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How Satellites Work

by [Gary Brown](#)

Not so long ago, satellites were exotic, top-secret devices. They were used primarily in a military capacity, for activities such as navigation and espionage. Now they are an essential part of our daily lives. We see and recognize their use in weather reports, television transmission by DIRECTV and the DISH Network, and everyday [telephone](#) calls. In many other instances, satellites play a background role that escapes our notice:

- Some [newspapers](#) and magazines are more timely because they transmit their text and images to multiple printing sites via satellite to speed local distribution.
- Before sending signals down the wire into our houses, [cable television](#) depends on satellites to distribute its transmissions.
- The most reliable taxi and limousine drivers are sometimes using the satellite-based [Global Positioning System](#) (GPS) to take us to the proper destination.

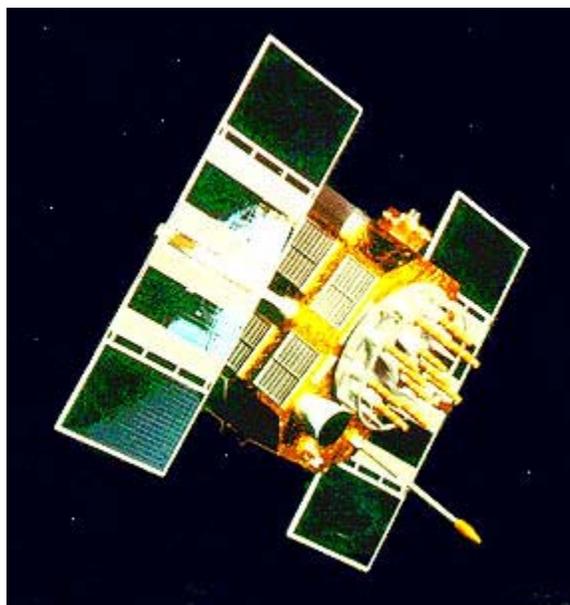


Photo courtesy [NASA](#)

NAVSTAR GPS satellite

- The goods we buy often reach distributors and retailers more efficiently and safely because trucking firms track the progress of their vehicles with the same GPS. Sometimes firms will even tell their drivers that they are driving too fast.
- [Emergency radio beacons](#) from downed aircraft and distressed ships may reach search-and-rescue teams when satellites relay the signal (read [this page](#) for details).

In this article, we will show you how satellites operate and what they do. You'll get to see what's inside a satellite, explore the different kinds of orbits and find out why the intended use of the satellite affects the choice of orbit. We'll even tell you how to see and track a satellite yourself!

What is a Satellite?

A satellite is basically any object that revolves around a planet in a circular or elliptical path. The moon is Earth's original, natural satellite, and there are many manmade (**artificial**) satellites, usually closer to Earth.

- The path a satellite follows is an **orbit**. In the orbit, the farthest point from Earth is the **apogee**, and the nearest point is the **perigee**.
- Artificial satellites generally are not mass-produced. Most satellites are **custom built** to perform their intended functions. Exceptions include the [GPS](#) satellites (with over 20 copies in orbit) and the Iridium satellites (with over 60 copies in orbit).
- Approximately 23,000 items of [space junk](#) -- objects large enough to track with radar that were inadvertently placed in orbit or have outlived their usefulness -- are floating above Earth. The actual number varies depending on which agency is counting. Payloads that go into the wrong orbit, satellites with run-down batteries, and leftover rocket boosters all contribute to the count. This [online catalog of satellites](#) has almost 26,000 entries!

Although anything that is in orbit around Earth is technically a satellite, the term "satellite" is typically used to describe a useful object placed in orbit purposely to perform some specific mission or task. We commonly hear about weather satellites, communication satellites and scientific satellites.

Whose Satellite Was the First to Orbit Earth?

The Soviet [Sputnik](#) satellite was the first to orbit Earth, launched on October 4, 1957.



Photo courtesy NASA

Sputnik 1, the first satellite, shown with four whip antennas

Because of Soviet government secrecy at the time, no photographs were taken of this famous launch. Sputnik was a 23-inch (58-cm), 184-pound (83-kg) metal ball. Although it was a remarkable achievement, Sputnik's contents seem meager by today's standards:

- [Thermometer](#)
- [Battery](#)
- [Radio transmitter](#) - changed the tone of its [beeps](#) to match temperature changes
- Nitrogen gas - pressurized the interior of the satellite

On the outside of Sputnik, four **whip antennas** transmitted on short-wave frequencies above and below what is today's Citizens Band (27 MHz). According to the [Space Satellite Handbook](#), by Anthony R. Curtis:

After 92 days, gravity took over and Sputnik burned in Earth's atmosphere. Thirty days after the Sputnik launch, the dog Laika orbited in a half-ton Sputnik satellite with an air supply for the dog. It burned in the atmosphere in April 1958.

Sputnik is a good example of just how simple a satellite can be. As we will see later, today's satellites are generally far more complicated, but the basic idea is a straightforward one.

How is a Satellite Launched into an Orbit?

All satellites today get into orbit by riding on a [rocket](#) or by riding in the cargo bay of the [Space Shuttle](#). Several countries and businesses have rocket launch capabilities, and satellites as large as several tons make it safely into orbit on a regular basis.

For most satellite launches, the [scheduled launch rocket](#) is aimed straight up at first. This gets the rocket through the thickest part of the atmosphere most quickly and best minimizes fuel consumption.

After a rocket launches straight up, the rocket control mechanism uses the **inertial guidance system** to calculate necessary adjustments to the rocket's nozzles to tilt the rocket to the course described in the **flight plan**. In most cases, the flight plan calls for the rocket to head east because Earth rotates to the east, giving the launch vehicle a free boost. The strength of this boost depends on the rotational velocity of Earth at the launch location. The boost is greatest at the equator, where the distance around Earth is greatest and so rotation is fastest.

How big is the boost from an equatorial launch? To make a rough estimate, we can determine Earth's circumference by multiplying its diameter by [pi](#) (3.1416). The diameter of Earth is approximately 7,926 miles (12,753 km). Multiplying by pi yields a circumference of something like 24,900 miles (40,065 km). To travel around that circumference in 24 hours, a point on Earth's surface has to move at 1,038 mph (1,669 kph). A launch from Cape Canaveral, Florida, doesn't get as big a boost from Earth's rotational speed. The Kennedy Space Center's [Launch](#)

Personal Reflection: Sputnik, October 4, 1957

Sputnik's transmissions died along with its battery after only three weeks, but its effects have been felt for decades. As a fifth-grader, I witnessed the stir caused by the launch of Sputnik. News reports showed that many people in the United States were embarrassed to see the Soviet Union achieving a scientific first, as well as frightened that a foreign country had placed something overhead (read [these Sputnik stories](#)). Soviet rocket development seemed well ahead of the United States' efforts. The push toward getting an American satellite into space started immediately. American schools and universities were soon stocked with new science books. One side effect that had a direct impact on many students like me was an increase in science homework, giving a personal dimension to the national wake-up call.



Photo courtesy Arianespace

ARIANE 44L (four liquid strap-on boosters) at liftoff from French Guiana, October 1998

[Complex 39-A](#), one of its launch facilities, is located at 28 degrees 36 minutes 29.7014 seconds north latitude. The Earth's rotational speed there is about 894 mph (1,440 kph). The difference in Earth's surface speed between the equator and Kennedy Space Center, then, is about 144 mph (229 kph). (Note: The Earth is actually **oblate** -- fatter around the middle -- not a perfect sphere. For that reason, our estimate of Earth's circumference is a little small.)

Considering that rockets can go thousands of miles per hour, you may wonder why a difference of only 144 mph would even matter. The answer is that rockets, together with their fuel and their payloads, are very heavy. For example, the February 11, 2000 lift-off of the Space Shuttle Endeavor with the [Shuttle Radar Topography Mission](#) required launching a total weight of 4,520,415 pounds (2,050,447 kg). It takes a huge amount of energy to accelerate such a mass to 144 mph, and therefore a significant amount of fuel. Launching from the equator makes a real difference.

Once the [rocket](#) reaches extremely thin air, at about 120 miles (193 km) up, the rocket's navigational system fires small rockets, just enough to turn the launch vehicle into a **horizontal** position. The satellite is then released. At that point, rockets are fired again to ensure some separation between the launch vehicle and the satellite itself.

Inertial Guidance Systems

A rocket must be controlled very precisely to insert a satellite into the desired orbit. An **inertial guidance system** (IGS) inside the rocket makes this control possible. The IGS determines a rocket's exact location and orientation by precisely measuring all of the accelerations the rocket experiences, using [gyroscopes](#) and **accelerometers**. Mounted in gimbals, the gyroscopes' axes stay pointing in the same direction. This gyroscopically-stable platform contains accelerometers that measure changes in acceleration on three different axes. If it knows exactly where the rocket was at launch and it knows the accelerations the rocket experiences during flight, the IGS can calculate the rocket's position and orientation in space.

Orbital Velocity and Altitude

A rocket must accelerate to at least 25,039 mph (40,320 kph) to completely escape Earth's gravity and fly off into space (for more on **escape velocity**, visit [this article at kidsplanet.com](#) and [this one at Northwestern University](#)).

Earth's escape velocity is much greater than what's required to place an Earth satellite in orbit. With satellites, the object is not to escape Earth's gravity, but to balance it. **Orbital velocity** is the velocity needed to achieve balance between gravity's pull on the satellite and the **inertia** of the satellite's motion -- the satellite's tendency to keep going. This is approximately 17,000 mph (27,359 kph) at an altitude of 150 miles (242 km). Without gravity, the satellite's inertia would carry it off into space. Even with gravity, if the intended satellite goes too fast, it will eventually fly away. On the other hand, if the satellite goes too slowly, gravity will pull it back to Earth. At the correct orbital velocity, gravity exactly balances the satellite's inertia, pulling down toward Earth's center just enough to keep the path of the satellite curving like Earth's curved surface, rather than flying off in a straight line (read [this page](#) for details on orbits).

The orbital velocity of the satellite depends on its altitude above Earth. The nearer Earth, the faster the required orbital velocity. At an altitude of 124 miles (200 kilometers), the required orbital velocity is just over 17,000 mph (about 27,400 kph). To maintain an orbit that is 22,223 miles (35,786 km) above Earth, the satellite must orbit at a speed of about 7,000 mph (11,300 kph). That orbital speed and distance permits the satellite to make one revolution in 24 hours. Since Earth also rotates once in 24 hours, a satellite at 22,223 miles altitude stays in a fixed position relative to a point on Earth's surface.

Because the satellite stays right over the same spot all the time, this kind of orbit is called "geostationary." **Geostationary orbits** are ideal for weather satellites and communications satellites.

The moon has an altitude of about 240,000 miles (384,400 km), a velocity of about 2,300 mph (3,700 kph) and its orbit takes 27.322 days. (Note that the moon's orbital velocity is slower because it is farther from Earth than artificial satellites.)

- To get a better feel for orbital velocities at different altitudes, check out [NASA's orbital velocity calculator](#).
- To learn more about orbits and other topics in space flight, check out [JPL's Basics of Space Flight Learners' Workbook](#).
- A detailed technical treatment of **orbital mechanics** can be found at [this site](#).

In general, the higher the orbit, the longer the satellite can stay in orbit. At lower altitudes, a satellite runs into traces of Earth's atmosphere, which creates drag. The **drag** causes the orbit to decay until the satellite falls back into the atmosphere and burns up. At higher altitudes, where the vacuum of space is nearly complete, there is almost no drag and a satellite can stay in orbit for centuries (take the moon as an example).

Satellites usually start out in an orbit that is **elliptical**. The ground control station controls small onboard rocket motors to provide correction. The goal is to get the orbit as circular as possible. By firing a rocket when the orbit is at the **apogee** of its orbit (its most distant point from Earth), and applying thrust in the direction of the flight path, the **perigee** (lowest point from Earth) moves further out. The result is a more circular orbit.

What is a Satellite Launch Window?

A [launch window](#) is a particular period of time in which it will be easier to place the satellite in the orbit necessary to perform its intended function.

With the Space Shuttle, an extremely important factor in choosing the launch window is the need to bring down the astronauts safely if something goes wrong. The astronauts must be able to reach a safe landing area where rescue personnel can be standing by. For other types of flights, including [interplanetary exploration](#), the launch window must permit the flight to take the most efficient course to its very distant destination. If weather is bad or a malfunction occurs during a launch window, the flight must be postponed until the next launch window appropriate for the flight. If a satellite were launched at the wrong time of the day in perfect weather, the satellite could end up in an orbit that would not pass over any of its intended users. Timing is everything!

What is Inside a Typical Satellite?

Satellites come in all shapes and sizes and play a variety of roles. For example:

- **Weather satellites** help meteorologists predict the weather or see what's happening at the moment. Typical weather satellites include the TIROS, COSMOS and GOES satellites. The satellites generally contain cameras that can return photos of Earth's weather, either from fixed geostationary positions or from polar orbits.
- **Communications satellites** allow [telephone](#) and data conversations to be relayed through the satellite. Typical communications satellites include Telstar and Intelsat. The most important feature of a communications satellite is the **transponder** -- a [radio](#) that receives a conversation at one [frequency](#) and then amplifies it and retransmits it back to Earth on another frequency. A satellite normally contains hundreds or thousands of transponders. Communications satellites are usually geosynchronous.

- **Broadcast satellites** broadcast [television](#) signals from one point to another (similar to communications satellites).
- **Scientific satellites** perform a variety of scientific missions. The [Hubble Space Telescope](#) is the most famous scientific satellite, but there are many others looking at everything from [sun spots](#) to [gamma rays](#).
- **Navigational satellites** help ships and planes navigate. The most famous are the [GPS NAVSTAR satellites](#).
- **Rescue satellites** respond to radio distress signals (read [this page](#) for details).
- **Earth observation satellites** observe the planet for changes in everything from temperature to forestation to ice-sheet coverage. The most famous are the LANDSAT series.
- **Military satellites** are up there, but much of the actual application information remains secret. Intelligence-gathering possibilities using high-tech electronic and sophisticated photographic-equipment reconnaissance are endless. Applications may include:
 - Relaying [encrypted](#) communications
 - [Nuclear](#) monitoring
 - Observing enemy movements
 - Early warning of [missile](#) launches
 - Eavesdropping on terrestrial [radio links](#)
 - [Radar](#) imaging
 - Photography (using what are essentially large [telescopes](#) that take pictures of militarily interesting areas)

Despite the significant differences between all of these satellites, they have several things in common. For example:

- All of them have a metal or composite frame and body, usually known as the **bus**. The bus holds everything together in space and provides enough strength to survive the launch.
- All of them have a source of **power** (usually [solar cells](#)) and [batteries](#) for storage.

Arrays of solar cells provide power to charge rechargeable batteries. Newer designs include the use of [fuel cells](#). Power on most satellites is precious and very limited. [Nuclear](#) power has been used on space probes to other planets (read [this page](#) for details). Power systems are constantly monitored, and data on power and all other onboard systems is sent to Earth stations in the form of telemetry signals.

- All of them have an **onboard computer** to control and monitor the different systems.
- All of them have a **radio** system and antenna. At the very least, most satellites have a radio transmitter/receiver so that the ground-control crew can request status information from the satellite and monitor its health. Many satellites can be controlled in various ways from the ground to do anything from change the orbit to reprogram the computer system.
- All of them have an **attitude control system**. The ACS keeps the satellite pointed in the right direction.

The [Hubble Space Telescope](#) has a very elaborate control system so that the telescope can point at the same position in space for hours or days at a time (despite the fact that the telescope travels at 17,000 mph/27,359 kph!). The system contains gyroscopes, accelerometers, a reaction wheel stabilization system, thrusters and a set of sensors that watch guide [stars](#) to determine position.

What Are the Types of Satellite Orbits?

There are three basic kinds of orbits, depending on the satellite's position relative to Earth's surface:

- **Geostationary** orbits (also called **geosynchronous** or **synchronous**) are orbits in which the satellite is always positioned over the same spot on Earth. Many geostationary satellites are above a band along the equator, with an altitude of about 22,223 miles, or about a tenth of the distance to the Moon. The "satellite parking strip" area over the equator is becoming congested with several hundred television, weather and communication satellites! This congestion means each satellite must be precisely positioned to prevent its signals from interfering with an adjacent satellite's signals. [Television](#), communications and weather satellites all use geostationary orbits. Geostationary orbits are why a [DSS](#) satellite TV dish is typically bolted in a fixed position.
- The [scheduled Space Shuttles](#) use a much lower, **asynchronous** orbit, which means they pass overhead at different times of the day. Other satellites in asynchronous orbits average about 400 miles (644 km) in altitude.
- In a **polar** orbit, the satellite generally flies at a low altitude and passes over the planet's poles on each revolution. The polar orbit remains fixed in space as Earth rotates inside the orbit. As a result, much of Earth passes under a satellite in a polar orbit. Because polar orbits achieve excellent coverage of the planet, they are often used for satellites that do mapping and photography.

How Are Satellite Orbits Predicted?

Special [satellite software](#), available for [personal computers](#), predicts satellite orbits. The software uses **Keplerian** data to forecast each orbit and shows when a satellite will be overhead. The latest "[Keps](#)" are available on the Internet for amateur radio satellites, too.

Satellites use a variety of light-sensitive sensors to determine their position. The satellite transmits its position to the ground station.

Satellite Altitudes

Looking up from Earth, satellites are orbiting overhead in various bands of altitude. It's interesting to think of satellites in terms of how near or far they are from us. Proceeding roughly from the nearest to the farthest, here are the types of satellites whizzing around Earth:

80 to 1,200 miles - Asynchronous Orbits

Observation satellites, typically orbiting at altitudes from 300 to 600 miles (480 to 970 km), are used for tasks like photography.

Observation satellites such as the [Landsat 7](#) perform tasks such as:

- Mapping
- Ice and sand movement
- Locating environmental situations (such as disappearing [rainforests](#))
- Locating mineral deposits
- Finding crop problems

Search-and-rescue satellites act as relay stations to rebroadcast emergency [radio](#)-beacon signals from a downed aircraft or ship in trouble.



Photo courtesy [USGS](#)

The island of Manhattan in New York City (Central Park at the

The Space Shuttle is the familiar [manned satellite](#), usually with a fixed duration and number of orbits. Manned missions often have the task of repairing existing expensive satellites or building future [space stations](#).

top)



The "glass cockpit" on Space Shuttle Atlantis, March 1, 2000

[Teledesic](#), with the financial backing of Bill Gates, promises broadband (high-speed) communications using many planned low Earth orbiting (LEO) satellites.

3,000 to 6,000 miles - Asynchronous Orbits

Science satellites are sometimes in altitudes of 3,000 to 6,000 miles (4,800 to 9,700 km). They send their research data to Earth via radio telemetry signals. Scientific satellite applications include:

- Researching plants and animals
- [Earth science](#), such as monitoring [volcanoes](#)
- Tracking wildlife
- Astronomy, using the [Infrared Astronomy Satellite](#)
- Physics, by NASA's [future study of microgravity](#) and the current [Ulysses Mission](#) studying solar physics

6,000 to 12,000 miles - Asynchronous Orbits

For **navigation**, the U.S. Department of Defense built the **Global Positioning System**, or [GPS](#). The GPS uses satellites at altitudes of 6,000 to 12,000 miles to determine the exact location of the receiver. The GPS receiver may be located:

- In a ship at sea
- In another [spacecraft](#)
- In an [airplane](#)
- In an automobile
- In your pocket

As consumer prices for GPS receivers come down, the familiar paper map may face tough competition. No more getting lost leaving the rental car agency at an unfamiliar [airport](#)!

- The U.S. military and the forces of allied nations used more than 9,000 [GPS receivers](#) during Operation Desert Storm.
- The National Oceanic and Atmospheric Administration ([NOAA](#)) used GPS to measure the [exact height of the Washington Monument](#).



Photo courtesy [NASA](#)

Taken while the Clementine spacecraft was orbiting the moon



Photo courtesy [NASA](#)

Advanced Communications Technology Satellite, launched in 1993, used multiple antennas for narrow-beam transmissions.

22,223 Miles - Geostationary Orbits

Weather forecasts visually bombard us each day with [images from weather satellites](#), typically 22,223 miles over the equator. You can directly receive many of the actual satellite images using radio receivers and special personal-computer software. Many countries use weather satellites for their weather forecasting and storm observations.

Data, television, image and some telephone transmissions are routinely received and rebroadcast by **communications** satellites. Typical satellite telephone links have 550 to 650 milliseconds of round-trip delay that contribute to consumer dissatisfaction with this type of long-distance carrier. It takes the voice communications that long to travel all the way up to the satellite and back to Earth. The round-trip delay forces many to use telephone conversations via satellite only when no other links exist. Currently, [voice over the Internet](#) is experiencing a similar delay problem, but in this case due to digital compression and bandwidth limitations rather than distance.

Communications satellites are essentially radio relay stations in space. Satellite dishes get smaller as satellites get more powerful transmitters with focused radio "footprints" and gain-type antennas. Subcarriers on these same satellites carry:

- Press agency news feeds
- [Stock market](#), business and other financial information
- International radio broadcasters moving from short-wave to (or supplementing their short-wave broadcasts with) satellite feeds using microwave uplink feeds
- [Global television](#), such as CNN and the BBC
- [Digital radio](#) for CD-quality audio

How Much Do Satellites Cost?

Satellite launches don't always go well, as shown by [this story on failed launches in 1999](#). There is a great deal at stake. For example, [this hurricane-watch satellite](#) mission cost \$290 million. [This missile-warning satellite](#) cost \$682 million.

Another important factor with satellites is the cost of the launch. According to [this report](#), a satellite launch can cost anywhere between \$50 million and \$400 million. A shuttle mission pushes toward half a billion dollars (a shuttle mission could easily carry several satellites into orbit). You can see that building a satellite, getting it into orbit and then maintaining it from the ground control facility is a major financial endeavor!

Major U.S. satellite firms include:

- [Hughes](#)
- [Ball Aerospace & Technologies Corp.](#)
- [Boeing](#)
- [Lockheed Martin](#)

How Can I See an Overhead Satellite?

This [satellite tracking Web site](#) shows how you can see a satellite overhead, thanks to the German Space Operations Center. You will need your coordinates for longitude and latitude, available from the [USGS Mapping Information](#) Web site or at the website [Topozone](#).

- Satellite-tracking software is available for predicting orbit passes. Note the exact times.
- Use binoculars on a clear night when there is not a bright moon.
- Ensure that your watch is set to exactly match a known [time standard](#).
- A north-south orbit often indicates a spy satellite!

What is AMSAT?

AMSAT is a non-profit organization of [ham radio](#) operators worldwide that uses its own membership-supported satellites. The official name for AMSAT is the Radio Amateur Satellite Corporation. Hams that belong to AMSAT participate in:

- The actual development and assembly of over 40 satellites to date
- Ground control after the satellite is in orbit
- Conversations using the satellite and listening to others using the satellite as a radio relay link



Photo courtesy [AMSAT](#)

Electronic modules in equipment bay of the [Phase 3D AMSAT satellite](#): At top left is camera equipment; along the bottom row are various receivers. (Launch date: late July 2000, on Ariane 507)

AMSAT satellites can often be heard by use of a short-wave receiver or a [radio scanner](#). Ham operators make use of the satellites during natural disasters when terrestrial links and [cell phone](#) systems may be down or overloaded.

The AMSAT-built satellites "hitch" a rocket launch on a "payload-space-available" basis. The first AMSAT satellite orbited in 1961 and was called OSCAR (Orbiting Satellite Carrying Amateur Radio). [Tracking software](#) is available for personal computers. Various AMSAT satellites have a combination of data, image and voice capabilities.

What Causes Space Junk?

Debris in orbit can come from many sources:

- Exploding rockets - This leaves behind the most debris in space.
- The slip of an astronaut's hand - Suppose an astronaut doing repair in space drops a wrench -- it's gone forever. The wrench then goes into orbit, probably at a speed of something like 6 miles per second. If the wrench hits any vehicle carrying a human crew, the results could be disastrous. Larger objects like a space station make a larger target for space junk, and so are at greater risk.
- Jettisoned items - Parts of launch canisters, [camera](#) lens caps, etc.

Items initially placed into high orbits stay in space the longest.

The [European Space Agency](#) tracks more than 7,500 orbiting items with a width of 4 inches (10 cm) or more. Space debris may also be a reason why space shuttles typically orbit with their windows to the rear. This protects the astronauts onboard, at least to some degree.

A special NASA satellite called Long Duration Exposure Facility (LDEF) was put in orbit to study the long-term effects of collisions with space junk. The [LDEF](#) was later brought back to Earth via a space shuttle for analysis.

For more information on satellites and related topics, check out the links on the next page.

Lots More Information

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General Satellite Information

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GPS

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- [European Space Agency: Space Debris Activities at ESOC](#)
- [Tracking "Space Junk"](#)
- [Photos: Impact Damage of LDEF Surfaces](#)

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Email. Facebook. Whatsapp. Pinterest. Twitter. Advertisement. Satellite Internet service appears to be becoming more and more popular. Once the exclusive domain of exploration companies and war journalists, there are now thousands of people with an extra dish on the home or RV. Part of the reason for this is that certain technologies have increased the bandwidth and decreased the cost. Now, there are geostationary satellites. That's a fancy word for saying the satellite stays still in relation to your position on Earth.