2 Overview of GPS

2.1 Basic concept

The Global Positioning System is the responsibility of the Joint Program Office (JPO), a component of the Space and Missile Center at El Segundo, California. In 1973, the JPO was directed by the U.S. Department of Defense (DoD) to establish, develop, test, acquire, and deploy a spaceborne positioning system. The present Navigation System with Timing and Ranging (NAVSTAR) Global Positioning System (GPS) is the result of this initial directive.

The Global Positioning System was conceived as a ranging system from known positions of satellites in space to unknown positions on land, at sea, in air and space. Effectively, the satellite signal is continually marked with its (own) transmission time so that when received the signal transit period can be measured with a synchronized receiver. The original objectives of GPS were the instantaneous determination of position and velocity (i.e., navigation), and the precise coordination of time (i.e., time transfer). A detailed definition given by W. Wooden in 1985 reads:

"The Navstar Global Positioning System (GPS) is an all-weather, space-based navigation system under development by the Department of Defense (DoD) to satisfy the requirements for the military forces to accurately determine their position, velocity, and time in a common reference system, anywhere on or near the Earth on a continuous basis."

Since the DoD is the initiator of GPS, the primary goals were military ones. But the U.S. Congress, with guidance from the President, directed DoD to promote its civil use. This was greatly accelerated by employing the Macrometer for geodetic surveying. This instrument was in commercial use at the time the military was still testing navigation receivers so that the first productive application of GPS was to establish high-accuracy geodetic networks.

As previously stated, GPS uses pseudoranges derived from the broadcast satellite signal. The pseudorange is derived either from measuring the travel time of the (coded) signal and multiplying it by its velocity or by measuring the phase of the signal. In both cases, the clocks of the receiver and the satellite are employed. Since these clocks are never perfectly synchronized, instead of true ranges "pseudoranges" are obtained where the synchronization error (denoted as clock error) is taken into account, cf. Eq. (1.2). Consequently, each equation of this type comprises four unknowns: the three point coordinates contained in the true range, and the clock error. Thus, four satellites are necessary to solve for the four unknowns. Indeed, the GPS concept assumes that four or more satellites are in view at any location on earth 24 hours a day. The solution becomes more complicated when using the measured phase. This observable is ambiguous by an integer number of signal wavelengths so that the model for phase pseudoranges is augmented by an initial bias, also called integer ambiguity.

The all-weather global system managed by the JPO consists of three segments:

- the space segment consisting of satellites which broadcast signals,
- the control segment steering the whole system,
- the user segment including the many types of receivers.

2.2 Space segment

2.2.1 Constellation

The GPS satellites have nearly circular orbits with an altitude of about 20 200 km above the earth and a period of approximately 12 sidereal hours. The constellation and the number of satellites used have evolved from earlier plans for a 24-satellite and 3-orbital plane constellation, inclined 63° to the equator. Later, for budgetary reasons, the space segment was reduced to 18 satellites, with three satellites in each of six orbital planes. This scheme was eventually rejected, since it did not provide the desired 24-hour worldwide coverage. In about 1986, the number of satellites planned was increased to 21, again three each in six orbital planes, and three additional active spares. The spare satellites were designated to replace malfunctioning "active" satellites. The present nominal constellation consists of 24 operational satellites deployed in six evenly spaced planes (A to F) with an inclination of 55° and with four satellites per plane. Furthermore, up to four active spare satellites for replenishment will be operational (Graviss 1992).

With the full constellation, the space segment provides global coverage with four to eight simultaneously observable satellites above 15° elevation at any time of day. If the elevation mask is reduced to 10°, occasionally up to 10 satellites will be visible; and if the elevation mask is further reduced to 5°, occasionally 12 satellites will be visible.

2.2.2 Satellites

General remarks

The GPS satellites, essentially, provide a platform for radio transceivers, atomic clocks, computers, and various ancillary equipment used to operate the system. The electronic equipment of each satellite allows the user to measure a pseudorange R to the satellite, and each satellite broadcasts a message which allows the user to determine the spatial position $\underline{\varrho}^S$ of the satellite for arbitrary instants. Given these capabilities, users are able to determine their position $\underline{\varrho}_R$ on or above the earth by resection (Fig. 1.1). The auxiliary equipment of each satellite, among others, consists of solar panels for power supply and a propulsion system for orbit adjustments and stability control.

The satellites have various systems of identification: launch sequence number, assigned pseudorandom noise (PRN) code, orbital position number, NASA catalogue number, and international designation. In agreement with the satellite navigation message and to avoid any confusion, the PRN number will be used throughout this textbook.

Satellite categories

There are six classes or types of GPS satellites. These are the Block I, Block II, Block IIA, Block IIR, Block IIF, and Block III satellites. Detailed information on launch dates, orbital position (designation letter for orbital plane plus number) and operational periods can be found on the Web site of the U.S. Coast Guard Navigation Center under http://www.navcen.uscg.mil/gps/geninfo/constell.htm.

Eleven Block I satellites (weighing 845 kg) were launched in the period between 1978 to 1985 from Vandenberg AFB, California, with Atlas F launch vehicles. With the exception of one booster failure in 1981, all launches were successful. Today, none of the original Block I satellites is in operation. Considering the 4.5-year design life of these satellites, however, it is remarkable that some of the Block I satellites were operational for more than 10 years.

The Block II constellation is slightly different from the Block I constellation since the inclination of their orbital planes is 55° compared to the former 63° inclination. Apart from orbital inclination, there is an essential difference between Block I and Block II satellites related to U.S. national security. Block I satellite signals were fully available to civilian users, while some Block II satellite signals are restricted.

The first Block II satellite, costing approximately $ 50 million and weighing more than 1 500 kg, was launched on February 14, 1989 from the Kennedy Space Center, Cape Canaveral AFB in Florida, using a Delta II Rocket. The design life of the Block II satellites is 7.5 years. Individual satellites, however, remained operational more than 10 years.

The Block IIA satellites ("A" denotes advanced) are equipped with mutual communication capability. Some of them carry retroreflectors and can be tracked by Laser ranging. The first Block IIA satellite was launched on

November 26, 1990. Today, no distinction is made between Block II and Block IIA satellites.

The Block IIR satellites ("R" denotes replenishment or replacement) weigh more than 2 000 kg and the $ 42 million cost are about the same as for the Block II's. The first Block IIR satellite was successfully launched on July 23, 1997 and 19 more launches are expected to follow. These satellites have a design life of 10 years. They are equipped with improved facilities for communication and intersatellite tracking. Satellites launched after 2005 will also transmit additional signal components.

The Block IIF satellites ("F" denotes follow on) will weigh more than 2 000 kg and will be launched from 2007 onwards. These satellites will have a design life of 15 years. They will be equipped with improved on-board capabilities (such as inertial navigation systems) and an augmented signal structure. An artist's rendering of a Block IIF satellite is shown on the front cover of this textbook.

Presently, the DoD undertakes studies for the next generation of GPS satellites, called Block III satellites. These satellites are expected to carry GPS into 2030 and beyond.

Satellite signal

The actual carrier broadcast by the satellite is a spread spectrum signal that makes it less subject to intentional (or unintentional) jamming. The spread spectrum technique is commonly used today by such diverse equipment as hydrographic positioning ranging systems and wireless local area network systems.

The key to the system's accuracy is the fact that all signal components are precisely controlled by atomic clocks. The Block II satellites have four on-board time standards, two rubidium and two cesium clocks. The long-term frequency stability of these clocks reaches a few parts in 10^{-13} and 10^{-14} over one day. The future hydrogen masers will have an even better stability of 10^{-14} to 10^{-15} over one day. These highly accurate frequency standards being the heart of GPS satellites produce the fundamental L-band frequency of 10.23 MHz. Coherently derived from this fundamental frequency are (presently) two signals, the L1 and the L2 carrier waves generated by multiplying the fundamental frequency by 154 and 120 respectively yielding

$$
\begin{aligned}
\mathrm{L1} &= 1575.42 \text{ MHz}\,,\\
\mathrm{L2} &= 1227.60 \text{ MHz}\,.
\end{aligned}
$$

These dual frequencies are essential for eliminating the major source of error, i.e., the ionospheric refraction (Sect. 6.3.2).

The pseudoranges that are derived from measured travel times of the signal from each satellite to the receiver use two pseudorandom noise (PRN) codes that are modulated (superimposed) onto the two base carriers.

The first code is the C/A-code (Coarse/Acquisition-code) which is available for civilian use. The C/A-code, designated as the Standard Positioning Service (SPS), has an effective wavelength of approximately 300 m. The C/A-code is presently modulated upon L1 only and is purposely omitted from L2. This omission allows the JPO to control the information broadcast by the satellite and, thus, denies full system accuracy to nonmilitary users.

The second code is the P-code (Precision-code) which has been reserved for U.S. military and other authorized users. The P-code, designated as the Precise Positioning Service (PPS), has an effective wavelength of approximately 30 m. The P-code is modulated on both carriers L1 and L2. Unlimited access to the P-code was permitted until the system was declared fully operational.

In addition to the PRN codes, a data message is modulated onto the carriers consisting of status information, satellite clock bias, and satellite ephemerides. A detailed signal description is given in Sect. 5.1.

It is worth noting that the present signal structure will be improved in the near future (Sect. 13.2).

2.2.3 Operational capabilities

There are two operational capabilities: (1) Initial Operational Capability (IOC) and (2) Full Operational Capability (FOC).

IOC was attained in July 1993 when 24 (Block I/II/IIA) GPS satellites were operating and were available for navigation. Officially, IOC was declared by the DoD on December 8, 1993.

FOC was achieved when 24 Block II/IIA satellites were operational in their assigned orbits and the constellation was tested for operational military performance. Even though 24 Block II and Block IIA satellites were available since March 1994, FOC was not declared before July 17, 1995.

2.2.4 Denial of accuracy and access

Two techniques are known for denying civilian users full use of the system. The first is Selective Availability (SA) and the second is Anti-spoofing (A-S).

Selective availability

Originally, the accuracy expected from C/A-code pseudorange positioning was in the range of some 400 m. Field tests achieved the surprising level of navigation accuracy of 15–40 m for positioning and a fraction of a meter

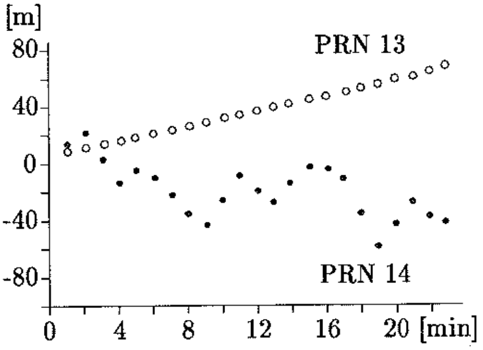

Fig. 2.1. Satellite clock behavior of PRN 13 (without SA) and of PRN 14 (with SA) on day 177 of 1992 after Breuer et al. (1993)

per second for velocity. The goal of SA was to deny this navigation accuracy to potential adversaries by dithering the satellite clock (δ-process) and manipulating the ephemerides (ε-process).

The δ-process is achieved by dithering the fundamental frequency of the satellite clock. The satellite clock bias has a direct impact on the pseudorange which is derived from a comparison of the satellite clock and the receiver clock. Since the fundamental frequency is dithered, code and carrier pseudoranges are affected in the same way. In Fig. 2.1, the different behavior of satellite clocks with and without SA is shown. With SA activated, there are variations of the pseudoranges with amplitudes of some 50 m and with periods of some minutes. When pseudoranges are differenced between two receivers, the dithering effect is eliminated.

The ε-process is the truncation of the orbital information in the transmitted navigation message so that the coordinates of the satellites cannot accurately be computed. The error in satellite position roughly translates to a like position error of stand-alone receivers. For baselines, the relative satellite position errors are (approximately) equal to the relative baseline errors. In Fig. 2.2, the behavior of the radial orbit error with and without SA is shown. In the case of SA, there are variations with amplitudes between 50 m and 150 m and with periods of some hours. The orbital errors cause pseudorange errors with similar characteristics. Thus, these errors are highly reduced when pseudoranges are differenced between two receivers,

SA has been in force since March 25, 1990. According to the specifications of the DoD, the accuracy for stand-alone receivers was degraded to 100 m for horizontal position and to 156 m for height. These specifications also implied a velocity error of $0.3\,\mathrm{m\,s^{-1}}$ and an error in time of 340 ns. All numbers are given at the 95% probability level. At the 99.99% probability

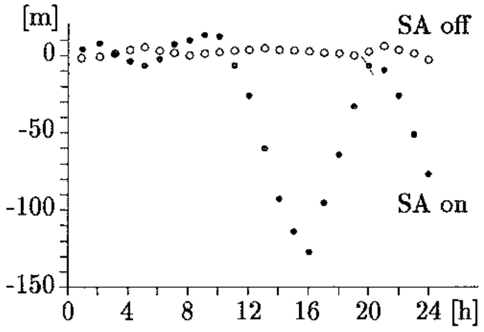

Fig. 2.2. Radial orbit error of PRN 21 on day 177 of 1992 with SA on and on day 184 of 1992 with SA off after Breuer et al. (1993)

level, the predictable accuracy decreased to 300 m for horizontal position and to 500 m for height (Department of Defense 1995).

Due to the undermined military effectiveness of SA by applying differential techniques, a joint recommendation of the U.S. National Academy of Public Administration and a committee of the National Research Council has proposed that SA should immediately be turned to zero and deactivated after some years (CGSIC 1995). The official answer to this proposal was released on March 29, 1996 in form of the Presidential Decision Directive (PDD) on GPS. The PDD expressed the intention to discontinue the use of SA within a decade in a manner that allows adequate time and resources for the military forces to prepare fully for operations without SA. In addition, the permanent Interagency GPS Executive Board (IGEB) was established. This board is commonly chaired by the DoD and the Department of Transportation (DoT) to balance military and civil interests. The full text of the public release statement on the PDD is published, e.g., in *GPS World* 1996, 7(5), page 50.

Somehow surprisingly, SA was turned off on May 2, 2000 at about 4:00 Universal Time (UT) after an announcement of the White House one day before. The benefits for civilian users are discussed in a fact sheet released by the U.S. Department of Commerce (2000). A prediction of the world after SA is given in Conley and Lavrakas (1999) and first experiences with SA off are discussed in Conley (2000), Jong (2000). One impressive result is presented in Fig. 2.3. Although the accuracy for stand-alone receivers is improved by a factor of ten, it must be kept in mind that despite turning off SA military advantages are ensured by new developments. One of these developments is Selective Denial (SD) which will deny access to the GPS signal for unauthorized users in regions of interest by ground-based jammers.

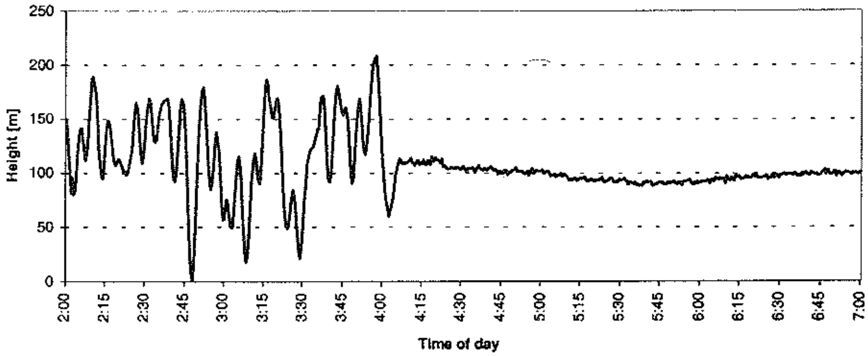

Fig. 2.3. Height variation in the station Kootwijk (The Netherlands) during the SA transition on May 2, 2000 (courtesy K. de Jong, Delft)

Anti-spoofing

The design of GPS includes the ability to essentially "turn off" the P-code or invoke an encrypted code as a means of denying access to the P-code to all but authorized users. The rationale for doing this is to keep adversaries from sending out false signals with the GPS signature to create confusion and cause users to misposition themselves.

A-S is accomplished by the modulo 2 sum of the P-code and an encrypting W-code. The resulting code is denoted as the Y-code. Thus, when A-S is active, the P-code on the L1 and the L2 carrier is replaced by the unknown Y-code. Note that A-S is either on or off. A variable influence of A-S (as was the case with SA) cannot occur.

For testing purposes, A-S was first turned on over the weekend of August 1, 1992 and later for several periods. It was expected that A-S would be switched on permanently when FOC had been attained; however, A-S was permanently implemented on January 31, 1994. In accordance with the DoD policy, no advance announcement of the implementation date was made.

The future signal structure will provide the C/A-code on both the L1 and the L2 carrier. Instead of the Y-code, a new military split-spectrum signal, denoted as M-code, will be introduced. This feature will make A-S superfluous.

2.3 Control segment

The Operational Control System (OCS) consists of a master control station, monitor stations, and ground control stations. The main operational tasks of the OCS are: tracking of the satellites for the orbit and clock determination and prediction, time synchronization of the satellites, and upload of the data message to the satellites. The OCS was also responsible for imposing SA on the broadcast signals. The OCS performs many nonoperational activities, such as procurement and launch activities, that will not be addressed here.

Note that the control segment will be improved within the next ten years during the GPS modernization process.

2.3.1 Master control station

The location of the master control station was first at Vandenberg AFB, California, but has been moved to the Consolidated Space Operations Center (CSOC) at Shriver AFB (formerly known as Falcon AFB), Colorado Springs, Colorado. CSOC collects the tracking data from the monitor stations and calculates the satellite orbit and clock parameters using a Kalman estimator. These results are then passed to one of the three ground control stations for eventual upload to the satellites. The satellite control and system operation is also the responsibility of the master control station.

2.3.2 Monitor stations

There are five monitor stations located at: Hawaii, Colorado Springs, Ascension Island in the South Atlantic Ocean, Diego Garcia in the Indian Ocean, and Kwajalein in the North Pacific Ocean. Each of these stations is equipped with a precise atomic time standard and receivers which continuously measure pseudoranges to all satellites in view. Pseudoranges are measured every 1.5 seconds and, using the ionospheric and meteorological data, they are smoothed to produce 15-minute interval data which are transmitted to the master control station.

The tracking network described above is the official network for determining the broadcast ephemerides as well as modeling the satellite clocks. The data of up to 14 additional sites operated by the National Imagery and Mapping Agency (NIMA) are used to compute the precise ephemerides. Other tracking networks exist. These networks generally have no part in managing the system. A private tracking network was operated by the manufacturer of the Macrometer during the early 1980s. Today, more globally oriented tracking networks are operated. More details on this subject are provided in Sect. 4.4.1.

2.3.3 Ground control stations

These stations collocated with the monitor stations at Ascension, Diego Garcia, and Kwajalein are the communication links to the satellites and mainly consist of the ground antennas. The satellite ephemerides and clock information, calculated at the master control station and received via communication links, are uploaded to each GPS satellite via S-band radio links. Formerly, uploading to each satellite was performed every eight hours; then the rate has been reduced to once (or twice) per day (Remondi 1991b). If a ground station becomes disabled, prestored navigation messages are available in each satellite to support a prediction span so that the positioning accuracy degrades quite gradually. The durations of positioning service of the satellites without contact from the OCS are given in Table 2.1.

Table 2.1. Positioning service without contact from the control segment

Block	Duration
I	3–4 days
II	14 days
IIA	180 days
IIR	>180 days

2.4 User segment

2.4.1 User categories

Military user
Strictly speaking, the term "user segment" is related to the DoD concept of GPS as an adjunct to the national defense program. Even during the early days of the system, it was planned to incorporate a GPS receiver into virtually every major defense system. It was envisioned that every aircraft, ship, land vehicle, and even groups of infantry would have an appropriate GPS receiver to coordinate their military activities. In fact, many GPS receivers were used as planned during, e.g., the 1991 Gulf War under combat conditions. In this war, SA which had been previously invoked was turned off so that troops could use more readily available civilian receivers. Handheld C/A-code receivers were particularly useful in navigating the desert.

There are various other military uses that have been proposed. One example is a receiver that can be connected to four antennas. When the antennas are placed in a fixed array (e.g., corners of a square), the attitude of the array can be determined in addition to its position. For example, placing antennas on the bow, stern, and port and starboard points of a ship would result in the determination of pitch, roll, yaw, and position of the vessel.

Civilian user
The civilian use of GPS occurred several years ahead of schedule in a manner not envisioned by the system's planners. The primary focus in the first few years of the system's development was on navigation receivers. As previously described in Chap. 1, the SERIES technique at JPL and the development of the Macrometer by C. Counselman started the GPS surveying revolution. The primary concept of using an interferometric rather than Doppler solution model meant that GPS could be used for not only long line geodetic measurements but also for the most exacting short line land survey measurements.

Today, GPS receivers are routinely being used to conduct all types of land and geodetic control surveys, and to precisely position photo-aircraft to reduce the amount of ground control needed for mapping.

The nonsurveyor civilian uses of GPS outnumber the survey uses of the system. One of the major uses of GPS is for fleet management and control. Several cities have equipped emergency vehicles with receivers and computers with screens that display the cities' road system. The location of each emergency vehicle can be sent to a dispatcher by radio link so that disposition of the resources are known, and vehicles can be rerouted when necessary. Similar systems are used to track trains and freight hauling vehicles. Probably, all aircraft and vessels will be equipped with GPS in the near future.

GPS is also being used by hikers and boaters to determine their locations. Some manufacturers are presently offering a combined system of GPS and computer graphics for use in automobiles at the cost of a good high-fidelity music system.

2.4.2 Receiver types

The uses of GPS described in the previous section are just a sample of the applications of this system. The diversity of the uses is matched by the type of receivers available today. This section will give an overview of the equipment marketed today; however, more details will be provided in Sect. 5.2. Based on the type of observables (i.e., code pseudoranges or carrier phases) and on the availability of codes (i.e., C/A-code, P-code, or Y-code), one can classify GPS receivers into four groups: (1) C/A-code pseudorange, (2) C/A-code carrier phase, (3) P-code carrier phase, and (4) Y-code carrier phase measuring instruments.

C/A-code pseudorange receivers
With this type of receiver, only code pseudoranges using the C/A-code are

measured. The receiver is usually a hand-held device powered by flashlight batteries. Typical devices output the three-dimensional position either in longitude, latitude, and height or in some map projection system (e.g., UTM coordinates and height). Receivers with four or more channels are preferred for applications where the receiver is in motion since simultaneous satellite ranges can be measured to produce more accurate positions. On the other hand, a single channel receiver would still be adequate for applications where the receiver is at a fixed location and the range measurements can be sequentially determined. The basic multichannel C/A-code pseudorange receiver is the type of receiver that is mostly used by hikers, boaters, and in automobiles.

C/A-code carrier receivers

With this type of receiver, code ranges and carrier phases from the L1 carrier only are obtained because the C/A-code is not modulated on L2. This means that no dual frequency data are available.

Most of the receivers for surveying in the early stage of GPS used the C/A-code to acquire and lock on to the L1 carrier. Most instruments have a minimum of four independent receiver channels and some of the more recent designs have 12 channels. These receivers perform all the functions of the previously described models and, in addition, store the time-tagged code range and carrier phase in some type of memory. Early models used laptop computers and magnetic tapes to store the measured data. Later models store measurement data in memory chips and PCMCIA cards.

This type of receiver has been augmented to measure the phases of the L2 carrier by the use of some codeless technique. The drawback is that the signal-to-noise ratio (SNR) of the L2 measurements is considerably lower than the C/A-code measurements on L1. Normally, the L2 phase is used in combination with the L1 measurement to reduce the ionospheric effect on the signal and, thus, provide a more accurate vector determination (especially for long lines).

These receivers can be used for all types of precise surveys including static, kinematic, and pseudokinematic methods.

P-code receivers

This type of receiver uses the P-code and is able to lock on to the L1 and L2 carrier. In the absence of A-S, the observables are derived by first correlating the signals with a replica of the P-code. After removing the P-code from the received satellite signal, phase measurements can be performed. One of the first receivers for surveying, point positioning, and navigation was the P-code TI-4100 receiver, completed in 1984. This receiver was developed more from a military perspective than a civilian one and only military-related development would have attempted this. Manufacturers of civilian receivers were able to justify P-code work around 1989–1990. In the fall of 1991, the two main advantages of the P-code receiver were demonstrated by another P-code receiver during FGCC tests. The first is its capability to measure long (100 km) lines to an accuracy of a few centimeters. The second advantage is that P-code instruments can measure moderate length lines (20 km) to an accuracy of a few millimeters with as little as some minutes of data using techniques based on a linear combination of the measured phases of L1 and L2.

With A-S activated, in the emitted signal the P-code is replaced by the unknown Y-code. Thus, traditional P-code correlation technique can no longer be applied. However, this type of receiver can operate in a codeless or quasi-codeless mode providing carrier phase data and code pseudoranges for the L2 frequency without knowledge of the Y-code. The L2 tracking is accomplished using four techniques which differ in their performance characteristics: signal squaring, cross correlation, code correlation followed by squaring, and the Z-tracking technique. More details on these techniques can be found in Sect. 5.2.

Y-code receivers
This type of receiver provides access to the P-code with A-S invoked. Thus, the code ranges and phases can be derived from L1 and L2 signals by the P-code correlation technique. The access to the P-code is achieved by installing Auxiliary Output Chips (AOC) in each receiver channel which allow the decryption of the Y-code. However, only users authorized by the DoD have access to the AOC.

2.4.3 Information services

Several governmental and private information services have been established to provide GPS status information and data to the civilian users. Generally, the information contains constellation status reports, scheduled outages, and the DoD Notice Advisories to Navstar Users (NANU). Orbital data are provided in the form of an almanac suitable for making GPS coverage and satellite visibility predictions, and as precise ephemerides suitable for making the most precise vector computations. General information is also provided by listing the various GPS papers and meetings.

The official source for civilian information is the Navigation Information Service (NIS), formerly the GPS Information Center. This service is run by the U.S. Coast Guard (USCG) and includes 24-hour operation of a telephone information service. In the U.S., call (703) 313- to enter the service and dial the extension 5900 for live information, the extension 5907 for GPS status voice recording and the extension 5920 for FAX. Information by the USCG Navigation Center is also disseminated via Internet. The e-mail address reads webmaster@smtp.navcen.uscg.mil and the Uniform Resource Locator (URL) in the World Wide Web (WWW) is included in Table 2.2. More details can be found in Department of Defense and Department of Transportation (2000).

Comprehensive information including precise ephemerides, satellite clock parameters, and other data is provided by the Central Bureau Information System (CBIS) of the International GPS Service for Geodynamics (IGS) located at the U.S. Jet Propulsion Laboratory (JPL). The CBIS is accessible through Internet and offers file transfer capability by anonymous file transfer protocol (FTP). More details on the CBIS can be found in, e.g., Gurtner (1995).

Outside the U.S., GPS information sources are also available. Among them are: the Australian Surveying and Land Information Group (AUSLIG), the Canadian Space Geodesy Forum (CANSPACE), the German GPS Information and Observation System (GIBS), and the Russian Interstate Navigation Information Center (INIC) to name a few. The actual coordinates of the information services are published regularly, for example, in the monthly magazine *GPS World*. Some Internet addresses are given in Table 2.2 providing a variety of links to other GPS related sites in the Internet. These include links to manufacturers, associations, governments, and universities. Some of them offer also basic information or tutorials for novice GPS users. A comprehensive overview of such tutorials can be found on the Web site http://www.gpsy.com/gpsinfo.

Table 2.2. GPS information services

Agency	Location	WWW address
AUSLIG	Australia	http://www.auslig.gov.au
CBIS	U.S.	http://igscb.jpl.nasa.gov
GIBS	Germany	http://gibs.leipzig.ifag.de
NIS	U.S.	http://www.navcen.uscg.mil