Unit-III: Satellites – Subsystems

Satellite Sub Systems

The major subsystems required on the Satellite are given below.

Attitude and Orbit control system (AOCS)

This subsystem consists of rocket motors that are used to move the satellite back to the correct orbit when external forces cause it to drift off station and gas jets or inertial devices that control the attitude of the satellite.

Telemetry, Tracking, Command and Monitoring (TTC&M):

These systems are partly on the satellite and partly at the controlling earth station. The telemetry system sends data derived from many sensors on the satellite, which monitors the satellite's health, via a telemetry link to the controlling earth station.

The tracking system is located at this earth station and provides information on the range and the elevation and the azimuth angles of the satellite.

Repeated measurement of these 3 parameters permits computation of orbital elements, from which changes in the orbit of the satellite can be detected.

Based on the telemetry data received from the satellite and orbital data obtained from the tracking system, the control system is used to correct the position and attitude of the satellite.

(1) configuration to suit current traffic requirements, and to operate switch on the satellite.

Power System

- All Communications satellites derive their electrical power from solar cells.
- The power is used by the communication system, mainly in its transmitter system, and also by all other electrical systems on the satellite.
- The later use is termed as house keeping since these subsystems serve to support the communications system.

Communications Subsystems

- The communications subsystem is the major component of a communications satellite, and the remainder of the satellite is there solely to support it.
- Frequently, the communications equipment is only a small part of the weight and volume of the whole satellite.
- It is usually composed of one or more antennas, which receive and transmit over wide bandwidths at ~~...~~ MW frequencies, and a set of receivers and transmitters that amplify and retransmit the incoming signals.
- The receiver–transmitter units are known as transponders.

– There are two types of transponders:

1. The linear or bent pipe transponder – that amplifies the received signals and retransmits it at a different lower frequency and 2. The baseband processing transponder which is used only ...

...gnal to baseband, processes it and ...en retransmits a digital signal.

Satellite Antennas

In large GEO satellites the antenna systems are very complex and produce beams with shapes carefully tailored to match the areas on the earth's surface served by the satellite.

Most satellite antennas are designed to operate in a single frequency band ∴ C band or Ku band

A satellite which uses multiple frequency bands usually has four or more antennas.

AOCS

The attitude and orbit of a satellite must be controlled so that the satellite's antennas point toward the earth and so that the user knows where in the sky to look for the satellite.

Earth station antennas are fixed, the movement satellite in the sky will cause a loss of signal.

Several forces acts on orbiting satellite that tend to change its altitude and orbit are:

- Gravitational fields of the sun and the moon,
- Irregularities in the earth's gravitational field,
- Solar pressure from the sun, and
- Variations in the earth's magnetic field.

The gravitational fields of the sun and the moon cause the orbit of the GEO satellite to change with time.

At GEO altitude, the moon's gravitational force is about twice as strong as the sun's.

[illegible] orbit is inclined [illegible] the equatorial

- The plane of the earth's rotation around the sun is inclined by 23° to the earth's equatorial plane.

• There is a net gravitational pull on the satellite that tends to change the inclination of the satellite's orbit, pulling it away from the earth's equatorial plane at 0.86°/year.

• The orbit control system of the satellite must be able to move the satellite back into the equatorial plane before the orbital inclination becomes excessive.

NOTE: LEO satellites are less affected by gravitational fields of the sun and moon

- since LEO satellites are closer to earth than GEO satellites, the earth's gravity is much stronger, and the pull from the sun and moon are proportionally weaker.

(2) The earth is not quite a perfect sphere

- At the equator, there are bulges of about 65m at longitudes 162°E and 348°E, with the result that a satellite is accelerated toward one of two stable points in the GEO orbit at longitude 75°E and 252°E.

• To maintain accurate station keeping, the satellite must be periodically accelerated in the opposite direction to the forces acting on it.

- This is done as a sequence of station-keeping maneuvers using small rocket motors (like gas jets or ion thrusters) that can be controlled from the earth via TTC&M system.

(3) Solar pressure acting on a satellite's solar sails and antennas and

(4) The earth's magnetic eddy currents in the satellite's metallic structure as it travels through the magnetic field [illegible] cause rotation of the satellite

- Careful design of the structure (2) can minimize these effects, but the orbital period of the satellite makes many of the effects cyclic.
- which can be nutation (a wobble) of the satellite.

The attitude control system must damp out nutation and counter any rotational torque & movement.

Attitude control system

There are two ways to make a satellite stable in orbit, when it is weightless:

1) The body of the satellite can be rotated between 30 and 100 rpm, to create a gyroscopic force that provides stability of spin axis and keeps it pointing in the same direction.
- Such satellites are known as ~~spp~~ spinners.

Ex: Boeing 376

2) The satellite can be stabilized by one or more momentum wheels.
- This is called a three-axis stabilized satellite

Ex: Boeing 701 series.

- The momentum wheel is usually a solid metal disk driven by an electric motor.
- Either there must be one momentum wheel for each of the three axes of the satellite or a single momentum wheel can be mounted on gimbals and rotated to provide a rotational force about any of the three axis.
- Increasing the speed of the momentum wheel causes the satellite to precess in the opposite direction, according the principle of conservation of angular momentum.

Fig. Forces on a synchronous satellite.

(1) The spinner design of satellite is typical consists of a cylindrical drum covered in solar cells that contains the power systems and rocket motors.
- The communication system is mounted at the top of the drum and is driven by an electric motor in opposite direction to the rotation of the satellite body to ~~keep~~ keep the antennas pointing towards the earth.
- Such satellites are called despun.

• The satellite is spun up by operating ~~sm~~ small radial gas jets mounted on the drum.

• A variety of liquid propulsion mixes have been used for the gas jets

1. Hydrazine (N_2H_4) — liquified under pressure and rapidly decomposed over a catalyst
   - By electrically heating the catalyst and ~~g~~ gas, increased power can be obtained.
2. Bipropellant fuels
   (i). Mono-methyl hydrazine + Nitrogen tetroxide
   (ii) Nitrogen tetroxide + Hydrazine
   - These are hypogolic: i.e, they ignite spontaneously on contact, so do not need either a catalyst or a heater.

The fuel stored on a GEO satellite is used for two purposes:

1. To fire the AKM, that injects the satellite into its final orbit, and
2. To maintain the satellite in that orbit over its lifetime.

If the launch is highly accurate, a minimum amount of fuel is used to attain the final orbit.

If the launch is less accurate, more fuel must be used up in maneuvering the satellite into position, and that reduces the amount left for station keeping.

There are two types of rocket motors used on satellites.

1) Traditional bipropellant thrusters
2) Arc jets or ion thrusters.
   - Uses a high voltage source to accelerate ions to very high velocity, which produces thrust.

The ion engine thrust is not large,
- It saves expendable fuel, because the engine can be driven by power from the solar cells
- Can also be used to slowly raise a GEO satellite from GTO to GEO (But the process takes months rather than hours as with conventional rocket engine.

Arc jets or ion thrusters are mainly used for N-S station keeping

They lack the total thrust required to move satellites quickly (ex. for major longitudinal changes in position) but a small, continuous thrust is required to maintain N-S and E-W position keeping.

- In 3-axis stabilized satellite, one pair of gas jets is needed for each axis – to provide for rotation in both directions of pitch, roll and yaw.
- An additional set of controls, allowing only one jet on a given axis to be operat — provides for velocity increments in the x, y and z directions.
- When motion is required along a given axis, the appropriate gas jet is operated for a specified period of time to achieve the desired velocity.
  - The opposite gas jet is operated for a specified period of time to achieve the desired velocity.
  - The opposing gas jets must be operate for the same length of time to stop the motion when the satellite reachs its new position.

NOTE: Fuel is saved, if velocity of the sate is kept small, but progress toward the destination is slow.

- Let us define a set of reference Cartesian axes (X_R, Y_R, Z_R) with the satellite at the origin as shown in Fig 2(3.4) below:

Fig. 2.4 (a) Forces on a satellite

- The Z_R axis is directed toward the center of the earth and is in the plane of the satellite orbit.
- It is aligned along the local vertical at the satellite subsatellite point.
- The X_R axis is tangent to the orbital plane and lies in the orbital plane.
- The Y_R is perpendicular to the orbital plane.
- For a satellite serving the Northern Hemisphere, the directions of X_R and Y_R are nominally East and south.
- Rotation about the X_R, Y_R and Z_R axes is defined as roll about X_R axis, pitch about Y_R axis, yaw about Z_R axis, in exactly the same way as for an aircraft or ship travelling in the x direction.
- The satellite must be stabilized w.r.t the reference axes to main the accurate positioning of its antenna beams.
- The axes X_R, Y_R and Z_R are defined w.r.t the location of the satellite.
- a second set of cartesian axes x, y, z (Fig. 3.4) define the orientation of the satellite.
- changes in attitude cause the angle θ, ϕ and ψ in Fig 3.4(b) to vary as the x, y and z axes move relative to the fixed reference axes X_R, Y_R and Z_R.
- the z-axis usually directed toward a reference point on the earth, called the the z-axis intercept.
- The location of the z-axis intercept defines the pointing of the satellite antennas;
- intercept point may be moved to repoint all antenna beams by changing the attitude of the satellite with the

(3)

- In spinner type satellite, the axis of rotation is usually the Y-axis, which is maintained close to the Y_R axis, perpendicular to the orbital plane.
- Pitch correction is required only on the despun antenna system and can obtained by varying the speed of the despin motor.
- Yaw and roll are controlled by pulsing radially mounted jets at the appropriate instant as the body of the satellite rotates.
- Attitude control of a 3-axes stabilized satellite requires an increase or decrease in the speed of the inertia wheel.
- If a constant torque exists about an axis of the satellite, a continual increase or decrease in momentum wheel speed is necessary to maintain the correct attitude.
- When the upper or lower speed limit of the wheel is reached, it must be unloaded by operating a pair of gas jets and simultaneously reducing or increasing the wheel speed.
- Closed loop control of attitude is employed on the satellite to maintain the correct attitude.
- When large, narrow beam antenna are used, the whole satellite may have to be stabilized within $\pm 0.1^\circ$ on each axis.
- The references for the attitude control system may be the outer edge of the earth's disk, as observed with IR sensors, the sun or one or more stars.

ig 3.5 illustrates how an IR sensor on the pinning body of a satellite can be used o control pointing toward the earth.

g. 3.6 below, shows a typical control system oop using the technique shown Fig. 3.5. he control system will be more complex for a 3-axis stabilized satellite and may employ ~~on~~ an onboard computer to process he sensor data and command the gas jets and momentum wheels.

ig. 3.6 Typical onboard control system for a spinner satellites.

Orbit Control System

- A Geostationary satellite is subjected to several forces that tend to accelerate it away from its required orbit.
  - G forces of the moon and the sun, which causes inclination of the orbital plane,
  - Non spherical shape of the earth around the equator, causes drift of the subsatellite point.
- Accurate prediction of the satellite position a week or 2 weeks ahead requires a computer program with up to 20 force parameters.

Fig. 3.1 Satellite in inclined orbit

- Fig 3.1 shows a diagram of an inclined orbital plane close to the geostationary orbit.
- For the orbit to be truely geostationary,
  - it must lie in the equatorial plane,
  - be circular, and
  - have correct altitude.
  - The various forces acting on the satellite will steadily pull it out of the correct orb it is the fn of the orbit control system return it to the correct orbit.
  - This cannot be done with momentum wheels since linear accelerations are required.
  - Gas jets than can impart velocity change along the three reference axes of the satellite are required.
- If the orbit is not circular, a velocity increase or decrease will have to be mad along the orbit in the x-direction (in fig.

⇒ On a spinning satellite, this is achieve by pulsing the radial jets when they point along the x-axis.

⇒ On a 3-axis stabilized satellite, there will usually be two pairs of x-axis jets acting in opposite directions, one pair of which will be operated for a predetermined length of time to provide the required velocity change.

- The orbit of a geostationary satellite remains approximately circular for long periods of time and does not nee frequent velocity corrections to maint circularity.
- Altitude corrections are made by operating the Z-axis gas jets.

- The inclination of the orbit of a satellite that starts out in a GEO orbit increases (4 with an average rate of about 0.85°/years with an intial rate of change of inclination for a satellite in an equatorial orbit between 0.75° to 0.94°/year.

Most GEO satellites are specified to remain within a box of ±0.05° and so The corrections called a north-south station keeping maneuver are made every 2 to 4 weeks to keep the error small.

It becomes normal to the E-W and N-S maneuvers so that at intervals of 2 weeks, the E-W corrections are made first and then after 2 more weeks, the N-S corrections are made.

If arc jets or ion thrusters are used for N-S station-keeping maneuvers, these tend to operate almost continuously since their thrust levels are low when compared with traditional liquid fueled engines.

Correcting the inclination of a satellite orbit requires more fuel to be expended than for any other orbital correction. This places a weight penalty on those satellites that must maintain very accurate station keeping, and reduces the communication payload they can carry. As much as half the total satellite weight at launch may be station keeping fuel, when the satellite's expected life time on orbit is 15 years.

East-West station keeping is effected by use of the x-axis jets of the satellite. For a ~~stable points~~ satellite located away from the stable points at 75°E and 252°E, a slow drift toward these points occur.

- Typically, the x-axis jets are pulsed every 2 or 3 weeks to counter the [illegible] drift [illegible] in the opposite direction.
- Then, the satellite drifts through its nominal position, stops at a point a fraction of a degree beyond it and then drifts back again.
- East-west station keeping requires only a modest amount of fuel and is necessary on GEO·SATs to maintain the spacing between adjacent satellites.
- with orbital locations seperated by 2° or 3°, east-west drifts in excess of a fraction of a degree can not be tolerated, and most GEOSATs are held within ±0.05° of their allotted longitude.

NOTE:

① LEO and MEO satellites also need ACC to maintain the correct orbit and attitude for continuous communication.

② Because of the much stronger G force of the earth in LEO orbit, attitude stabilization is often ~~stabilized~~ accomplished with a rigid gravity gradient boom"

- This is a long pole that points toward the center of the earth, providing damping of oscillations about the satellite's z-axis by virtue of the differences in gravitational field at the top of the pole and at the bottom

2(b)

lemetry, Tracking, Command and Monitoring:

e TTC & M System is essential to the uccessful operations of a comm. satellite. It is a part of satellite management task, which also involves an earth station, and group of personnel.

The main functions satellite management are
- to control the orbit and attitude of the satellite,
- monitor the status of all sensors and subsystems, and
- switch on or off sections of the communication system.

The TTC & M earth station may be owned and operated by the satellite owner, or it may be owned by a 3rd party and provide TTC & M services under contract.

E: ① On large geostationary satellites, some repointing of individual antennas may be possible, under the command of the TTC & M system.

Tracking is performed by the earth station.

ig. 3.8 illustrates the functions of a controlling earth station.

Telemetry and Monitoring System

- The monitoring system collects [illegible] satellite and sends these data to the controlling earth station.
- There may be several 100 sensors located on the satellite to monitor pressure in the fuel tanks, voltage and current in power conditioning unit, current drawn by each subsystem, and critical voltage and currents in the comm. electron.
- The temperature of many subsystems must be kept within predetermined limits, so many sensors are fitted.
- The sensor data, the status of each system and the positions of switches in comm. sys are reported back to the earth by the telemetry system.
  - The sighting devices used to maintain attitude are also monitored via the telemetry link; this is essential in case one should fail and cause the satellite to point in wrong direction.
  - Then the faulty unit must be ~~discontin~~ disconnected and a spare brought in via command system.
- Telemetry data are usually digitized and transmitted as PSK of low-power carrier using TDM.
  - A low data rate is used to allow the Rx at earth station to have narrow BW and thus maintain high C/N ratio.
  - The entire TDM frame may contain 1000's of bits of data and take several seconds to transmit.
  - At the controlling earth station, a comput can be used to monitor, store, and decod the telemetry data so that the status of any system or sensor on satellite can be [illegible] immediately by the controlle

- Alarms can also be sounded if any vital parameter goes outside allowable limits.

Tracking

A number of techniques can be used to determine the current orbit of a satellite. Velocity and acceleration sensors on the satellite can be used to establish the change in orbit from the last known position, by integration of data.

- The earth station can observe the Doppler shift of the telemetry carrier or beacon transmitter carrier to determine the range rate at which range is changing.
- Together with accurate angular measurements from the earth station antenna, range is used to determine the orbital elements.
- Active determination of range can be achieved by transmitting a pulse or sequence of pulses to the satellite and observing the time delay before the pulse is received again.
- The propagation delay in the satellite transponder must be accurately known, and more than one earth station may make range measurements.
- If a sufficient number of earth stations with an adequate seperation are observing the satellite, its position can be established by triangulation method.
- With precision equipment at earth stations, the position of the satellite can be determined within 10m.
- **Ranging tones** are also used for range measurement. A carrier generated onboard the satellite is modulated with series of [illegible]
  - The phase of the [illegible] components is compared at an earth station, [illegible] of each frequency is calculated.
  - Ambiguities in numbers are resolved by reference to lower frequencies, and prior knowledge of the approximate range of the satellite.
  - If sufficiently high frequencies are used range can be measured to millimeter accuracy.
- This technique is similar to the terrestial telurometer and aircraft radar altimeter.

Command

- A secure and effective command structure is vital to the successful launch and operation of any comm. satellite.
- Command system is used to make changes in attitude and corrections to the orbit and to control the comms
- During launch, it is used to control the firing of the apogee kick motor and to spin up a spinner or extend the solar sails and antennas of a three axis stabized satellite.
- The command structure must posses safe guards against unathorized attempts to make changes to the satellite's operation, and also inadvertent operation of a control due to error in a received command.
- Encryption of commands and responses is used to provide security in the command system.
- The control code is converted into a command word, which sent in a TDM frame to the satellite.
  - After checking the validity in the satellite, the word is sent back to the control station via telemetry link, where it is checked again in the computer.
  - [illegible]

be sent to the satellite so that
command is executed.
he entire response may take 5 to 10s,
it minimizes the risk of erroneous
commands causing a satellite malfunction.
The command and telemetry links are
usually seperate from comm. system
During the launch phase and injection
into geostationary orbit, the main TTC&M
may be inoperable because the satellite
does not have the correct altitude or has
extended its solar sails.
A back up system is used at this time,
which controls only the most important
sections the satellite.
Near omnidirectional antennas are
used at either UHF or S band (2-4 GHz),
and sufficient margin is allowed in SNR
at the satellite receiver to guarantee
control under the most adverse conditions.
The back-up system provides control
of AKM, the AOCS thrusters, the solar
sail deployment and power conditioning
unit.
With these controls, the satellite can be
injected into the GEO orbit, turned
to face the earth, and switched to full
electrical power so that handover to the
main TTC&M system is possible.
In the event of failure of the main
TTC&M system, the back up system
can be used to keep the satellite on
station.
It is also used to eject the satellite
from geostationary orbit and to switch
off all transmitters, when the satellite
eventually reaches the end of its
useful life.