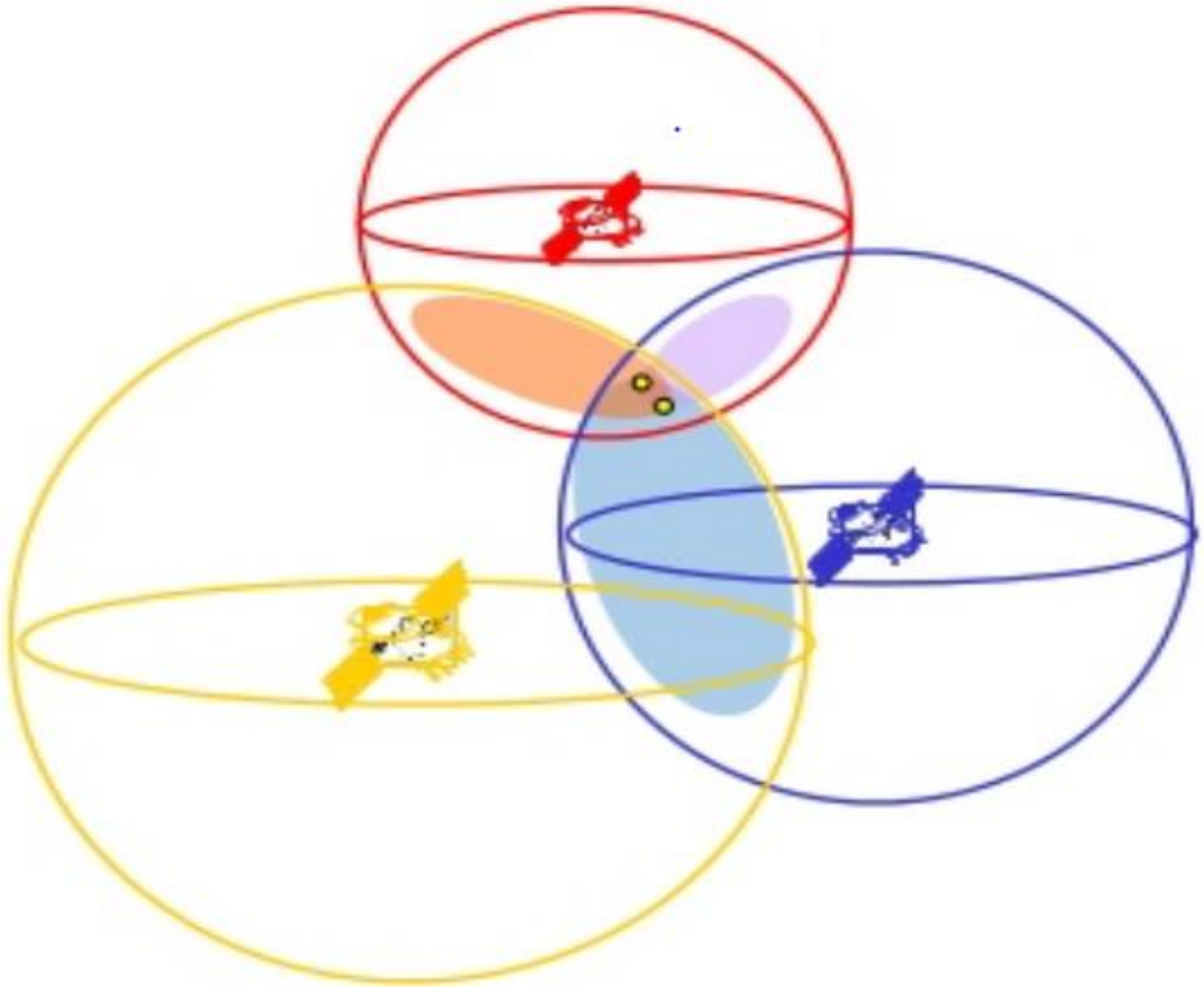
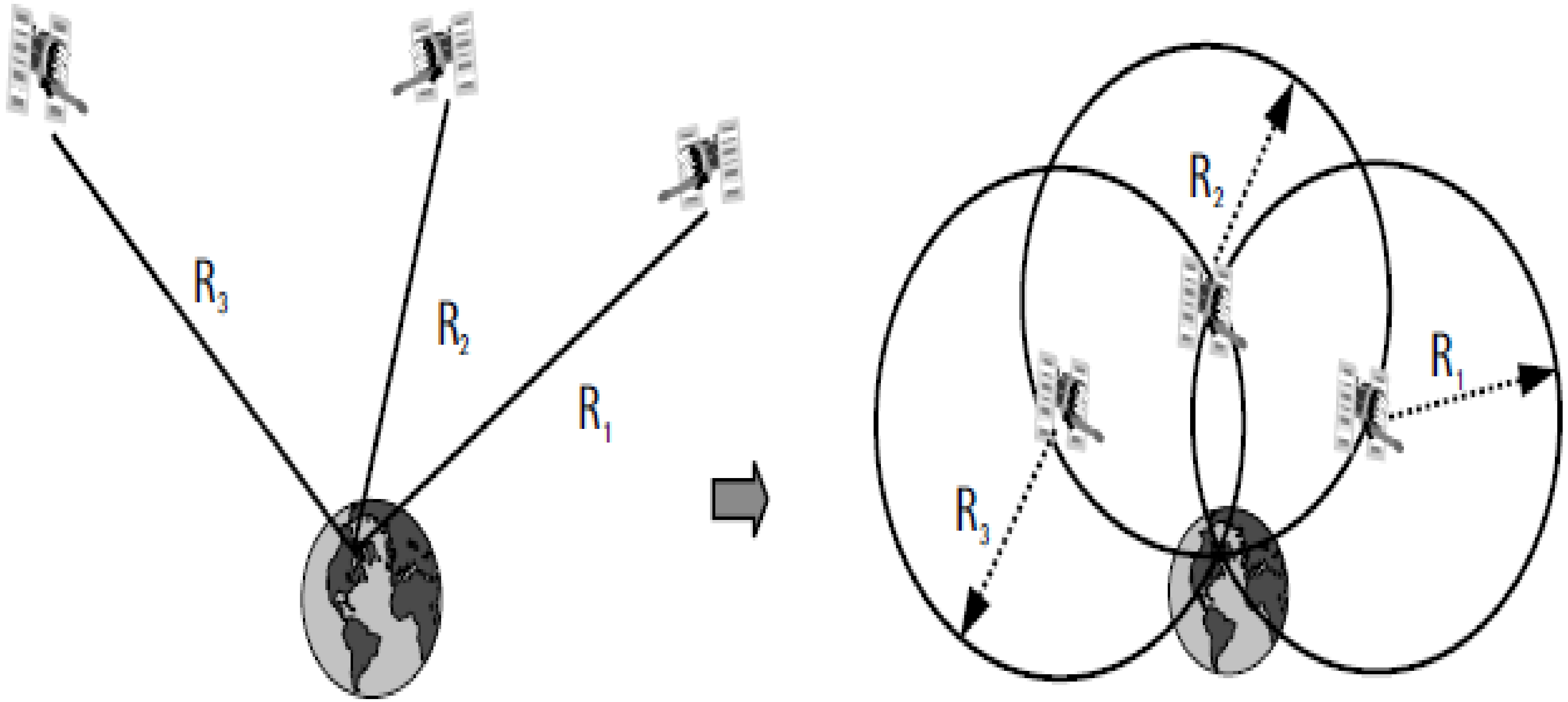


- A third measurement narrows our location to just two points.

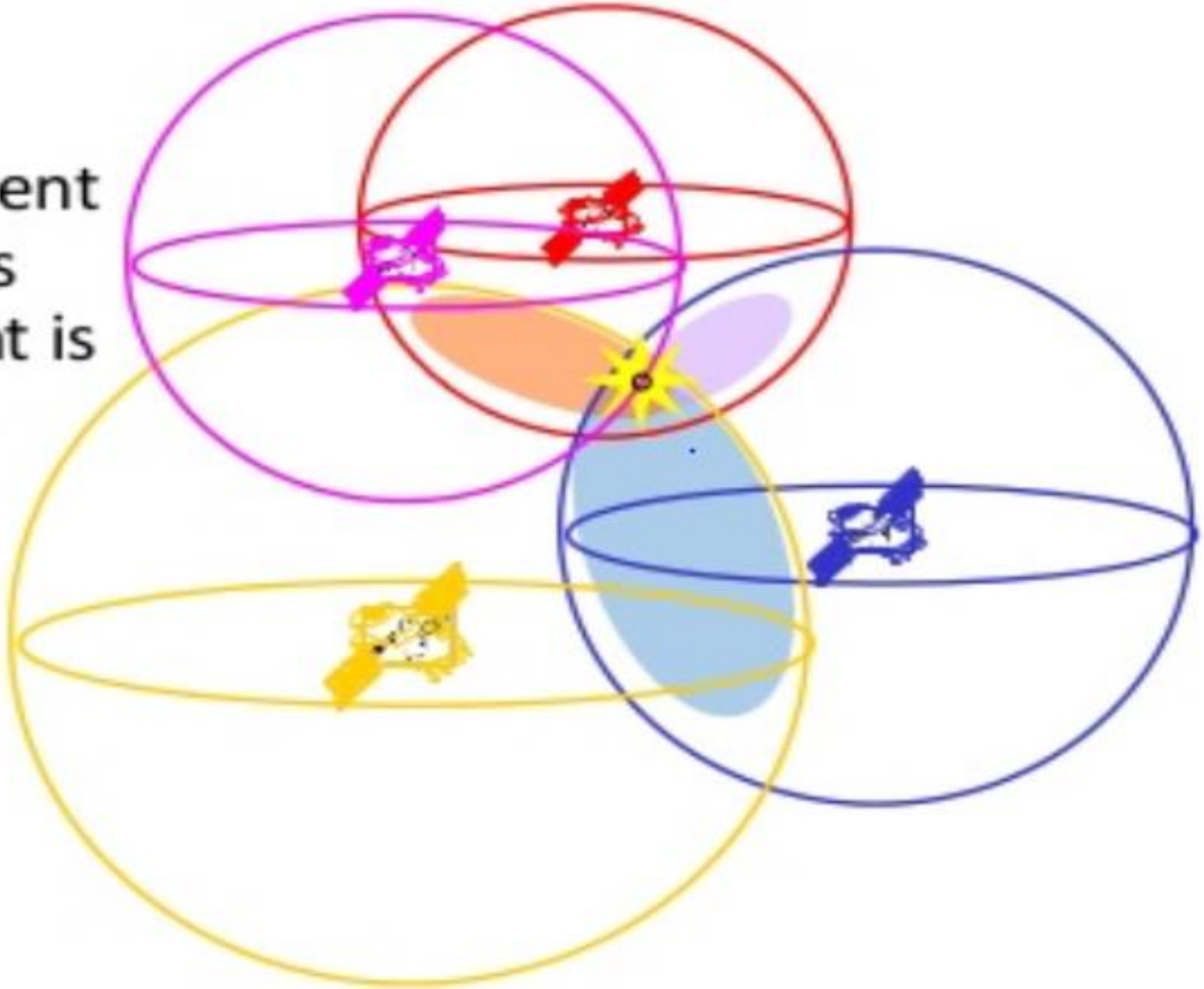
Contd…

- In principle, three satellites are enough to fix a position on the earth surface



Contd…

- A fourth measurement determines which point is our true location



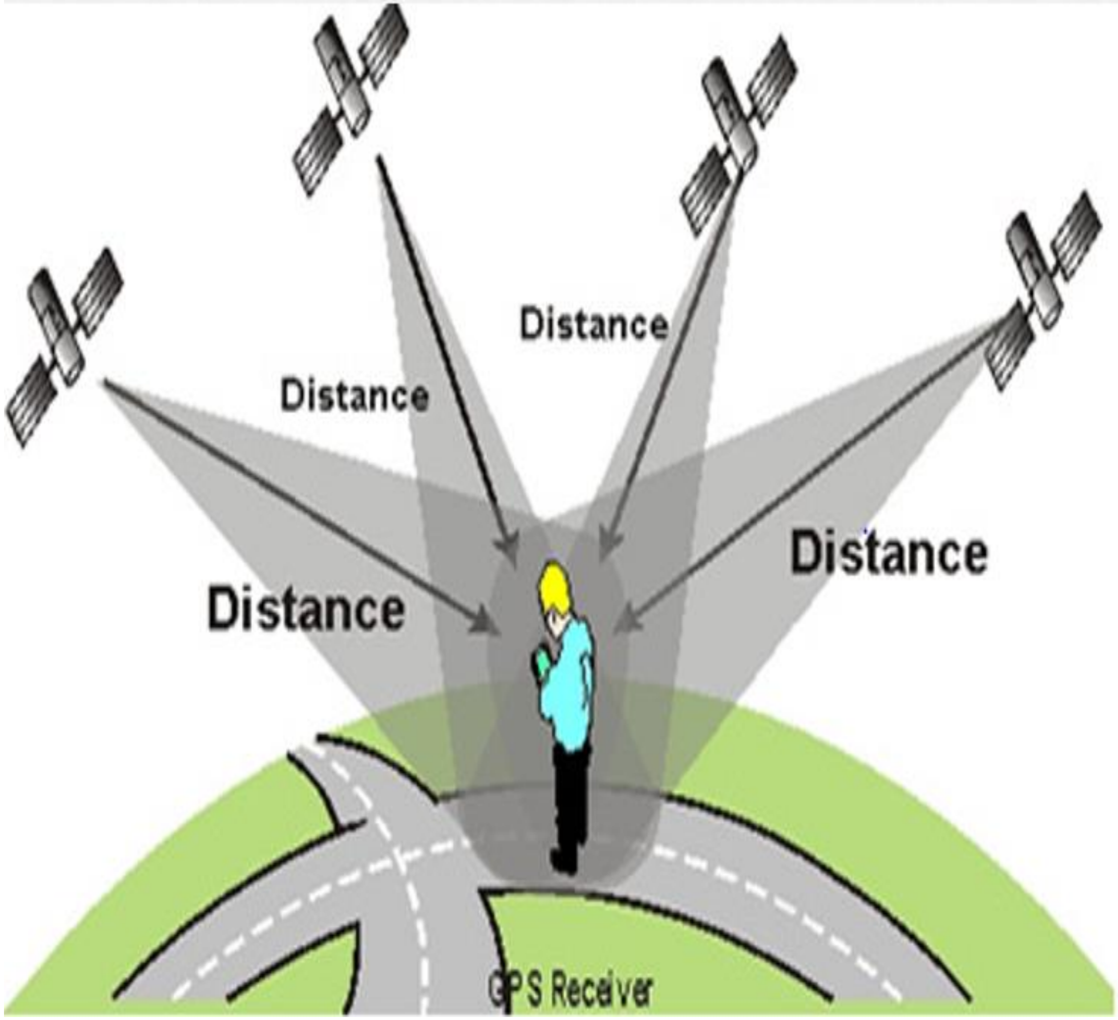
Contd…

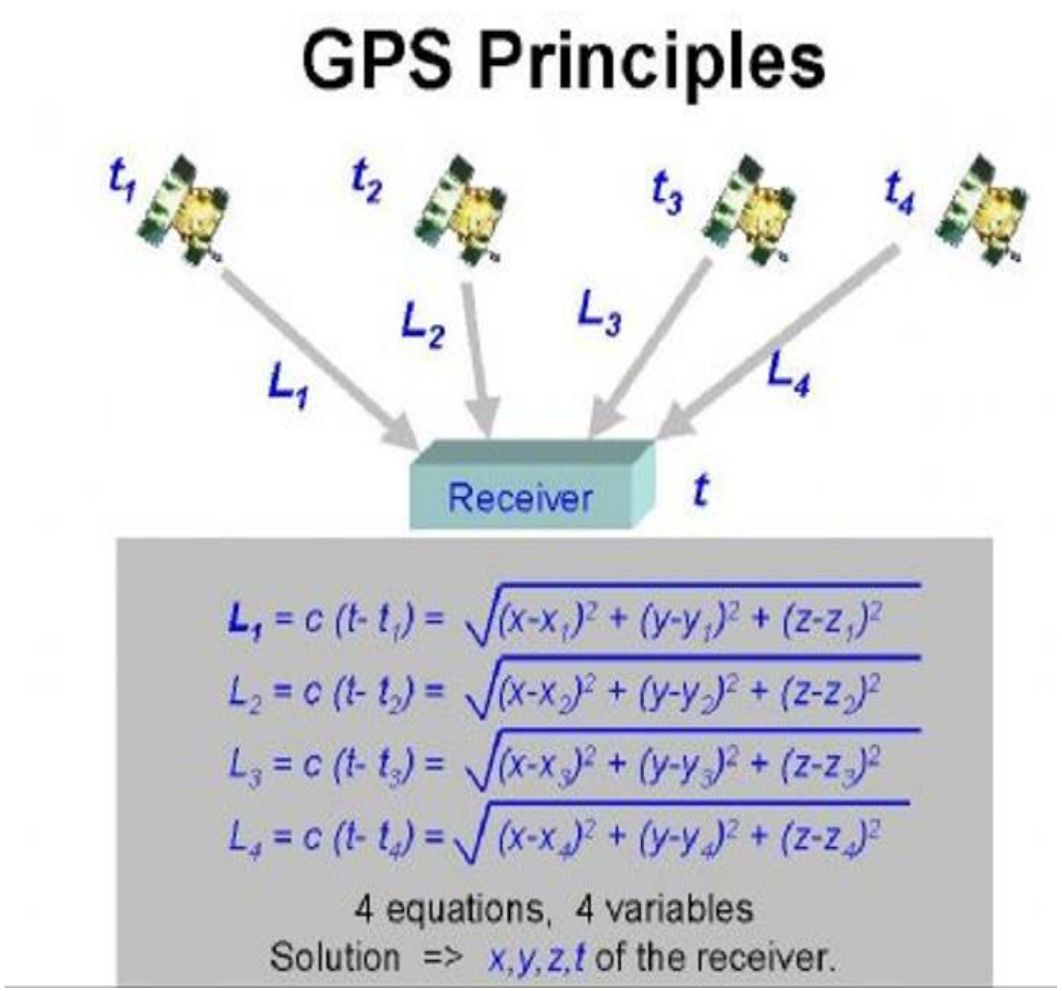
- But the clocks may have errors, especially the clocks at the receivers end are not exactly synchronised with the satellite clocks.
- This synchronization error is the reason for the term “pseudorange”
- For the receiver to measure time precisely a highly accurate, synchronized clock is needed.
- If the transit time is out by just 1 μs this produces a positional error of 300m.
- As the clocks onboard all three satellites are synchronized, the transit time in the case of all three measurements is inaccurate by the same amount.

Contd…

- To solve the problem, we can use a well known mathematical solution of equations
- If N variables are unknown, we need N independent equations.
- If the time measurement is accompanied by a constant unknown error, we will have four unknown variables in 3-D space:
  - Longitude (X)
  - Latitude (Y)
  - Height (Z)
  - time error (Δt)
- It therefore follows that in three-dimensional space four satellites are needed to determine a position.

Contd


Distance
Distance
Distance
Distance
Distance
GPS Receiver


GPS Principles
t_1
t_2
t_3
t_4
L_1
L_2
L_3
L_4
Receiver
t
$L_1 = c\,(t - t_1) = \sqrt{(x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2}$
$L_2 = c\,(t - t_2) = \sqrt{(x-x_2)^2 + (y-y_2)^2 + (z-z_2)^2}$
$L_3 = c\,(t - t_3) = \sqrt{(x-x_3)^2 + (y-y_3)^2 + (z-z_3)^2}$
$L_4 = c\,(t - t_4) = \sqrt{(x-x_4)^2 + (y-y_4)^2 + (z-z_4)^2}$
4 equations, 4 variables
Solution => x, y, z, t of the receiver.

Contd…

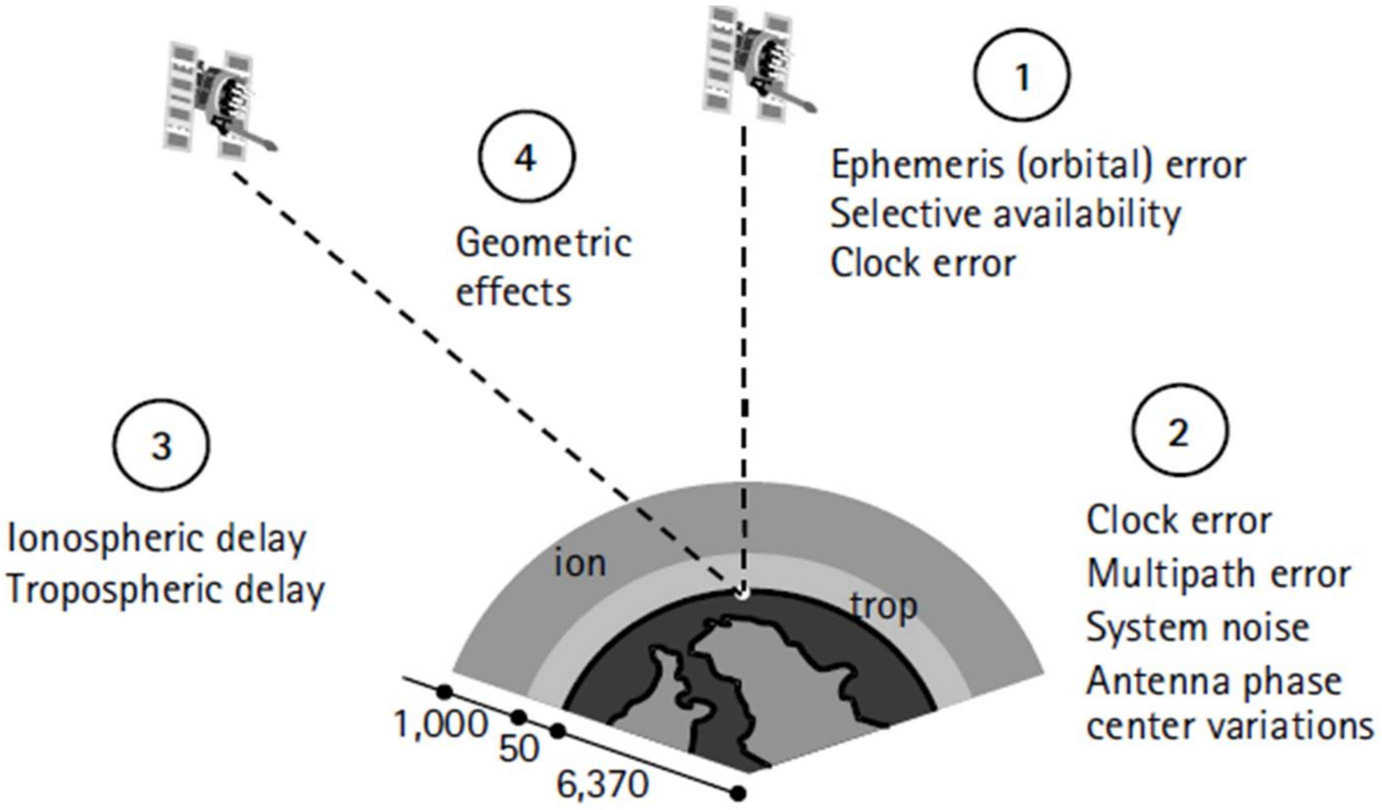
- In order to determine these four unknown variables, four independent equations are needed.
- The four transit times required, are supplied by the four different satellites
- The 24 GPS satellites are distributed around the globe in such a way that at least 4 of them are always “visible” from any point on Earth
- Despite receiver time errors, a position on a plane can be calculated very accurately
- It should be pointed out that if more than four satellites are tracked, the so-called least-squares estimation is applied.

Cont…

- GPS pseudo-range and carrier phase measurement are both affected by several types of errors
- Errors are classified as those originating at : Satellite

  Receiver

  Propagation



gure 3.1 GPS errors and biases.

Note: Apart from these error the result obtained is affected by :

i. Geometric Location of GPS satellite

Cont..

1. Ephemeris error(Orbital error)

- Expected orbit that the satellite follows are disturbed by various external(perturbation), gravity force
- So the actual position or the expected position for satellite may not be perfect
- Thus error ranges can vary from 2-5 m and can reach upto 50m under Selective availability
- For particular satellite this error is identical to all user
- But user see same satellite at different view angle so this affect the range measurement differently thus computed position.

Cont…

2. Selective availability (It was cancelled after 2002)

- Intentional error
- For security purpose
- Implemented first on Block II GPS satellite
- Officially activated in March 25, 1990
- Two types

i. Delta error = introduced by reducing(dithering) the satellite clock frequency and is common to all user

ii. Epsilon error = is slowly varying orbital error

Cont…

- Selective Availability (S/A) was the intentional degradation of the satellite signals by a time varying bias.
- Selective Availability is controlled by the DOD to limit accuracy for non - U.S. military and government users and was originally instituted for security reasons.

Cont…

- When SA turned on :

✓Nominal horizontal and vertical error reached upto 100m, 156m resp.

- For user at short separation range error due to epsilon error is identical
- How to minimize = ?????? DGPS
- With SA turned off:

✓ Hor. And Ver. Error in order of 22m, and 33m resp.

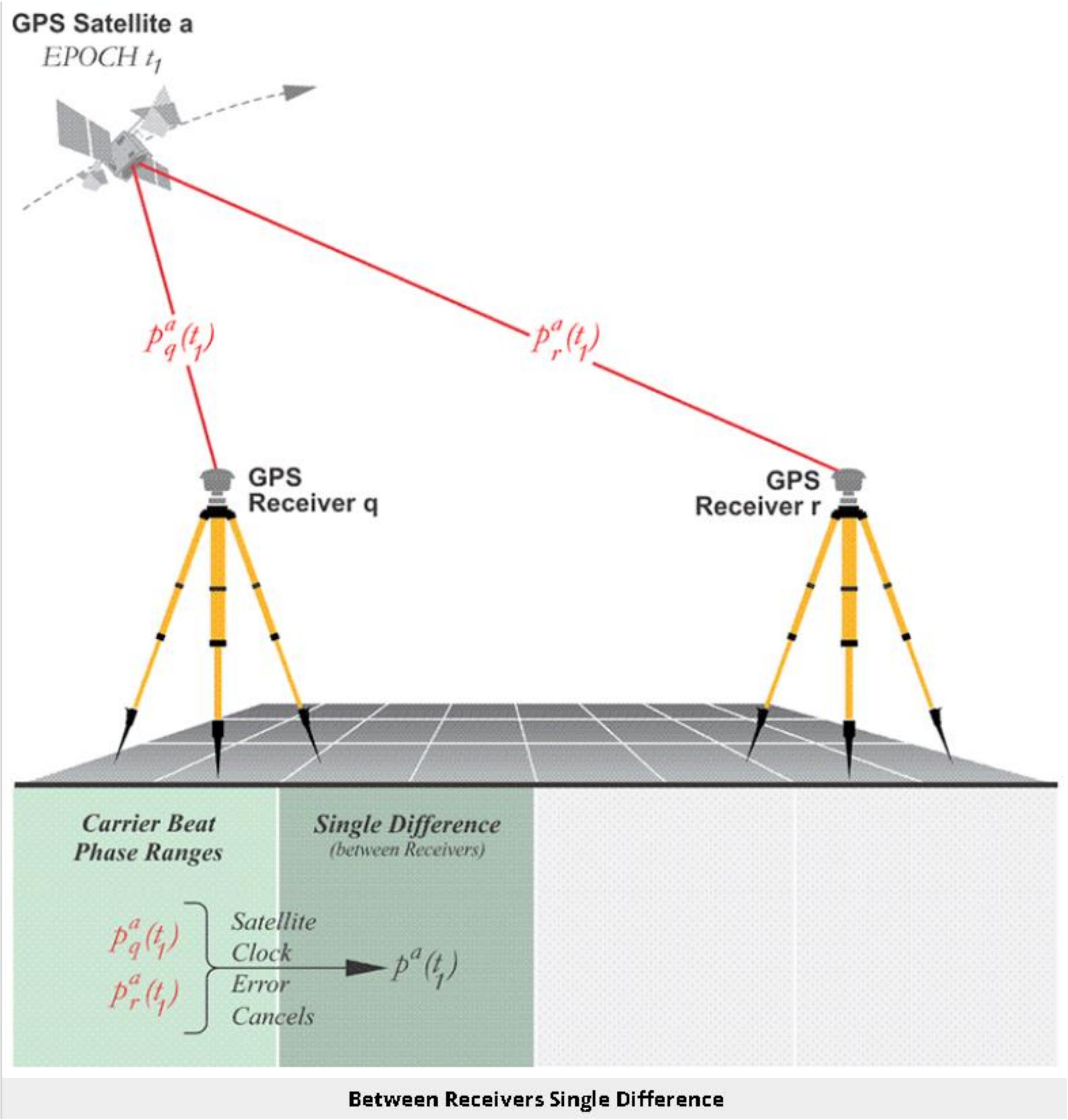
Satellite and receiver clock error

a.Satellite clock

- Highly accurate but not perfect
- Primarily made of cesium and rubidium
- Clock error ranges form 8.64 – 17.28 ns and corresponding range(distance) error 2.59m – 5.18m
- Control by Master control station
- Common to all user observing same satellite
- How removed =???? Differencing between receiver

Concept of differencing

- Between-receiver
  - One of the foundations of differencing is the idea of the baseline as it is used in GNSS.
  - For example, a single difference, also known as a between-receivers difference, can refer to the difference in the simultaneous carrier phase measurements from one GPS satellite as measured by two different receivers.
  - Since the two receivers are both observing the same satellite at the same time, the difference between the satellite clock bias, *dt*, at the first receiver and *dt* at the second receiver, *Δdt*, tends to be zero.



Contd…

- Also, since the baseline is typically short compared with the 20,200-km altitude of the GPS satellites, the atmospheric biases and the orbital errors, i.e., ephemeris errors, recorded by the two receivers at each end are similar.
- This correlation obviously decreases as the length of the baseline increases. Generally, this correlation allows centimeter level carrier phase positioning with baselines up to 10km
- And meter level positioning with baselines of a few hundreds of kilometers using pseudorange observations.

Cont…

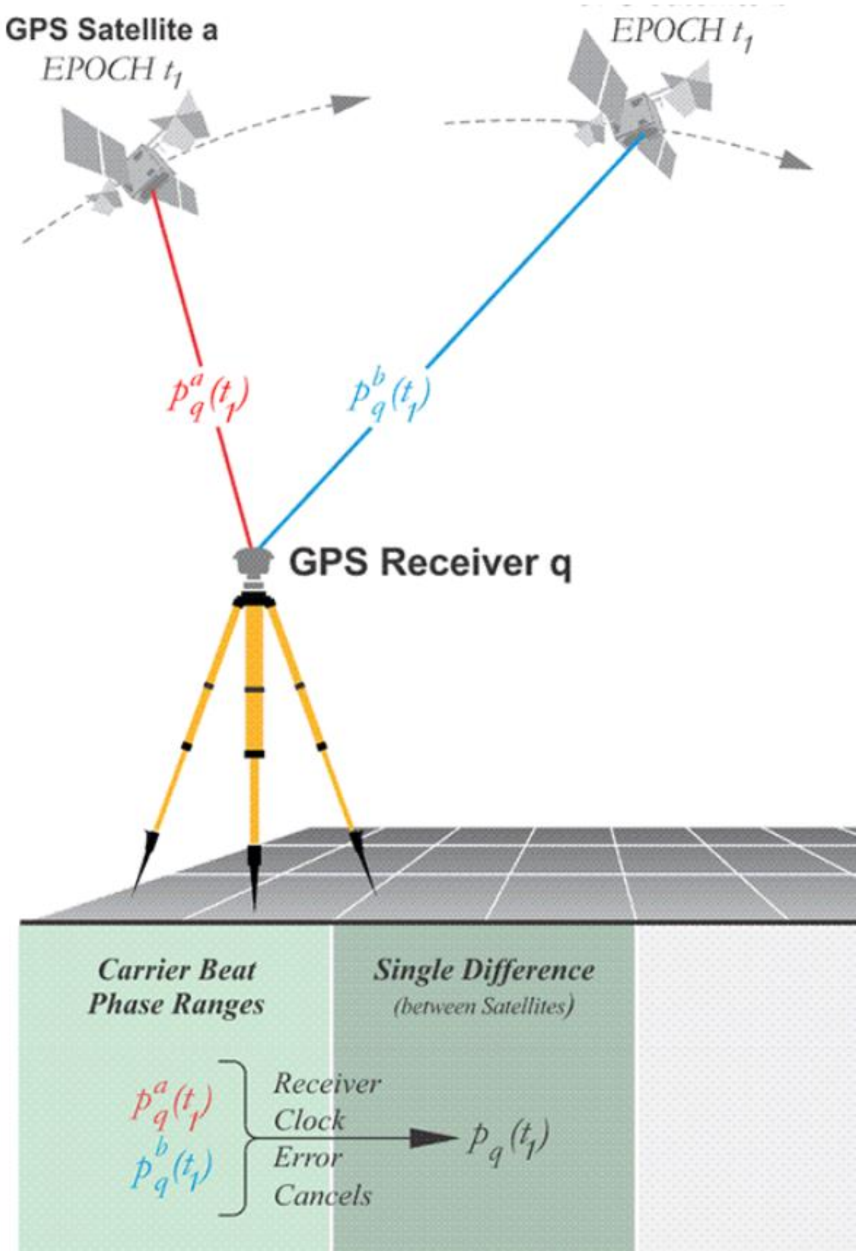
b. **<u>Receiver error</u>**

- use inexpensive crystal clock
- Less accurate the satellite clock
- How removed =??? Differencing between satellite
- cost of clock few thousand dollars for the rubidium clocks to about $20,000 for the cesium clocks.

Contd...

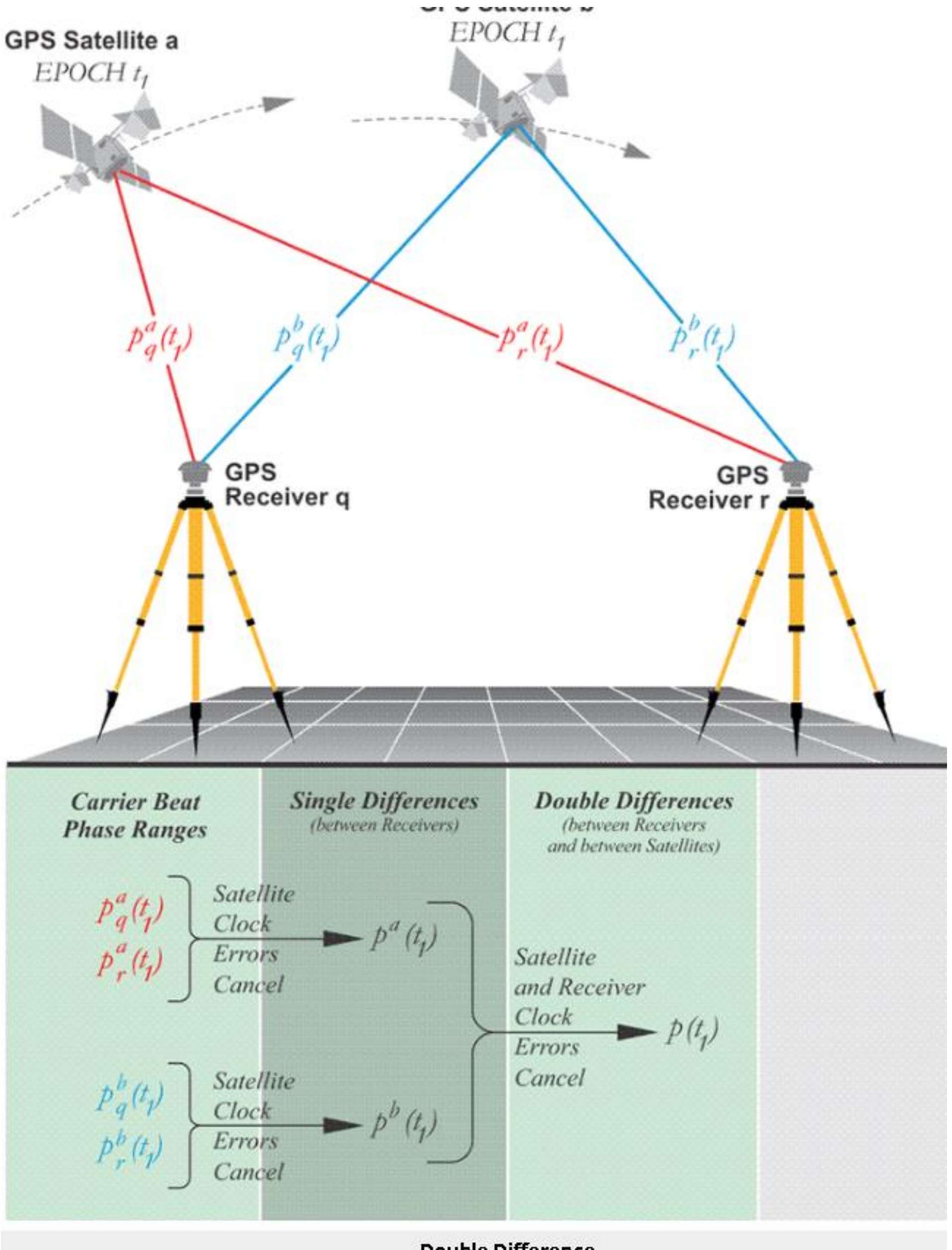
- Between satellite

  - The between-satellites single difference involves a single receiver observing two GPS satellites simultaneously and the code and/or phase measurement of one satellite are *differenced*, subtracted, from the other.
  - The data available from the between-satellites difference allows the elimination of the receiver clock error because there is only one involved. And the atmospheric effects on the two satellite signals are again nearly identical as they come into the single receiver, so the effects of the ionospheric and tropospheric delays are reduced.



Contd…

- Double differencing
  - ➢When the two types of single differences are combined, the result is known as a double difference. A double difference can be said to be a between-satellite single difference of a between-receiver single difference.



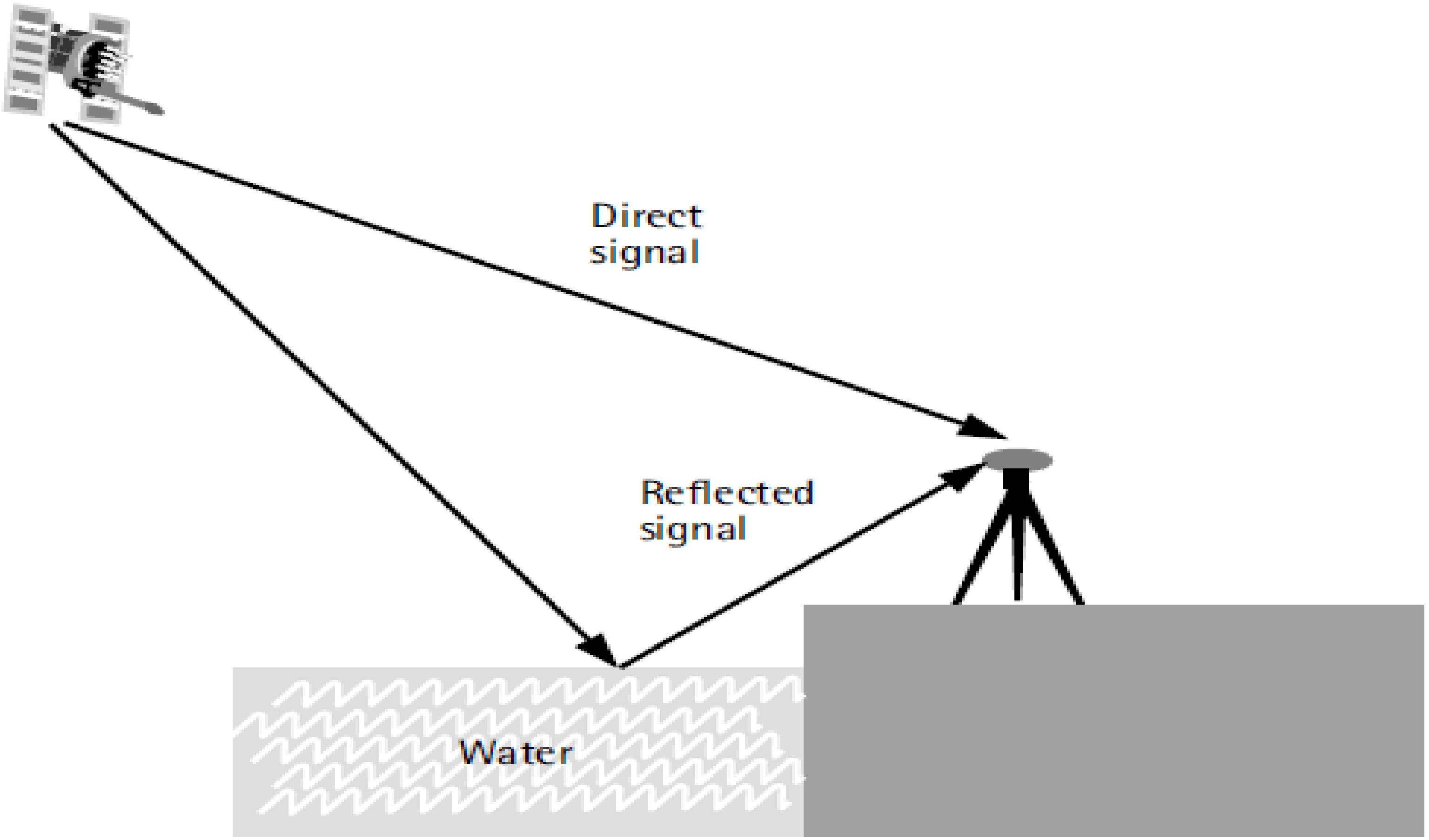
Cont…

3.Multi-path error

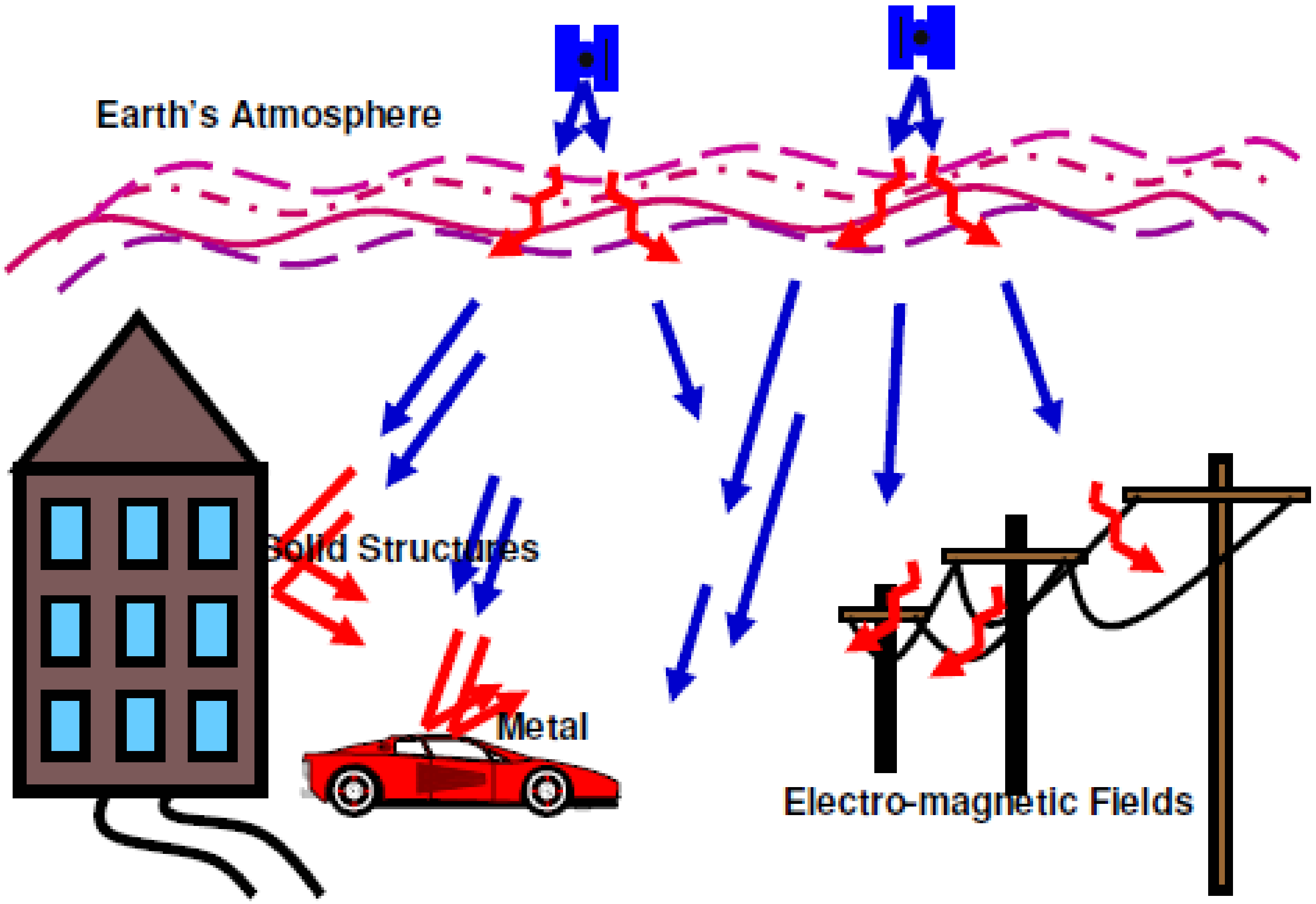
- Major source of error
- Occur when GPS signal arrives at receiver antenna through different path
- It distorts the original signal through interference with the reflected signal at GPS antenna
- Multipath error in

    pseudo-range > carrier phase measurement

Multipath interference



Multipath interference



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How removed

✓As possible avoid obstruction

✓Use of chock ring antenna (is concentric metal hoops)

➢ *Go through :* https://www.intechopen.com/chapters/72133

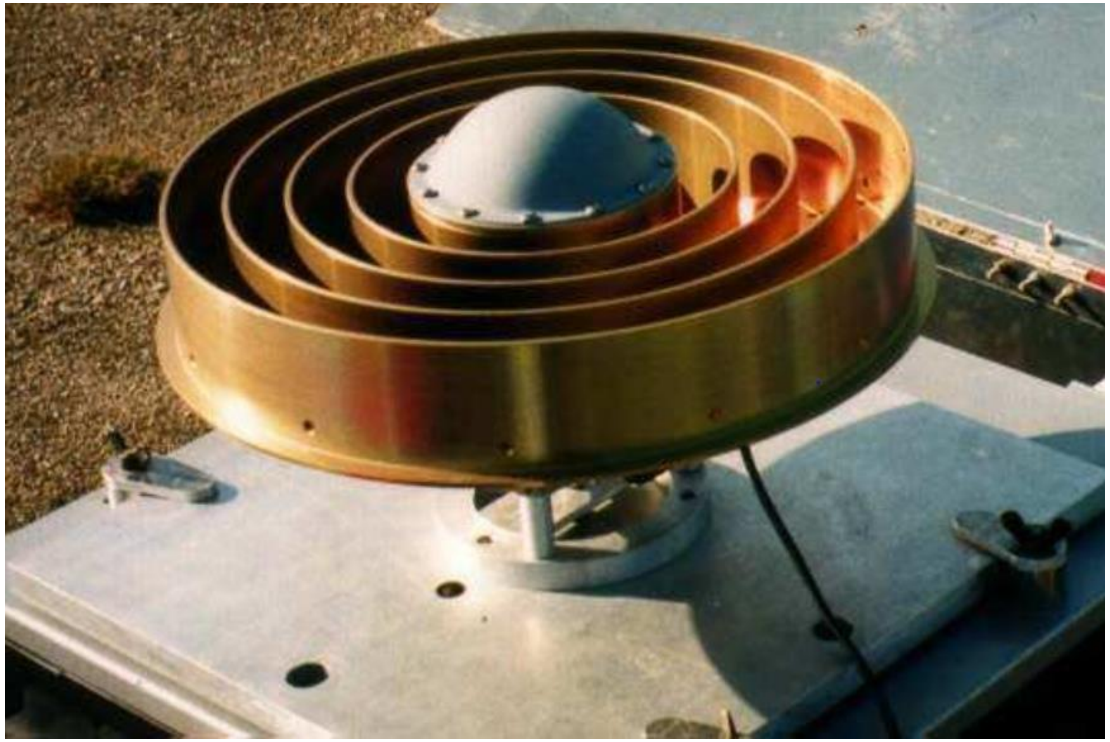

Fig : Chock ring antenna type receiver

Ionospheric interference

- The ionosphere is the layer of the atmosphere from 50 to 1000 km altitude that consists primarily of ionized air.
- Ionospheric interference causes the GPS satellite radio signals to be refracted as they pass through the earth's atmosphere – causing the signals to slow down or speed up.
- This results in inaccurate position measurements by GPS receivers on the ground.
- Even though the satellite signals contain correction information for ionospheric interference, it can only remove about half of the possible 70 nanoseconds of delay, leaving potentially up to a ten meter horizontal error on the ground.
- GPS receivers also attempt to "average" the amount of signal speed reduction caused by the atmosphere when they calculate a position fix.

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- Tropospheric delay
  - ➢Electrically neutral region
  - ➢50 km from surface of earth
  - ➢In non dispersive medium for radio frequency below 15GHz
  - ➢Depends on : temperature, pressure , humidity
  - ➢Tropospheric delay is maximum at user zenith
  - ➢Minimum near horizon

- **Number of satellites visible:** The more satellites the receiver can “see”, the better the accuracy. Signal reception can be blocked by buildings, terrain, electronic interference and sometimes dense foliage. The clearer the view, to the receiver, the better the reception.
- **Satellite geometry:** This refers to the relative position of the satellites at any given time. Ideal satellite geometry exists when the satellites are located at wide angles relative to each other. Poor geometry exists when the satellites are located in a line or in a tight grouping.

- The satellite geometry effect can be measured by a single dimensionless number called the dilution of precision (DOP). The lower the value of the DOP number, the better the geometric strength, and vice versa.
- The DOP number is computed based on the relative receiver-satellite geometry at any instance, that is, it requires the availability of both the receiver and the satellite coordinates.

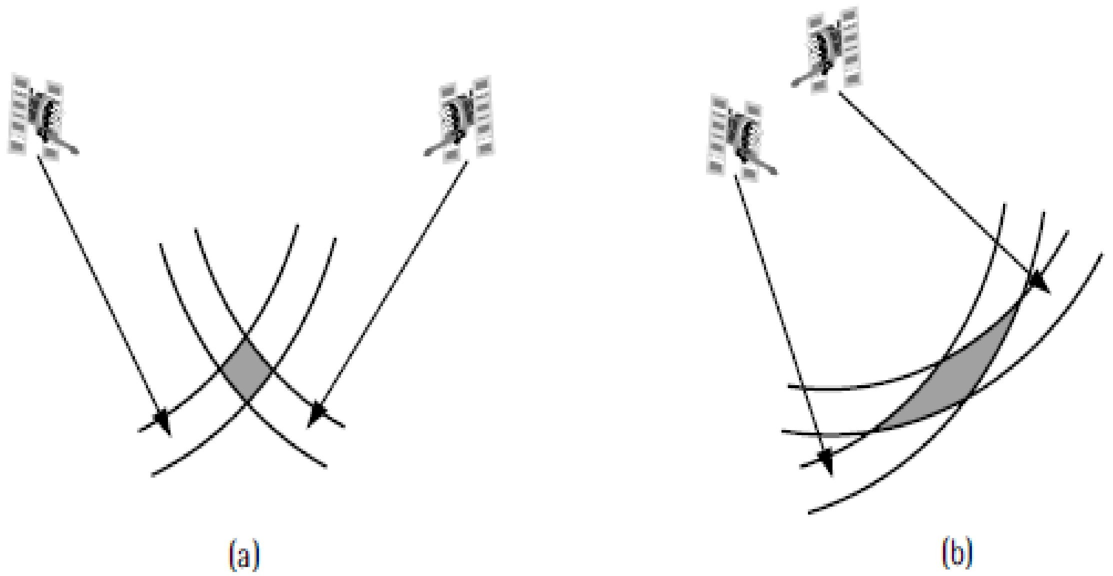

Figure 3.7 (a) Good satellite geometry; and (b) bad satellite geometry.

Almanac

- Data transmitted by a GPS satellite which includes orbit information on all the satellites and health of satellites, satellite clock correction, and atmospheric delay parameters.
- These data are used to facilitate rapid SV acquisition. The orbit information is a subset of the ephemeris data with reduced accuracy. Information on the entire GPS constellation is transmitted by each GPS satellite. For reading a complete new almanac it takes 12.5 minutes. There are two different Almanac formats: the SEM format and the YUMA format The YUMA format, which is used by a variety of satellite tracking programs, defines 13 parameters:

➢ ID

➢ PRN of the SVN Health:

➢ Eccentricity: This shows the amount of the orbit deviation from circular (orbit). It is the distance between the foci divided by the length of the semi-major axis (our orbits are very circular).

➢ Time of Applicability: The number of seconds in the orbit when the almanac was generated.

➢ Orbital Inclination: The angle to which the SV orbit meets the equator (GPS is at approx. 55 degrees). Roughly, the SV's orbit will not rise above approx. 55 degrees latitude.

Almanac

- ➢Rate of Right Ascension: Rate of change of the angle of right ascension
- ➢RightS QRT(A) Square Root of Semi-Major Axis: This is defined as the measurement from the center of the orbit to either the point of apogee or the point of perigee.
- ➢ Ascension at Time of Almanac (TOA): Right Ascension is the angle between the vernal equinox and the ascending node.
- ➢Argument of Perigee: An angular measurement along the orbital path measured from the ascending node to the point of perigee, measured in the direction of the SV's motion.
- ➢ Mean Anomaly: Angle (arc) traveled past the longitude of ascending node (value= 0-180 degrees or 0-negative 180 degrees). If the value exceeds 180 degrees, subtract 360 degrees to find the mean anomaly. When the SV has passed perigee and heading towards apogee, the mean anomaly is positive. After the point of apogee, the mean anomaly value will be negative to the point of perigee. Af(0): SV clock bias in seconds Af(1): SV clock Drift in seconds per seconds week: GPS week (0000-1024), every 7 days since 6 Jan 1980/0000z

- Constellation

Refers to either the specific set of satellites used in calculating a position, or all the satellites visible to a GPS receiver at one time, or the entire ensemble of GPS satellites comprising the Space Segment.

- Cutoff Angle

The minimum acceptable satellite elevation angle (above the horizon) to avoid blockage of line of-sight, multipath errors or too high Tropospheric or Ionospheric Delay values. May be preset in the receiver, or applied during data post-processing. For navigation receivers may be set as low as 5°, while for GPS Surveying typically a cutoff angle of 15° is used.

- Cycle Slip

A discontinuity in the carrier phase measurement resulting from a temporary loss of lock in the carrier tracking loop of a GPS receiver. It indicates that a receiver has momentarily lost the signal from a satellite

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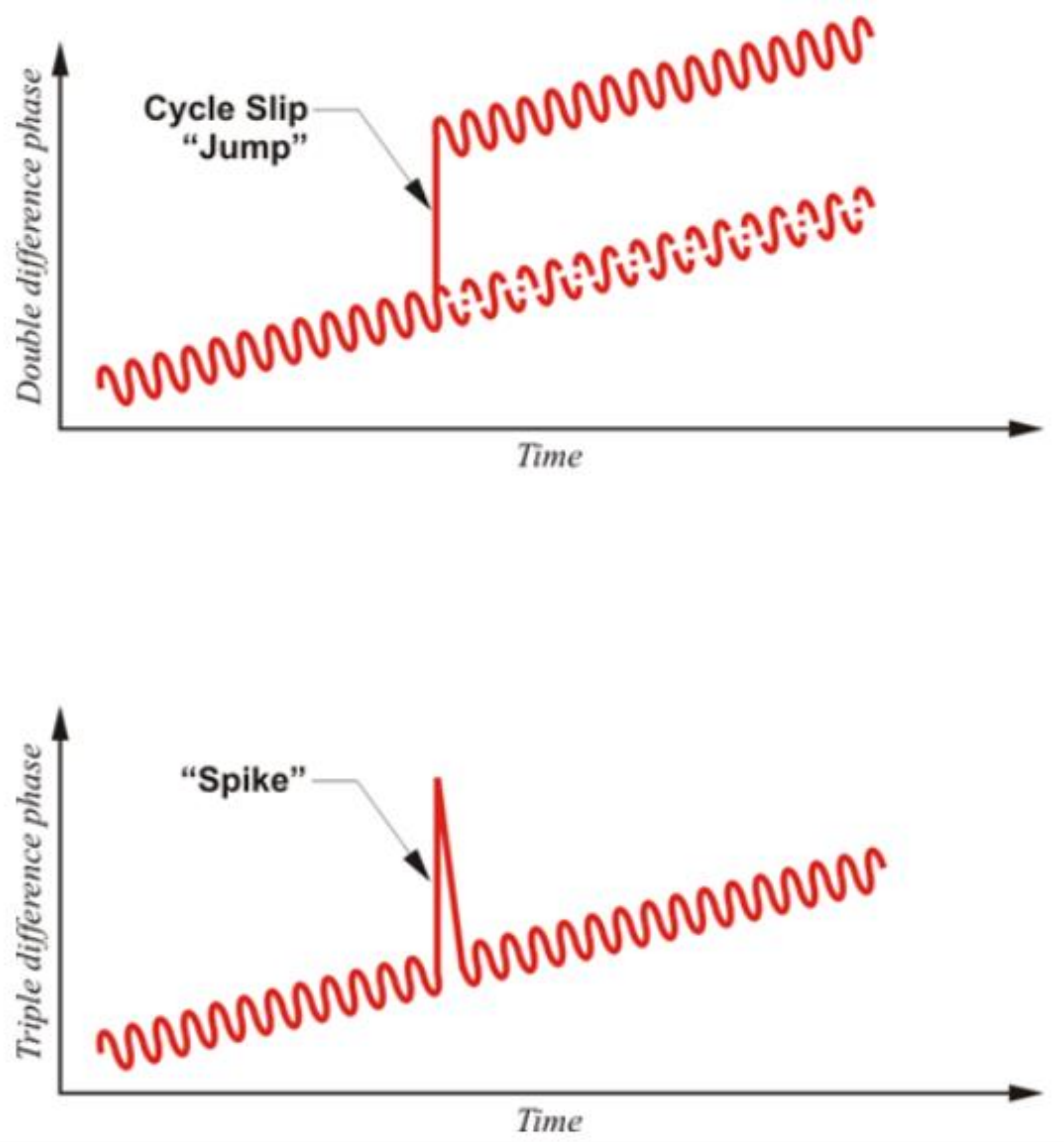
- A power loss, a very low *SNR,* a failure of the receiver software, a malfunctioning satellite oscillator can cause a cycle slip
- *The signal-to-noise ratio (SNR) is the ratio of the signal power to the noise power and is routinely measured by GNSS receivers to indicate the signal strength of the received satellite signal and the noise density (i.e., the antenna and receiver noise temperature).*
- It can also be caused by severe ionospheric conditions.
- Most common, however, are obstructions such as buildings, trees, etc., that are so solid they prevent the satellite signal from being tracked by the receiver.
- Coded pseudorange measurements are not as affected by cycle slips as are carrier phase measurments.
- They are mostly controlled in post-processing rather than real-time.



A Cycle Slip