# Global Positioning System

Over fifty **GPS** satellites such as this NAVSTAR have been launched since 1978.

The **Global Positioning System**, usually called **GPS** (the US military refers to it as **NAVSTAR GPS - Navigation Signal Timing and Ranging Global Positioning System**), is the only operational satellite navigation system. For a list of other proposed and partially developed systems, including Russia's GLONASS and Europe's Galileo, see satellite navigation system.

Satellite Navigation Systems can be used for determining one's precise location and providing a highly accurate time reference almost anywhere on Earth or in Earth orbit. The accuracy of the GPS signal itself is about 5 meters (16 ft) as of 2005 and has steadily improved over the last 15 years. Using differential GPS and other error-correcting techniques, the accuracy can be improved to about 1 cm (.4 in) over short distances.

The GPS system was designed by and is controlled by the United States Department of Defense and can be used by anyone, free of charge. The GPS system is divided into three segments: space, control and user. The space segment comprises the GPS satellite constellation of at least 24 satellites in an intermediate circular orbit (ICO) . The control segment comprises ground stations around the world that are responsible for monitoring the flight paths of the GPS satellites, synchronizing the satellites' onboard atomic clocks, and uploading data for transmission by the satellites. The user segment consists of GPS receivers used for both military and civilian applications. A GPS receiver decodes time signal transmissions from multiple satellites and calculates its position by trilateration.

Daily management of the GPS satellite constellation is conducted by the 2d Space Operations Squadron at Schriever Air Force Base. The cost of maintaining the system is approximately US$400 million per year, including the replacement of aging satellites. The first GPS satellite was launched in February 1978, and the most recent launch was in September 2005. The oldest GPS satellite still in operation was launched in February 1989.

## Applications

### Military

The primary military purposes are to allow improved command and control of forces through improved locational awareness, and to facilitate accurate targeting of smart bombs, cruise missiles, or other munitions. The satellites also carry nuclear detonation detectors, which form a major portion of the United States Nuclear Detonation Detection System.

### Civilian Navigation

This Taxi in Kyoto, equipped with GPS navigation, is an example of how **GPS** technology can improve everyday life.

Even fixed systems may use GPS, in order to get precise time. This antenna is mounted on the roof of a hut containing a scientific experiment needing precise timing.


Magellan GPS receiver in a marine application.

The system is used by countless civilians as well, who can use the GPS's Standard Positioning Service worldwide free of charge. Low cost GPS receivers (price $100 to $200) are widely available, often combined in a bundle with a PDA, car computer, or vehicle tracking system. The system is used as a navigation aid in airplanes, ships and cars.

The system can be used by computer controlled harvesters, mine trucks and other vehicles. Hand held devices are used by mountain climbers and hikers. Glider pilots use the logged signal to verify their arrival at turnpoints in competitions. More costly and precise receivers are used by land surveyors to locate boundaries, structures, and survey markers. Commercial use can be land measurement, navigation and road construction.

### Precise Time Reference

Many synchronization systems use GPS as a source of accurate time, hence one of the most common applications of this use is that of GPS as a reference clock for time code generators or NTP clocks. For instance, when deploying sensors (for seismology or other monitoring application), GPS may be used to provide each recording apparatus with some precise time source, so that the time of events may be recorded accurately.

### GPS for the visually impaired

There have been many attempts at integrating GPS into a navigation-assistance system for the blind:

- MoBIC
- Drishti
- Brunel Navigation System for the Blind
- NOPPA
- BrailleNote GPS
- Trekker

### Geocaching

The availability of hand-held GPS receivers for a cost of about $90 and up (March 2005) has led to recreational applications including the popular activity Geocaching, in which a GPS unit is used to search for objects deliberately hidden in nature, by traveling to the GPS coordinates. Geocaching is popular with both children and adults.

### GPS tracking

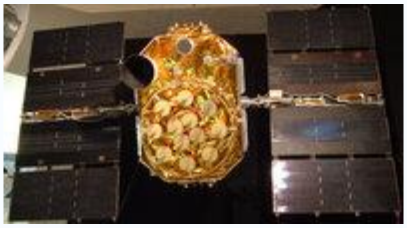
A GPS tracking system uses either GPS and some radio technology to automatically track and record a vehicle's, person's, or pet's field activities. Position is determined using GPS and recorded by modules attached to each vehicle.

The data can be transmitted back to a variety of locations, or to a central, internet-connected computer, using radio communications such as a GSM/GPRS, CDMA, or iDEN or other cellular modem, or 2-way radio or satellite. The data can then be analyzed and reports can be downloaded in real-time using either web browser based tools or customized software.

### GPS on airplanes

Most airlines allow private use of ordinary GPS units on their flights, except during landing and take-off, like all other electronic devices. Portable GPS units do not transmit radio signals like mobile phones; however there is some concern that the local oscillator, used to match the GPS frequency to the internal receiver could cause interference to communications equipment on the aircraft. This is a concern, as stray emissions from GPS units in the aircraft are electronically shielded to prevent the energy from the oscillator from leaking into the equipment. Additionally, some airline companies disallow use of hand-held receivers for security reasons, such as unwillingness to let ordinary passengers track the flight route. On the other extreme, some airlines integrate GPS tracking of the aircraft into their aircraft's seat-back television entertainment systems, available even during takeoff and landing to all passengers.

## Technical description


GPS satellite

The system consists of a constellation of at least 24 satellites in 6 orbital planes. The GPS satellites were initially manufactured by Rockwell and now manufactured by Lockheed Martin. The first was launched in February 1978, and the most recent was launched September 25, 2005. Each satellite circles the Earth twice every day at an altitude of 20,200 kilometres (12,600 miles). The satellites carry atomic clocks and constantly broadcast the precise time according to their own clock, along with administrative information including the orbital elements of their own motion, as determined by a set of ground-based observatories.

The receiver does not need a precise clock, but does need a clock with good short-term stability and the ability to receive signals from four satellites in order to determine its own latitude, longitude, elevation, and the precise time. The receiver computes the distance to each of the four satellites from the difference between local time and the time the satellite signals were sent (this distance is called a pseudorange). It then decodes the satellites' locations from their radio signals and an internal database. The receiver should now be located at the intersection of four spheres, one around each satellite, with a radius equal to the time delay between the satellite and the receiver multiplied by the speed of the radio signals. Because the receiver does not have a very precise clock it cannot compute the time delays. However, it can measure with high precision the differences between the times when the various messages were received and hence use multilateration to accurately locate itself. This yields 3 hyperboloids of revolution of two sheets, whose intersection point gives the precise location of the receiver. This is why at least four satellites are needed: fewer than 4 satellites yield 2 hyperboloids, whose intersection is a curve; it is impossible to know where the receiver is located along the curve without supplemental information, such as elevation. If elevation information is already known, only signals from three satellites are needed (the point is then defined as the intersection of two hyperboloids and an ellipsoid representing the Earth at this altitude).

When there are $n > 4$ satellites, the $n$-1 hyperboloids should, assuming a perfect model and measurements, intersect on a single point. In reality, the surfaces rarely intersect, because of various errors. The question of finding the point $P$ can be reformulated into finding its three coordinates as well as $n$ numbers $r_i$ such that for all i, $PS_i - r_i$ is close to zero, and the various $r_i - r_j$ are close to $C.\Delta_{ij}$ where $C$ is the speed of light and $\Delta_{ij}$ are the time differences between signals $i$ and $j$. For instance, a least squares method may be used to find an optimal solution. In practice, GPS calculations are more complex (repeat measurements, etc.).

There are several causes: The initial local time is a guess due to the relatively imprecise clock of the receiver, the radio signals move more slowly as they pass through the ionosphere, and the receiver may be moving. To counteract these variables, the receiver then applies an offset to the local time (and therefore to the spheres' radii) so that the spheres finally do intersect in one point. Once the receiver is roughly localized, most receivers mathematically correct for the ionospheric delay, which is least when the satellite is directly overhead and becomes greater toward the horizon, as more of the ionosphere is traversed by the satellite signal. Since it is common for the receiver to be moving, some receivers attempt to fit the spheres to a directed line segment.

The receiver contains a mathematical model to account for these influences, and the satellites also broadcast some related information which helps the receiver in estimating the correct speed of propagation. High-end receiver/antenna systems make use of both L1 and L2 frequencies to aid in the determination of atmospheric delays. Because certain delay sources, such as the ionosphere, affect the speed of radio waves based on their frequencies, dual frequency receivers can actually measure the effects on the signals.

In order to measure the time delay between satellite and receiver, the satellite sends a repeating 1,023 bit long pseudo random sequence; the receiver knows the seed of the sequence, constructs an identical sequence and shifts it until the two sequences match.

Different satellites use different sequences, which lets them all broadcast on the same frequencies while still allowing receivers to distinguish between satellites. This is an application of Code Division Multiple Access, or CDMA.

Several frequencies make up the GPS electromagnetic spectrum:

- L1 (1575.42 MHz):
  Carries a publicly usable coarse-acquisition (C/A) code as well as an encrypted precision P(Y) code.
- L2 (1227.60 MHz):
  Usually carries only the P(Y) code. The encryption keys required to directly use the P(Y) code are tightly controlled by the U.S. government and are generally provided only for military use. The keys are changed on a daily basis. In spite of not having the P(Y) code encryption key, several high-end GPS receiver manufacturers have developed techniques for utilizing this signal (in a round-about manner) to increase accuracy and remove error caused by the ionosphere. Recognizing the civilian need for increased accuracy, "modernized" IIR-M (IIR-14 (M) and later) satellites carry a civilian signal interleaved with an improved military signal on both the L1 and L2 frequencies.
- L3 (1381.05 MHz):
  Carries the signal for the GPS constellation's alternative role of detecting missile/rocket launches (supplementing Defense Support Program satellites), nuclear detonations, and other high-energy infrared events.
- L4 (1841.40 MHz):
  Being studied for additional ionospheric correction.
- L5 (1176.45 MHz):
  Proposed for use as a civilian safety-of-life signal. This frequency falls into an internationally protected range for aeronautical navigation, promising little or no interference under all circumstances. The first Block IIF satellite that would provide this signal is set to be launched in 2007.

**GPS Time**

A minor detail is that the atomic clocks on the satellites are set to "GPS time", which is the number of seconds since 04:00:00 (4 A.M.), January 6, 1980. It is ahead of UTC because it does not follow leap seconds. Receivers thus apply a clock correction factor (which is periodically transmitted along with the other data), and optionally adjust for a local time zone in order to display the correct time. The clocks on the satellites are also affected by both special and general relativity, which causes them to run at a slightly faster rate than do clocks on the Earth's surface. This amounts to a discrepancy of around 38 microseconds per day, which is corrected by electronics on each satellite. This offset is a dramatic proof of the special theory of relativity in a real-world system, as it is exactly that predicted by the theory, within the limits of accuracy of measurement.

The inspiration for the GPS system came when the Soviets launched the first Sputnik in 1957. A team of U.S. scientists led by Dr. Richard B. Kershner were monitoring Sputnik's radio transmissions. They discovered that, due to the Doppler effect, the frequency of the signal being transmitted by Sputnik was higher as the satellite approached, and lower as it continued away from them. They realized that since they knew their exact location on the globe, they could pinpoint where the satellite was along its orbit by measuring the Doppler distortion. It was only a small leap of logic to realize that the converse was also true; if the satellite's position was known then they could identify their own position on Earth.

GPS receivers come in a variety of formats, from devices integrated into cars, phones, and watches, to dedicated devices such those shown here from manufacturers Trimble, Garmin and Leica (respectively, left to right).

**Sources of GPS measurement errors**

Ideally, GPS receivers would easily be able to convert the C/A and P(Y)-code measurements into accurate positions. However, a system with such complexity leaves many openings for errors to affect the measurements. The following are several causes of error in GPS measurements.

**Clocks**

Both GPS satellites and receivers are prone to timing errors. Ground stations throughout the world monitor the satellites to ensure that their atomic clocks are kept synchronized. Receiver clock errors depend upon the oscillator provided within the unit. However, they can be calculated and then eliminated once the receiver is tracking at least four satellites.

**Ionosphere**

The Ionosphere is one of the leading causes of GPS error. The speed of light varies due to atmospheric conditions. As a result, errors greater than 10 meters may arise. To compensate for these errors, the second frequency band L2 was provided. By comparing the phase difference between the L1 and L2 signals, the error caused by the ionosphere can be calculated and eliminated.

**Multipath**

The antenna receives not only direct GPS signals, but also multipath signals: reflections of the radio signals off the ground and/or surrounding structures (buildings, canyon walls, etc). For long delay multipath signals, the receiver itself can filter the signals out. A variety of receiver techniques, most notably Narrow Correlator spacing, have been developed to mitigate multipath error contributions to pseudorange measurements. For shorter delay multipath signals that result from reflections from the ground, special antenna features may be used such as a ground plane, or a choke ring antenna. Shorter multipath signals from ground reflections can often be very close to the direct signals, and can greatly reduce precision.

**GPS Jamming**

A large part of modern munitions, the so-called "*smart bombs*" or precision-guided munitions, use GPS. GPS jammers are available, from Russia, and are about the size of a cigarette box. The U.S. government believes that such jammers were used occasionally during the U.S. invasion of Afghanistan. Some officials believe that jammers could be used to attract the precision-guided munitions towards noncombatant infrastructure, other officials believe that the jammers are completely ineffective. In either case, the jammers are attractive targets for anti-radiation missiles.

The U.S. Air Force conducted GPS jamming exercises in 2003. A detailed description of how to build a GPS jammer was posted on a hackers' site by an anonymous author. And there has been at least one well-documented case of unintentional jamming; if similar, but stronger, signals were generated on purpose, they could interfere with aviation GPS receivers at a range of 50 km. According to the reference below "IFR pilots should have a fallback plan in case of a GPS malfunction".

There were also incidents of unintentional jamming, traced back to malfunctioning TV antenna preamplifiers.

- GPS jamming
- The hunt for an unintentional GPS jammer
- GPS Anti-Jamming Protection

### Selective Availability

When it was first deployed, GPS included a "feature" called **Selective Availability** (or **SA**) that introduced intentional errors of up to a hundred meters into the publicly available navigation signals, making it difficult to use for guiding long range missiles to precise targets. Additional accuracy was available in the signal, but in an encrypted form that was only available to the United States military, its allies and a few others, mostly government users.

SA typically added signal errors of up to about 10 m horizontally and 30 m vertically. The inaccuracy of the civilian signal was deliberately encoded so as not to change very quickly, for instance the entire eastern US area might read 30 m off, but 30 m off everywhere and in the same direction. In order to improve the usefulness of GPS for civilian navigation, **Differential GPS** was used by many civilian GPS receivers to greatly improve accuracy.

In the 1990s the FAA started pressuring the military to turn off SA permanently. This would save the FAA millions of dollars every year in maintenance of their own, less accurate, radio navigation systems. The military resisted for most of the 1990s, but SA was eventually turned off in 2000. On May 1, 2000, then US President Bill Clinton announced that this **"Selective Availability"** would be turned off, allowing all users to enjoy nearly the same level of access. Although global SA was discontinued in 2000 [1], the US maintains the capability to selectively deny GPS signals on a regional basis at any time, for military or national defense purposes.

On May 1, 2000, US President Bill Clinton announced that **"Selective Availability"** would be turned off. However, for military purposes, **"Selective Deniability"** may still be used to, in effect, jam civilian GPS units in a war zone or global alert while still allowing military units to have full functionality. In reality, the shortage of military GPS units and the wide availability of civilian ones among personnel resulted in disabling the Selective Availability in the time of the Gulf War. However, European concern about the level of control over the GPS network and commercial issues has resulted in the planned Galileo positioning system. Russia already operates an independent system called GLONASS (global navigation system), although with only twelve active satellites as of 2004, the system is of limited usefulness.

Military (and selected civilian) users still enjoy some technical advantages which can give quicker satellite lock and increased accuracy. The increased accuracy comes mostly from being able to use both the L1 and L2 frequencies and thus better compensate for the varying signal delay in the ionosphere (see above). Commercial GPS receivers are also required to have limits on the velocities and altitudes at which they will report fix coordinates; this is to prevent them from being used to create improvised cruise or ballistic missiles.

- noaa.gov Selective Availability Factsheet (pdf) or [2]

### Techniques to improve GPS accuracy

The accuracy of GPS can be improved in a number of ways:

- **Differential GPS (DGPS)** can improve the normal GPS accuracy of 4-20 meters to 1-3 meters.[3] DGPS uses a network of stationary GPS receivers to calculate the difference between their actual known position and the position as reported by the GPS signal. The "difference" is broadcast as a local FM signal, allowing many civilian GPS receivers to "fix" the signal for greatly improved accuracy.

- The Wide Area Augmentation System (**WAAS**). This uses a series of ground reference stations to calculate GPS correction messages, which are uploaded to a series of additional satellites in geosynchronous orbit for transmission to GPS receivers, including information on ionospheric delays, individual satellite clock drift, and suchlike. Although only a few WAAS satellites are currently available as of 2004, it is hoped that eventually WAAS will provide sufficient reliability and accuracy that it can be used for critical applications such as GPS-based instrument approaches in aviation (landing an airplane in conditions of little or no visibility). The current WAAS system only works for North America (where the reference stations are located), and due to the satellite location the system is only generally usable in the eastern and western coastal regions. However, variants of the WAAS system are being developed in Europe (EGNOS, the Euro Geostationary Navigation Overlay Service), and Japan (**MSAS**, the Multi-Functional Satellite Augmentation System), which are virtually identical to WAAS.
- A Local Area Augmentation System (**LAAS**). This is similar to WAAS, in that similar correction data are used. But in this case, the correction data are transmitted from a local source, typically at an airport or another location where accurate positioning is needed. These correction data are typically useful for only about a thirty to fifty kilometre radius around the transmitter.
- Exploitation of DGPS for Guidance Enhancement (**EDGE**) is an effort to integrate DGPS into precision guided munitions such as the Joint Direct Attack Munition (**JDAM**).
- A Carrier-Phase Enhancement (**CPGPS**). This technique utilizes the 1.575 GHz L1 carrier wave to act as a sort of clock signal, resolving ambiguity caused by variations in the location of the pulse transition (logic 1-0 or 0-1) of the C/A PRN signal. The problem arises from the fact that the transition from 0-1 or 1-0 on the C/A signal is not instantaneous, it takes a non-zero amount of time, and thus the correlation (satellite-receiver sequence matching) operation is imperfect. A successful correlation could be defined in a number of various places along the rising/falling edge of the pulse, which imparts timing errors. CPGPS solves this problem by using the L1 carrier, which has a period 1/1000 that of the C/A bit width, to define the transition point instead. The phase difference error in the normal GPS amounts to a 2-3 m ambiguity. CPGPS working to within 1% of perfect transition matching can achieve 3 mm ambiguity; in reality, CPGPS coupled with DGPS normally realizes 20-30 cm accuracy.
- Wide Area GPS Enhancement (**WAGE**) is an attempt to improve GPS accuracy by providing more accurate satellite clock and ephemeris (orbital) data to specially-equipped receivers.
- Relative Kinematic Positioning (**RKP**) is another approach for a precise GPS-based positioning system. In this approach, accurate determination of range signal can be resolved to an accuracy of less than 10 centimetres. This is done by resolving the number of cycles in which the signal is transmitted and received by the receiver. This can be accomplished by using a combination of differential GPS (DGPS) correction data, transmitting GPS signal phase information and ambiguity resolution techniques via statistical tests—possibly with processing in real-time (real-time kinematic positioning, RTK).
- Many automobile GPS systems combine the GPS unit with a gyroscope and speedometer pickup, allowing the computer to maintain a continuous navigation solution by dead reckoning when buildings, terrain, or tunnels block the satellite signals. This is similar in principle to the combination of GPS and inertial navigation used in ships and aircraft, but less accurate and less expensive because it only fills in for short periods.

### System reliability

The GPS signal is more fragile than might be supposed. A network of at least 24 satellites is required for full coverage. Satellites cannot be repaired and have a limited life. As of 2005:

- there are 28 satellites in orbit, of which 16 are already beyond their design life—the oldest have nearly reached twice their design life.
- The failure rate is about two satellites per year.
- The launch rate of new satellites is about two per year.

If the older satellites start to fail faster—which may well happen—and if the launch rate cannot be increased proportionately, full coverage could be lost. The article GPS users must plan for outages discusses this possibility from the perspective of a backer of the competing Galileo system. Fortunately, this is not a concern in practice for at least two reasons. First, the Air Force monitors the health of SVs closely and maintains at least one on-orbit spare in each orbital plane. Second, the Air Force could easily increase the launch rate with SVs and ELVs already on hand.

### GPS and Relativity

Many relativistic corrections are applied to the GPS system. Neil Ashby presented in Physics Today (May 2002) a good account of how these relativistic corrections are applied, why, and which are their orders of magnitude [4]. Whether relativity must be considered as a mere correction to a Newtonian GPS theory, or, rather, as the necessary foundation of a cleaner (and more fundamental) GPS theory, is currently under debate. Bartolomé Coll has recently developed the basic notions necessary for a fully relativistic theory of Positioning Systems [5].

### GPS is free for private and commercial use

It was announced that once ready the GPS system would be made available for civilian use in response to the KAL 007 incident in 1983 (see external link below). Since its completion then, the GPS system is free for everyone to use.

### Awards

Two GPS developers have received the National Academy of Engineering Charles Stark Draper prize year 2003:

- Ivan Getting, emeritus president of The Aerospace Corporation and engineer at the Massachusetts Institute of Technology established the basis for GPS, improving on the World War II land-based radio system called LORAN (**Lo**ng-range **R**adio **A**id to **N**avigation).
- Bradford Parkinson, teacher of aeronautics and astronautics at Stanford University developed the system.

On February 10, 1993, the National Aeronautic Association selected the Global Positioning System Team as winners of the 1992 Robert J. Collier Trophy, the most prestigious aviation award in the United States. This team consists of researchers from the Naval Research Laboratory, the U.S. Air Force, the Aerospace Corporation, Rockwell International Corporation, and IBM Federal Systems Company. The citation accompanying the presentation of the trophy honors the GPS Team "for the most significant development for safe and efficient navigation and surveillance of air and spacecraft since the introduction of radio navigation 50 years ago."

### Other systems

For a list of other systems, see satellite navigation system.

**Satellite navigation systems**

*Transit* | **GPS** | **GLONASS** | **Galileo** | **Beidou**

*Related topics: EGNOS* | *WAAS* | *LAAS*

### See also

Wikimedia Commons has media related to:
***Global Positioning System***

- Glonass - Russian alternative to GPS
- Galileo positioning system - European alternative to GPS
- EGNOS - European alternative to WAAS
- Air traffic control
- Allan variance
- Automatic Dependent Surveillance-Broadcast (also called ADS-B)
- AGPS
- Geocaching
- Geodashing
- GSM localization
- GPX - GPS eXchange Format
- Mobile phone integration
- Multilateration - the mathematical technique used for GPS location
- Open Geospatial Consortium (OpenGIS)
- RAIM
- Waypoint
- WikiGPS, Wikimedia proposed project.

### External links

### Documentation

- Peter H. Dana: Global Positioning System Overview - Large amount of technical information and discussion.
- GPS SPS Signal Specification, 2nd Edition - The official (civilian) signal specification.
- History of GPS, including information about each satellite's configuration and launch.
- U.S. Army Corps of Engineers manual: NAVSTAR HTML and PDF (22.6 MB, 328 pages)

- Is it Safe to use a handheld GPS Receiver on a Commercial Aircraft? - Discusses the safety of personal use of a GPS on commercial aircraft.
- How Stuff Works - Explanation about How GPS works
- Palowireless GPS Resource Center Articles, news and resources.

**Government agencies**

- USCG Navigation Center: Status of the GPS constellation, government policy, and links to other references. Also includes satellite almanac data.
- Schriever Airforce Base Webserver: Even more up-to-date almanac data and NANUs
- Interagency GPS Executive Board - Established in 1996 to manage GPS across the various stakeholder agencies.
- The GPS Joint Program Office (GPS JPO) - Still exists and distinct from IGEB.
- The FAA has more information on GPS, WAAS, LAAS, and DGPS at http://gps.faa.gov/FAQ/index.htm
- GPS Weapon Guidance Techniques

**Software**

- Dale Priest's guide to navigation with GPS and Palm PDAs
- GPS3d, a 3D gps visualization tool
- GPSd, a GPS daemon program
- GpsDrive, external link - **GNU** Map-based navigation system. It displays your position on a zoomable map provided from a NMEA-capable GPS receiver.
- GPSTk: A free Open Source GPS Toolkit
- GPS Visualizer - A free online utility that creates maps and profiles in SVG, JPEG/PNG, or Google Maps/Google Earth format from GPS waypoints and tracks.
- Magnificient Logs - Create interactive GPS logs online, find photo location by linking GPS and Exif timestamp.
- Opanda IExif - a handy tool for viewing detailed GPS data in digital image in Windows Local folder & Internet Explorer & Mozilla Firefox & ACDSee.
- Opanda PowerExif Editor - a powerful editer for adding GPS data into Exif tags of digital images or modifying the GPS data in digital images freely and easily.
- Bernese GPS Software - scientific GPS/GLONASS post processing package
- Microsoft Streets & Trips with GPS Locator
- Global Tracking Technologies' Global GPS tracking system platform

**Makers of popular GPS hardware and vehicle navigation systems**

- Alpine
- Clarion
- Cobra
- Fujitsu Ten
- Garmin
- Lowrance Electronics
- Magellan
- Mobile Crossing
- Pioneer Electronics
- TomTom
- VDO Dayton
- pharos

**GPS software for car navigation**

- CoPilot
- Navi BT GPS Scytex
- PocketGPS Pro Moscow
- TomTom
- ViaMichelin Navigation

**Hardware**

- GPS Buying Guide - A guide to selecting the right consumer GPS receiver based on intended use.
- GPS Time Server solutions Time Server solutions for all your computer time Synchronisation needs
- Septentrio - Makers of high-end receivers for precise applications
- u-blox GPS products (chipsets, modules, receiver boards, antennas and accessories)
- GPS NTP Server GPS time servers and NTP servers for computer network timing.

**Usenet newsgroups**

- sci.geo.satellite-nav Direct or via the Google Groups web site.
- uk.rec.gps Direct or via the Google Groups web site.

**Other information**

- Hacking GPS sales website for book
- u-blox GPS Tutorial — Tutorial designed to introduce you to the principles behind GPS
- Geoplace — GPS & GIS Industry information
- [6] GPS and Relativity
- Neil Ashby: "Relativity in the Global Positioning System"
- Trimble's Online GPS Tutorial — excellent introduction for newbies
- The Practical Guide to GPS UTM
- Information on the GPS week rollover
- GPS Articles
- PDF document on the history of the GPS system
- GISWiki Tutorials and News (in German)
- MacMap Discussion Group GPS on Macintosh platform; e-mail discussion

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