POSITIONING SATELLITES

Key Words: TRANSIT satellites, NAVSTAR-GPS satellites,
Satellite Orbits, Ephemeris or Ephemerides

There were two satellite systems developed in the U.S. that were capable of locating three-dimensional positions on earth. They were

- U.S. Navy Navigational Satellites *(TRANSIT)*

- Navigation Satellite Timing And Ranging *(NAVSTAR)* Global Positioning System

TRANSIT System

- First deployed in 1961, fully operational by 1964
- Declassified in 1967, i.e. available for civil use
- Had 6 operational satellites in circular, polar orbits evenly spaced around the equator
- Altitude roughly 1100 km., and a period of 107 minutes
- Two signal frequencies 400 MHz and 150 MHz
- Receivers used Doppler shift for positioning
- Sub-meter accuracy if observed for more than one day and with precise ephemeris
- Long waiting periods between satellites (>1.5 hrs)
- Orbit affected by gravity variations due to low altitude
- Low frequencies of the signal were more susceptible to atmospheric delay
- Nevertheless, this was instrumental in improving datum and geodetic positions in the national net

NAVSTAR Global Positioning System (GPS)

- Initiated in 1974 by the United States Department of Defense
- The block-I system consisted of six operational satellites in 1986
- Block-I satellites provided only a 6-8 hours window of observations
- The block-II system consists of 24 satellites with 3 spares on six evenly spaced orbits
- New satellites that are being launched now are block-2R (Replenish) satellites
- Orbital planes inclined at 55° to the equator and the satellites are more than 20,000 km. in altitude
- Each orbit is near circular with a corresponding period of 12 sidereal hours which is one half the earth's period of rotation
- Because of this the satellite trajectory on the earth or ground track repeats itself daily
- This configuration will allow a minimum of four satellites to be observed, 15° above horizon, at any time from anywhere on the earth

Satellites are being deployed on a routine basis and there are around 29 functioning satellites in space now

The Global Positioning System satellites are now being used routinely for different positioning applications of which surveying and mapping is a small part

Satellite positioning has following advantages

- three dimensional positioning
- intervisibility between points not needed
- weather independent
- day or night operation
- coordinates of points spread over a large area can be determined in a common reference system
- data processing for computing coordinates is very fast and the software includes quality control
- very high precision is routinely achieved
- less labor intensive/cost effective compared with conventional methods

Satellite positioning is a global surveying method, and therefore, uses global coordinates to locate or define surveyed points

Specifically, GPS uses World Geodetic System of 1984 (WGS-84) as a reference datum, and the coordinates of points determined by GPS are almost identical to those in NAD-83 datum

Coordinates, if necessary, can be transformed to local systems such as project coordinates

SATELLITE ORBITS

Key Words: Normal Orbit, Perturbations, Keplarian Orbital Elements, Ephemeris

Motion of the satellite is due to the attraction of the earth, assumed to follow *Newton's* law of gravitation

Orbit of the satellite is *Keplerian*, i.e. orbit is an ellipse with earth at one of the foci

Assumptions are:

- Earth is a point mass or equivalently a sphere with uniform density so the attraction is toward center
- Mass of the satellite is negligible
- Satellite moves in a vacuum

Exceptions:

- Gravity field variation, attraction of sun, moon and other planets
- Atmospheric drag and solar radiation pressure
- Relativistic effects etc.

Above are forces disturbing the *normal* orbit of the satellite that would be the case if the satellite is orbiting in a pure spherical gravity field

Such disturbances are called orbital *perturbations* and the orbit is a *perturbed* orbit

Most perturbations are due to the effect of gravity field variations and atmospheric drag and are minimized by a high altitude orbit

The desired orbit of the satellite decided before launch and the launch trajectory is computed accordingly

A *normal* orbit is completely given by the following keplerian orbital elements, see figures

- a = semi-major axis
- e = eccentricity
- i = inclination
- Ω = R.A. of ascending node
- ω = argument of perigee
- T_o = epoch of perigee passage

The first four elements describe the size, shape, and orientation of the orbit

The fifth element along with an angular quantity called *anomaly* determines the position of the satellite in its orbit at any instant

The true anomaly (v) is referenced to the earth center whereas the *eccentric anomaly* (E) is referenced to the center of the ellipse

Mean anomaly (M) is a pure mathematical quantity given below by Kepler's equation

$$M = E - e \sin E$$

The position of the satellite must be corrected for the extraneous effects stated earlier

Satellite ephemeris (or ephemerides), just as solar or star ephemeris, contain information about the location of a satellite at any given time

As the orbit of a satellite is not quite Keplerian, its location can only be predicted from the information collected by tracking its orbit constantly

In the case of positioning satellites, ephemeris information consists of Keplerian parameters at a certain epoch, rate of change of these elements, clock information and clock correction terms

Accurate ephemeris information is required for locating precise positions on earth using the signals from satellites

For this reason, all positioning satellites include ephemeris information in its signal sent to earth

QUESTIONS

1. What is a Keplerian orbit and what is a perturbed orbit?
2. What is reason for orbital perturbations?
3. What is satellite ephemeris and what information does it contain?
4. Why is it necessary to update ephemeris information at frequent intervals