GNSS and GPS

Introduction

- During the 1970s, the *global positioning system* (GPS) emerged in the US. This system, which grew out of the space program, relies upon signals transmitted from satellites for its operation. Now, several other countries are developing their own systems, including India.

- The entire scope of satellite systems used in positioning is now referred to as *global navigation satellite systems* (GNSS).

Advantages of GNSS

1. 3- Dimensional with no need of site Intervisibility.
2. All weather and day or night operation.
3. Data processing with high speed having Common Reference System.
4. High quality control with achieving high precision.
5. Less labor but skilled persons are needed.

Brief History

- Development of the first generation of satellite positioning systems began in 1958. This early system, known as the *Navy Navigation Satellite System* (NNSS), more commonly referred to as the TRANSIT system. It operated based on the Doppler principle, where changes in frequency of signals from the satellites were observed by receivers on the ground. The surveying community quickly adopted the new technology, finding it particularly useful for control surveying.

- Based on the success of TRANSIT system, the U.S. Department of Defense (DoD) began development of the ***NAV****igation* ***S****atellite* ***T****iming* ***a****nd* ***R****anging* (NAVSTAR) *Global Positioning System.* The first satellite to support the development and testing of the system was placed in orbit in 1978.
- The global positioning system, developed at a cost of approximately $12 billion, became fully operational in December of 1993.

Brief History

- **GLONASS (Russian Navigation Satellite System):** Global Navigation Satellite System by Russian Aerospace Defence Forces is a space-based satellite navigation system. It provided an alternative to the NAVSTAR GPS of U.S., during the cold war time of last decades of twentieth century. The modern age GPS receivers are compatible to both NAVSTAR and GLONASS, thus providing more flexibility of positioning and better accuracy. GLONASS was conceived in 1976 and the satellite launching started in 1982.
- GALILEO is the European Navigation Satellite system which is being developed by collaboration of European Union and European Space Agency. The system is not fully operational yet. The Satellites are being launched from 2011 and they are controlled by Galileo control centre in Germany. The headquarters of Galileo project is in Prague.

Brief History

- BEIDOU is the Chinese Navigation Satellite system which is currently under limited operation. It comprises of BEIDOU-1, which is limited test operating system which has been operational since 2000. The full scale navigation system is still under construction. It will finally comprise of 35 satellites in orbit.

- IRNSS (Indian Regional Navigation Satellite System) It is a regional satellite navigation system that is being developed by ISRO. The IRNSS will comprise of two service:
- standard service for civilian users
- Restricted service for authorized military personnel.

- In the next few slides, we will study working of the NAVSTAR system.

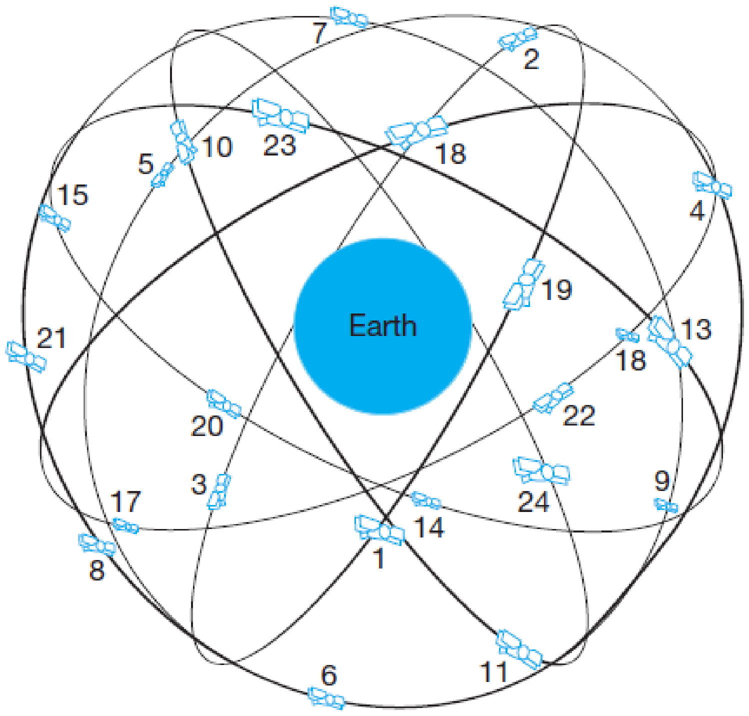
Overview of GPS

- Precise distances from the satellites to the receivers are determined from timing and signal information, enabling receiver positions to be computed.
- In satellite surveying, the satellites become the reference or *control* stations, and the *ranges* (distances) to these satellites, are used to compute the positions of the receiver.

- The global positioning system can be arbitrarily broken into three parts:
- (a) the *space segment,*
- (b) the *control segment,* and
- (c) the *user segment*.

Space Segment-NAVSTAR

- The **space segment** consists nominally of 24 satellites operating in six orbital planes spaced at 60° intervals around the equator. Four additional satellites are held in reserve as spares. The orbital planes are inclined to the equator at 55°. This configuration provides 24-hr satellite coverage between the latitudes of 80°N and 80°S. The satellites travel in near-circular orbits that have a mean altitude of 20,200 km above the Earth. Orbital period of the satellites is of 12 sidereal hours.



Overview of GPS

- Precise atomic clocks are used in the satellites to control the timing of the signals they transmit. These are extremely accurate clocks,2 and extremely expensive as well.

- The clocks in the receivers are controlled by the oscillations of a quartz crystal that, although also precise, are less accurate less expensive than atomic clocks.

Control Segment

- The **control segment** consists of *monitoring stations*, which monitor the signals and track the positions of the satellites over time. These are located in different locations of USA and the master control station is located at Schriever Air Force base in Colorado Springs. The tracking information is relayed from different control stations to the *master control station.* The master control station uses this data to make precise, near-future predictions of the satellite orbits, and their clock correction parameters. This information is uploaded to the satellites, and, in turn, transmitted by them as part of their *broadcast message* to be used by receivers to predict satellite positions and their clock *biases.*

User Segment

- The **user segment** in GPS consists of two categories of receivers that are classified by their access to two services that the system provides. These services are referred to as *Standard Position Service* (*SPS*) and the *Precise Positioning Service* (*PPS*).
- The SPS is provided on the L1 broadcast frequency and more recently the L2 at no cost to the user. This service was initially intended to provide accuracies of 100 m in horizontal positions, and 156 m in vertical positions at the 95% error level. However, improvements in the system and the processing software have substantially reduced these error estimates.
- The PPS is broadcast on both the L1 and L2 frequencies, and is only available to receivers having valid cryptographic keys, which are reserved for military and authorized users only. This message provides a published accuracy of 18 m in the horizontal, and 28 m in the vertical at the 95% error level.

User Segment

- The GPS receiver receives the signals from the SV and converts them into position, velocity and time estimates. Minimum four satellites are required to compute the positional dimensions of X,Y,Z along with time. The receivers are used for navigation and precise positioning.

GPS Signals

- As the GPS satellites are orbiting, each continually broadcasts a unique signal on the two *carrier frequencies.* The carriers, which are transmitted in the L band of microwave radio frequencies, are identified as the L1 signal with a frequency of 1575.42 MHz and the L2 signal at a frequency of 1227.60 MHz. These frequencies are derived from a fundamental frequency, f_0, of the atomic clocks, which is 10.23 MHz. The L1 band has frequency of $154f_0$ and the L2 band has a frequency of $120f_0$.

- Several different types of information (messages) are modulated upon these carrier waves using a phase modulation technique. Some of the information included in the broadcast message is the almanac, broadcast ephemeris, satellite clock correction coefficients, ionospheric correction coefficients, and satellite condition (also termed *satellite health*).

GPS signals

- In order for receivers to independently determine the ground positions of the stations they occupy in real time, it was necessary to devise a system for accurate measurement of signal travel time from satellite to receiver. This was accomplished by modulating the carriers with *pseudorandom noise* (PRN).

- The L1 frequency is modulated with the *precise code,* or *P code,* and also with the *coarse/acquisition code,* or *C/A code.* This C/A code allows receivers to acquire the satellites as well as determine their approximate positions. Until recently, the L2 frequency was modulated only with the P code.

- The C/A and P codes are old technology. *Modernized satellites* are being equipped with new codes.

Fundamentals of Satellite Positioning

- The precise travel time of the signal is necessary to determine the distance, or so-called *range,* to the satellite. Since the satellite is in an orbit approximately 20,200 km above the Earth, the travel time of the signal will be roughly 0.07 sec after the receiver generates the same signal. If this time delay between the two signals is multiplied by the signal velocity (speed of light in a vacuum) *c,* the range to the satellite can be determined from
- $r = \mathrm{c} \times t$
- where *r* is the range to the satellite and *t* the elapsed time for the wave to travel from the satellite to the receiver.
- Satellite receivers in determining distances to satellites employ two fundamental methods: *code ranging* and *carrier phase-shift measurements.* From distance observations made to multiple satellites, receiver positions can be calculated.

GPS Data Formats

- **RINEX (Receiver Independent Exchange Format)** It is defined as GPS data exchange format of data collected by more than 60 GPS receivers proposed by Astronomical Institute of the University of Berne.
- This format includes four ASCII file types:-

1. Observation Data File
2. GEO and GLONASS Navigation Message File
3. Meteorological Data File
4. Satellite & Receiver Clock Data File

- Another data format that is commonly used is the SP3 (Standard Product) data format which has been adopted after certain modifications. The SP3 format includes some aided information related to corrections of satellite clock, orbit accuracy exponents, header structure and GPS seconds of week.

Reference Coordinate Systems

- In determining the positions of points on Earth from satellite observations, three different reference coordinate systems are important. First of all, satellite positions at the instant they are observed are specified in the “space-related” *satellite reference coordinate systems.* These are three-dimensional rectangular systems defined by the satellite orbits.

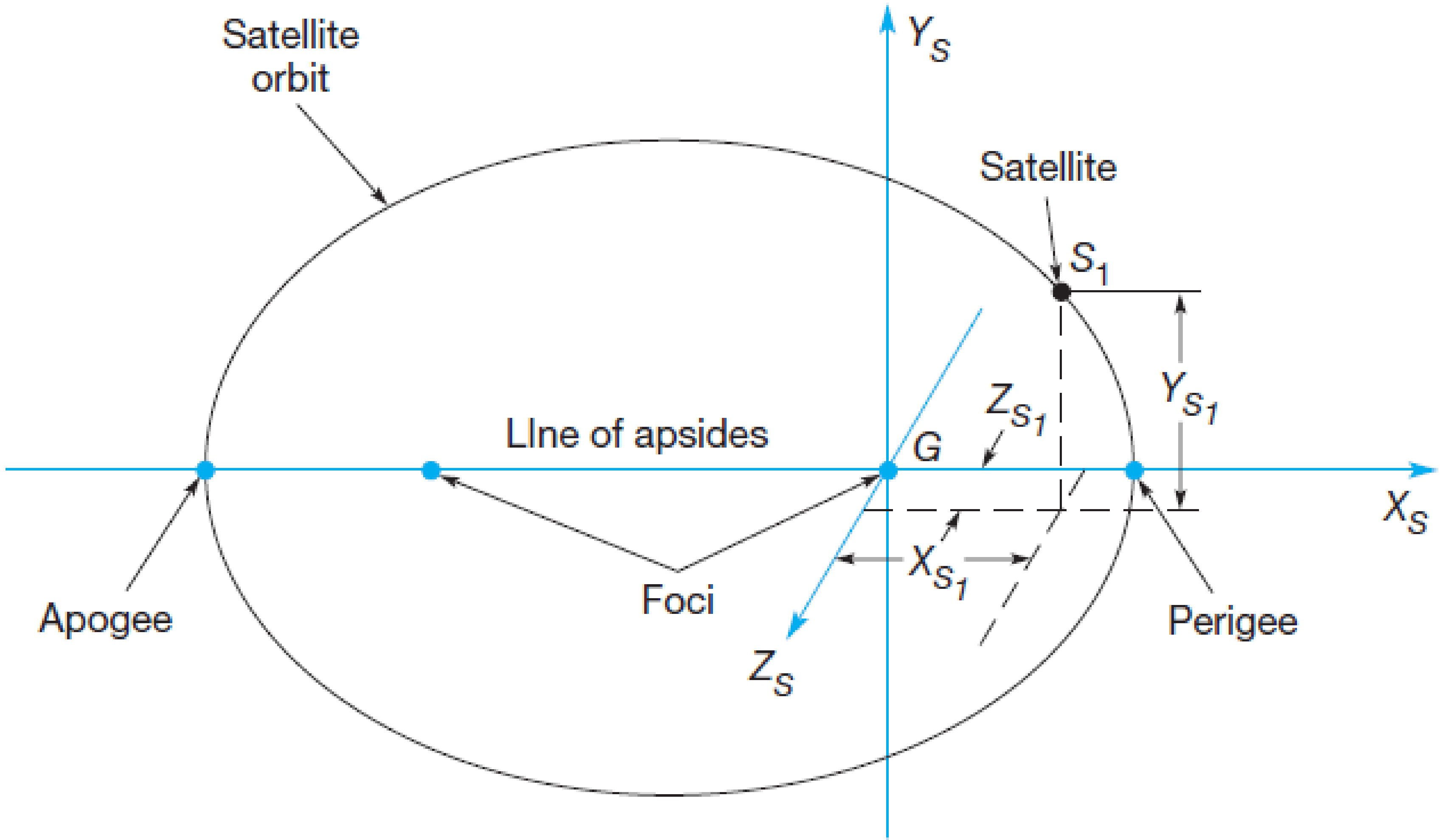
- Satellite positions are then transformed into a three-dimensional rectangular *geocentric coordinate system,* which is physically related to the Earth. As a result of satellite positioning observations, the positions of new points on Earth are determined in this coordinate system.

- Finally, the geocentric coordinates are transformed into the more commonly used and locally oriented *geodetic coordinate system.*

Satellite Coordinate System

- The movement of a satellite within its orbit is governed primarily by the Earth's gravitational force and to a lesser degree by the gravitational forces exerted by the sun and moon, as well as solar radiation.
- These forces are not uniform and hence satellite movements vary somewhat from their ideal paths.
- Ignoring all forces except the Earth's gravitational pull, a satellite's idealized orbit is elliptical. One of its two foci is at *G,* the Earth's mass center.
- The figure in the next slide illustrates a satellite reference coordinate system, X_S, Y_S, Z_S.
- *Perigee* and *apogee* are points where the satellite is closest to, and farthest away from *G.*
- The *line of apsides* joins these two points, passes through the two foci, and is the reference axis X_s.
- The origin of the coordinate system is at G.

Satellite Coordinate System

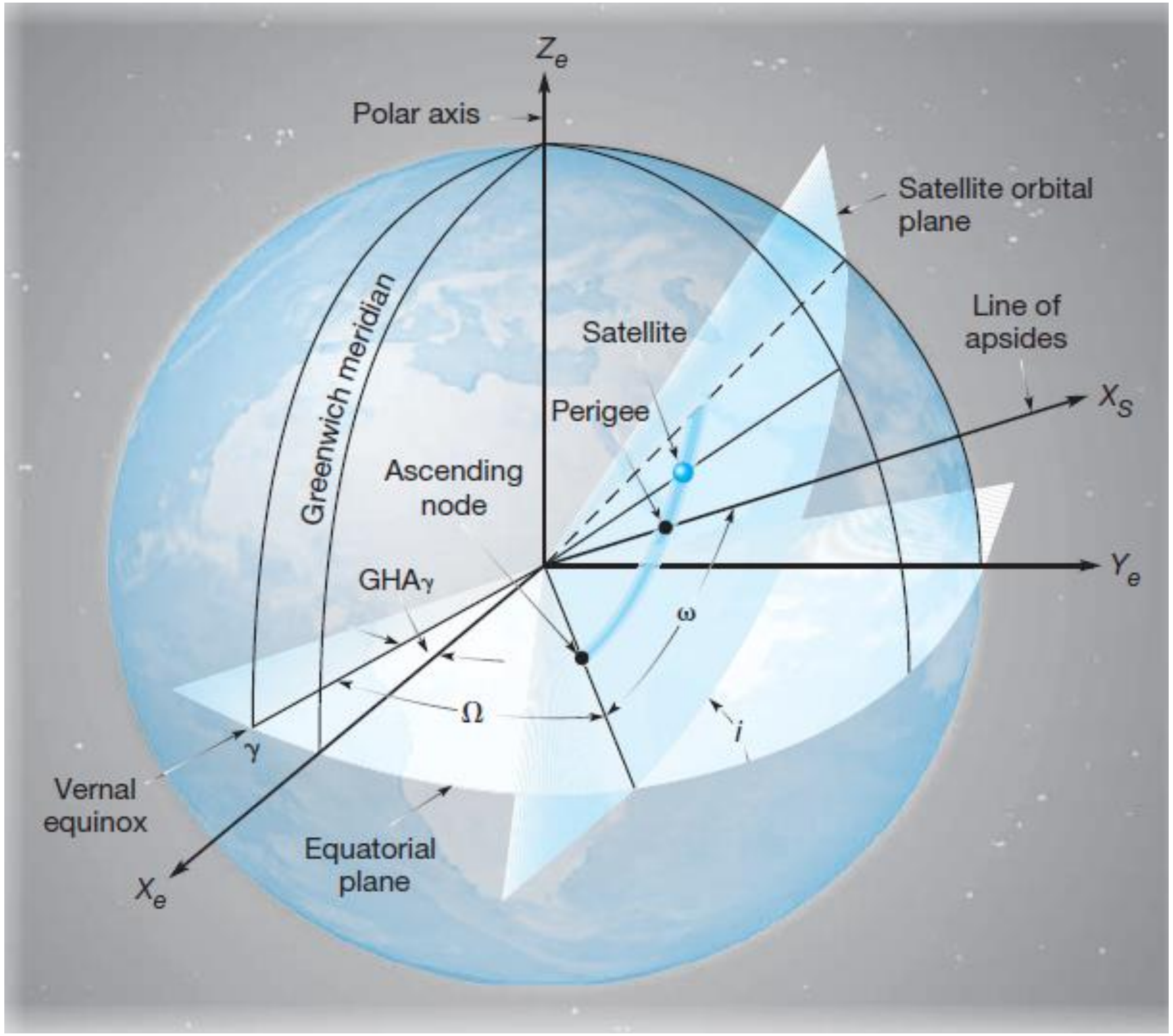


Geocentric Coordinate System

- The frame of reference used for points located on the surface of the Earth is the geocentric coordinate system. Figure in next slide illustrates a quadrant of a *reference ellipsoid* with a geocentric coordinate system (*Xe*, *Ye*, *Ze)* superimposed.

- This three-dimensional rectangular coordinate system has its origin at the mass center of the Earth.
- Its *Xe* axis passes through the Greenwich meridian in the plane of the equator, and its *Ze* axis coincides with the *Conventional Terrestrial Pole* (CTP).
- Its *Ye* axis lies in the plane of the equator and creates a right-handed coordinate system.

Geocentric Coordinate System



The Geodetic Coordinate System

- Location of points using the geocentric coordinate system is inconvenient for use by surveyors (geomatics engineers).

- This is the case for three reasons:
- (1) with their origin at the Earth’s center, geocentric coordinates are typically extremely large values.
- (2) with the *X*-*Y* plane in the plane of the equator, the axes are unrelated to the conventional directions of north–south or east–west on the surface of the Earth, and
- (3) geocentric coordinates give no indication about relative elevations between points.

The Geodetic Coordinate System

- For these reasons, the *geocentric* coordinates are converted to *geodetic* coordinates of latitude (ϕ), longitude (λ), and height (h) so that reported point positions become more meaningful and convenient for users.