EENG 470
Satellite Communications

Lecture # 2
Introduction to Satellite Communications (part 2)

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Propulsion

- Rocket motors produce thrust in a process which can be explained by Newton's third law (for every action there is an equal but opposite reaction).

- In the case of rocket engines, the reactionary force is produced by the combustion of fuel in a combustion chamber.

- This force then acts upon the rocket nozzle, causing the reaction which propels the vehicle. Since rocket motors are designed to operate in space, they require an oxidizer in order for combustion to take place.

- This oxidizer is, in many cases, liquid oxygen. There are three different types of rocket engines:

1. Solid propelled rockets

2. Liquid propelled rockets

3. Nuclear rockets

Solid Fueled Rockets

- In solid fueled rockets, the fuel and oxidizer both in solid form and thoroughly mixed during manufacture.
- The section where the fuel is stored is also the combustion chamber. One end of the chamber is closed (the payload of the rocket would be attached to this end) and the other end of the chamber is a rocket nozzle.
- Advantages of solid fuel rockets include simplicity and reliability, since there are no moving parts and high propellant density, which results in a smaller sized rocket.
- Among the disadvantages are these: once you turn on a solid rocket motor, you can't shut it off. You have to wait for the fuel to run out. Also, the thrust of a solid fuel rocket decreases greatly during its burn time.

Liquid Fueled Rockets

- In liquid fueled rockets the fuel and oxidizer are stored in liquid form and pumped into the combustion chamber.

- There are two types of liquid propellent rockets;

- bi-propellant rockets, which have separate fuel and oxidizer,
- mono-propellant rockets, which have their fuel and oxidizer combined into a single liquid.

- Liquid fueled rockets are superior to solid fuel rockets in many respects;

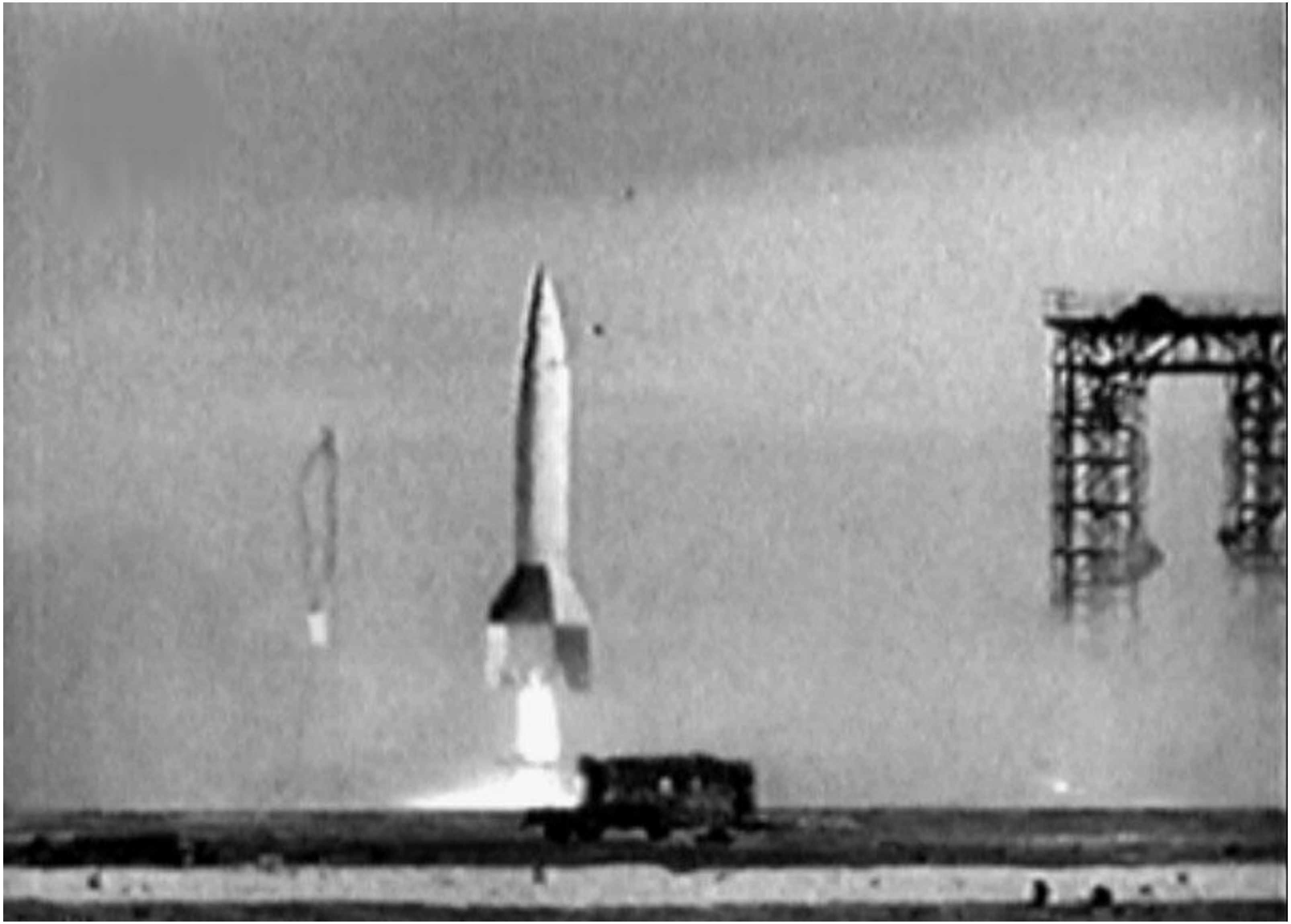
- they can be shut off and subsequently restarted, they generally have a higher exhaust velocity, which means lower burn times are required, and they can be throttled to produce more or less thrust, as needed.

- However, liquid fuel rockets are highly complex, and therefore have a lower rate of reliability.

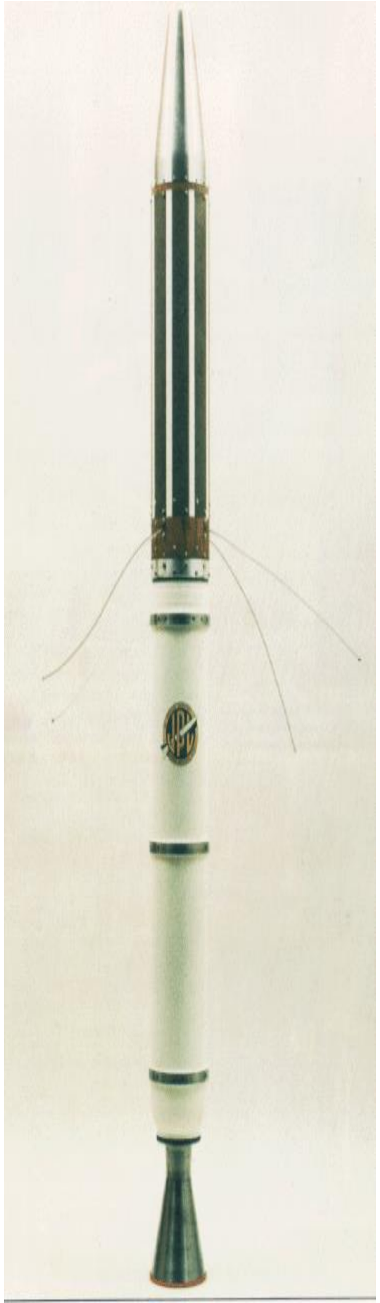
Nuclear Rockets

- Nuclear rockets work by routing hydrogen through a nuclear reactor.
- The reactor is at a high temperature, which causes the hydrogen fuel to expand as it leaves the nozzle, producing a high amount of thrust. Nuclear rockets do not need an oxidizer, and they require much less fuel per pound of payload than liquid or solid fuel rockets.
- This allows a vehicle using a nuclear rocket to be more versatile than one which uses chemical rockets.
- Disadvantages of nuclear rockets include radiation effects caused by the nuclear reactor, and the high weight of the engine assembly.

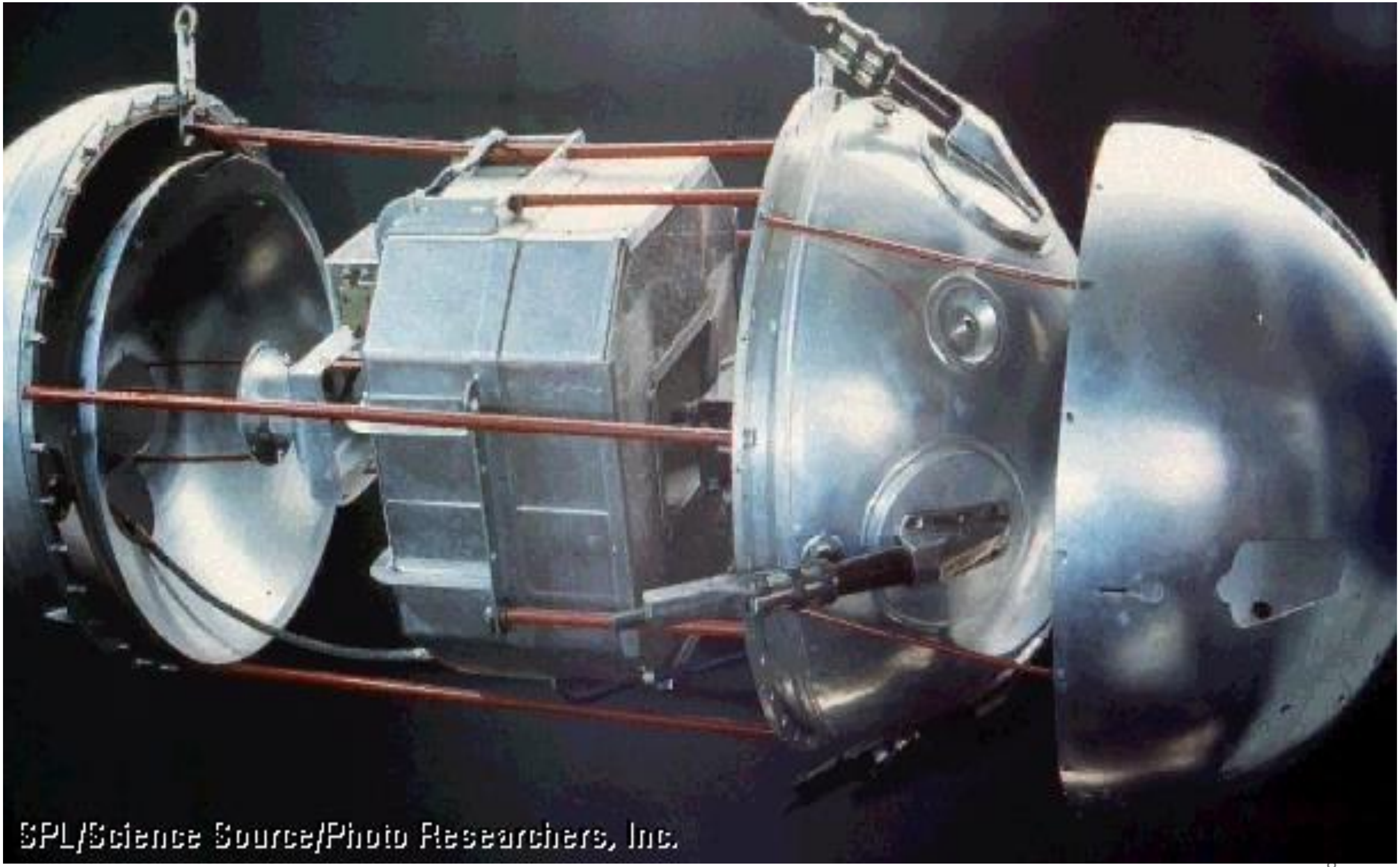
V2 Rocket



Explorer - I



Sputnik - I

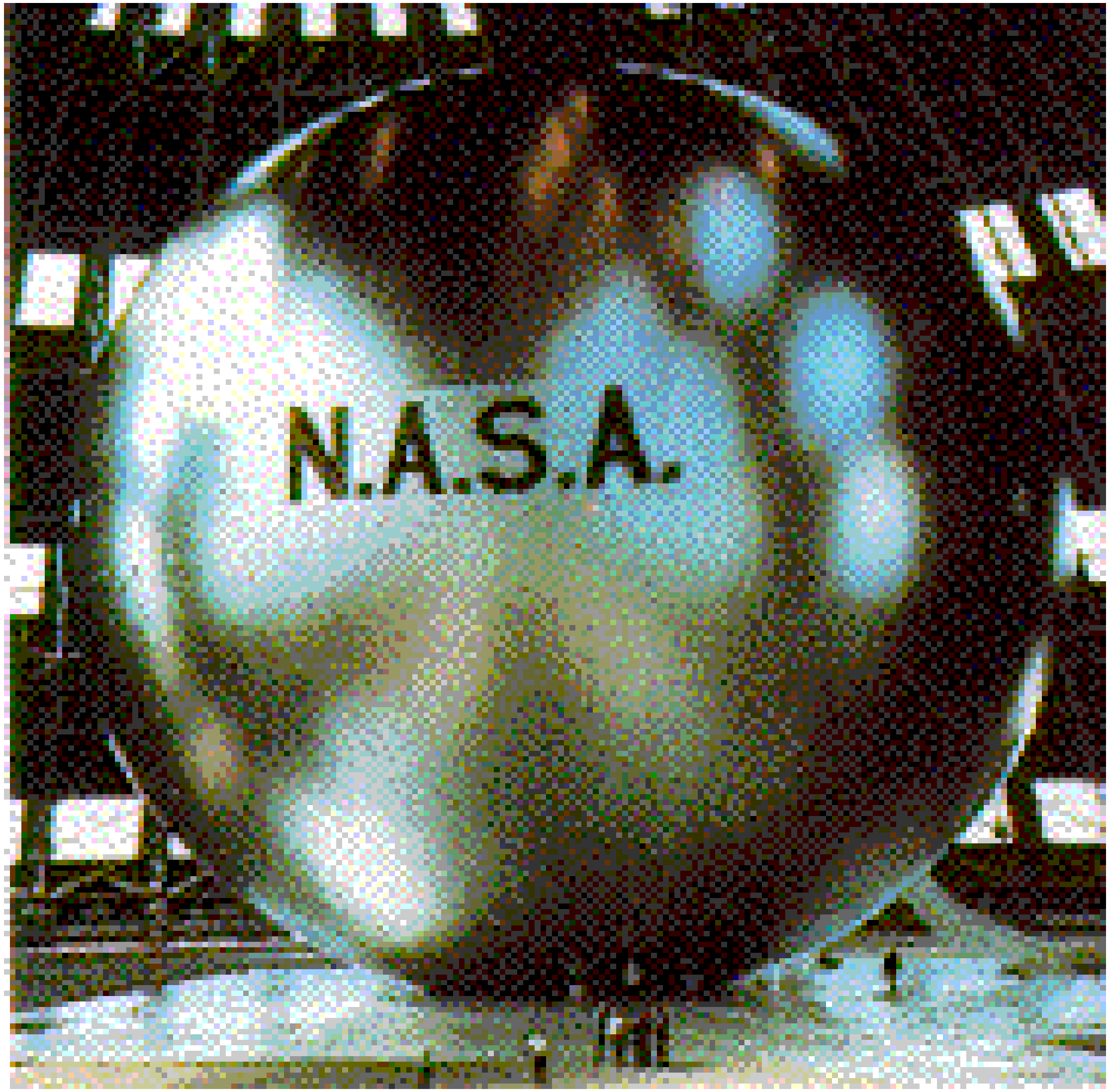


Important Milestones (1960's)

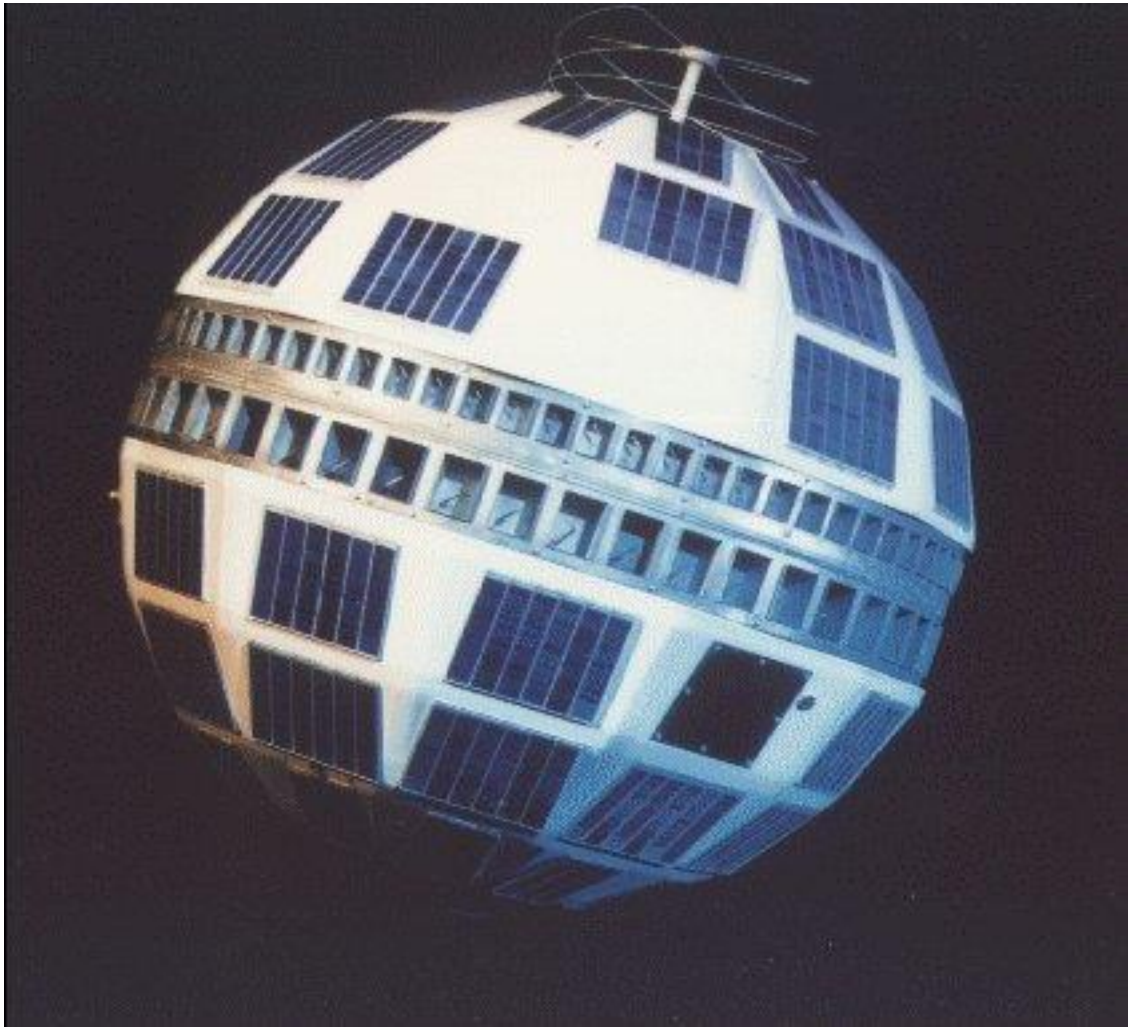
First satellite communications

- 1960 First passive communication satellite launched into space (Large balloons, Echo I and II).
- 1962: First non-government active communication satellite launched Telstar I (MEO).
- 1963: First satellite launched into geostationary orbit Syncom 1 (comms. failed).
- 1964: International Telecomm. Satellite Organization (INTELSAT) created.
- 1965 First communications satellite launched into geostationary orbit for commercial use Early Bird (re-named INTELSAT 1).

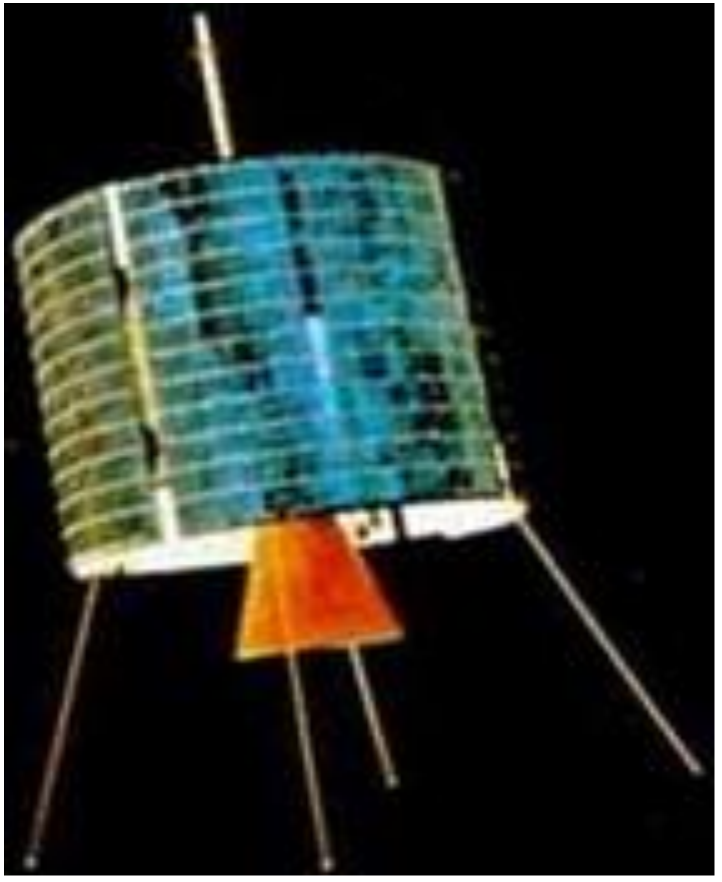
ECHO I



Telstar I



Intelsat I



Important Milestones (1970's)

GEO applications development

- 1972 First domestic satellite system operational (Canada). INTERSPUTNIK founded.
- 1975 First successful direct broadcast experiment (one year duration; USA-India).
- 1977 A plan for direct-to-home satellite broadcasting assigned by the ITU in regions 1 and 3 (most of the world except the Americas).
- 1979 International Mobile Satellite Organization (Inmarsat) established.

Important Milestones (1980's)

GEO applications expanded

- 1981 First reusable launch vehicle flight.
- 1982 International maritime communications made operational.
- 1983 ITU direct broadcast plan extended to region 2.
- 1984 First direct-to-home broadcast system operational (Japan).
- 1987 Successful trials of land-mobile communications (Inmarsat).
- 1989-90 Global mobile communication service extended to land mobile and aeronautical use (Inmarsat)

Important Milestones (1990's)

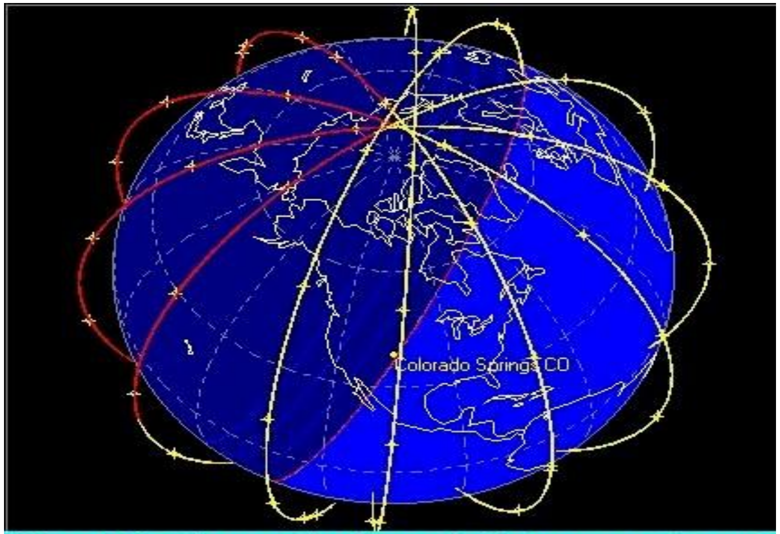
- 1990-95:

  - Several organizations propose the use of non-geostationary (NGSO) satellite systems for mobile communications.

  - Continuing growth of VSATs around the world.
  - Spectrum allocation for non-GEO systems.
  - Continuing growth of direct broadcast systems. DirectTV created.
- 1997:

  - Launch of first batch of LEO for hand-held terminals (Iridium).
  - Voice service telephone-sized desktop and paging service pocket size mobile terminals launched (Inmarsat).
- 1998: Iridium initiates services.
- 1999: Globalstar Initiates Service.
- 2000: ICO initiates Service. Iridium fails and system is sold to Boeing.

Iridium



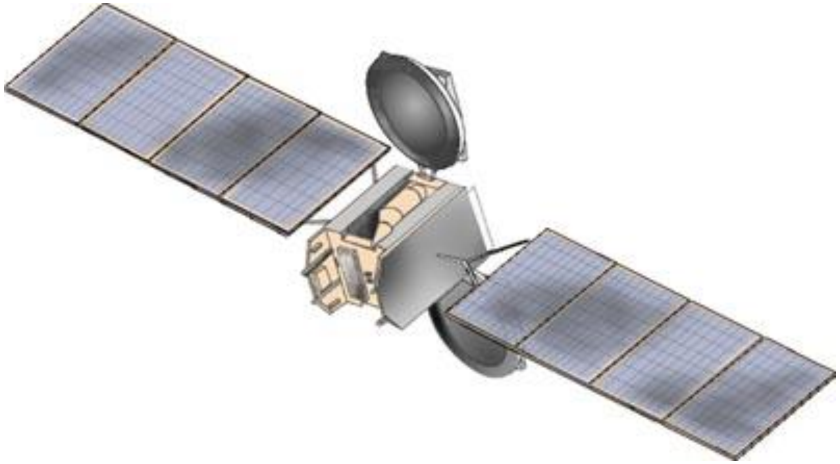
Graphic from SatSpy 3.0 (pre-release)

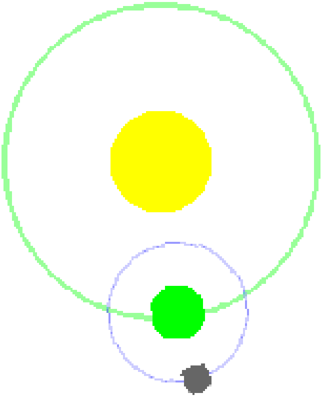
Orbiting Machines

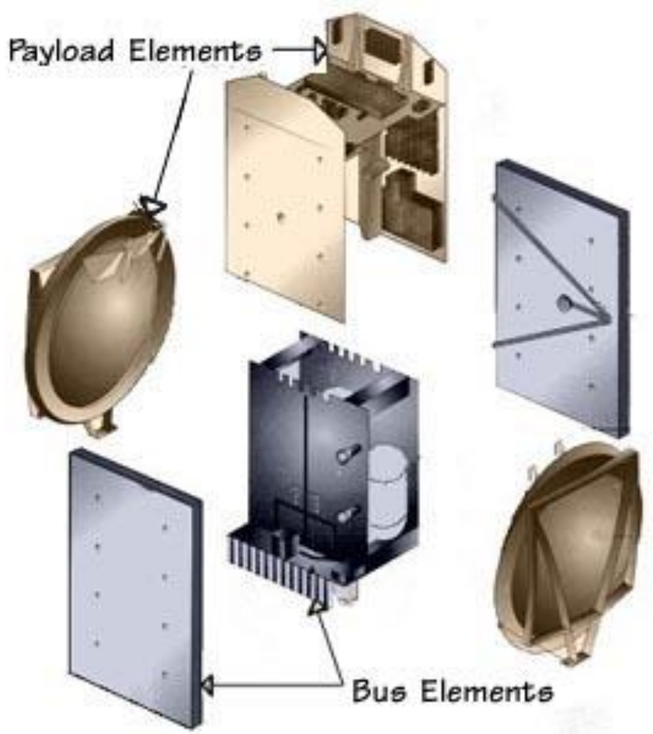
In this exhibit we'll look at the man-made satellites that orbit Earth and the Sun -- highly specialized tools that do thousands of tasks every day. Each of these satellites has many parts, but two parts common to all satellites are called the payload and the bus.

What is a satellite anyway?

A satellite is any object that orbits or revolves around another object. For example, the Moon is a satellite of Earth, and Earth is a satellite of the Sun.





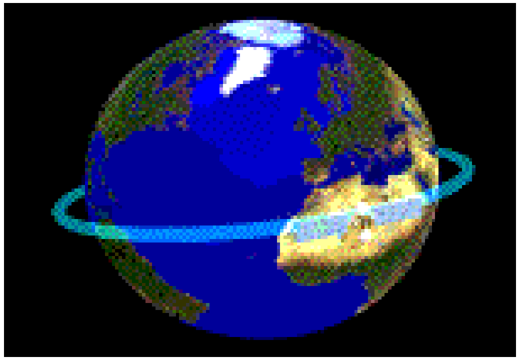


Satellite Elements

The **payload** is all the equipment a satellite needs to do its job. This can include antennas, cameras, radar, and electronics. The payload is different for every satellite. For example, the payload for a weather satellite includes cameras to take pictures of cloud formations, while the payload for a communications satellite includes large antennas to transmit TV or telephone signals to Earth.

The **bus** is the part of the satellite that carries the payload and all its equipment into space. It holds all the satellite's parts together and provides electrical power,computers, and propulsion to the spacecraft. The bus also contains equipment that allows the satellite to communicate with Earth.

Low Earth Orbit



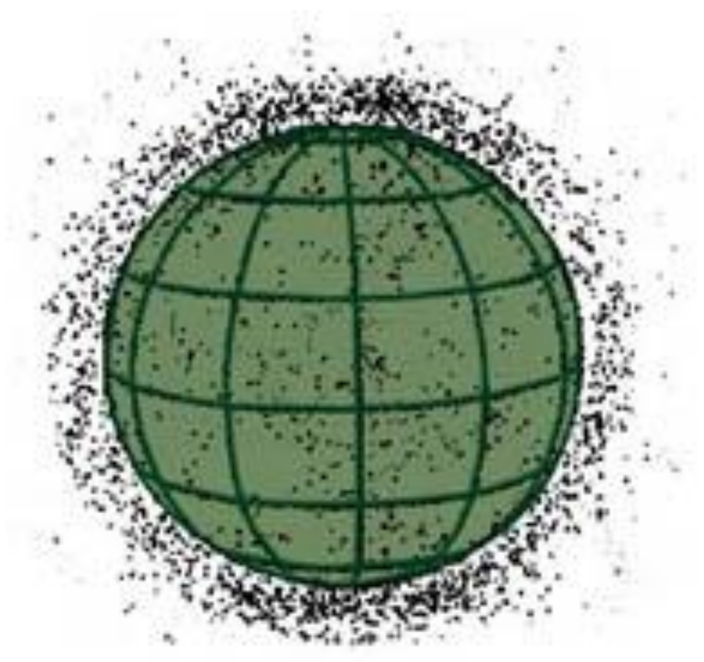
When a satellite circles close to Earth we say it's in Low Earth Orbit (LEO). Satellites in LEO are just 200 - 500 miles (320 - 800 kilometers) high. Because they orbit so close to Earth, they must travel very fast so gravity won't pull them back into the atmosphere. Satellites in LEO speed along at 17,000 miles per hour (27,359 kilometers per hour)! They can circle Earth in about 90 minutes.

What a view!
A Low Earth Orbit is useful because its nearness to Earth gives it spectacular views. The crew in a Space Shuttle traveling in low earth orbit took this picture. Satellites that observe our planet, like Remote Sensing and Weather satellites, often travel in LEOs because from this height they can capture very detailed images of Earth's surface.

Space Junk

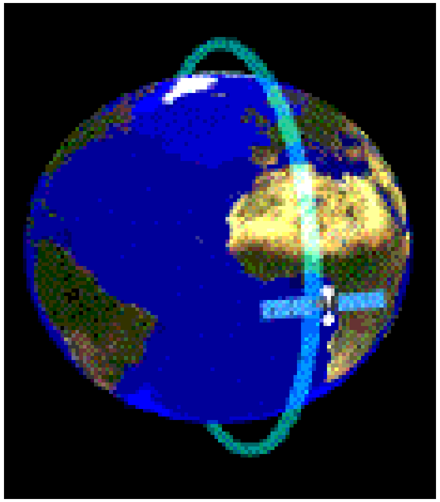
The LEO environment is getting very crowded. The United States Space Command keeps track of the number of satellites in orbit. This is a graphic display of the objects in low earth orbit. According to the USSC, there are more than 8,000 objects larger than a softball now circling the globe.

Some people worry about the number of items now in low earth orbit. Not all of these things are working satellites. There are pieces of metal from old rockets, broken satellites, even frozen sewage. At 17,000 mph, even a small bolt can hit a space shuttle with the impact of a hand grenade. Which is exactly why the US Space Command keeps track of these things!

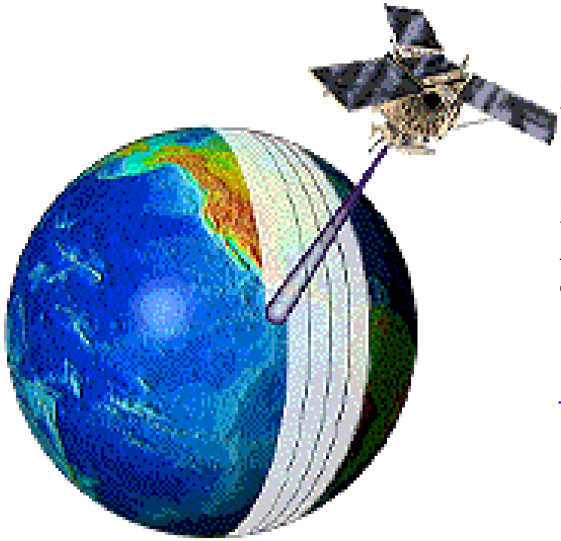


Polar Orbit

A Polar orbit is a particular type of Low Earth Orbit. The only difference is that a satellite in polar orbit travels a north-south direction, rather than the more common east-west direction.



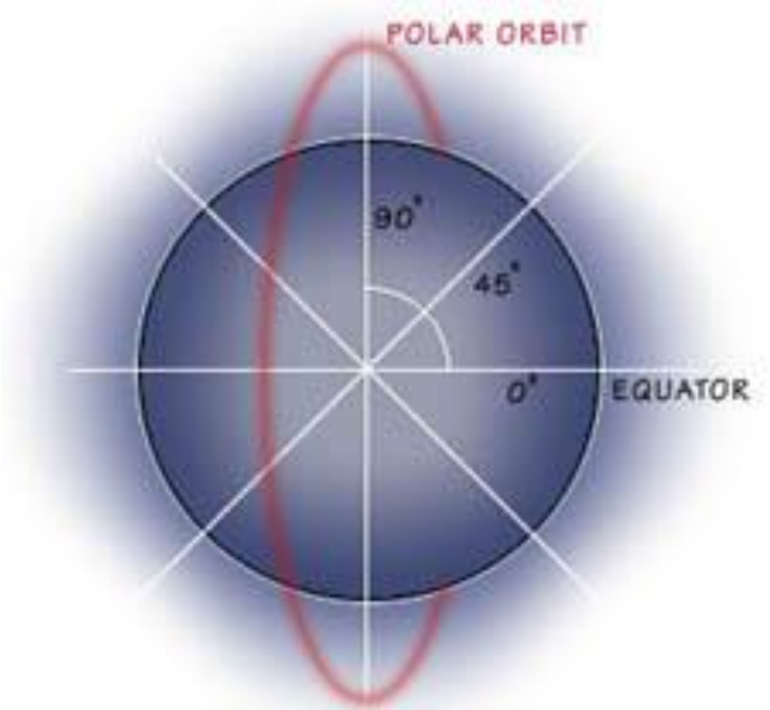
Why use a Polar Orbit?



Polar orbits are useful for viewing the planet's surface. As a satellite orbits in a north-south direction, Earth spins beneath it in an east-west direction. As a result, a satellite in polar orbit can eventually scan the the entire surface. Its like pealing an orange in one piece. Around and around, one strip at a time, and finally you've got it all. For this reason, satellites that monitor the global environment, like remote sensing satellites and certain weather satellites, are almost always in polar orbit. No other orbit gives such thorough coverage of Earth.

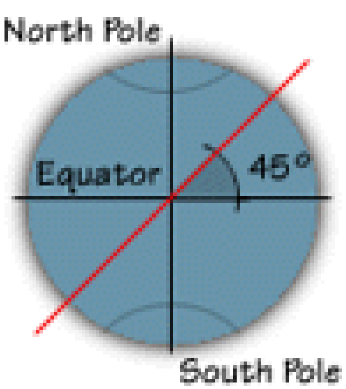
Inclinations

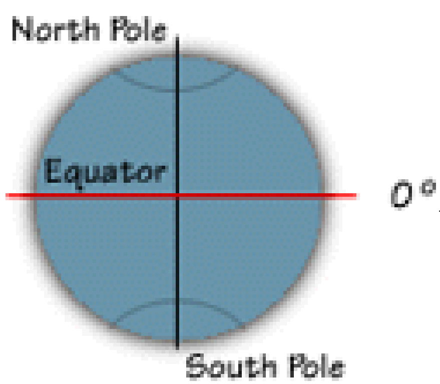
We say that a polar orbit has an inclination, or angle, of 90 degrees. It is perpendicular to an imaginary line that slices through Earth at the equator.



What do you think the inclination would be of a satellite that orbits around the equator?

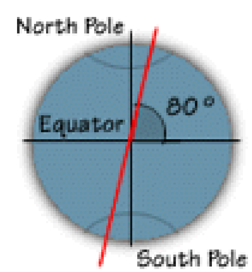
No.
45 degrees would angle the orbit halfway between the equator and the poles.



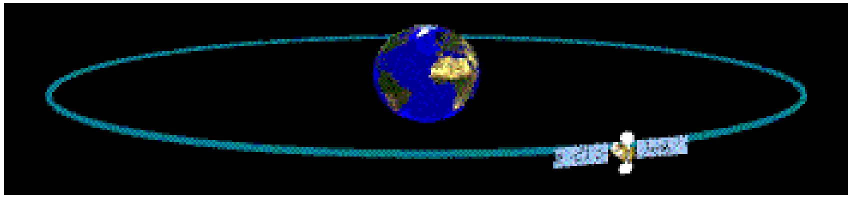


Nope.
An orbit with an inclination of 80 degrees is highly inclined, and would be considered a polar orbit.

Right.
An orbit around the equator would have an inclination of 0 degrees.



Geosynchronous Equatorial Orbit

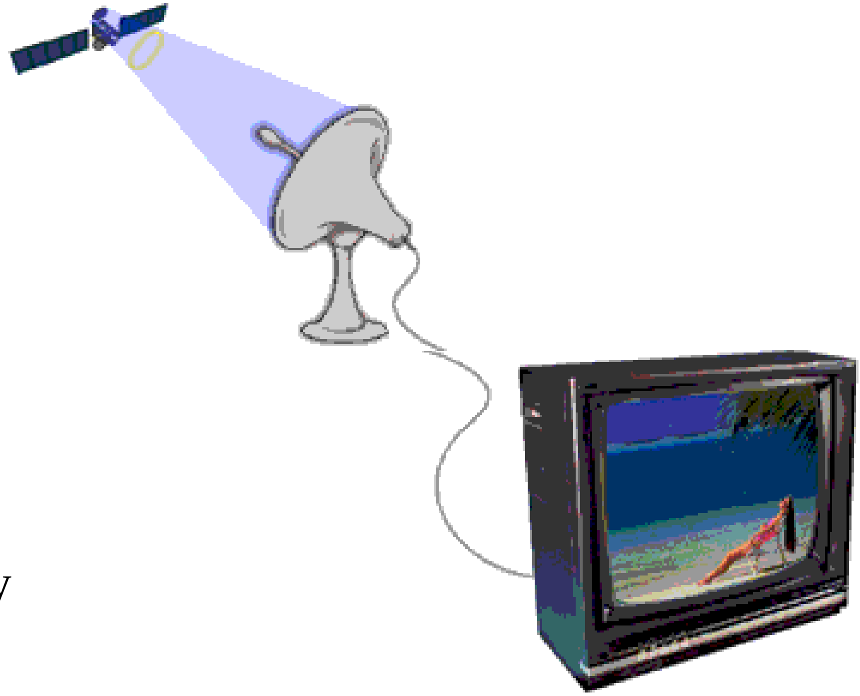


(from ***geo*** = Earth + ***synchronous*** = moving at the same rate).
A satellite in geosychonous equatorial orbit (GEO) is located directly above the equator, exactly 22,300 miles out in space. At that distance, it takes the satellite a full 24 hours to circle the planet. Since it takes Earth 24 hours to spin on in its axis, the satellite and Earth move together. So, a satellite in GEO always stays directly over the same spot on Earth. (A geosynchronous orbit can also be called a GeoSTATIONARY Orbit.)

Footprints

Because they're so far away, GEO satellites have a very broad vie
Earth. For instance, the footprint of one EchoStar broadcast satelli
covers almost all of North America.

GEO



And, since they stay over the same spot on Earth, we always know where GEO satellites are. If our antenna points in the right direction, we'll always have direct contact with the satellite.

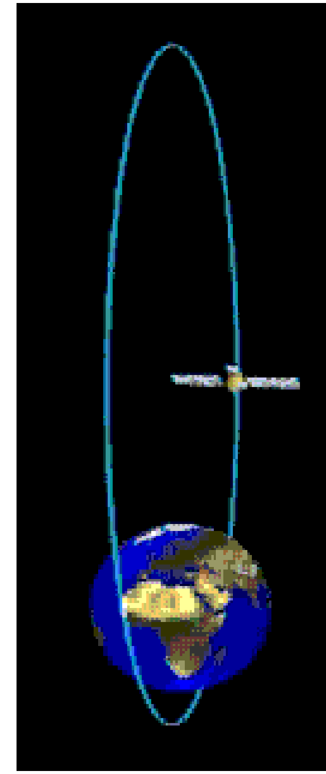
Many communications satellites travel in geosynchronous orbits, including those that relay TV signals into our homes.

Do you know who first proposed geosynchronous orbits for satellites?

The famous science fiction writer Arthur C. Clarke (the same person who wrote **2001, a Space Odyssey**) first proposed geosynchrous orbits for communications satellite in 1945. That was 25 years before the first communications satellite was placed in geosynchronous orbit!

Elliptical Orbit

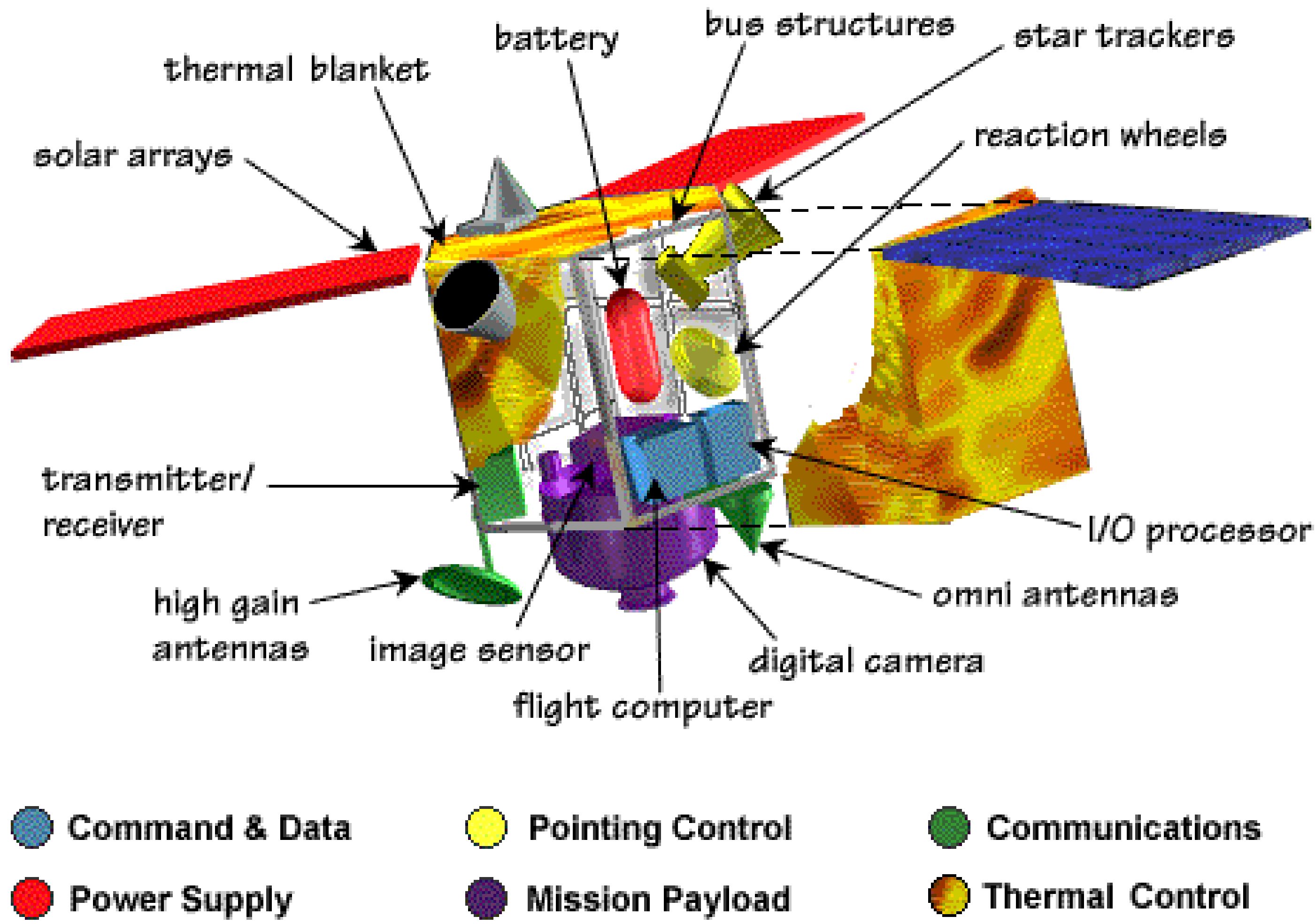
A satellite in elliptical orbit follows an oval-shaped path. One part of the orbit is closest to the center of Earth (perigee) and the other part is farthest away (apogee). A satellite in this orbit takes about 12 hours to circle the planet. Like polar orbits, elliptical orbits move in a north-south direction.



Polar Coverage

While most communications satellites are in Geosynchronous orbit, the footprints of GEO satellites do not cover the polar regions of Earth. So communications satellites in elliptical orbits cover the areas in the high northern and southern hemispheres that are not covered by GEO satellites.

Satellite Anatomy



A satellite is a complex machine. All satellites are made up of several subsystems that work together as one large system to help the satellite achieve its mission. This simplified illustration shows the key parts of a remote-sensing satellite. The main subsystems are grouped by color.

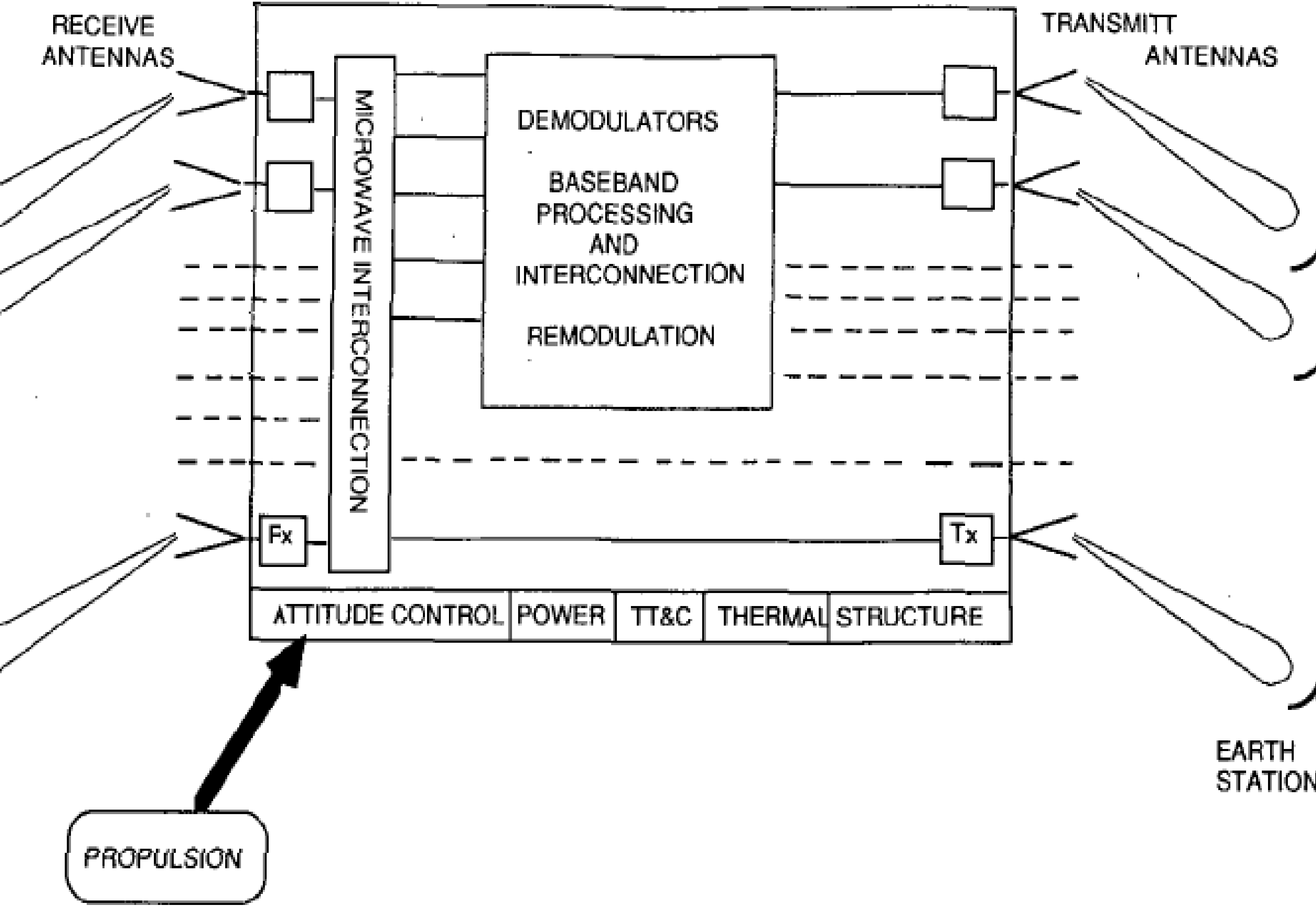
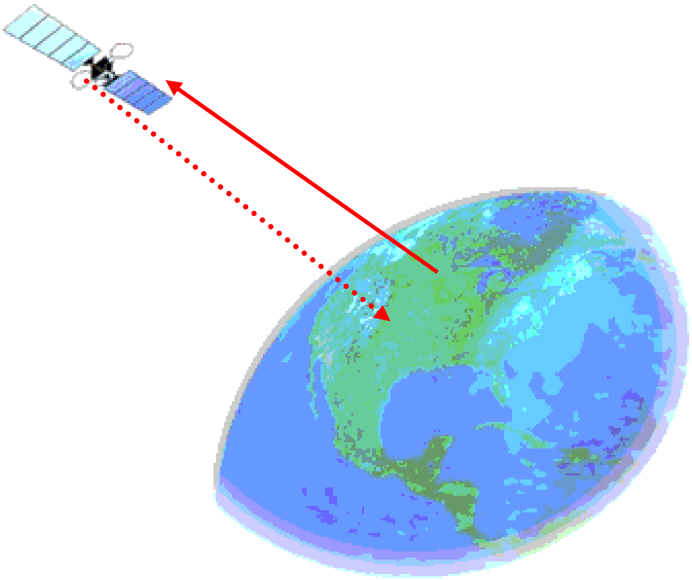


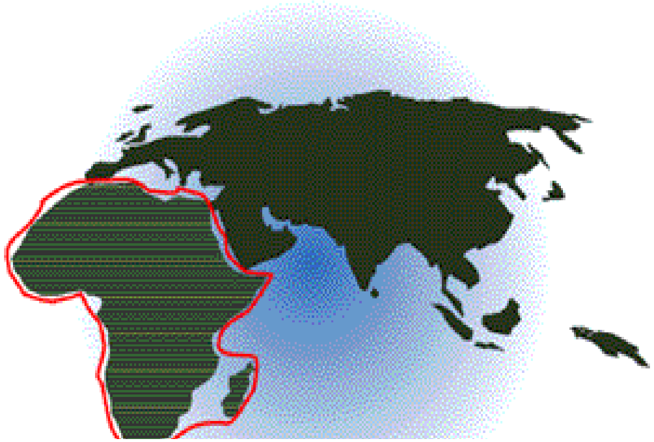
Fig. 4. Generic satellite block diagram.

Communications



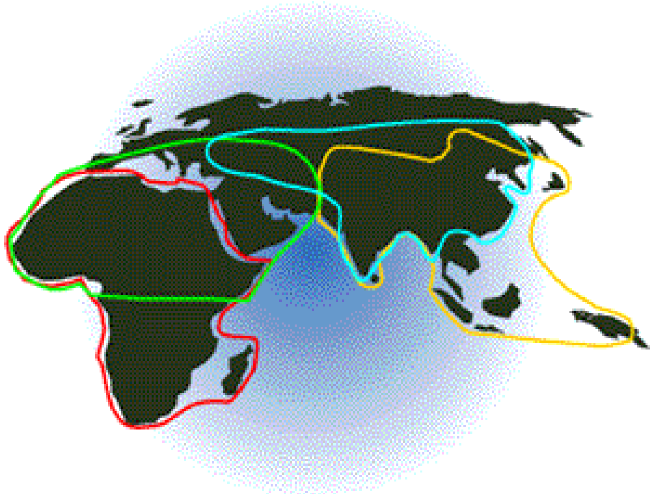
Relay Stations

Communications satellites act as relay stations in space. People use them to bounce messages from one part of the world to another. These messages can be telephone calls, TV pictures, or even Internet connections like the one you're using now.



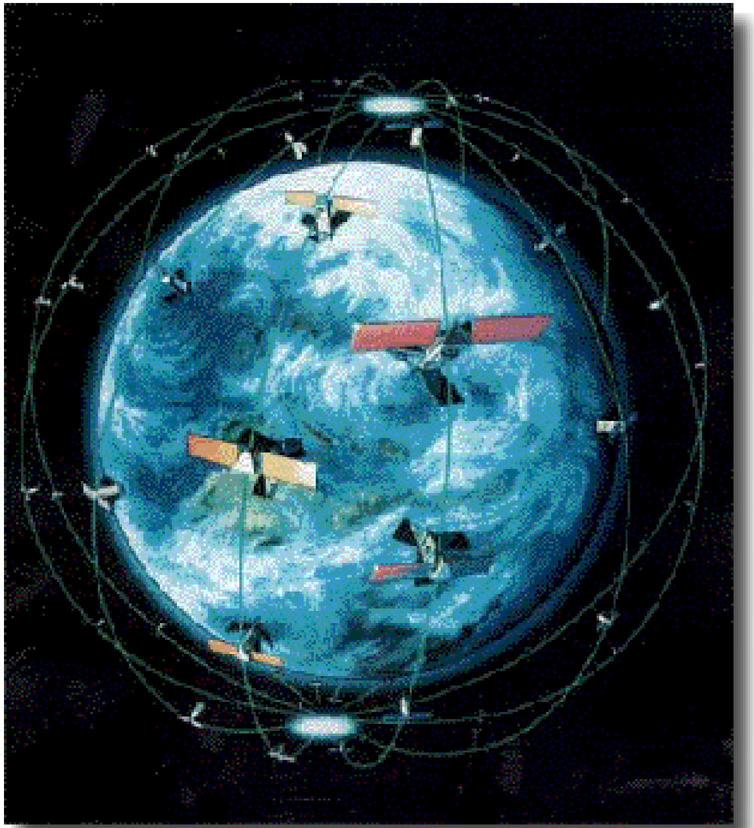
Footprints

Communications satellites like EchoStar are in geosynchronous orbit (from ***geo*** = Earth + ***synchronous*** = moving at the same rate). That means that the satellite always stays over one spot on Earth. The area on Earth that it can "see" is called the satellite's "footprint." Here is one footprint that covers all of Africa. A person in Africa can use this satellite to communicate with anyone else in Africa. We can also use satellites as a relay system to send signals anywhere on Earth. Here you can see the overlapping footprints of four different satellites. If you wanted to send a signal from Africa to Southeast Asia, you could bounce, or relay, the signal using more than one satellite.



MSS

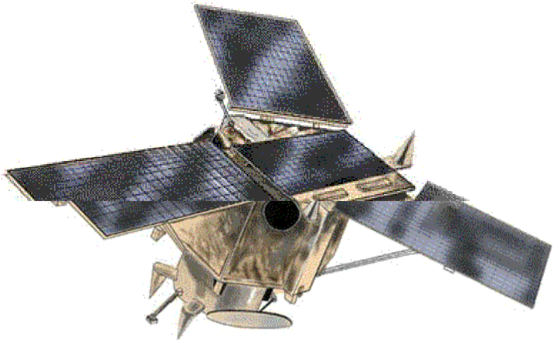
Iridium is a communications satellite developed by Motorola. Actually, Iridium is designed as a. There will be 66 Iridium satellites in all that will provide mobile telephone and paging services worldwide. Anyone with an Iridium telephone will be able to make calls to and from anywhere on Earth.



Last year, Motorola began launching its satellites into low earth orbit. As of January 1st, 1998 there were 46 satellites already in position. Additional launches will take place early this year. Global service is scheduled to begin in 1998. Stay tuned for updates on Iridium's status.

Earth Remote Sensing

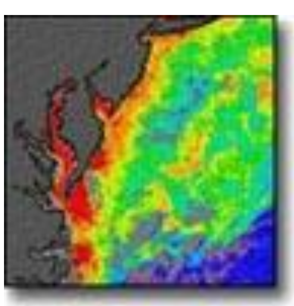
Remote-sensing satellites, like the one shown on the left, study Earth's surface. From 300 miles (480 km) up, this satellite uses powerful cameras to scan the planet. The satellite then sends back valuable data about global environments.

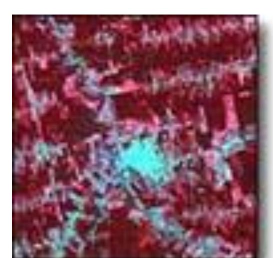


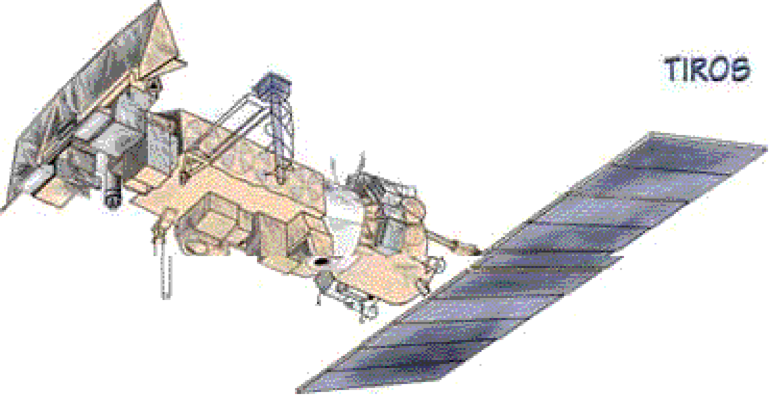
How we use Satellite Imaging

The instruments on remote-sensing satellites study Earth's plant cover, chemical composition, and surface water, among many other features. People who work in farming, fishing, mining, and many other industries find this information very useful.

We can also use remote sensing satellites to study changes in the earth's surface that are caused by people. Examples of this include the parts of West Africa that are turning into desert (desertification), and the destruction of the rainforest in South America (deforestation).







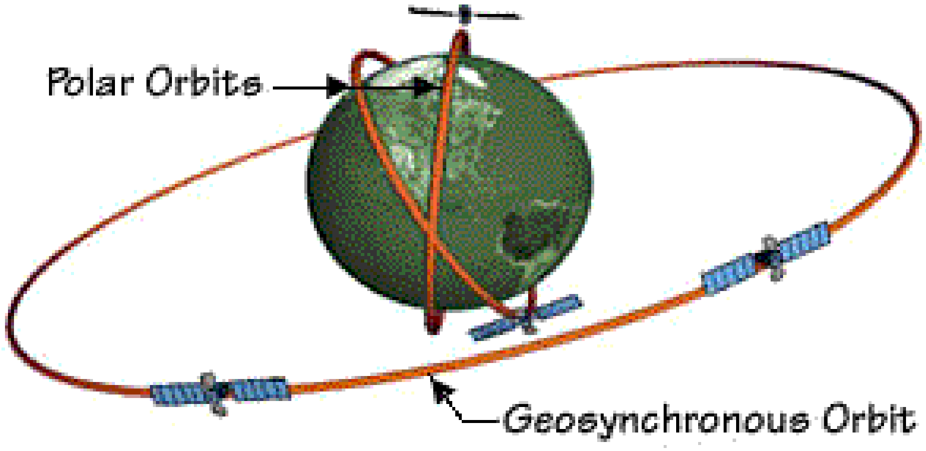
Weather Satellites

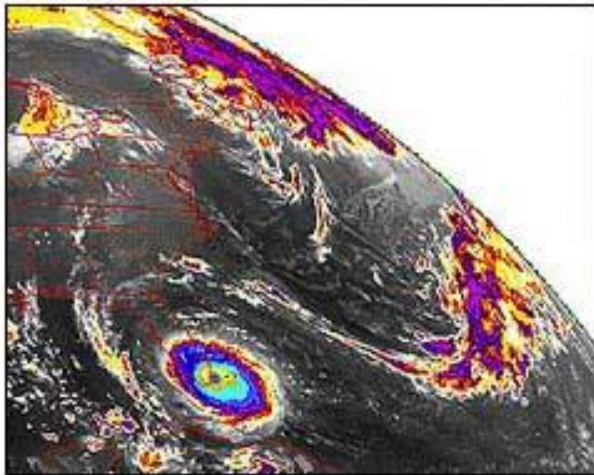
This satellite is called TIROS (Television Infrared Observational Satelite). It records weather patterns around the world. Many countries use TIROS data to forecast weather, track storms, and do scientific research.

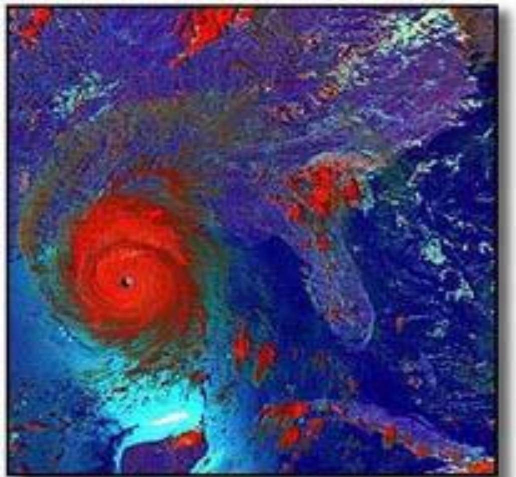
NOAA System

TIROS is part of a system of weather satellites operated by **the National Oceanic and Atmospheric Administration** (NOAA). There are two TIROS satellites circling Earth over the poles. They work with another set of satellites in geosynchronous orbit called Geostationary Operational Environmental Satellites (GOES). Using this group of satellites, meteorologists study weather and climate patterns around the world.

Weather satellites have many instruments. You're familiar with pictures of cloud formations taken by weather satellite cameras-you see them on TV news. But there are other instruments that measure temperature, moisture, and solar radiation in the atmosphere. There are even sensors that can help in search and rescue operations.







Hurricane

Hurricanes are some of the most important weather events tracked by satellites. These two pictures show Hurricane Andrew. In 1992 this storm caused widespread damage in the Bahamas, Florida, and Louisiana. The artificial color shows the intensity of the storm's winds. Satellites can warn people of a hurricane's approach and give them time to get out of its path.

Volcano

In 1991, a NOAA weather satellite took this photo of Mt. Pinatubo erupting in the Philippines. Mt. Pinatubo is the column of smoke rising in the center of the picture. Weather satellites track volcanic activity because the smoke from large eruptions, like Pinatubo, can affect our global weather patterns.

examples of what weather satellites do

Search and Rescue

Many weather satellites have sensors that can pick up distress calls from people equipped with a receiver. Climbers stranded on a mountain or boaters marooned at sea can tell rescue teams where they are, anywhere in the world, any time of day or night.

The NOAA satellites also participate in satellite *search and rescue (SAR) operations*, known generally as *Cospas-Sarsat*, where Cospas refers to the payload carried by participating Russian satellites and Sarsat to the payloads carried by the NOAA satellites. Sarsat-6 is carried by NOAA-14, and Sarsat-7 is carried by NOAA-15. The projected payloads Sarsat-8 to Sarsat-10 will be carried by NOAA-L to NOAA-N. The Cospas-Sarsat Web page is at *http://www.cospas-sarsat.org/*. As of January 2000, there were 32 countries formally associated with Cospas-Sarsat. Originally, the system was designed to operate only with satellites in low earth orbits (LEOs), this part of the search and rescue system being known as *LEOSAR*. Later, the system was complemented with geostationary satellites, this component being known as *GEOSAR*.

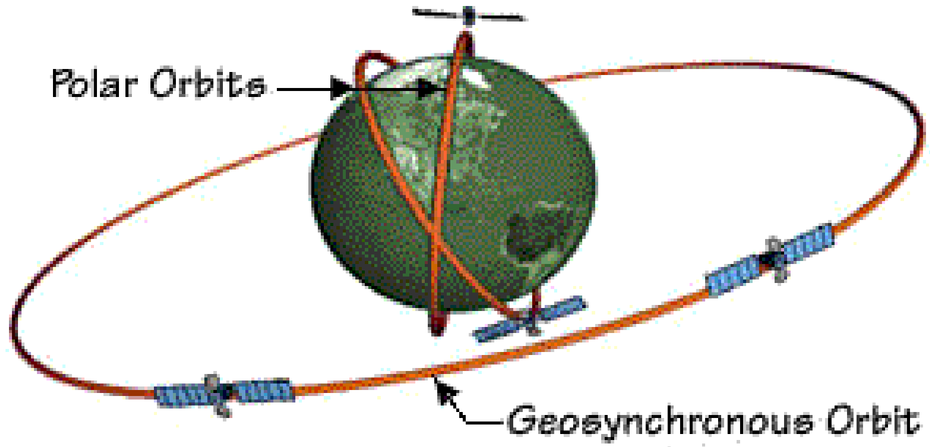


Figure 1.7 shows the combined LEOSAR-GEOSAR system.

The nominal space segment of LEOSAR consists of four satellites, although as of January 2000 there were seven in total, three Cospas and four Sarsat. In operation, the satellite receives a signal from an emergency beacon set off automatically at the distress site. The beacon transmits in the VHF/UHF range, at a precisely controlled frequency. The satellite moves at some velocity relative to the beacon, and this results in a Doppler shift in frequency received at the satellite. As the satellite approaches the beacon, the received frequency appears to be higher than the transmitted value. As the satellite recedes from the beacon, the received frequency appears to be lower than the transmitted value. Figure 1.8 shows how the beacon frequency, as received at the satellite, varies for different passes. In all cases, the received frequency goes from

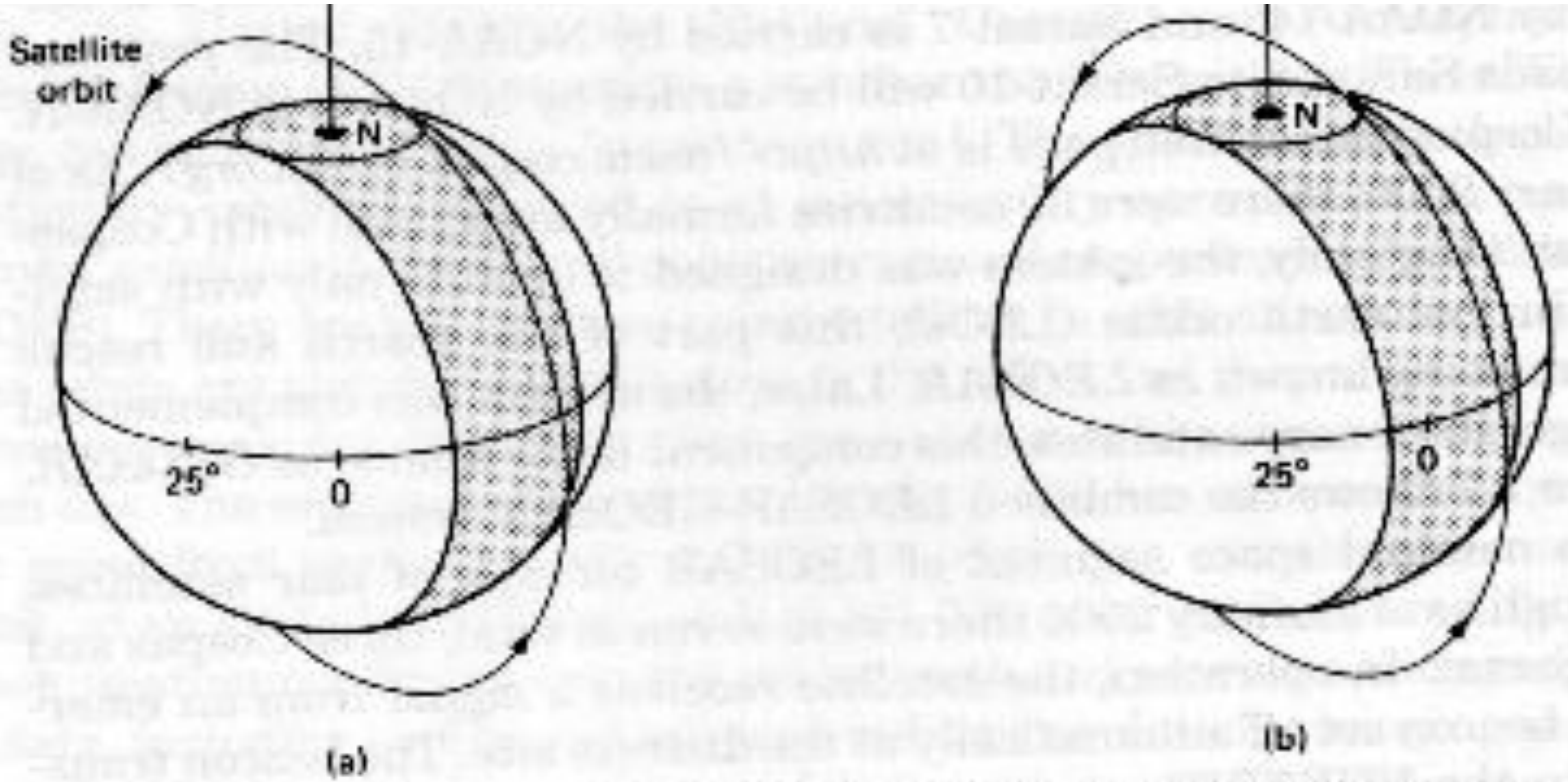


Figure 1.8 Polar orbiting satellite: (*a*) first pass; (*b*) second pass, earth having rotated 25°. Satellite period is 102 min.

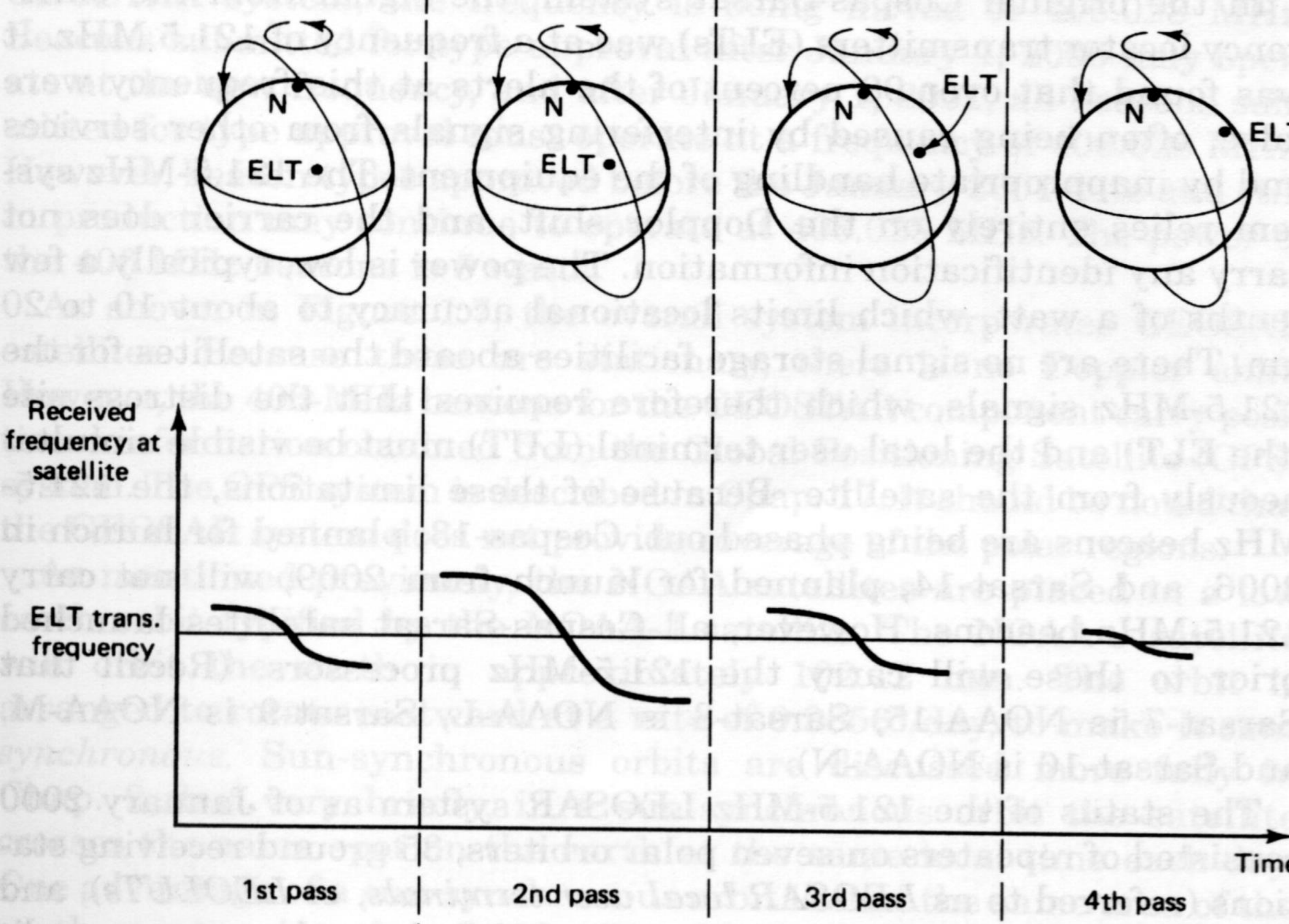
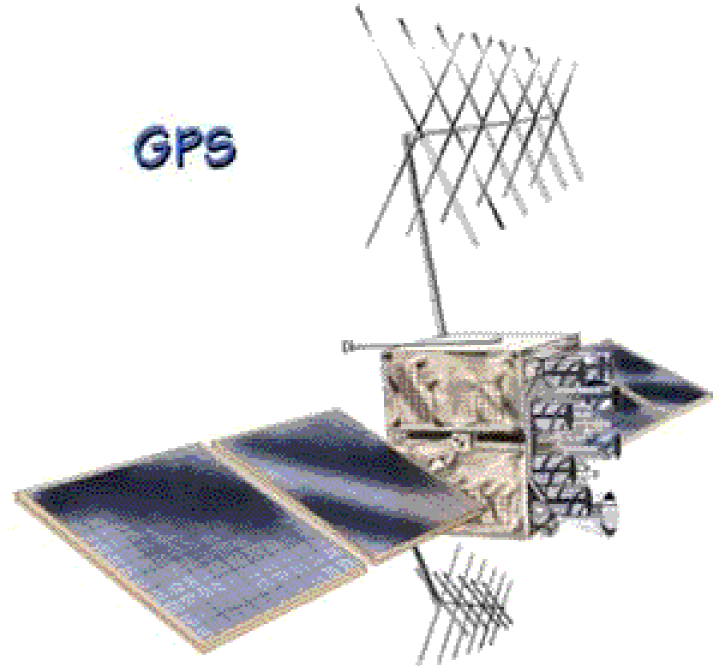


Figure 1.9 Showing the Doppler shift in received frequency on successive passes of the satellite. ELT = emergency locator transmitter.

being higher to being lower than the transmitted value as the satellite approaches and then recedes from the beacon. The longest record and the greatest change in frequency are obtained if the satellite passes over the site, as shown for pass no. 2. This is so because the satellite is visible for the longest period during this pass. Knowing the orbital parameters for the satellite, the beacon frequency, and the Doppler shift for any one pass, the distance of the beacon relative to the projection of the orbit on the earth can be determined. However, whether the beacon is east or west of the orbit cannot be determined easily from a single pass. For two successive passes, the effect of the earth's rotation on the Doppler shift can be estimated more accurately, and from this it can be determined whether the beacon is approaching or receding from the orbital path. In this way, the ambiguity in east-west positioning is resolved. Figure 1.9 illustrates the Doppler shifts for successive passes.

The satellite must of course get the information back to an earth station so that the search and rescue operation can be completed, successfully one hopes. The Sarsat communicates on a downlink frequency of 1544.5 MHz to one of several local user terminals (LUTs) established at various locations throughout the world.

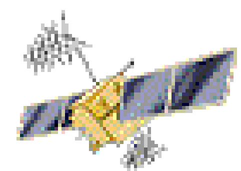
Global Positioning System

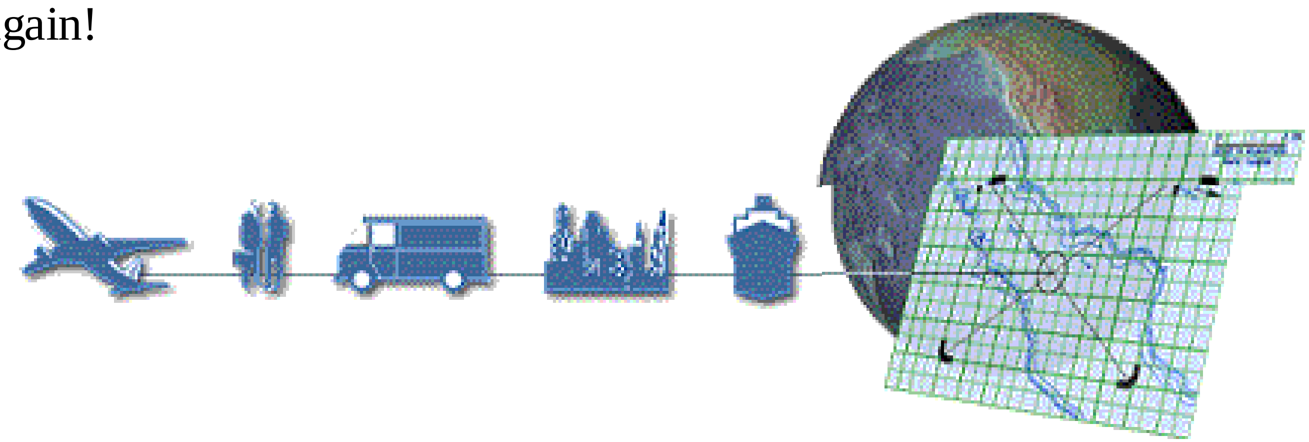


This satellite is part of a group of satellites that can tell you your exact latitude, longitude, and altitude. The military developed the Global Positioning System (GPS), but now people everywhere can use these satellites to determine where in the world they are.

Other Uses for GPS Satellites

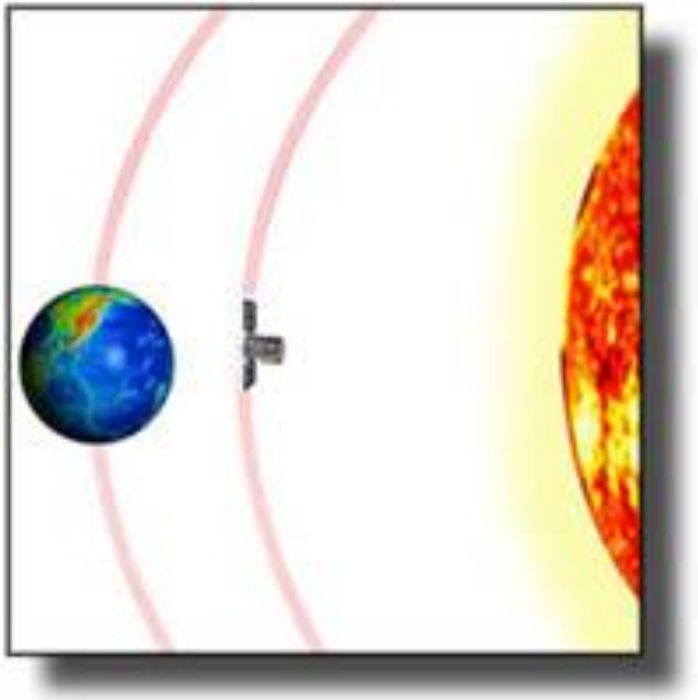
GPS satellites are used for navigation almost everywhere on Earth -- in an airplane, boat, or car, on foot, in a remote wilderness, or in a big city. Wherever you are, if you have a GPS receiver, you'll never be lost again!





Science Research Satellites

Many satellites in orbit conduct scientific experiments and observations. This is SOHO (SOlar and Heliospheric Observation). It's studying the Sun.



What is SOHO?

SOHO is an international project managed by Europe and the United States. Its very sophisticated instruments can measure activity inside the Sun, look at its atmosphere or corona, and study its surface.

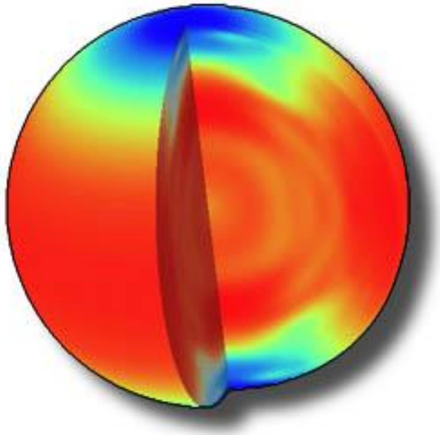
A different kind of orbit

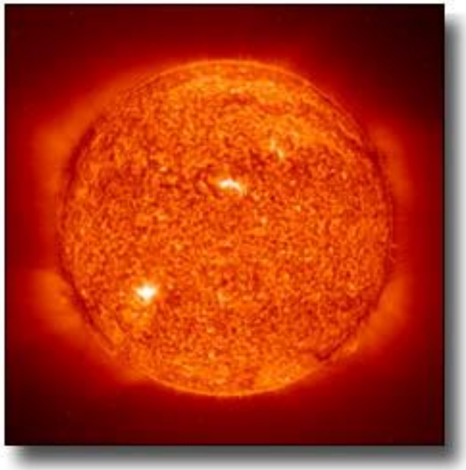
Can you think of another famous satellite that looks out to space rather than back towards earth?

The Hubble Space Telescope is a satellite in orbit around Earth, and its mission is to study distant planets, stars and galaxies. Hubble can only look out into space. It is not capable of viewing our own planet. The Hubble Space Telescope was launched in 1990.

MDI

The SOHO satellite used the Michelson Doppler Imager (MDI) to make this picture. The MDI uses sound waves to measure the rotation speed of the hot plasma that makes up the Sun. The fastest moving areas are red and the slowest are blue. Scientists think that the difference in speeds accounts for the Sun's changing magnetic energy.



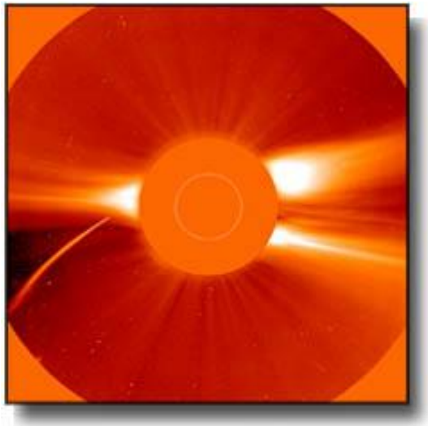


EIT

The Extreme Ultraviolet Imaging Telescope (EIT) took this picture of the Sun. EIT can see the Sun's ultraviolet radiation, which isn't visible to us. This view shows many interesting details. For instance, the Sun's surface and atmosphere are not uniform, but vary in energy and activity.

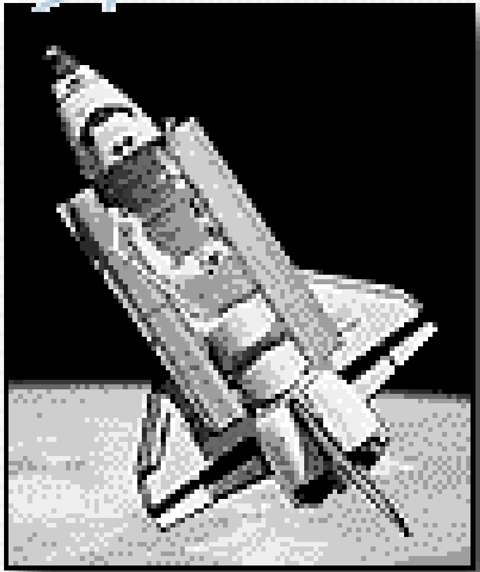
LASCO

The Large Angle and Spectrometric Coronograph (LASCO) took this picture of the Sun. LASCO blocks out the Sun's bright surface so it can see the much dimmer atmosphere, or corona. You can see how uneven the corona is. The Sun is very active, so the corona is always changing. The streak on the left side of the picture is a comet passing near the Sun.

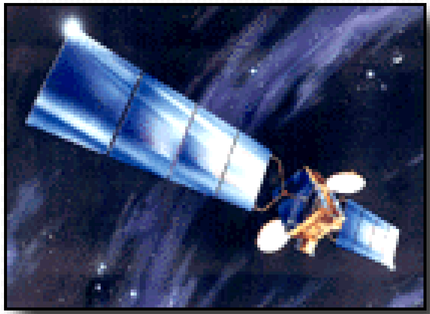


TheTech museum of innovation

LOCKHEED MARTIN



The Space Shuttle does orbit Earth, and sometimes it's crews conduct astronomical observations, but the Space Shuttle has many other functions. These include medical and biological research, testing new space technology, and launching or repairing other satellites.



TELSTAR is a fleet of communications satellites owned by AT&T and is used to transmit telephone calls. The newest one, TELSTAR 402, was launched in 1995.

Sputink was the first man made satellite to orbit Earth, The Soviets Union launched Sputnik in 1957.

http://www.thetech.org/hyper/satellite/home.html

Starlink

Starlink is a satellite internet constellation operated by private aerospace company SpaceX,[3] providing coverage to over 70 countries. It also aims for global mobile phone service after 2023.

SpaceX started launching Starlink satellites in 2019. As of early January 2024, it consists of over 5,289 mass-produced small satellites in low Earth orbit (LEO) that communicate with designated ground transceivers.

Nearly 12,000 satellites are planned to be deployed, with a possible later extension to 42,000. SpaceX announced reaching more than 1 million subscribers in December 2022.

1.5 million subscribers in May 2023, and 2 million subscribers in September 2023.

Starlink has had a key role in the Russo-Ukrainian War.

The SpaceX satellite development facility in Redmond, Washington houses the Starlink research, development, manufacturing and orbit control facilities.

In May 2018, SpaceX estimated the total cost of designing, building and deploying the constellation would be at least US$10 billion.

In January 2017, SpaceX expected annual revenue from Starlink to reach $12 billion by 2022 and exceed $30 billion by 2025.

Revenues from Starlink in 2022 were reportedly $1.4 billion accompanied by a net loss, with a small profit being reported by Musk starting in 2023.This performance was characterized as "falling short" of SpaceX's growth estimates.

Manufacturer	SpaceX
Country of origin	United States
Operator	SpaceX
Applications	Internet service
Website	www.starlink.com
ASN	14593
Specifications	
Spacecraft type	Small satellite
Launch mass	v 0.9: 227 kg (500 lb) v 1.0: 260 kg (570 lb) v 1.5: ~306 kg (675 lb)[1] v 2 mini: 800 kg (1,800 lb) v 2.0: ~1,250 kg (2,760 lb)[2]
Equipment	Ku-, Ka-, and E-band phased array antennas Laser transponders (some units) Hall-effect thrusters
Regime	Low Earth orbit Sun-synchronous orbit
Production	
Status	Active since 2019; 5 years ago

STARLINK

Launching Orbits

- Satellites can be directly injected into low-altitude orbits (up to about 200 km) from a launch vehicle.

- Launch vehicles are categorized as expendable or reusable.

- Examples of expendable launchers include U.S. Atlas-Centaur, Delta rockets, and the European Space Agency Ariane rocket.

- Japan, China, and Russia have their own expendable launch vehicles, leading to potential competition for commercial launches.

- Before the 1986 Space Shuttle tragedy, the Space Shuttle (STS) was intended to be the primary transportation system for the United States. The STS, as a reusable launch vehicle, was planned to replace expendable launch vehicles in the long term.

- For orbital altitudes beyond 200 km, direct injection becomes uneconomical, and satellites must be placed into a transfer orbit between the initial Low Earth Orbit (LEO) and the final high-altitude orbit.

- The transfer orbit, often a Hohmann transfer orbit, is selected to minimize energy requirements, although the transfer time is longer compared to other possible transfer orbits.

- Transfer between two circular orbits is considered with the assumption that all orbits are in the same plane.

- Illustrated in Fig. 3.10, the Hohmann elliptical orbit is tangent to the low-altitude orbit at perigee and the high-altitude orbit at apogee.

- In rocket launches, at perigee, the rocket injects the satellite with the required thrust into the transfer orbit.

- For Space Shuttle (STS) launches, the satellite carries a perigee kick motor to provide the necessary thrust at perigee.

- Details of expendable vehicle launches are depicted in Fig. 3.11, and STS launches are illustrated in Fig. 3.12.

- At apogee, the apogee kick motor (AKM) changes the velocity of the satellite to place it into a circular orbit.

- It takes 1 to 2 months for a satellite to become fully operational after launch (Fig. 3.11).
- A network of ground stations globally is required for tracking, telemetry, and command (TT&C) functions during launch and acquisition phases.
- Velocity changes in the same plane alter orbit geometry but not inclination.
- Changing inclination requires a velocity change normal to the orbital plane, achievable at either of the nodes without affecting other orbital parameters.
- To minimize fuel expenditure for orbital changes, geostationary satellites should be launched with low initial orbital inclination.
- The smallest inclination at initial launch equals the launch site's latitude, making sites farther from the equator less efficient.
- Russia's absence of launch sites below 45°N makes launching geostationary satellites more expensive compared to equatorial launch sites.

- Prograde (direct) orbits (Fig. 2.4) with an easterly component benefit from Earth's rotational velocity.

- Larger payloads can be launched in an easterly direction for a given launcher size, particularly for the initial launch into geostationary orbit.

- The relationship between inclination, latitude, and azimuth is analyzed based on Bate et al. (1971).

- The launch azimuth must be easterly for a prograde orbit, confirming known principles.
- To minimize inclination on initial launch, cos i should be a maximum, requiring sin Az to be maximum, or Az ≈ 90°.

- The lowest inclination possible on initial launch is equal to the launch site's latitude, confirming the converse statement that the greatest latitude north or south equals the inclination.

- From Cape Kennedy, the smallest initial inclination achievable for easterly launches is approximately 28°.

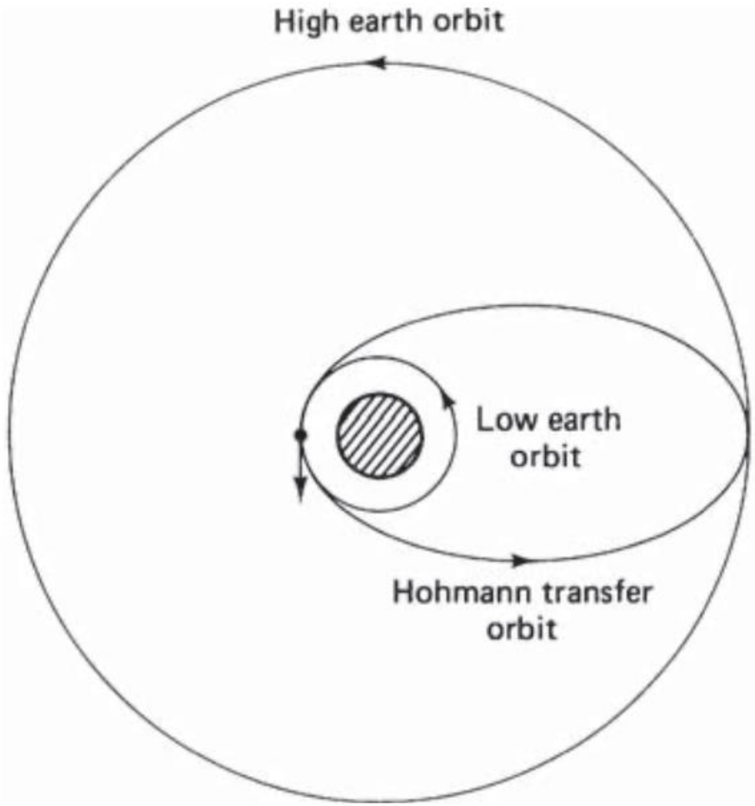


Figure 3.10 Hohmann transfer orbit.

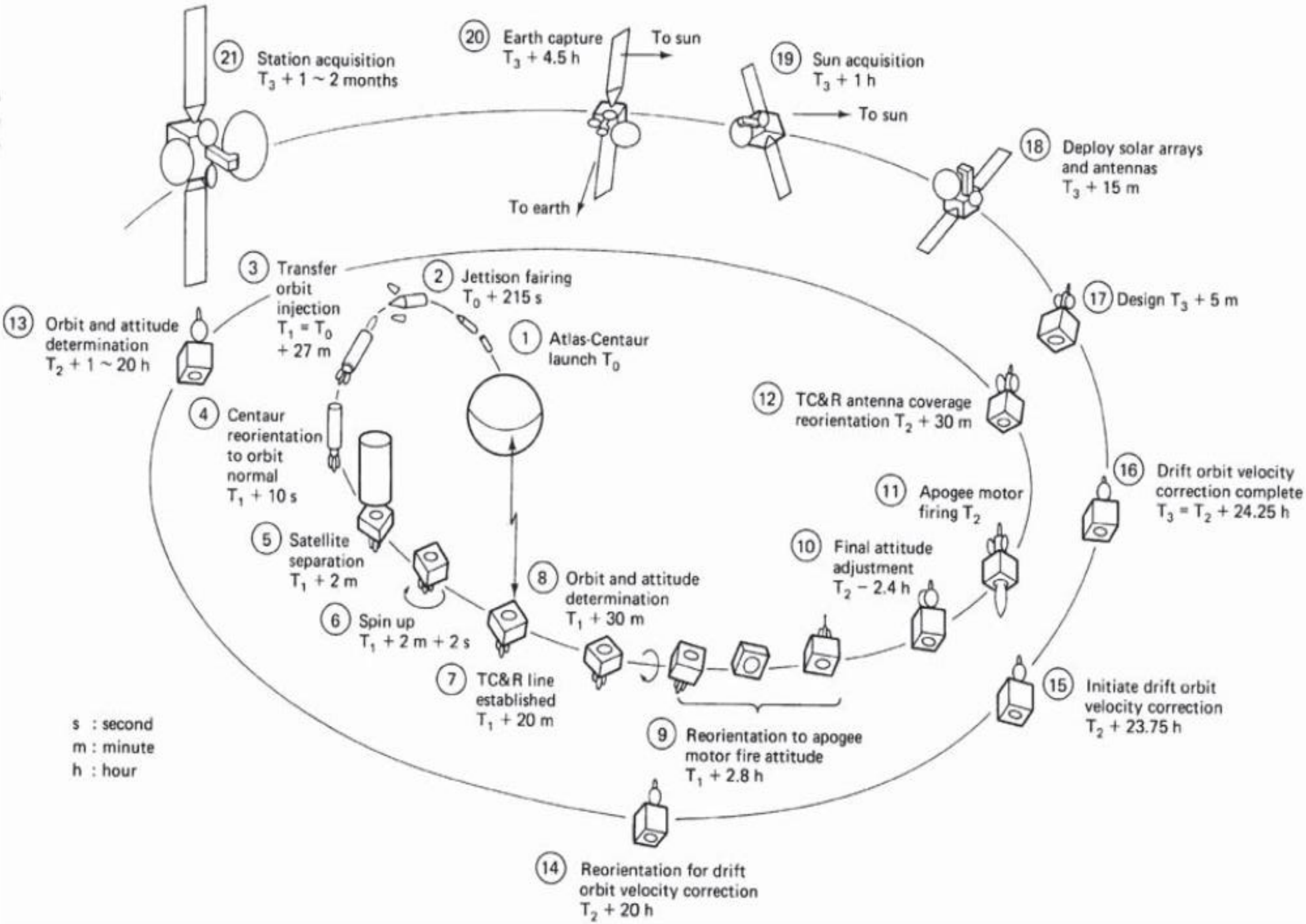


Figure 3.11 From launch to station of INTELSAT V (by Atlas-Centaur). (*From Satellite Communications Technology, edited by K. Miya, 1981; courtesy of KDD Engineering & Consulting, Inc., Tokyo.*)

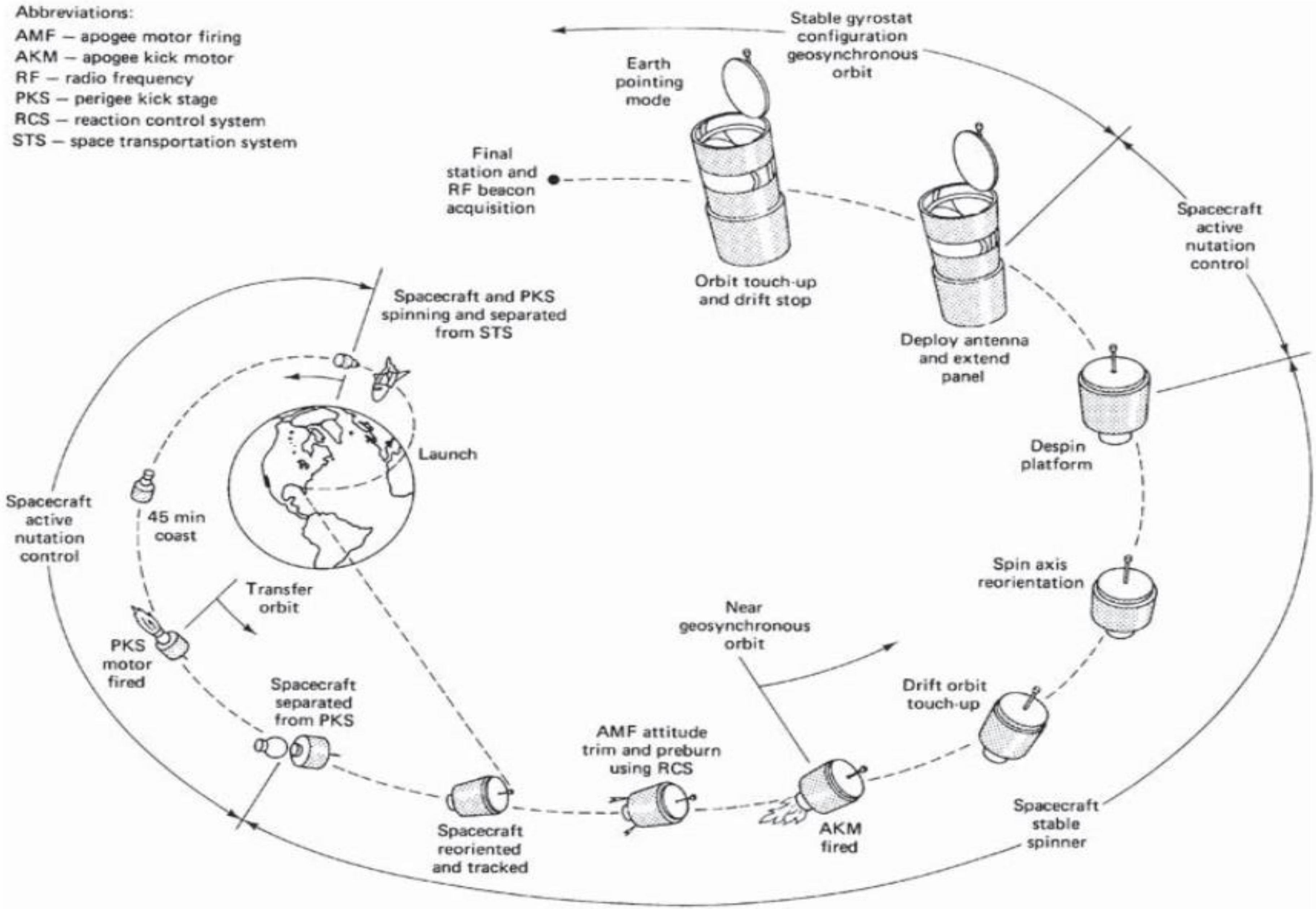


Figure 3.12 STS-7/Anik C2 mission scenario. (*From Anik C2 Launch Handbook; courtesy of Telesat, Canada.*)