Chapter 14

U.S. SATELLITE NAVIGATION SYSTEMS

Satellite navigation systems, such as the U.S. NAVSTAR Global Positioning System (GPS) came of age with the Gulf War of 1991. GPS supported coalition forces in targeting, navigation, reconnaissance, refueling, air- and sea-launched cruise missiles and providing the Army logistics forces with accurate navigation across the trackless desert to keep up with moving ground forces. Today, GPS is used in a variety of applications, both military and civilian, and the uses are continually expanding.

TRANSIT

Transit, the first navigation satellite, was developed by the Applied Physics Laboratory of Johns Hopkins University for updating the inertial navigation systems of the U.S. Navy's Polaris submarines. The Transit System, which had an 80-100 meter accuracy, was operational in the 1960s. Transit Systems provided navigational support to the U.S. Navy and commercial users. The Transit System was deactivated in December 1996 after the Navigation Satellite Timing and Ranging Global Positioning System (NAVSTAR GPS) constellation was declared fully operational on 27 April, 1995. (see **Fig. 14-1**).

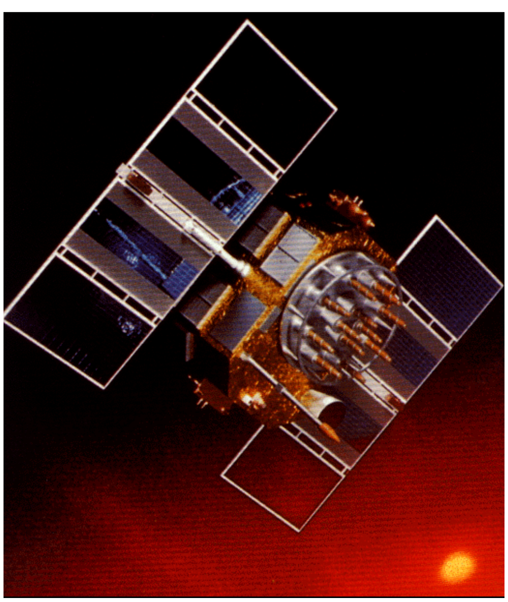

Fig. 14-1. Block II GPS Satellite

NAVSTAR GPS

The NAVSTAR GPS is a dual-use (civil and military) radio navigation system. GPS is the Department of Defense (DOD) solution to the requirement for a worldwide, continuous, all weather positioning system. GPS provides extremely accurate latitude, longitude, altitude and velocity information, together with system time, to suitably equipped users anywhere on or near the earth. In terms of navigation, GPS is nothing short of revolutionary. GPS provides three-dimensional positioning anywhere in the world, in any weather. In terms of accuracy, GPS has an accuracy of 16 meters Spherical Error Probable (SEP), which is a factor of 10 better than its nearest competitor (LORAN-C) in two-dimensional positioning, and it has no equal in three-dimensional positioning. Very rarely does the military develop a system which has specific and tangible benefits to both the military and civilian community. GPS is one of those systems.

From a civilian perspective, NAVSTAR GPS represents a navigational aid which is available at the cost of a NAVSTAR GPS user set. The use of GPS in civilian applications is widespread and changes daily. By 1999 over 700 different models of GPS receivers were available for purchase with prices as low as $100. Examples of civilian use of GPS include public health and safety, aviation, survey/mapping, scientific research, transportation, maritime navigation, agriculture and recreation.

From the military perspective, NAVSTAR is employed in methods ranging from stand-alone systems for supporting ground troops to support of fully integrated systems capable of weapons delivery. GPS is a space-based radio navigation system which is managed for the U.S. government by the U.S. Air Force and the Department of Transportation; the Air Force is the system operator. GPS was originally developed as a military force enhancement system and will continue to play this role.

Services

In an effort to make GPS service available to the greatest number of users while ensuring that national security interests of the United States are protected, two levels of GPS service are provided:

- The Standard Positioning Service (SPS) is designed to provide accurate positioning capability for civil users throughout the world.
- The Precise Positioning Service (PPS) provides full system accuracy, primarily to U.S. and allied military users. Although the military is the prime user of PPS, authorized civilians are also allowed to use the service.

Standard Positioning Service (SPS)

SPS is the standard specified level of positioning and timing accuracy that is available to any user on a continuous worldwide basis. The accuracy of this service will be established by the DOD and DOT based on U.S. security interests, although current policy is to allow the maximum available accuracy.

Both SPS and PPS accuracy specifications are expressed in terms of probability. Currently, SPS 2-D (horizontal) accuracy is 10-20 meters, twice distance root mean squared (2 drms). During the 1990s, the only formal SPS specification called for a 2-D accuracy of 100 meters, 2 drms. In general terms, this meant that 95 percent of the time, SPS accuracy had to be within 100 meters of a receiver's actual location on the earth's surface. This was equivalent to 76 meters, spherical error probable (SEP), meaning that 50 percent of the time a receiver's position solution had to be within a spherical radius of 76 meters from the receiver's actual location. SPS time transfer accuracy was normally to be within 340 nanoseconds (billionths of a second) of Universal Coordinated Time (UTC, or Zulu time, 95 percent) although there was no formal specification for SPS timing or velocity accuracy.

In times of crisis, SPS accuracy could have been degraded much more than the 100 meter specification. (The technical method, called Selective Availability [SA] will be discussed later.) This decision rests with the US National Command Authorities but there is no intent by the US government to ever use SA again.

PPS is invariably the most accurate direct positioning, velocity and timing information available worldwide. PPS is limited to users specifically authorized by the U.S.

Precise Positioning Service (PPS)

Figure 14-2 shows the published accuracy specifications for GPS as determined with four satellites in view.

	SPS	PPS
Position	10M(2-D,95%)*	16M (3-D, 50%)
Velocity	N/A	0.1M/s
Time	40ns*	100ns

* New SPS specifications are still to be determined

Fig. 14-2. SPS/PPS Position Accuracies

There are three formal PPS accuracy specifications, as opposed to only one for SPS. PPS 3-D (spherical) position accuracy must be 16 meters (SEP) . In general, PPS position and timing specifications are about five times as accurate as SPS. PPS timing accuracy must be within 100 nanoseconds, drms (i.e., one sigma, or 68 percent of the time). Finally, PPS velocity accuracy must be within 0.1 meter per second, drms (again, 68 percent).

Architecture: Three Segments

The Global Positioning System does not refer only to the NAVSTAR satellites that orbit the earth. It consists of three distinct segments: the Space Segment, the Control Segment, and the User Segment. All three have a role to play in providing users with accurate position, velocity, and timing data.

Space Segment

The GPS Space Segment is composed of nominally 24 satellites in six orbital planes (see **Fig. 14-3**). The satellites operate in circular 20,200km (10,900nm) orbits at an inclination angle of 55 degrees with a 12-hour period. There are four satellites in each orbital plane. The spacing of satellites in orbit are arranged so that five to eight satellites are always visible to users worldwide.

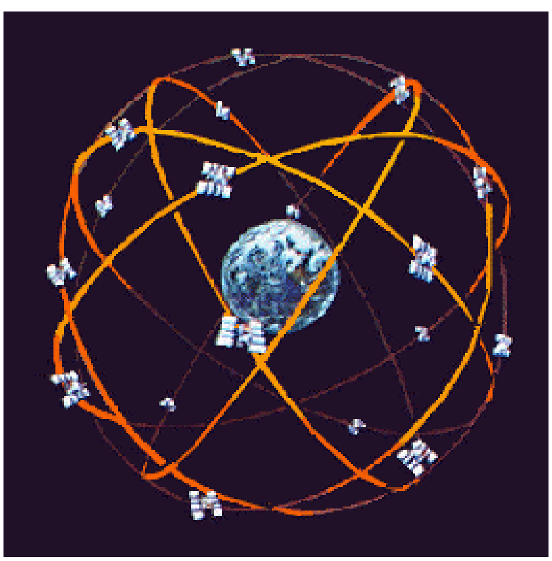

Fig. 14-3. GPS Constellation

Most of the satellites in the constellation are the second generation Block II/IIA satellites. Originally projected to have a design life of seven years. The Air Force revised the projected life of the Block II's to 8.6 years. The last of 28 Block II satellites was launched 6 November 1997. The current generation of satellites is called Block IIR ("R" for "replacement"). They have a ten year design life and are able to operate autonomously (without Control Segment intervention) for up to 180 days. The first successful Block IIR launch took place on 22 July 1997. The follow-on to the Block IIR generation of satellites is in development and will be called Block IIF. Originally, there was a contract for six Block IIF satellites with options for an additional 27, a total of 33. Currently, however, new requirements for 2nd and 3rd civil signals, a new military signal and spot beam capability (described later) have driven DoD to plan for only 6 more Block IIFs for a total of 12. Then a new GPS Block III contract will be let to build the satellites that will incorporate the new requirements.

Nuclear Detection (NUDET) Payload

The GPS satellites carry a secondary payload for detecting the characteristic optical, x-ray, and electromagnetic pulse emissions from nuclear explosions. The payload can pinpoint ground zero to within a 1.5 kilometer radius. NUDET data can be crosslinked between satellites and downlinked to the appropriate agencies on earth.

Control Segment

A worldwide network of GPS ground facilities known as the GPS Control Segment is in place to ensure that the NAVSTAR satellites are operational and passing accurate positioning data to GPS users. These facilities include a Master Control Station, ground antennas, and monitor stations.

The Master Control Station (MCS) at Schriever Air Force Base, Colorado (see

Fig. 14-4) is operated and maintained by the 2nd Space Operations Squadron (2SOPS) of the 50th Space Wing. The 2SOPS at the MCS is responsible for all routine, day-to-day NAVSTAR satellite operations. Another unit, the 1st Space Operations Squadron (1SOPS), provides support during launch, early orbit, and anomaly resolution. An Alternate Master Control Station (ACMS) is under construction at Vandenberg AFB. It's projected operational date is 2005.

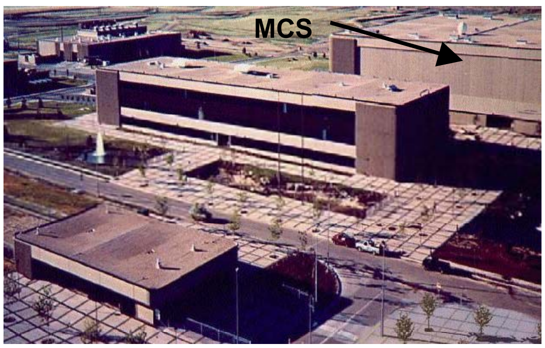

Fig. 14-4. GPS Master Control Station

The other elements of the Control Segment allow the MCS to monitor the quality of the satellites' navigation data and to control the satellites. To monitor the navigation data, monitor stations passively track navigation signals from all NAVSTAR satellites in view and transmit the data to the MCS for processing and error detection.

Navigation error corrections are generated at the MCS and sent to each satellite once every 24 hours as a "navigation upload". The navigation uploads are uplinked to the satellites via ground antennas. The ground antennas also receive and pass telemetry and tracking data to the MCS from the satellites and transmit commands from the MCS to the satellites, as depicted in **Figure 14-5**. The ground antennas are similar to the Remote Tracking Stations used by the Air Force Satellite Control Network (AFSCN); however, the GPS ground antennas can only communicate with GPS satellites. In contrast, the 1SOPS uses the Air Force Satellite Control Network (AFSCN) for launch and anomaly resolution.

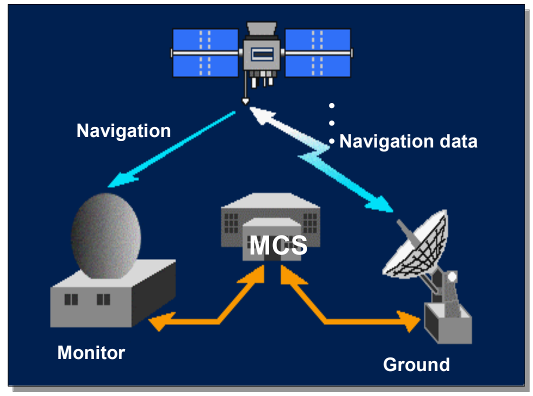

Fig. 14-5. Control Segment Interactions

A total of six monitor stations are located around the world to provide a constant monitoring capability. A total of five ground antennas are located around the world to provide control of the satellites. Most ground antennas are collocated with a monitor station.

The 2SOPS has four dedicated ground antennas collocated with monitor stations at Diego Garcia **(Fig. 14-6)**, Kwajalein Atoll, Ascension Island and Cape Canaveral (currently used only for launch but will eventually become fully operational). The fifth ground antenna is

Fig. 14-6. GPS Ground Site at Diego Garcia

the Colorado Tracking Station (Pike) located at Schriever AFB, Colorado. Pike is an AFSCN resource, but has the necessary hardware and software to allow 2 SOPS usage.

Stand-alone monitor stations are at Schriever AFB (not part of the Pike

Tracking Station) and Oahu Island, Hawaii. Future plans call for adding data from fourteen monitor stations operated by the National Imagery and Mapping Agency to enhance navigation data monitoring and processing.

Telemetry, Tracking and Commanding (TT&C)

The three major functions of satellite control, known as telemetry, tracking and commanding (TT&C), are executed by a four-person mission control crew in the MCS who conduct 24-hour operations. The crew consists of a crew commander, payload system operator (for navigation payload and monitor station operations), a space vehicle officer (for satellite bus subsystem operations), and a satellite system operator (for ground antenna/data communications connectivity). Orbital analysts and program engineers provide program specific knowledge and support to the crews. The operators perform pre-contact planning, real time contact and post-contact evaluation.

User Segment

The GPS User Segment is made up of a wide variety of military and civilian users with their GPS receivers, often referred to as user equipment (UE). GPS UE consists of a variety of configurations and integration architectures that typically include an antenna and receiver-processor to receive and compute navigation solutions to provide positioning, velocity and precise timing to the user.

How GPS Works

The basic principle behind GPS is "time of arrival" ranging. It is not quite the same thing as triangulation. To determine a 3-D position on the earth, a GPS receiver typically calculates the distance to four NAVSTAR satellites overhead and mathematically solves for time, latitude, longitude and altitude. It essentially uses "four equations to solve for four unknowns". The receiver determines the distance to a satellite by measuring the amount of time for a special radio signal from the satellite to arrive at the receiver's antenna. Since radio waves travel at the speed of light, the receiver multiplies the radio signal travel time by the speed of light to calculate the distances. If only three satellites are used, the receiver can only solve for a 2-D position, i.e., latitude and longitude. Using more than four satellites yields an increase in 3-D position accuracy (i.e., "six equations, four unknowns").

Each satellite broadcasts navigation signals on two frequencies, L1 (1575.42 MHz) and L2 (1227.6 MHz). A satellite-specific coarse acquisition (C/A) code is modulated onto L1. A satellite-specific precision code (P-code) is modulated onto both L1 and L2. A navigation message is superimposed onto both the C/A and the P-code. It contains the "almanac", or orbit data for all the satellites in the constellation, as well as other information on satellite operational status, etc.

Most civilian GPS receivers can only acquire the C/A code on L1, which is a significant limitation on their accuracy. Since the GPS signals refract and are delayed as they pass through the earth's ionosphere, ionospheric error data is included on the navigation message to allow L1-only SPS receivers to *estimate* the signal delay. However, most PPS military receivers can acquire not only the C/A code on L1 but also the P-code on both L1 and L2. Receiving on two frequencies allows for a real time *measurement* of ionospheric delays. This, combined with the inherent design of the P-code, contributes to a more accurate position solution for PPS receivers than is possible with only one frequency.

Sources of Error

Several sources of error exist which can degrade the accuracy of UE position solutions. Most involve things that produce uncertainty in the time it takes for the signal is space to reach a receiver's antenna. Space Segment errors such as satellite clock errors, variations in satellite subsystem stability, and unexpected orbital perturbations produce timing errors, as do ionospheric and tropospheric delays. Control Segment error contributions include minor errors in the orbital data predictions included in the navigation uploads to the satellites. On the ground, navigation signals reflected from terrain or buildings can create signal time of arrival delays known as multipath errors. Receiver noise and resolution is also a significant source of error, especially in civilian receivers where quality varies based on model and price.

A very important potential source of human error to keep in mind involves the datum, or type of map, being used with the GPS receiver. Most receivers display coordinates in World Geodetic System 1984 (WGS84) mode as well as many other reference frames. Users should double check the datum in use to precluded plotting GPS coordinates based in one datum on a map drawn in another datum. Mixed up datums and grids can cause misinterpretations of position data

Fig. 14-7. GPS Receiver used by Ground Forces in Open Terrain

of up to a *kilometer* (over 0.5 nm).

Finally, terrain can affect whether GPS signals are received at all. Receivers give best results when used outdoors in open areas, as in **Figure 14-7**. Tall buildings, canyon walls, foliage, etc. can block the satellite's signals.

Denial of Accuracy and Access

There are two primary methods for denying unauthorized users full use of the Global Positioning System. The first, as mentioned before, is Selective Availability (SA) and the second is Anti-Spoofing (A-S).

Selective Availability (SA)

Selective Availability, the intentional degradation of positioning accuracy, was discontinued by presidential directive on 1 May 2000 and there is no intent to ever use SA again. The SA feature allows the intentional introduction of errors into the satellites' navigation data to prevent unauthorized users from receiving full system accuracy. The errors can come from altering the satellite's atomic clocks (dithering) or altering the orbital data in the satellites' navigation messages (epsilon) or a combination of the two. The epsilon error in satellite position roughly translates to a like position error in the receiver. Encrypted correction parameters are included in the navigation signal that allow PPS receivers with the correct crypto keys to remove the SA errors from the navigation data.

SA was originally activated on 4 July 1991. For almost ten years national policy set the level of SA to limit SPS accuracy to the 100 meter (95 percent) specification. Now that SA is set to zero (it's always turned on), the SPS accuracy is 10-20 meters (95 percent).

Anti-Spoofing (A-S)

A-S is meant to negate hostile imitation of the GPS signals (i.e., fake satellite transmissions) by encrypting the P-code into the Y-code. Otherwise, the false transmissions could lead to false position solutions. The encrypted code is usually referred to as the P(Y) code. The A-S feature was activated when the system became operational. To decrypt the P(Y) code back into usable P-code, a GPS receiver must a have special decryption device. The first generation device was called the Auxiliary Output Chip (AOC). An improved device called the PPS Security Module came next. A new device known as the Selective Availability Anti-Spoofing Module (SAASM) is under development. SAASM will be tamper-resistant and will greatly simplify crypto key distribution and handling.

A receiver that has the ability to decrypt the SA correction parameters or the P(Y) code or both is considered to be a PPS receiver. SPS receivers, by definition, have neither SA nor A-S decryption capability.

GPS Augmentation and Improvements

Many means of making GPS even more accurate by using a second source of data (augmentation) or by some other means are available or are in development. Some of the more prominent methods are described below.

Differential GPS (DGPS)

DGPS is a means of augmenting GPS based on the principle that GPS position errors are generally the same for receivers in the same geographical region. DGPS requires a network of differential stations and special DGPS-capable receivers. A differential station is established at a precisely surveyed position. The station uses a GPS receiver to compare the GPS coordinates to the known location, then transmits the errors to DGPS-capable receivers in the region. DGPS essentially corrects for all errors in the navigation data, including the Selective Availability errors. With the differential corrections, DGPS receivers can achieve accuracies of less than one meter, SEP. Static receivers collecting data over several hours can achieve accuracies of a few centimeters. The US Coast Guard has a fully operational DGPS network along the US coastline with coverage extending approximately 90 kilometers (50 nm) inland and out to sea.

Exploitation of DGPS for Guidance Enhancement (EDGE)

EDGE is an effort to integrate DGPS into precision guided munitions such as the Joint Direct Attack Munition (JDAM). A munition guidance package equipped with a DGPS receiver uses differential corrections to enhance weapon accuracy. The concept has been proven with GBU-15 tests at Eglin AFB, Florida.

Wide Area Augmentation System (WAAS)

WAAS is a Federal Aviation Administration project to expand on DGPS by broadcasting differential corrections not just from a ground based differential station, but from a geostationary communications satellite for continent-sized regions. The architecture calls for 24 Wide area reference stations throughout the US to provide satellite-relayed differential corrections for the entire region. WAAS will allow pilots to perform "Category 1" precision approaches – a technique used in bad weather where a pilot must see the runway at no less than 200 feet above the ground and at a distance of one-half mile – throughout the WAAS coverage area. Accuracies of 3-5 meters (SEP) are expected. A related FAA system under development called the Local Area Augmentation System (LAAS) will be based at major airports and will provide for the more stringent Category 2 and 3 precision approaches. Plans to provide initial WAAS capability have slipped from September 2000 to 2002 due to software problems and increasing costs. One problem area resulting in cost overruns is the requirement for the system to virtually never fail to warn pilots of an erroneous GPS signal, a feature known as integrity.

Wide Area GPS Enhancement (WAGE)

WAGE is an attempt to improve GPS accuracy by providing more accurate satellite clock and ephemeris (orbital) data to specially-equipped receivers. In the current system, accuracy degrades slightly as the data in the daily navigation uploads ages. New software at the Master Control Station allows the latest error corrections for all satellites to be uploaded each time a navigation upload is sent to a satellite. The special receivers are able to use the constellation clock and orbital data from the most recently updated satellite in view. WAGE has the equivalent effect of changing the navigation upload rate from once every 24 hours to once every three hours. Other WAGE related improvements involve including the NIMA monitor station data in MCS navigation data calculations and automating and streamlining the navigation upload process to allow operations focused on a given theater. Accuracy is expected to be 2.5-5 meters (SEP).

Accuracy Improvement Initiative (AII)

AII is planned to enhance GPS accuracy by improving the quality of navigation data calculated at the MCS. It includes several attributes of WAGE including the improved MCS software, data connectivity to fourteen NIMA monitor stations, and shorter navigation uploads to support up to three (vice one) uploads per day per satellite. Unlike WAGE, no special receivers are required to take advantage of the improved accuracy. AII is also compatible with the Block IIF AUTONAV feature described below. The performance objective is a 33% improvement in overall GPS accuracy from 1995 levels.

Autonomous Navigation (AUTONAV)

The AUTONAV feature on Block IIR and IIF satellites is based on crosslinking navigation data between satellites. Currently, each Block IIA satellite requires a dedicated navigation upload every 24 hours. With AUTONAV, all navigation upload data for the whole constellation will be uplinked to one satellite, then crosslinked to all the others. The AUTONAV crosslinks use the same frequency, L3, used for the NUDET data crosslinks. AUTONAV will significantly reduce the MCS crew's workload. Instead of performing one navigation upload per day per satellite, only one upload per month will allow the system to meet accuracy specifications. Full AUTONAV capability will be available by Block IIF flight 18 and will provide accuracies of less than 2.5 meters (SEP) .

GPS Aiding

GPS aiding refers to coupling non-GPS navigation data sources into a composite navigation solution. These sources include inertial navigation systems (INS), barometric altimeters, and/or non-GPS derived data on satellite positions or time. These external inputs can help in acquiring or maintaining lock on GPS signals, thus maximizing the efficiency and reliability of the composite navigation system. The GPS/INS combination in particular synergistically increases the performance and reliability of both systems. INS drift is reduced by frequent GPS updates and in most cases can continue to provide acceptable navigation data if the GPS signal is lost.

Second and Third Civil Signals

The addition of two new GPS "civil signals" was announced in March 1998 by Vice President Al Gore. These second and third civil frequencies would significantly enhance the accuracy of civilian receivers, allowing the ionospheric delays to be measured as PPS receivers do now by using both the L1 and L2 P(Y) Code signals. The second civil signal would be at 1227.6 along with the military L2 signal, and would be used for general, non-safety critical applications. This signal is to be on GPS satellites launched starting in 2003, with initial operational capability (IOC) for users in 2009 when 18 satellites with the new signal are on orbit. The third signal, proposed for 1176.45 MHz (neither L1 nor L2, but a new frequency designated "L5"), is designated for safety-of-life applications such as search and rescue and is planned for GPS satellites launched in 2005 and afterwards. IOC for the L5 civil signal is planned for 2012. The extra signals would increase SPS accuracy down to 7 meters (95 percent).

New Military Signal and Spot Beam

Another upgrade to GPS is a new military signal to allow the US and its allies to keep a navigational advantage over their adversaries. Plans call for the new military signal, along with the new 2nd civil signal, to be on flights 9-14 of the new Block IIR satellites and any subsequent GPS satellites. Just as with the 2nd civil signal, this signal is to be on GPS satellites launched starting in 2003, with initial operational capability (IOC) for military users in 2009 when 18 satellites with the new signal are on orbit. Plans also call for a military spot beam, intended to overcome jamming by increasing the power over a limited area. The spot beam will be on board GPS satellites starting with the seventh Block IIF.

Limitations of GPS

Although GPS has demonstrated a tremendous capability, there are several areas of concern with the system. It is dependent on the Control Segment ground sites, which are potentially vulnerable to attack. If a Differential GPS system is in use, a special DGPS receiver must be used. Also, the satellite signals travel line-of-sight, and tall buildings, canyon walls, foliage, etc. can block the satellite's signals. From a military perspective, however, the most serious limitation is GPS susceptibility to jamming.

GPS Jamming

Any signal can be jammed. The most common jamming method, "brute force" jamming, involves overpowering an adversary's desired radio signals by transmitting noise on the same frequency being used by the adversary. The GPS signal is particularly easy to overpower because the signal strength received at the earth's surface is very low, about –166 dbw for the P(Y) code on L2, even lower than the natural background radio noise of the earth. (The unique nature of the code is what allows a receiver to detect the GPS signal against the earth's background noise.) If the jamming-to-signal ratio is above the level that the receiver can maintain lock on, then all it "hears" is the noise until the jamming stops or the receiver is removed from the area being jammed. However, no one has the resources to jam the entire frequency spectrum.

To maintain a measure of jam resistance, GPS uses several techniques. The first method was designed into the navigation signal at the outset. It involves the bandwidth of the P(Y) code, which is about 20 MHz centered on the L1 and L2 frequencies. This transmission technique is called "spread spectrum" transmission. The result of using spread spectrum is that an adversary must jam the entire 20 MHz bandwidth to effectively jam the navigation signal. Jamming only part of the bandwidth does not prevent users from receiving and reconstructing the navigation signal.

GPS aiding is another method currently available to counter the effects of GPS jamming since an external data source can compensate for the loss of the GPS data. For example, if a GPS receiver is coupled with an INS in an aircraft, the INS can continue to provide navigation data as the plane approaches a jammer and loses lock on the GPS signals.

Spoofing, considered a form of "smart" jamming, is effectively prevented by the encryption of the P-Code into the Y-Code as previously described.

NAVWAR Program

In 1996, President Clinton issued a Presidential Decision Directive (PDD) declaring that within a decade, possibly as soon as the year 2000, GPS Selective Availability would be set to zero. On 1 May 2000, the President decided to set SA to zero, immediately increasing SPS accuracy by a factor of ten. This decision was prompted by the increasing worldwide civilian dependence on GPS. There is a corresponding military dependence and threat from the guidance accuracy provided by GPS. The Navigation Warfare, (NAVWAR) acquisition program was commissioned to investigate technological means to protect the friendly use of satellite navigation, prevent an enemy's use of satellite navigation, and preserve the civilian sector's use of satellite navigation outside a military area of operations.

Protection innovations from the NAVWAR program center on three areas: user equipment improvements, signal augmentation, and improvements to the GPS signal in space. User equipment improvements include jam-resistant antennas and improved receiver electronics. Augmentation efforts include ground-based or airborne "pseudolites" to transmit a signal in a jamming environment that helps receivers acquire and maintain lock on the satellite's signals. The signal in space improvement ideas range from increasing satellite transmitting power to changing the waveform of the signal. An analysis of alternatives is ongoing.

Military Applications of GPS

GPS provides a large share of the terrestrial force enhancement provided by Air Force space forces. Military applications for precision navigation and positioning are prevalent throughout all services. These applications include mine emplacement and location, sensor emplacement, instrument approaches, low-level navigation, guided munitions, target acquisition, and command and control. **(Fig. 14-8)** As in the civilian sector, new military applications are continually being invented.

Fig. 14-8. GPS Military Applications

Military GPS Receivers

GPS receiver capabilities have progressed steadily over the past few years. This discussion will begin with older model military receivers because they may still be in use, perhaps with allied forces if not with US forces. Older model military receivers fall into three categories: low, medium and high dynamic receiver sets. The main differences between the sets are the number of channels and the dynamic range of the environment suitable for the receivers. The number of channels primarily affects the speed at which the receiver can be initialized.

A three dimensional position fix requires four satellites. Old single channel systems, such as the low dynamic sets primarily used by ground units, must lock onto one satellite at a time. The accuracy is not affected, but the time to initialize the set is. Medium dynamic sets add a second channel, while the high dynamic sets are installed on aircraft because they have five or more channels.

In general, as the receivers go from low to high dynamic sets, there is a substantial increase in the number of channels and the acceptable range of velocity, acceleration and jerk is greater. The more turbulence a vehicle experiences, the more channels these sets require. Newer model military receivers are multi-channel sets. The hand-held Precision Lightweight GPS Receiver (PLGR), for example, can lock onto five GPS satellites at once (see **Fig. 14-9**). Its follow-on, the Defense Advanced GPS Receiver (DAGR), like modern aircraft GPS receivers (see **Fig. 14-10**), will be a 12-channel set, allowing it to lock onto all satellites in view.

Fig. 14-9. Hand-held Precision Lightweight GPS Receiver (PLGR)

Fig. 14-10. Miniaturized Aircraft GPS Receiver (MAGR)

Weapon Systems

A wide variety of weapon systems are dependent on GPS or a GPS/INS combination navigation system to provide all-weather day or night precision attack. Many of these weapons were used in Operation Allied Force in Serbia and Kosovo in 1999. For example, the B-2 uses the GPS-Aided Targeting System (GATS) to accurately geolocate fixed targets on the ground which it can then attack with the Joint Direct Attack Munition (JDAM). The JDAM is a 2000 lb. “dumb” bomb with a GPS guidance tail kit that transforms it into an independently targetable, adverse-weather, seekerless precision munition. Other GPS-guided systems in development include the Joint Stand Off Weapon (JSOW) and the Joint Air-to-Surface Standoff Missile (JASSM). Conventional Air Launched Cruise Missiles (CALCMs), the Navy’s Tactical Land Attack Missile (TLAMs), and ICBMs all use GPS. US Army indirect fire weapons such as the Multiple Launch Rocket System (MLRS) and the Army Tactical Missile System (ATACMS) take advantage of GPS positioning. The Army also uses the precision timing available from GPS to synchronize its frequency-hopping Single Channel Ground and Air Radio System (SINCGARS) radios. Foreign weapon systems are also incorporating GPS as the French have done with their new Apache cruise missile.

Other GPS applications continue to be explored, two of which will be discussed here: the Hook-112 SAR Radio and the Combat Survivor/Evader Locator (CSEL).

Hook-112 Search and Rescue (SAR) Radio

The Hook-112 SAR radio (see **Fig. 14-11**) combines an aircrew survival radio with a GPS receiver to provide the precise location of a downed crewman. The process, a burst transmission to a satellite then down to a rescue unit, ensures that an enemy cannot easily locate a downed crewman. The system also provides rescue teams with a precise location (within 100 meters, 95 percent) to use in finding the crewman.

In addition, SAR aircraft equipped with interrogator equipment can receive the Hook-112 signal as far as 100 miles away. Image how useful this would have been for Captain O'Grady when his F-16 was shot down in Bosnia and he had to spend several days evading capture, afraid to talk on his radio because the enemy was monitoring the SAR frequencies.

The Hook-112 Survival Radio System provides voice communications, a beacon and a distance measuring equipment transponder, all of which currently exist with the AN/PRC-112 Survival Radio. It also provides accurate GPS Standard Positioning Service, custom or "canned" messages that can be added to location and identification messages as well as location coordinates (using global latitude and longitude or local area military grids).

The U.S. Air Force plans to install interrogator equipment on unmanned aerial vehicles to further reduce the risks to airborne rescue personnel until the pick-up phase of the rescue missions begins.

Combat Survivor/Evader Locator (CSEL)

The Hook 112 radio is an interim solution until the Combat Survivor/Evader Locator becomes available. The CSEL (see **Fig. 14-12**) is a lightweight, low-power, over-the-horizon radio using an integrated GPS receiver. The CSEL is capable of reliable, precise GPS geolocation, over-the-horizon satellite data communication with the Joint Service Rescue Centers, line-of-sight voice communications with rescue teams, and a GPS encryption feature, the new Selective Availability Anti-Spoofing Module (SAASM), that

Fig. 14-11. Hook 112 SAR Radio

adds improved security in battlefield environments.

Fig. 14-12. CSEL

The first 30 CSELs were delivered in December 1997 for operational test and evaluation. However, technical and human factors problems have delayed fielding the CSEL until 2002. Plans for initial buys call for the Army, Navy, and Air Force to share 11,000 handheld units.

SUMMARY

The NAVSTAR Global Positioning System is a concept with practically unlimited potential. The capabilities of GPS as a navigation aid make the NAVSTAR satellite constellation an extremely valuable asset to our armed forces in the terms of force projection, enhancement and management. As users develop confidence in the ability of GPS to deliver on its promises, user sets will undoubtedly proliferate and be employed in almost limitless ways.

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