SATELLITE SUBSYSTEMS

ECE 521E SATELLITE COMMUNICATION

Monday, 14 September 2026

SATELLITE SUBSYSTEMS

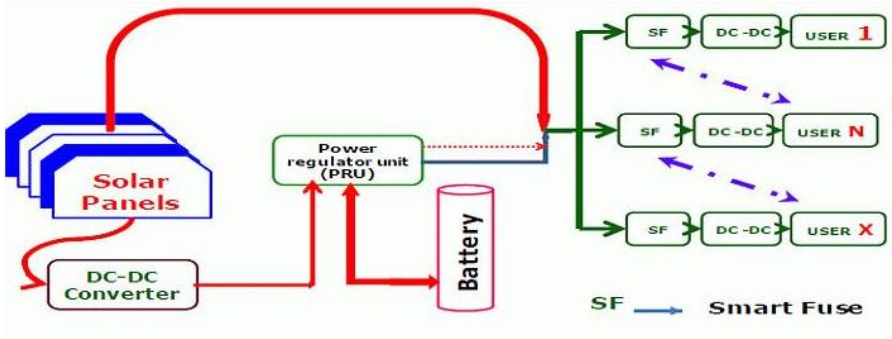
A complete satellite consists of four subsystems:

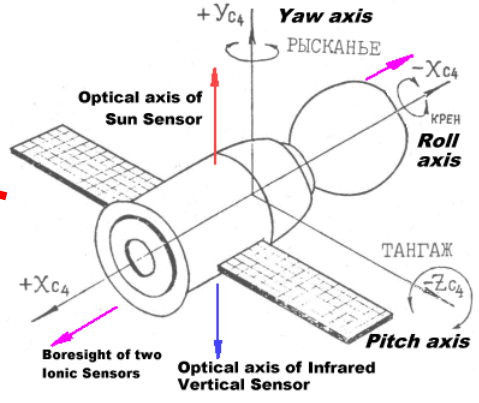
1. **The power Subsystem** consisting of:
   - (a) Solar Array
   - (b) Battery
   - (c) Power supply control unit

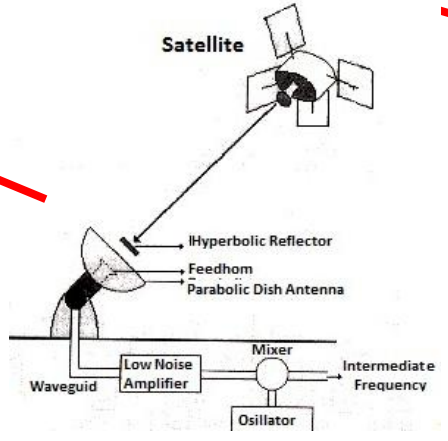
2. **Attitude and Orbit Subystem** consisting of:
   - (a) Sensors
   - (b) Propulsion System
   - (c) Attitude Control
   - (d) Orbit control

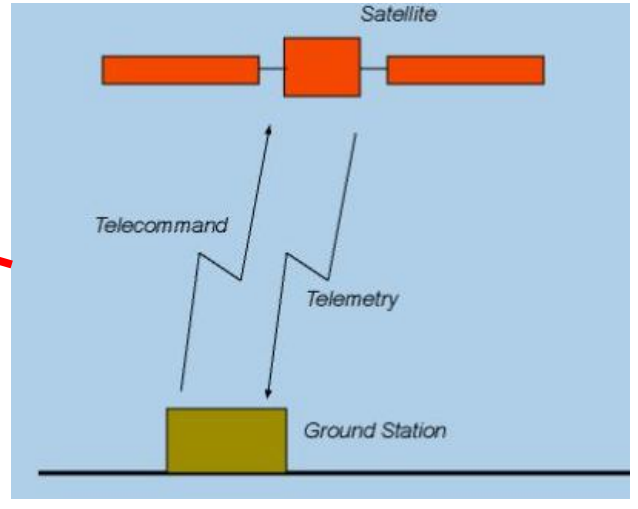
3. **Telemetry, Tracking and Command Subsystem**
   - (a) Telemetry system
   - (b) Tracking and ranging subsystem
   - (c) Command Subsystem

4. **Communication Subsystem**
   - (a) Transponders
   - (b) Antennas
   - (c) Switching









1. POWER SUBSYSTEM (1)

Functions & Size:

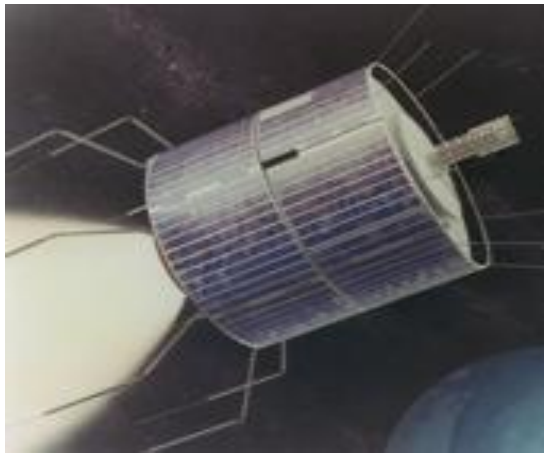
- The power subsystem generates, stores, regulates, and distributes electrical energy.
- It is one of the largest and heaviest bus subsystems, and it directly limits payload capability (number of transponders, transmit power).

Primary Power Generation:

- Solar cells convert sunlight directly to DC power.
- Modern satellites use triple-junction gallium arsenide (GaAs) cells with efficiencies of ~29–32%, much better than silicon (~15–18%).

Body-Mounted Vs Wing-Mounted Solar Cells:

- **Body-mounted panels:** simple, used on spinning spacecraft.
- **Sun-tracking solar wings:** two deployable arrays with drive motors to keep them normal to the Sun — standard on three-axis stabilised satellites.



(a) Body-mounted Solar Cells



(b) Sun-tracking solar wings

POWER SUBSYSTEM- CALCULATION OF BATTERY CAPACITY

- **Batteries supply power during eclipse** (when the Earth blocks the Sun) and support peak loads.
- **Battery Capacity in Watt-hours, C** is given by:

$$C = \frac{P_{eclipse} \times t_{eclipse}}{DOD \times n}$$

where

$P_{eclipse}$ is load during eclipse;

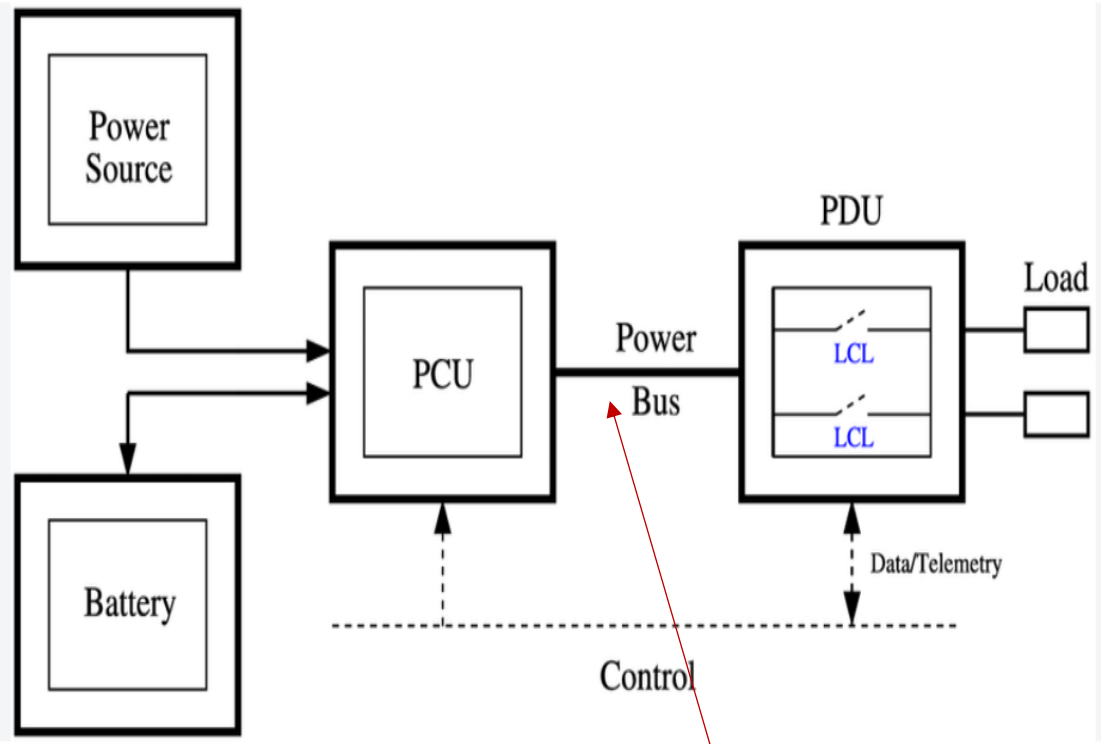
$t_{eclipse}$ is duration of eclipse

DOD = depth of discharge (typically 30–50 % for long-life NiH_2 / Li-ion);

η is discharge efficiency.

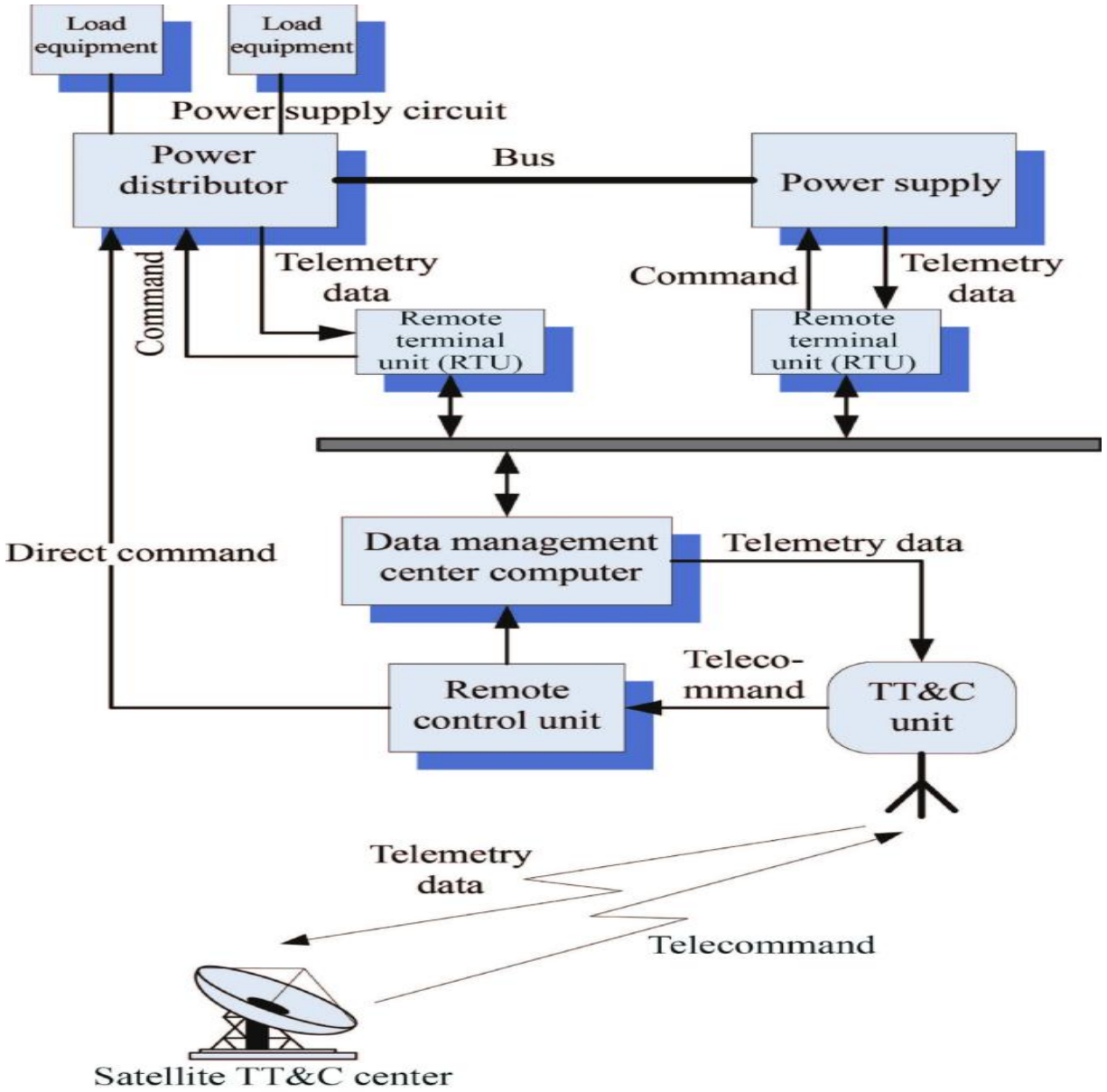
POWER CONDITIONING , DISTRIBUTION & CONTROL

1. **Power Conditioning Unit (PCU):** regulates array output, controls battery charge/discharge (with charge regulators), and provides protection.
2. **Power Distribution Unit (PDU):** switches and fuses (latching current limiters) distribute power to other subsystems and supports switching for fault isolation.
3. **Protection unit:** Uses Low Current Limiters (LCL) and electronic fuses to isolate short circuits and prevent full system failure.
4. **Telemetry unit:** Monitors voltage, current, and temperature to send real-time health data back to ground control



Bus voltage: regulated DC buses of 28 V (traditional), 50 V, or 100 V are typical; p

POWER SYSTEM TELEMETRY



1. POWER SUBSYSTEM

1. Satellite systems use **Solar Cells** or **Radioisotope thermoelectric generators** to supply energy.

(a) Solar Cells:

i. Solar Cells are photovoltaic cells that convert solar radiation to light with an efficiency of 12-15%.

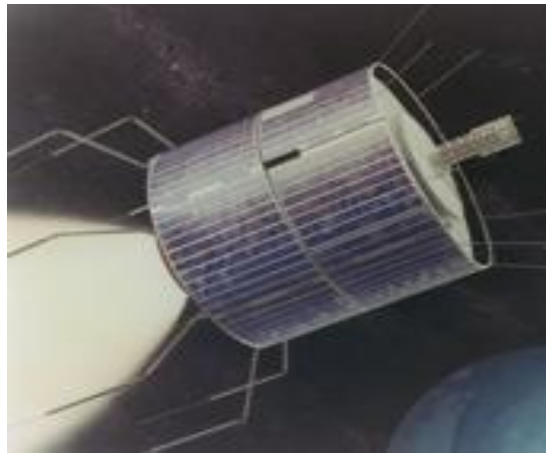
ii. On a typical station, the solar cells will generate 1-2KW of power.

iii. The number of solar cells on typical satellite may be as many as 1000 covering most of the surface of the satellite.

iv. If the surface area is inadequate, then the satellite is equipped with solar panels.

v. The efficiency of the solar panels usually decreases by approximately 30-35% in seven years.

vi. Rechargeable batteries are installed and are useful during the satellite eclipse period.

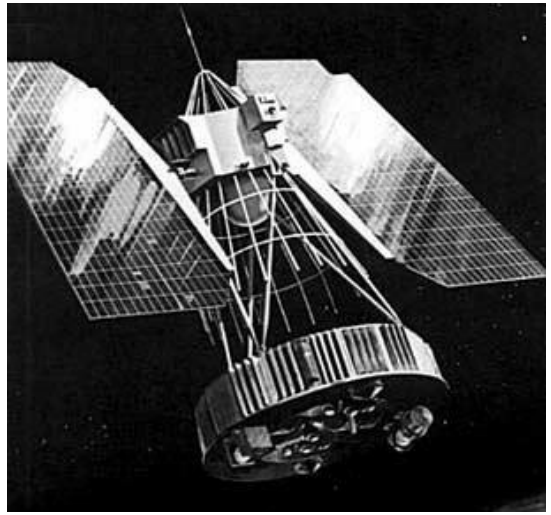


(b) Radioisotope Thermoelectric Generators:

I. They convert heat from decaying radioisotope (usually plutonium) directly into electrical power

II. They are only about 7% efficient

III. 93% of the heat is lost or can be used to heat a cold part of the satellite



2. The Communication subsystem consumes most of the power.

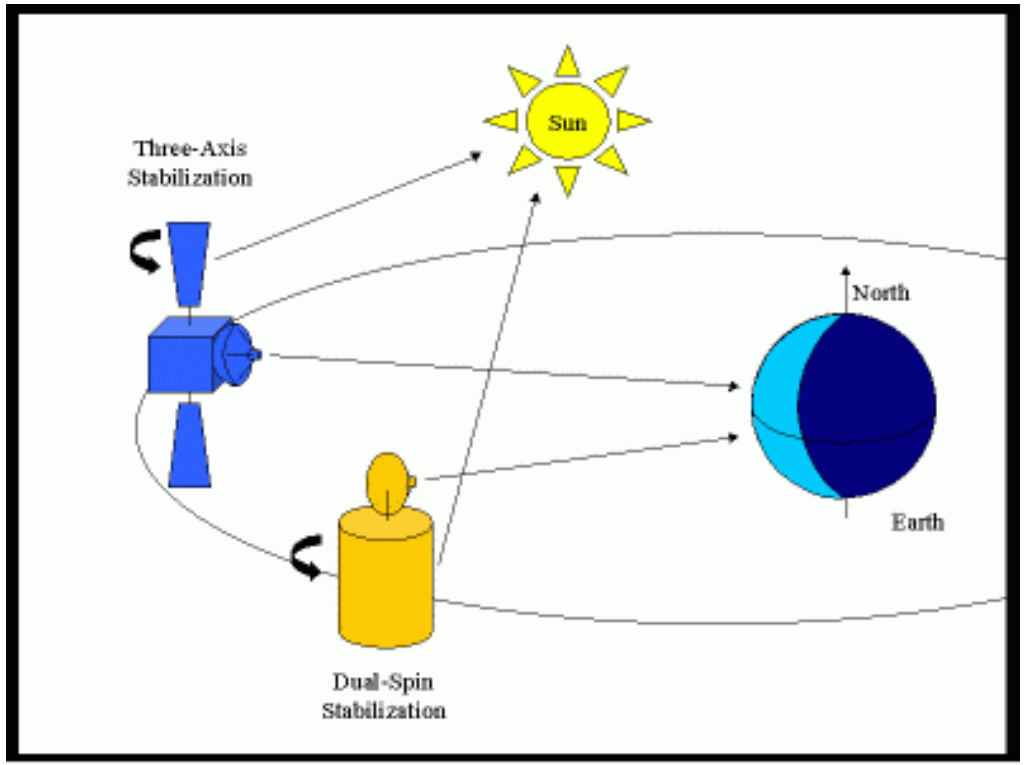
Further Reading:

Radioisotope thermoelectric generator – Wikipedia

Radioisotope Thermoelectric Generators (RTGs) - NASA Science

2. SATELLITE STABILIZATION

1. Satellite Stabilization is required to keep the satellite in the desired orientation in relation to the Earth and the Sun
2. There are two methods to stabilize a satellite in space, i.e
   a) **Dual Spin Stabilization** where the antenna, is despun while the other portion of spacecraft spins to provide gyroscopic stability.
   b) **Three-axis stabilization** where satellites have small spinning wheels, called reaction wheels or momentum wheels, that rotate in order to keep the satellite in the desired orientation in relation to the Earth and the Sun



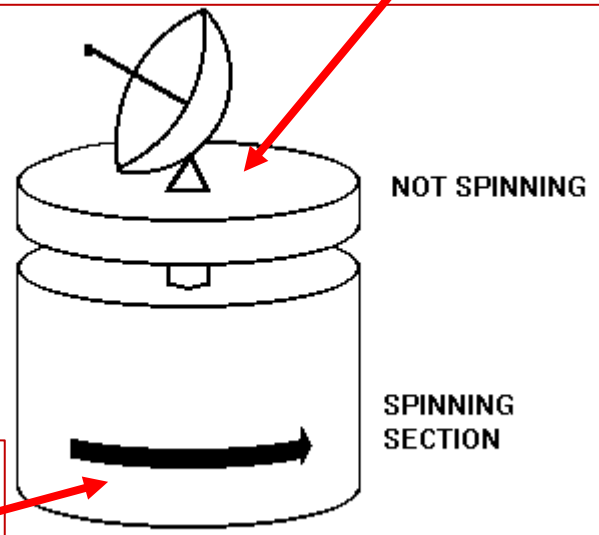
Further Reading:

Terrawatch: why has the Earth's spinning inner core slowed down? | Science | The Guardian

2.1 DUAL SPIN SATELLITE STABILIZATION

1. **Spinning Section** (lower) which provide gyroscopic stability.
2. **A despun section** (Upper) does not spin (or spins very slowly or intermittently) to point antenna and/or other sensors in a specific direction towards the earth (or other satellite)

Despun section
Rotates, too, at a much slower rate of one rotation per orbit (day)—keeping the antennas pointed at the earth and preventing the satellite from going into a flat spin (which is the natural tendency).



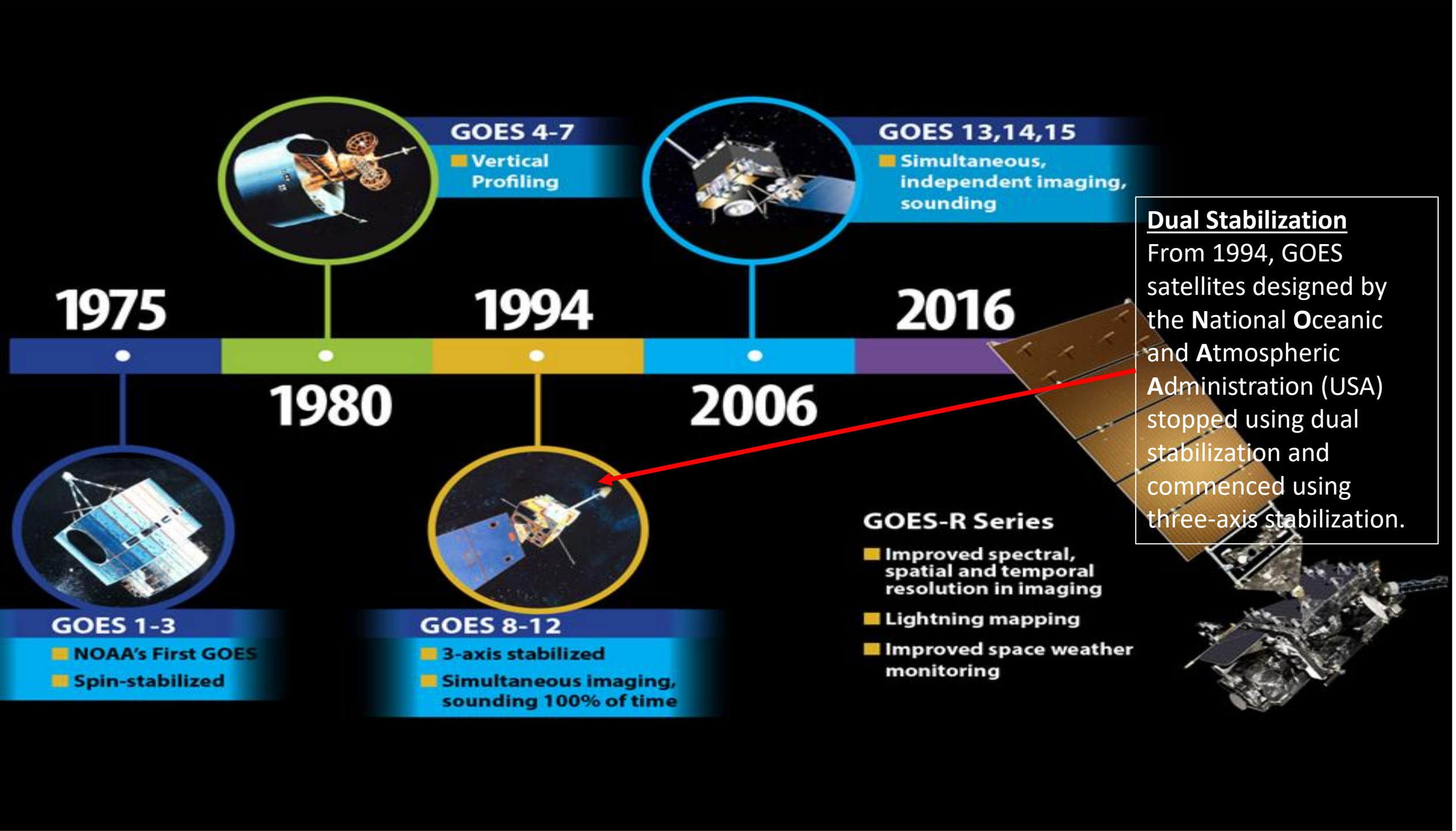
Spinning section
Provides basic stabilization and can rotate as fast as 100 RPM (in the case of the early GOES satellites)

SPIN STABILIZED SATELLITE WITH SOLAR PANNELS



Despun section
Rotates at a much slower rate of one rotation per orbit day,

Spinning section
Provides basic stabilization .



Dual Stabilization

From 1994, GOES satellites designed by the **N**ational **O**ceanic and **A**tmospheric **A**dministration (USA) stopped using dual stabilization and commenced using three-axis stabilization.

2. 3 ATTITUDE & ORBIT CONTROL SUBSYSTEM (AOCS)

1. **Attitude** of a satellite refers to its orientation is space so that:
   a) the antennas and cameras point their narrow beam towards desired areas on the earth, and
   b) the solar panels point to the sun.
2. Forces that tend to alter the attitude of the satellite include:
   a) Asymmetry of the earth's gravitational field;
   b) Gravitational forces of the sun and moon;
   c) Pressure from sun radiation;
   d) Magnetic field of the earth.

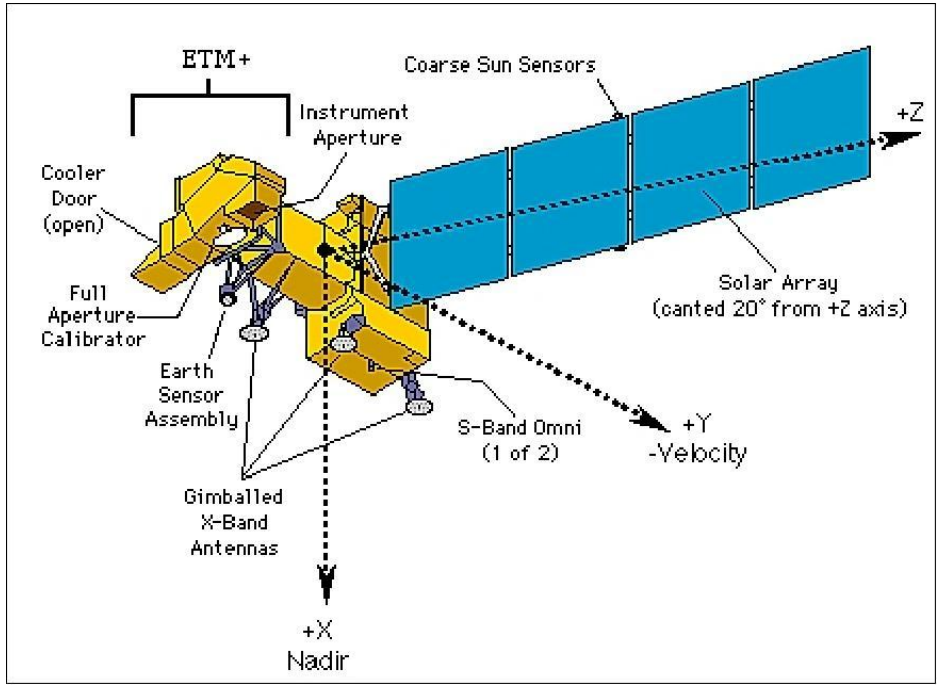
2.4 ATTITUDE CONTROL - SENSORS

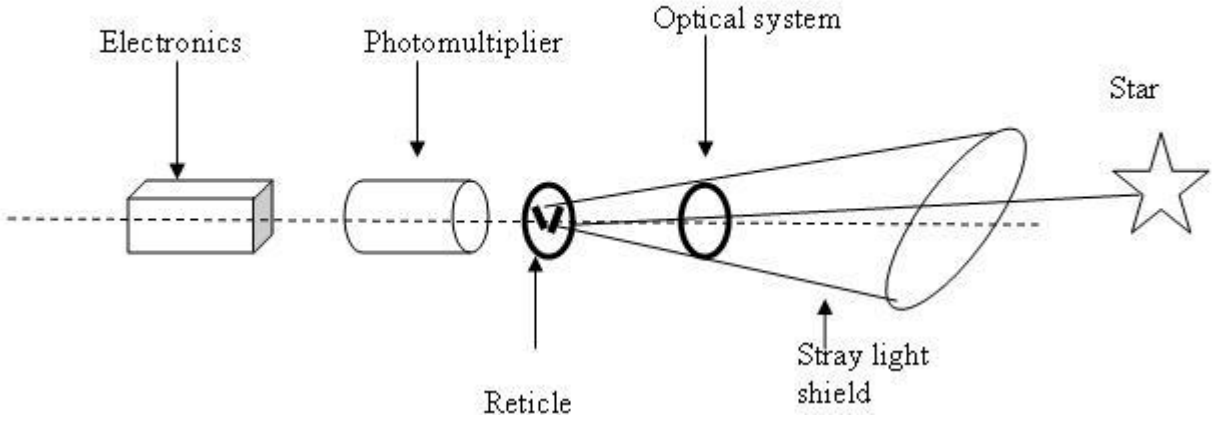
Three types of sensors are used in a satellite system, i.e

1. **Earth Sensors:** Senses the direction to Earth. They are usually an infrared cameras. Used for attitude control, antenna pointing and gyro updating.

2. **Sun Sensors:** Devices used to detect the direction of the sun. Sun sensors are used for attitude control, solar array pointing, gyro updating, and fail-safe recovery.

3. **Star Sensors:** star coordinates in the spacecraft frame and provide attitude information when these observed coordinates are compared with known star directions obtained from a star catalogue.





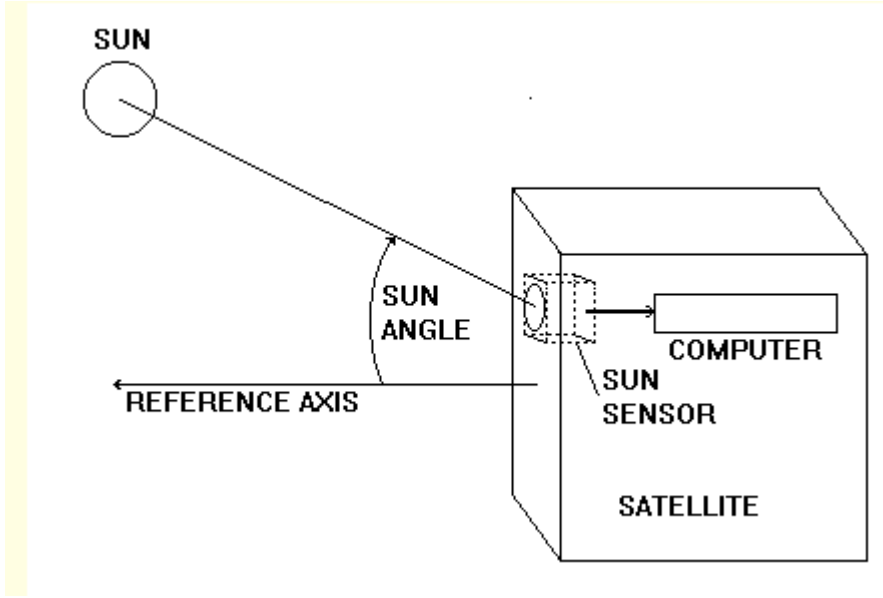
2.5 EARTH SENSORS

Earth Sensors on Dual-Spin Satellites

1. Consist of passive infra-red sensors in the 14-16 μm wavelength which senses infrared rays coming from earth.
2. Two earth sensors are positioned at 5^{o} north and 5^{o} south of the spin axis.
3. An on-board circuit measures the phase difference between the two sensors and sends the information (earth aspect angle) through the telemetry system to the earth control station

2.6 SUN SENSORS

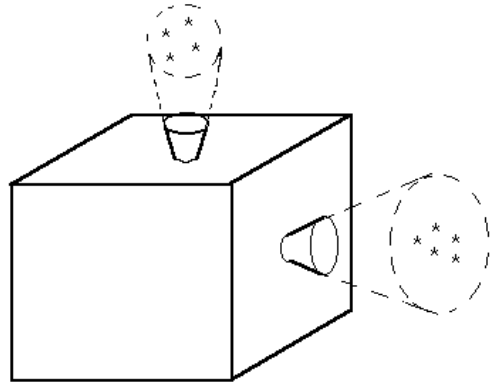
1. The sun-sensor measures angle between "sun line" and a reference axis in the satellite.
2. Sun Sensor uses two sensors operating in the visible spectrum as shown.
3. One sensor is mounted parallel to the spin axis while the other is canted 35^{o}.
4. Data from the on-board processor is transmitted to the earth control station to determine the solar aspect angle.

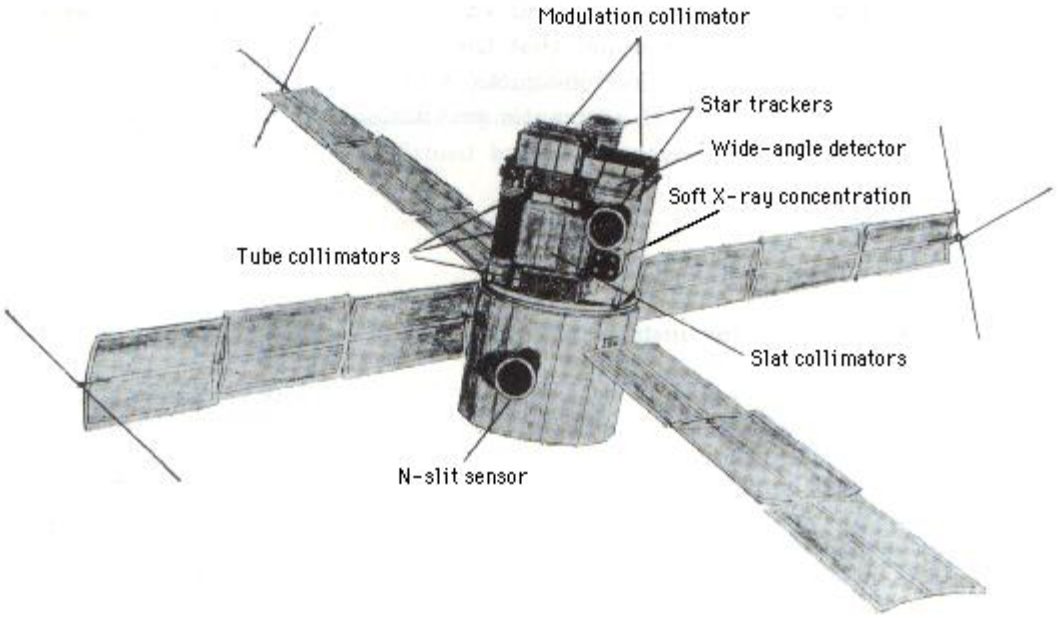


2.7 STAR SENSORS

Star sensor

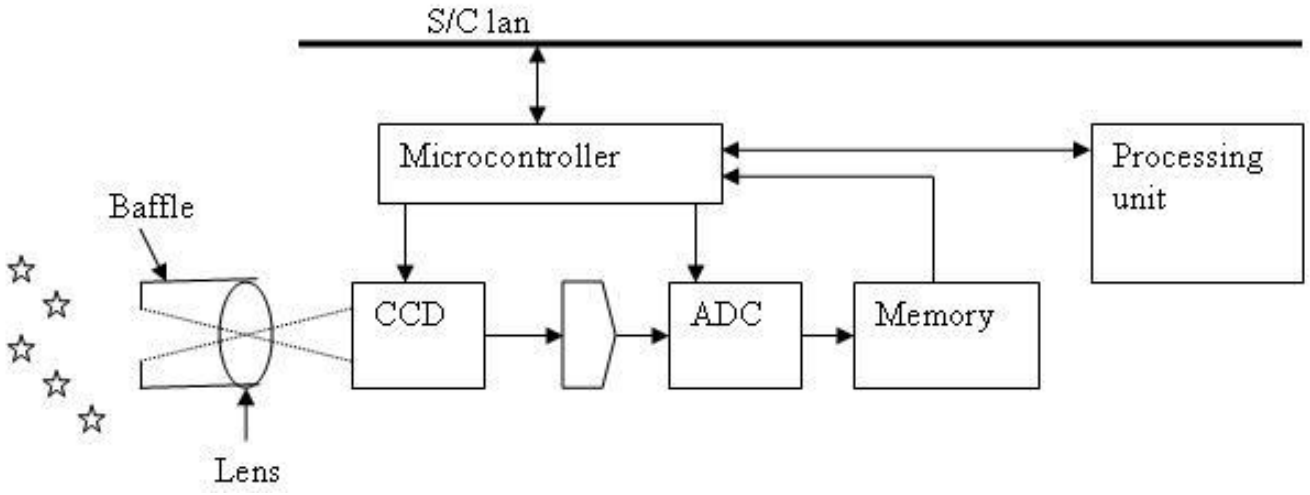
1. Cameras mounted on the satellite in different directions used to identify different star patterns.
2. On-board computer compares camera images with stored star catalogue to determine which way the satellite is oriented.





2.7.1 STAR SENSOR COMPONENTS

1. **Star tracking system** consists of the following:
   a) The star tracker control
   b) Star image processing
   c) Star pattern identification
   d) Attitude estimation
2. **CCD or "charge couple devices" star trackers** are the most popular nowadays because in comparison with the other sensors they have the highest value for the quantum efficiency parameter while they also cover a wide wavelength region.



SUMMARY OF SATELLITE SENSORS

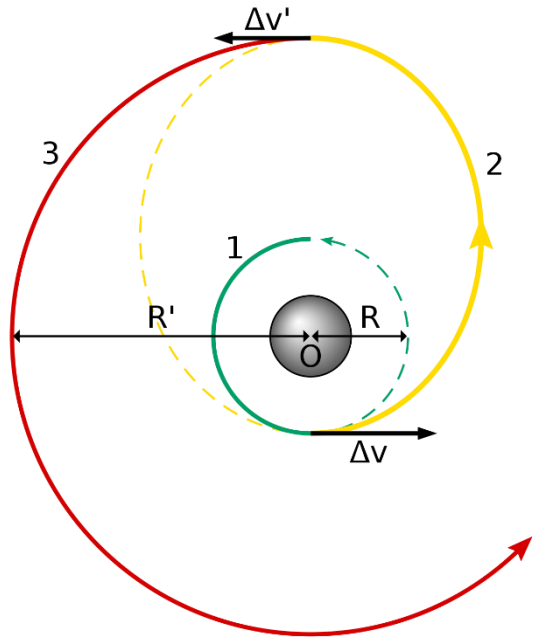
SENSOR	MEASURES	TYPICAL USE
Earth horizon sensors (IR)	Roll/pitch relative to Earth's limb	GEO pointing, ±0.1°
Sun sensors	Sun direction; safe-mode acquisition	Coarse + acquisition
Star trackers	Attitude vs. star catalog	High accuracy (arc-second class)
Gyroscopes (gyros)	Angular rates	Rate estimation between fixes
Magnetometers	Earth's magnetic field vector	LEO, coarse attitude
GPS receivers	Position/velocity/time	LEO orbit determination

3.0 PROPULSION SYSTEM

1. The propulsion system is an on-board reaction control system used to generate forces on the satellite when orbit and attitude control is required.
2. The propulsion system uses two types of actuators:

   (a) Low thrust actuators – used for attitude and orbit corrections with velocity corrections of less than 50 m/s

   (b) High thrust actuators – used for orbit transfers such as the geostationary orbit injection from the transfer orbit.



3.1 LOW-THRUST ACTUATORS

1. The low-thrust actuators can be further classified as:

(a) Chemical thrusters which generate gases through chemical reaction of propellants. The gases are then released through nozzles.

(b) Electric thrusters which provide thrust by accelerating ionized mass in an electromagnetic field.

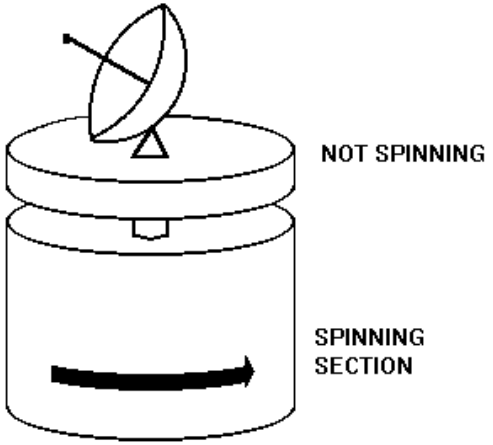
2. Communication satellites usually use Chemical thrusters.

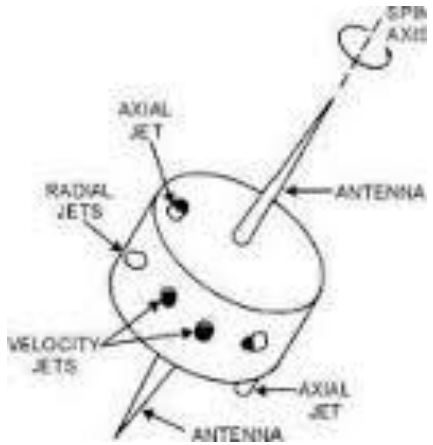
3.2 ATTITUDE CONTROL-DUAL SPIN REVISITED

1. In order to control attitude of a satellite in space, the satellite must be properly oriented and stabilized.
2. Two common methods of stabilization are:

(a) **Spin stabilization**

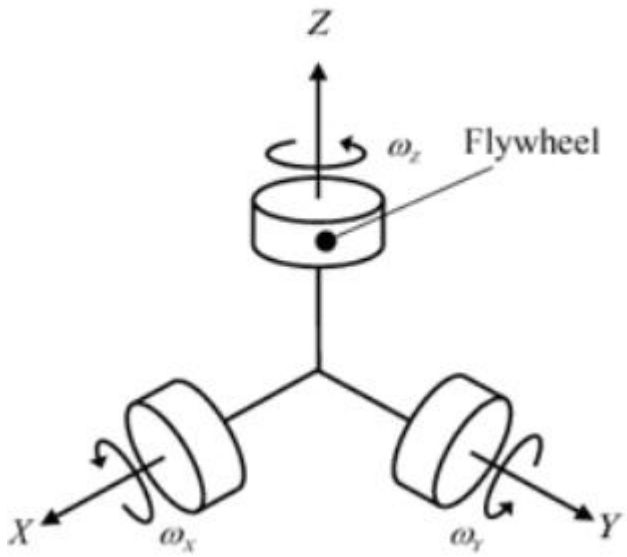
   i. The spacecraft is rotated at 30-60 rotations per minute.
   ii. The spin provides a powerful gyroscopic action that maintains the axis is a correct direction.
   iii. The antenna is usually mounted at one end of the drum and spun in the opposite direction to that of the drum (despun).
   iv. The despun section is kept stationary by counter rotation.





3.3 THREE AXIS BODY STABILIZATION

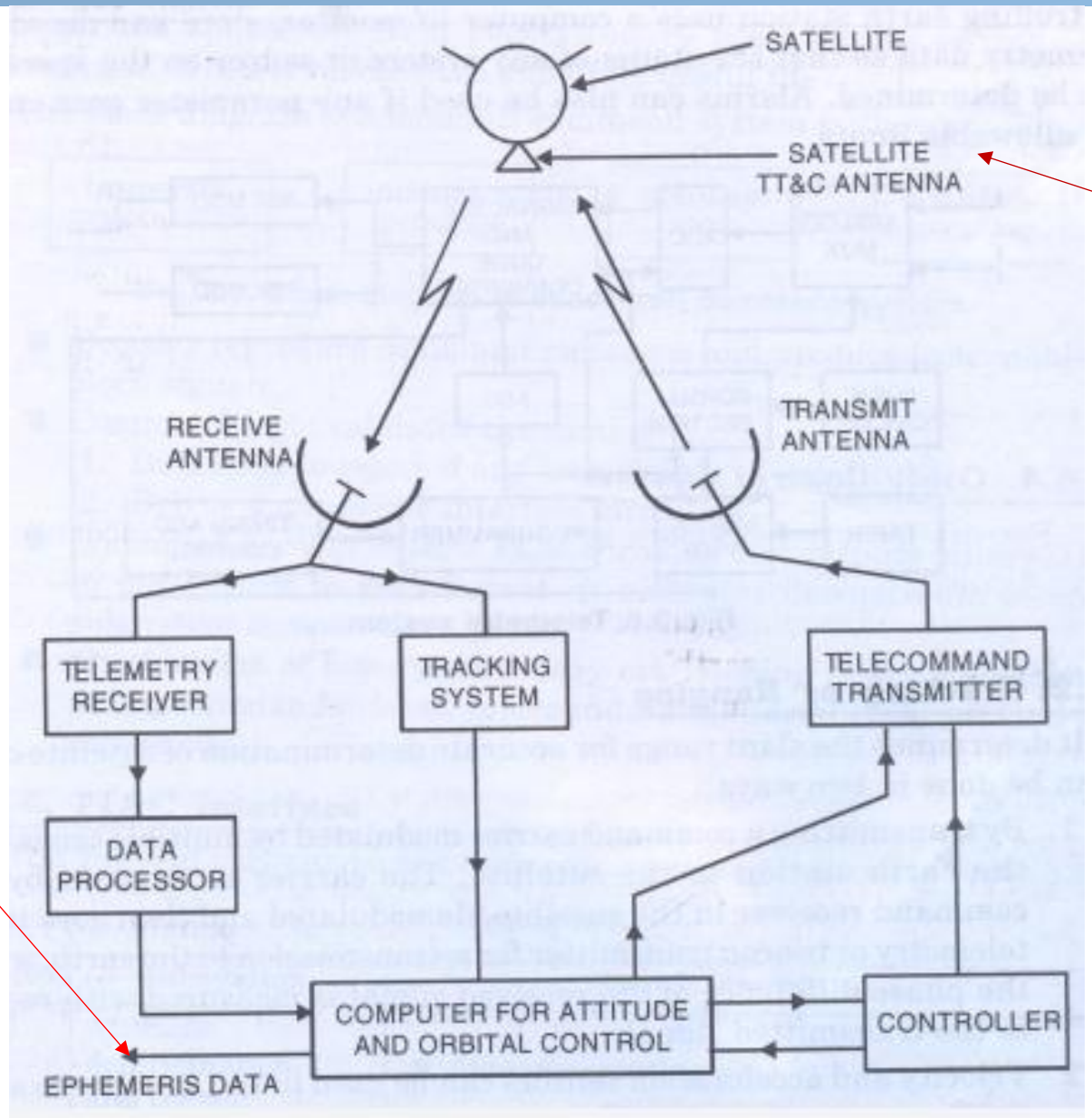
1. **Three-axis stabilization** is achieved by rotating it round three axes, i.e yaw, roll and pitch.
2. **Three momentum wheels** are mounted on three perpendicular axis corresponding to yaw, roll and pitch.
3. A momentum wheel is a high speed wheel driven by a motor and kept in a sealed chamber.
4. Changes in attitude are measured by the sensors and transmitted to the earth control station.
5. The data is analysed by the ground station and commands are sent to increase or decrease the speed of the momentum wheels.



4.0 TELEMETRY, TRACKING AND COMMAND

1. **Telemetry, Tracking and Control (TT&C)** subsystem provides vital control and monitoring function required to maintain the functionality of a satellite.
2. **TT&C** is the only way to observe and to control the satellite's functions and condition from the ground.
3. **TT& C functions** include:
   a) Carrier tracking
   b) Command reception and detection
   c) Telemetry modulation and transmission
   d) Ranging
   e) Subsystem operation control

4.1 BLOCK DIAGRAM OF TT&C SYSTEM



TT&C Antenna
Special antenna used for Telemetry, Traffic and Control (TT&C)

Ephemeris data
Data file giving the calculated positions of the satelliteat regular intervals throughout a period.

4.2 TELEMETRY SECTION

1. **The telemetry section** collects data from many sensors on the satellite and sends data to the controlling earth station.
2. The information transmitted includes:
   a) The pressure in the fuel tank
   b) Voltage and currents in the power conditioning unit
   c) Current drawn by each subsystem
   d) Critical voltages and currents in the communication subsystem
   e) Temperature in the subsystems
   f) Attitude
   g) Position of various switches
   h) Typically 100 sensors are required to monitor the above.

4.3 TRACKING AND RANGE

Slant range of a satellite can be accurately determined by using two methods:

(a) By transmitting a **command modulated carrier** which is received by the satellite transponder and retransmitted back to the earth after a specific delay. Same methods as that used in radar and DME.

(b) Use of velocity and acceleration sensors mounted on the satellite to sense change in the orbital position. The earth-based controller station receives these data through telemetry and after analysis relays orbit correction.

COMMUNICATION PAYLOAD

- The payload is the reason the satellite exists.
- For a bent-pipe communication satellites payload comprises:

receive antennas → low-noise receivers → transponders → high-power amplifiers → transmit antennas.

SATELLITE FREQUENCY PLAN (GEO EXAMPLES)

BAND	UPLINK	DOWNLINK	APPLICATION
C	5.925–6.425 GHz	3.7–4.2 GHz	Legacy, rain-resistant
Ku	14.0–14.5 GHz	11.7–12.2 GHz	Broadcast / VSAT; rain fade matters
Ka	27.5–31 GHz	17.7–21.2 GHz	High throughput, spot beams; heavy rain fade

Different uplink and downlink frequencies are used avoid self-interference between the powerful transmitted downlink and the faint received uplink