UNIT 4

GNSS SEGMENTS AND SIGNAL STRUCTURE

SYLLABUS

Overview of Space Segment
Control Segment
User Segment
GPS Signal Structure
Standard Positioning Service (SPS) and Precise Positioning Service (PPS)
GPS Receivers
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Signal Acquisition
GPS Observables
GPS navigation and observation data formats (RINEX)

GPS SEGMENTS

GPS consists of three segments: the space segment, the control segment, and the user segment as shown in Figure 4.1.

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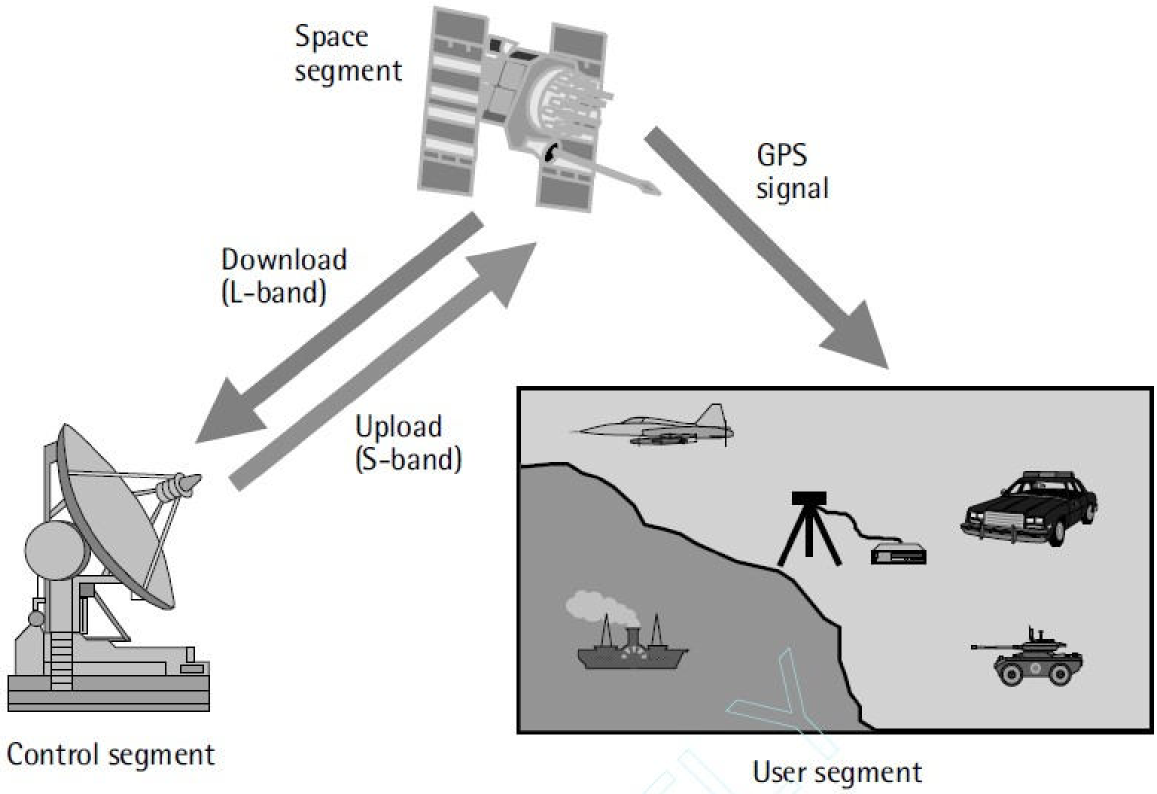

Fig. 4.1. GPS Segments

SPACE SEGMENT

The space segment consists of the 24-satellite constellation introduced in the previous section as shown in Figure 4.2.

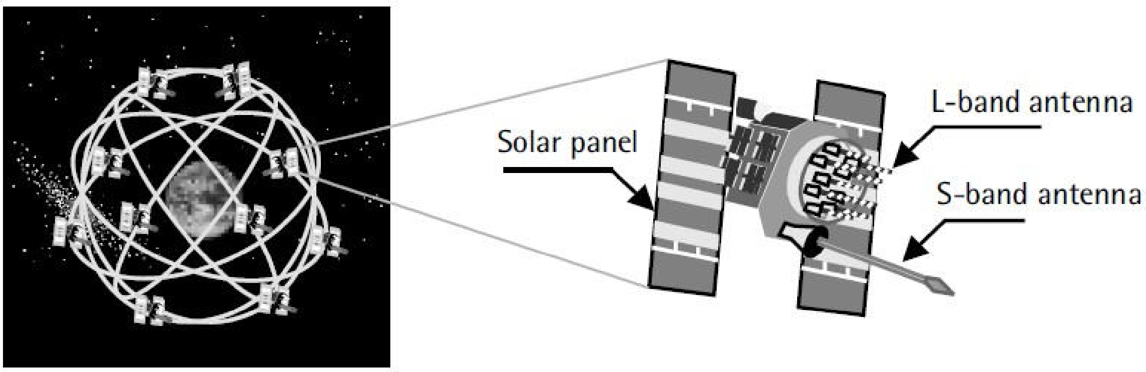

Fig. 4.2. GPS Constellation

Each GPS satellite transmits a signal, which has a number of components: two sine waves (also known as carrier frequencies), two digital codes, and a navigation message.

The codes and the navigation message are added to the carriers as binary bi phase modulations.

The carriers and the codes are used mainly to determine the distance from the user's receiver to the GPS satellites.

The navigation message contains, along with other information, the coordinates (the location) of the satellites as a function of time.

The transmitted signals are controlled by highly accurate atomic clocks onboard the satellites.

The U.S. government baseline configuration for the constellation consists of 24 satellites.

Within this configuration, the satellites are positioned in six Earth-centered orbital planes with four satellites in each plane.

The nominal orbital period of a GPS satellite is one-half of a sidereal day or 11 hours, 58 minutes.

The orbits are nearly circular and equally spaced around the equator at a 60° separation with a nominal inclination relative to the equatorial plane of 55°.

The orbital radius (i.e., nominal distance from the center of mass of the Earth to the satellite) is approximately 26,600 km.

This satellite constellation provides a 24-hour global user navigation and time determination capability.

CONTROL SEGMENT

The control segment of the GPS system consists of a worldwide network of tracking stations, with a master control station (MCS) located in the United States at Colorado Springs, Colorado.

The primary task of the operational control segment is tracking the GPS satellites in order to determine and predict satellite locations, system integrity, behavior of the satellite atomic clocks, atmospheric data, the satellite almanac, and other considerations.

This information is then packed and uploaded into the GPS satellites through the S-band link.

The CS is responsible for maintaining the satellites and their proper functioning.

This includes maintaining the satellites in their proper orbital positions (called Station keeping) and monitoring satellite subsystem health and status.

The CS also monitors the satellite solar arrays, battery power levels, and propellant levels used for maneuvers.

Furthermore, the CS activates spare satellites (if available) to maintain system availability.

The CS updates each satellite's clock, ephemeris, and almanac and other indicators in the navigation message at least once per day.

Updates are more frequently scheduled when improved navigation accuracies are required.

The ephemeris parameters are a precise fit to the GPS satellite orbits and are valid only for a time interval of 4 hours with the once-per-day normal upload schedule.

Depending on the satellite block, the navigation message data can be stored for a minimum of 14 days to a maximum of a 210-day duration.

Almanac data is used to predict the approximate satellite position and aid in satellite signal acquisition.

The almanac is a reduced precision subset of the ephemeris parameters.

The almanac consists of 7 of the 15 ephemeris orbital parameters.

Furthermore, the CS resolves satellite anomalies, controls SA and AS and collects pseudorange and carrier phase measurements at the remote monitor stations to determine satellite clock corrections, almanac, and ephemeris.

To accomplish these functions, the CS is comprised of three different physical components: the master control station (MCS), monitor stations, and the ground antennas as shown in Figure 4.3.

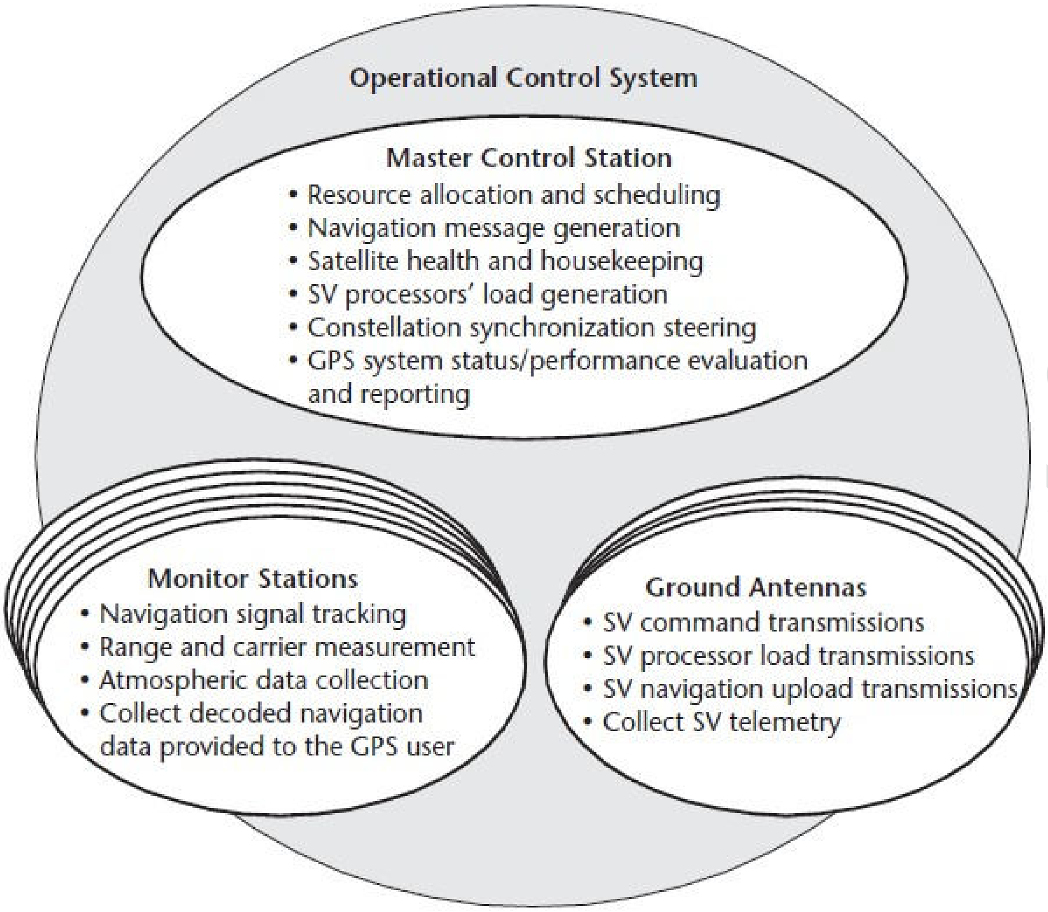

Fig. 4.3 Control Segment Components

<u>USER SEGMENT</u>

The user segment includes all military and civilian users.

With a GPS receiver connected to a GPS antenna, a user can receive the GPS signals, which can be used to determine his or her position anywhere in the world.

GPS is currently available to all users worldwide at no direct charge.

The user receiving equipment comprises the user segment.

Each set of equipment is typically referred to as a *GPS receiver*, which processes the L-band signals transmitted from the satellites to determine user Position Velocity and Time (PVT).

Technology trends in component miniaturization and large-scale manufacturing have led to a proliferation of low-cost GPS receiver components.

GPS receivers are embedded in many of the items we use in our daily lives.

These items include cellular telephones, PDAs, and automobiles.

Selection of a GPS receiver depends on the user's application (e.g., civilian versus military, platform dynamics, and shock and vibration environment).

GPS SIGNAL COMPONENTS

Each GPS satellite simultaneously transmits on two L-band frequencies:
L1 1575.42 MHz and L2 1227.60 MHz

The carrier of the L1 signal consists of an in-phase and a quadrature-phase component.

The in-phase component is bi-phase modulated by a 50-bps (bits per second) data stream and a pseudorandom code.
The pseudorandom code is called the *C/A-code* consisting of a 1023-chip sequence that has a period of 1 ms and a chipping rate of 1.023 MHz.

The Quadrature phase component is also bi-phase modulated by the same 50-bps data stream but with a different pseudorandom code called the *P-code*, which has a 10.23-MHz chipping rate and a one-week period.

The mathematical model of the L1 waveform is
$s(t) = 2PId(t)c(t) \cos(\omega t + \theta) + 2PQd(t)p(t) \sin(\omega t + \theta)$

where PI and PQ are the respective carrier powers for the in-phase and Quadrature phase carrier components,

$d(t)$ is the 50-bps data modulation,

$c(t)$ and $p(t)$ are the respective C/A and P pseudorandom code waveforms,

ω is the L1 carrier frequency in radians per second,

θ is phase shift in radians.

The quadrature carrier power PQ is approximately 3 dB less than PI .

L2 signal is modulated with 50- bps data and the P-code, although there is the option of not transmitting the 50-bps data stream.

The mathematical model of the L2 waveform is
$s(t) = 2PQd(t)p(t) \sin(\omega t + \theta).$

50-bps (bits per second) Data Stream
The 50-bps data stream conveys the *navigation message,* which includes the following information:

1. ***Satellite Almanac Data.*** Each satellite transmits orbital data called the *almanac*.

It enables the user to calculate the approximate location of every satellite in the GPS constellation at any given time.
Almanac data are not accurate enough for determining position but can be stored in a receiver where they remain valid for many months.

They are used primarily to determine which satellites are visible at a given location so that the receiver can search for those satellites when it is first turned on.

2. ***Satellite Ephemeris Data.*** Ephemeris data are similar to almanac data but enable a much more accurate determination of satellite position needed to convert signal propagation delay into an estimate of user position.

   Ephemeris data for a particular satellite are broadcast only by that satellite, and the data are valid for only several hours.

3. ***Signal Timing Data.*** The 50-bps data stream includes the transmission time of specific points on the GPS signal.

   This information is needed to determine the satellite-to-user propagation delay used for ranging.

4. ***Ionospheric Delay Data.*** Ranging errors due to ionospheric effects can be partially canceled by using estimates of ionospheric delay that are broadcast in the data stream.

5. ***Satellite Health Message.*** The data stream also contains information regarding the current health of the satellite, so that the receiver can ignore that satellite if it is not operating properly.

Structure of the Navigation Message
The information in the navigation message has the basic frame structure shown in Fig.4.4.

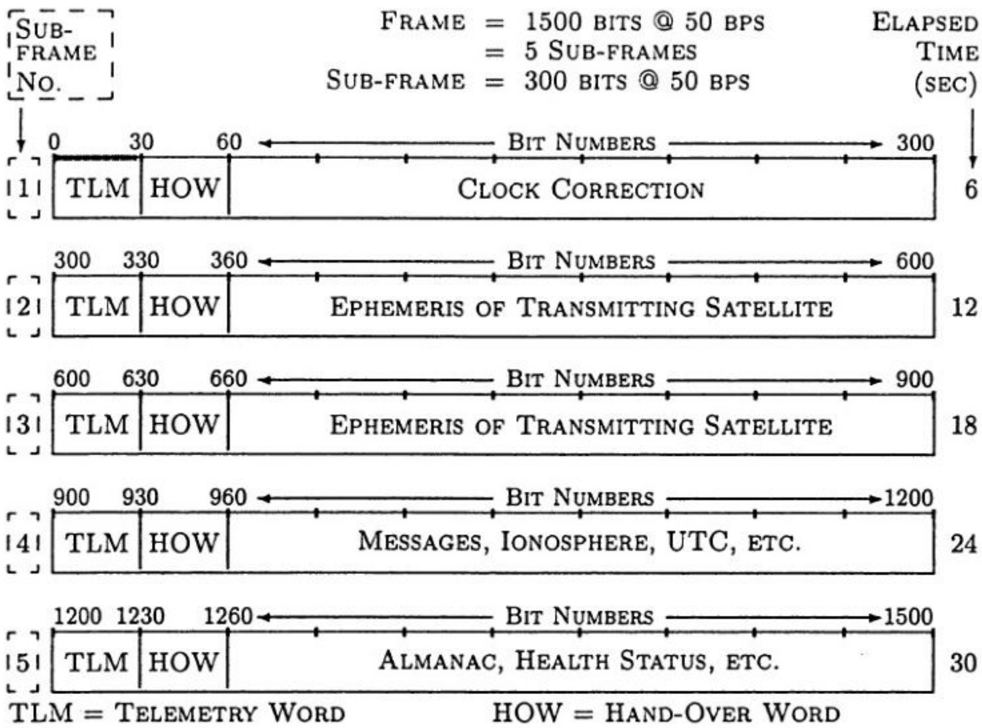

Fig. 4.4 GPS Signal Structure

A complete message consists of 25 frames, each containing 1500 bits.

Each frame is subdivided into five 300-bit subframes.

Each subframe consists of 10 words of 30 bits each.

The most significant bit (MSB) of the word transmitted first.

At the 50-bps rate it takes 6s to transmit a subframe (300 bits).

It takes 30s to complete one frame (1500 bits).

Transmission of the complete 25-frame navigation message requires 750 s, or 12.5 min.

Each subframe begins with a *telemetry word* (TLM).

The first 8 bits of the TLM is a preamble that enables the receiver to determine when a subframe begins.

The remainder of the TLM contains parity bits and a telemetry message that is available only to authorized users.

The second word of each subframe is called the *handover word* (HOW).

Z-Count Information contained in the HOW is derived from a 29-bit quantity called the *Z-count*.

The *Z*-count is not transmitted as a single word, but part of it is transmitted within the HOW.

The 19 LSBs of the *Z*-count, called the *time-of-week* (TOW) count, indicate the number of epochs that have occurred since the start of the current week.

The start of the current week occurs at approximately midnight of Saturday night/Sunday morning.

The TOW count increases from zero at the start of the week and then rolls over to zero again at the start of the following week.

A TOW count of zero always occurs at the beginning of subframe 1 of the first frame.

Since the receiver can use the TLM preamble to determine precisely the time at which each subframe begins, the time of transmission of any part of the GPS signal can be determined.

GPS Week Number The 10 MSBs of the *Z*-count contain the GPS *week number* (WN), which is a modulo-1024 week count.

The *zero state* is defined to be that week that started at midnight on the night of January 5, 1980/morning of January 6, 1980.

Because WN is a modulo-1024 count, an event called the *week rollover* occurs every 1024 weeks (a few months short of 20 years), and GPS receivers must be designed to accommodate it.

The WN is not part of the HOW but appears as the first 10 bits of the third word in subframe 1.

Frame and Subframe Identification Three bits of the HOW are used to identify which of the five subframes is being transmitted.

Information by Subframe In addition to the TLM and HOW, which occur in every subframe, the following information is contained within the remaining eight words of subframes 1–5 :

1. ***Subframe 1.*** The WN portion of the *Z*-count is part of word 3 in this subframe.

Subframe 1 also contains GPS clock correction data for the satellite in the form of polynomial coefficients defining how the correction varies with time.

Time defined by the clocks in the satellite is commonly called *SV time* (space vehicle time).

The time after corrections have been applied is called *GPS time*.

Thus, even though individual satellites may not have perfectly synchronized SV times, they do share a common GPS time.

Additional information in subframe 1 includes the quantities t_{0c}, T_{GD}, and IODC.

The clock reference time *t*0*c* is used as a time origin to calculate satellite clock error.

The ionospheric group delay *TGD* is used to correct for ionospheric propagation delay errors.

IODC (issue of date, clock) indicates the issue number of the clock data set to alert users to changes in clock parameters.

2. ***Subframes 2 and 3.*** These subframes contain the ephemeris data, which are used to determine the precise satellite position and velocity required by the navigation solution.

Unlike the almanac data, these data are very precise, are valid over a relatively short period of time (several hours), and apply only to the satellite transmitting it.

Each time new parameters are uploaded from the GPS control segment, the IODE number changes.

3. ***Subframe 4.*** *T*his subframe contain the almanac for satellites with PRN (pseudorandom code) numbers 25 and higher, as well as special messages, ionospheric correction terms, and coefficients to convert GPS time to UTC time.
   The components of an almanac are very similar to those of the ephemeris, and the calculation of satellite position is performed in essentially the same way.

4. ***Subframe 5.*** *T*his subframe includes the almanac for satellites with PRN numbers from 1 to 24.

Almanac data for all satellites are transmitted by every satellite.

Almanac data remain valid for long periods (months) but are much less precise.

Additional data contained in the navigation message are user range error (URE), which estimate the range error due to errors in satellite ephemeris, timing errors, and selective availability (SA) and flags to indicate the health status of the satellites.

STANDARD PRSITIONING SERVICE (SPS) AND PRECISE POSITIONING SERVICE (PPS)

GPS was originally developed as a military system, but was later made available to civilians as well.

However, to keep the military advantage, the U.S. DoD provides two levels of GPS positioning and timing services: the Precise Positioning Service (PPS) and the Standard Positioning Service (SPS)

The Precise Positioning Service (PPS) is available primarily to the military of the United States and its allies for users properly equipped with PPS receivers.

PPS is the most precise autonomous positioning and timing service.

It uses one of the transmitted GPS codes, known as P-code, which is accessible by authorized users only.

The expected positioning accuracy provided by the PPS is 16m for the horizontal component and 23m for the vertical component (95% probability level).

The Standard Positioning Service (SPS) was originally designed to provide civil users with a less accurate positioning capability than PPS.

SPS, however, is less precise than PPS.

It uses the second transmitted GPS code, known as the Coarse Acquisition C/A-code, which is available free of charge to all users worldwide, authorized and unauthorized.

Originally, SPS provided positioning accuracy of the order of 100m for the horizontal component and 156m for the vertical component (95% probability level).

This was achieved under the effect of selective availability (SA).

With the presidential decision of discontinuing the SA, the SPS autonomous positioning accuracy is presently at a comparable level to that of the PPS.

C/A-Code and Its Properties

Each satellite has a unique C/A-code, but all the codes consist of a repeating sequence of 1023 chips occurring at a rate of 1.023 MHz with a period of 1 ms.

The C/A-code has the following functions:

1. ***To enable accurate range measurements and resistance to errors caused by multipath.***

To establish the position of a user to within 10–100 m, accurate user-to-satellite range estimates (pseudorange) are needed.

The estimates are made from measurements of signal propagation delay from the satellite to the user.

To achieve the required accuracy in measuring signal delay, the GPS carrier must be modulated by a waveform having a relatively large bandwidth.

The needed bandwidth is provided by the C/A-code modulation.

Because the C/A-code causes the bandwidth of the signal to be much greater than that needed to convey the 50-bps (bits per second) data stream, the resulting signal is called a *spreadspectrum* signal.

Using the C/A-code to increase the signal bandwidth also reduces errors in measuring signal delay caused by multipath since the ability to separate the direct path signal from the reflected signal improves as the signal bandwidth is made larger.

2. ***To permit simultaneous range measurement from several satellites.***

The use of a distinct C/A-code for each satellite permits all satellites to use the same L1 and L2 frequencies without interfering with each other.

This is possible because the signal from an individual satellite can be isolated by correlating it with a replica of its C/A-code in the receiver.

This causes the C/A-code modulation from that satellite to be removed so that the signal contains only the 50-bps data and is therefore narrowband.

This process is called *despreading* of the signal.

The interfering signals can be rejected by passing the desired despread signal through a narrowband filter.

3. ***To provide protection from jamming.***

The C/A-code also provides a measure of protection from intentional or unintentional jamming of the received signal by another man-made signal.

The correlation process that despreads the desired signal has the property of spreading any other signal.

Therefore, the signal power of any interfering signal, even if it is narrowband, will be spread over a large frequency band, and only that portion of the power lying in the narrowband filter will compete with the desired signal.

The C/A-code provides about 20–30 dB of improvement in resistance to jamming from narrowband signals.

P-Code or Precision Code and Its Properties

The P-code, which is used primarily for military applications, has the following functions:

1. ***Increased Jamming Protection***.

The bandwidth of the P-code is 10 times greater than that of the C/A-code.

So it offers approximately 10 dB more protection from narrowband interference.

In military applications the interference is likely to be a deliberate attempt to jam the received GPS signal.

2. ***Provision for Antispoofing.*** *E*nemy can radiate a signal that appears to be a GPS signal (*spoofing*), but in reality is designed to confuse the GPS receiver.

This is prevented by encrypting the P-code.

The spoofer cannot know the encryption process and cannot make the contending signal look like a properly encrypted signal.

Thus the receiver can reject the false signal and decrypt the desired one.

3. ***Denial of P-Code Use.***
The structure of the P-code is published in the open literature

So, anyone may generate it as a reference code for despreading the signal and making range measurements.

However, encryption of the P-code by the military will deny its use by unauthorized parties.

4. ***Increased Code Range Measurement Accuracy.***
The accuracy in range measurement improves as the signal bandwidth increases.

Thus, the P-code provides improved range measurement accuracy as compared to the C/A-code.

Simultaneous range measurements using both codes are even better.

Because of its increased bandwidth, the P-code is also more resistant to range errors caused by multipath.

P-Code Characteristics Unlike the C/A-code, the P-code modulates both the L1 and L2 carriers.

Its chipping rate is 10.23 MHz, which is precisely 10 times the C/A rate, and it has a period of one week.

Each satellite broadcasts a unique P-code.

GPS RECEIVERS

In 1980, only one commercial GPS receiver was available on the market, at a price of several hundred thousand U.S. dollars.

More than 500 different GPS receivers are available in today's market.

The current receiver price varies from about Rs.3,000 for the simple handheld units to several lakhs for the sophisticated geodetic quality units.

The price will continue to decline in the future as the receiver technology becomes more advanced.

A GPS receiver requires an antenna attached to it, either internally or externally.

The antenna receives the incoming satellite signal and then converts its energy into an electric current, which can be handled by the GPS receiver.

Commercial GPS receivers may be divided into four types, according to their receiving capabilities.

These are:

1. single-frequency code receivers
2. single-frequency carrier-smoothed code receivers
3. single-frequency code and carrier receivers
4. dual-frequency receivers.

Single-frequency receivers access the L1 frequency only, while dual-frequency receivers access both the L1 and the L2 frequencies.

GPS receivers can also be categorized according to their number of tracking channels, which varies from 1 to 12 channels.

A good GPS receiver would be multichannel, with each channel dedicated to continuously tracking a particular satellite.

Presently, most GPS receivers have 9 to 12 independent channels.

Features such as cost, ease of use, power consumption, size and weight, internal and/or external data-storage capabilities, interfacing capabilities, and multipath mitigation are to be considered when selecting a GPS receiver.

The first receiver type, the single-frequency code receiver, measures the pseudoranges with the C/A-code only.

No other measurements are available.

It is the least expensive and the least accurate receiver type, and is mostly used for recreation purposes.

The second receiver type, the single frequency carrier-smoothed code receiver, also measures the pseudoranges with the C/A-code only.

However, with this receiver type, the higher resolution carrier frequency is used internally to improve the resolution of the code pseudorange, which results in high-precision pseudorange measurements.

Single-frequency code and carrier receivers output the raw C/A-code pseudoranges, the L1 carrier-phase measurements, and the navigation message.

In addition, this receiver type is capable of performing the functions of the other receiver types discussed above.

Dual-frequency receivers are the most sophisticated and most expensive receiver type.

PSEUDORANGE MEASUREMNTS

The pseudorange is a measure of the range, or distance, between the GPS receiver and the GPS satellite.

As stated before, the ranges from the receiver to the satellites are needed for the position GPS Details 19 computation.

Either the P-code or the C/A-code can be used for measuring the pseudorange.

The procedure of the GPS range determination, or pseudoranging, can be described as follows.

Let us assume for a moment that both the satellite and the receiver clocks, which control the signal generation, are perfectly synchronized with each other.

When the PRN code is transmitted from the satellite, the receiver generates an exact replica of that code.

After some time, equivalent to the signal travel time in space, the transmitted code will be picked up by the receiver.

By comparing the transmitted code and its replica, the receiver can compute the signal travel time.

Multiplying the travel time by the speed of light (299,729,458 m/s) gives the range between the satellite and the receiver.

Unfortunately, the assumption that the receiver and satellite clocks are synchronized is not exactly true.

In fact, the measured range is contaminated, along with other errors and biases, by the synchronization error between the satellite and receiver clocks.

For this reason, this quantity is referred to as the pseudorange, not the range.

GPS was designed so that the range determined by the civilian C/A-code would be less precise than that of military P-code.

This is based on the fact that the resolution of the C/A-code, 300m, is 10 times lower than the P-code.

Surprisingly, due to the improvements in the receiver technology, the obtained accuracy was almost the same from both codes.

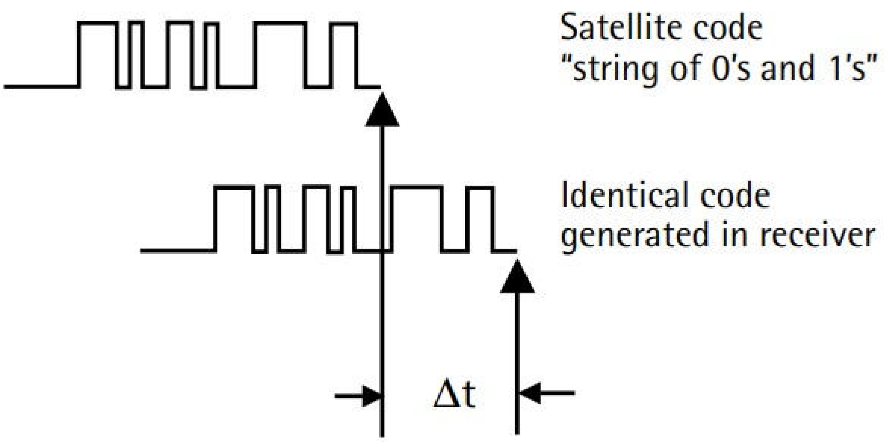

Fig. 4.5 Matching of Satellite Code at the Receiver

CARRIER-PHASE MEASUREMENTS

Another way of measuring the ranges to the satellites can be obtained through the carrier phases.

The range would simply be the sum of the total number of full carrier cycles plus fractional cycles at the receiver and the satellite, multiplied by the carrier wavelength (see Figure 2.4).

The ranges determined with the carriers are far more accurate than those obtained with the codes (i.e., the pseudoranges).

This is due to the fact that the wavelength (or resolution) of the carrier phase, 19 cm in the case of L1 frequency, is much smaller than those of the codes.

There is, however, one problem.

The carriers are just pure sinusoidal waves, which means that all cycles look the same.

Therefore, a GPS receiver has no means to differentiate one cycle from another.

In other words, the receiver, when it is switched on, cannot determine the total number of the complete cycles between the satellite and the receiver.

It can only measure a fraction of a cycle very accurately (less than 2 mm), while the initial number of complete cycles remains unknown, or ambiguous.

This is, therefore, commonly known as the initial cycle ambiguity, or the ambiguity bias.

Fortunately, the receiver has the capability to keep track of the phase changes after being switched on.

This means that the initial cycle ambiguity remains unchanged over time, as long as no signal loss (or cycle slips) occurs.

It is clear that if the initial cycle ambiguity parameters are resolved, accurate range measurements can be obtained, which lead to accurate position determination.

This high accuracy positioning can be achieved through the so-called relative positioning techniques, either in real time or in the post-processing mode.

Unfortunately, this requires two GPS receivers simultaneously tracking the same satellites in view.

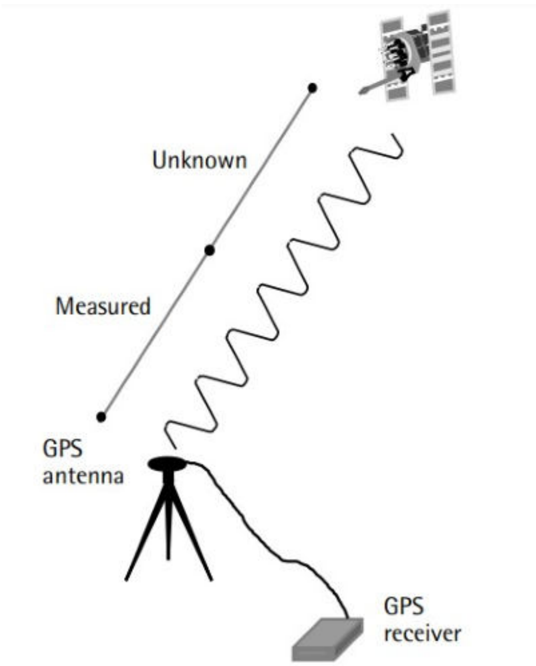

Fig. 4.6 Carrier Phase Measurement

CYCLE SLIPS

A cycle slip is defined as a discontinuity or a jump in the GPS carrier-phase measurements, by an integer number of cycles, caused by temporary signal loss.

Signal loss is caused by obstruction of the GPS satellite signal due to buildings, bridges, trees, and other objects.

This is mainly because the GPS signal is a weak and noisy signal.

Radio interference, severe ionospheric disturbance, and high receiver dynamics can also cause signal loss.

Cycle slips could occur due to a receiver malfunction.

Cycle slips may occur briefly or may remain for several minutes or even more.

Cycle slips could affect one or more satellite signals.

The size of a cycle slip could be as small as one cycle or as large as millions of cycles.

Cycle slips must be identified and corrected to avoid large errors in the computed coordinates.

In some extreme cases, such as severe ionospheric activities, it might be difficult to correctly detect and repair cycle slips.

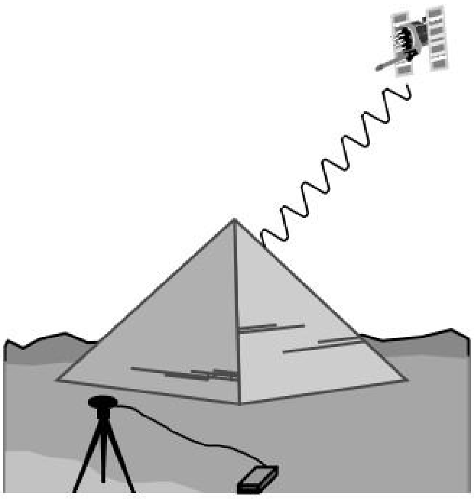

Fig. 4.7 Cycle Slip

SIGNAL ACQUISITION AND TRACKING

When a GPS receiver is turned on, a sequence of operations must ensue before information in a GPS signal can be accessed and used to provide a navigation solution.

In the order of execution, these operations are as follows:

1. Determine which satellites are visible to the antenna.
2. Determine the approximate Doppler of each visible satellite.
3. Search for the signal both in frequency and C/A-code phase.
4. Detect the presence of a signal and confirm detection.
5. Lock onto and track the C/A-code.

1. Determine which satellites are visible to the antenna.
In many GPS receiver applications it is desirable to minimize the time from receiver turn on until the first navigation solution is obtained.

This time interval is commonly called *time to first fix* (TTFF).

Depending on receiver characteristics, the TTFF might range from 30 s to several minutes.

An important consideration in minimizing the TTFF is to avoid a fruitless search for those satellite signals that are blocked by the earth, that is, below the horizon.

A receiver can restrict its search to only those satellites that are visible if it:

- knows its approximate location (within several hundred miles)
- knows its approximate time (within approximately 10 min)
- has satellite almanac data obtained within the last several months.

Using the approximate time, approximate position, and almanac data, the receiver calculates the elevation angle of each satellite and identifies the visible satellites as those whose elevation angle is greater than a specified value.

This elevation angle called the *mask angle*, which has typical values of 5° to 15°.

At elevation angles below the mask angle, tropospheric attenuation and delays tend to make the signals unreliable.

Most receivers automatically update the almanac data when in use.

If the receiver is just "out of the box" or has not been used for many months, it will need to search "blind" for a satellite signal to collect the needed almanac.

2. Determine the approximate Doppler of each visible satellite.

The TTFF can be further reduced if the approximate Doppler shifts of the visible satellite signals are known.

This permits the receiver to establish a frequency search pattern in which the most likely frequencies of reception are searched first.

The expected Doppler shifts can be calculated from knowledge of approximate position, approximate time, and valid almanac data.

Once the first satellite signal is found, a fairly good estimate of receiver clock frequency error can be determined by comparing the predicted Doppler shift with the measured Doppler shift.

This error can then be subtracted out while searching in frequency for the remaining satellites, thus significantly reducing the range of frequencies that need to be searched.

3. Search for the signal both in frequency and C/A-code phase.
Why is a signal search necessary?

1. GPS signals are *spread-spectrum* signals in which the C/A- or P-codes spread the total signal power over a wide bandwidth.

The signals are therefore virtually undetectable unless they are *despread* with a replica code in the receiver that is precisely aligned with the received code.

Since the signal cannot be detected until alignment has been achieved, a search over the possible alignment positions (code search) is required.

2. A relatively narrow post-despreading bandwidth (perhaps 100–1000 Hz) is required to raise the signal-to-noise ratio to detectable and/or usable levels.

4. Detect the presence of a signal and confirm detection.
There is a tradeoff between the probability of detection *PD* and probability of false alarm *PFA*.

As the detection threshold is decreased, *PD* increases but *PFA* also increases.

Thus, the challenge in receiver design is to achieve a sufficiently large *PD* so that a signal will not be missed but at the same time keep *PFA* small enough to avoid difficulties with false detections.

When a false detection occurs, the receiver will try to lock onto and track a nonexistent signal.

By the time the failure to track becomes evident, the receiver will have to initiate a completely new search for the signal.

When a detection failure occurs, the receiver will waste time continuing to search remaining search cells that contain no signal, after which a new search must be initiated.

Detection Confirmation
To obtain the detection probability *PD* = 0.95 with a typical medium-strength GPS signal, we obtain the false-alarm probability *PFA* = 10^{-3}.

This means that on the average, there will be one false detection in every 1000 frequency/code cells searched.

By performing a confirmation of detection before turning the signal over to the tracking loops, PD can be increased and PFA can be decreased.

In the event that confirmation indicates no signal, the search can continue without the large time delay in detecting the failure to track.

5. Lock onto and track the C/A-code.
At the time of detection confirmation the receiver-generated reference C/A-code will be in approximate alignment with that of the signal (usually within 0.5 chip).

The reference code chipping rate will be approximately that of the signal.

However, the residual Doppler on the signal will eventually cause the received and reference codes to drift out of alignment and the signal frequency to drift outside the frequency bit at which detection occurred.

If the code alignment error exceeds one chip in magnitude, the incoming signal will no longer despread and will disappear below the noise level.

Thus there is the need to continually adjust the timing of the reference code so that it maintains accurate alignment with the received code by a process called *code tracking*.

The process of maintaining accurate tuning to the signal carrier, called *carrier tracking*, is also necessary.

Code tracking is initiated as soon as signal detection is confirmed, and the goal is to make the receiver-generated code line up with incoming code as precisely as possible.

GPS OBSERVABLES

The word *observable* is used throughout GPS literature to indicate the signals whose measurement yields the range or distance between the satellite and the receiver.

The word is used to draw a distinction between the thing being measured, "the observable" and the measurement, " the observation."

In GPS, there are two types of observables.

1. The codes
2. The carrier itself without the codes.

The carrier is used for high-precision GPS surveys.

In the image, you see the pseudorange code observable illustrated as square waves of code states.

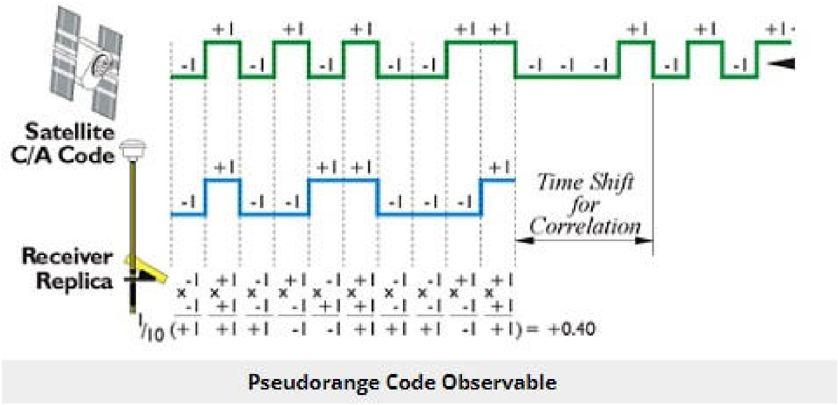

Fig. 4.8 Pseudorange Code Matching at the Receiver

The carrier wave observable is just a constant sine wave, not modulated.

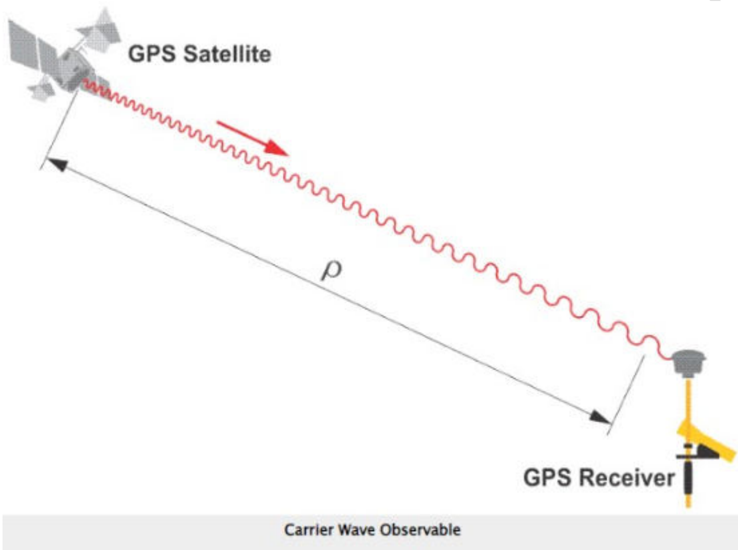

Fig. 4.9 Carrier Wave Observable

The code solution provides a pseudorange.

The pseudorange can serve applications when virtually instantaneous point positions are required and relatively low accuracy will suffice.

These basic observables can also be combined in various ways to generate additional measurements that have certain advantages.

Many GPS receivers use the pseudorange code observable as sort of the front door, a way to begin the determination of a position, and then, frequently, they switch to the carrier to refine that position.

The foundation of pseudoranges is the correlation of code carried on a modulated carrier wave received from a GPS satellite with a replica of that same code generated in the receiver.

Most of the GPS receivers used for surveying applications are capable of code correlation.

That is, they can determine pseudoranges.

RINEX (RECEIVER INDEPENDENT EXCHANGE) FORMAT

Since individual GPS receiver manufacturers have their own proprietary formats for storing GPS measurements, it can be difficult to combine data from different receivers.

A similar problem is encountered when interfacing various devices, including the GPS system.

To overcome these limitations, a number of research groups have developed standard formats for various user needs.

The most widely used standard formats are RINEX, NGS-SP3, RTCM SC-104, and NMEA 0183.

RINEX format

To save storage space, proprietary formats developed by GPS receiver manufacturers are mostly binary, which means that they are not directly readable when displayed.

This creates a problem when combining data (in the post processing mode) from different GPS receivers.

To overcome this problem, a group of researchers have developed an internationally accepted data exchange format.

This format, known as the RINEX format, is in the standard ASCII format (i.e., readable text).

Although a file in the ASCII format is known to take more storage space than a file in the binary format, it provides more distribution flexibility.

A RINEX file is a translation of the receiver's own compressed binary files.

RINEX defines six different RINEX files; each contains a header and data sections:
(1) observation data file
(2) navigation message file
(3) meteorological file
(4) GLONASS navigation message file
(5) geostationary satellites (GPS signal payloads) data file
(6) satellite and receiver clock data file

For the majority of GPS users, the first three files are the most important, and therefore will be the only ones discussed here.

The record, or line, length of all RINEX files is restricted to a maximum of 80 characters.

The recommended naming convention for RINEX files is .ssssdddf.yyt..

The first four characters, .ssss,. represent the station name (hyde, iisc,lck1,pbr2)
The following three characters, .ddd,. represent the day of the year of first record
The eighth character, .f,. represents the file sequence number within the day
The file extension characters .yy. and .t. represent the last two digits of the current year and the file type, respectively.

The file type takes the following symbols:
.O. for observation file

.N. for navigation file

.M. for meteorological data file

.G. for GLONASS navigation file

and .H. for geostationary GPS payload navigation message file.
For example, a file with the name .abcd032.01o. is an observation file for a station .abcd,. which was observed on February 1, 2001.

Observation File
The observation file contains in its header information that describes the file's contents such as :
the station name,
antenna information,
the approximate station coordinates,
number and types of observation,
observation interval (epoch) in seconds,
time of first observation record,
and other information.

The observation types are defined as L1 and L2, and represent the phase measurements on L1 and L2 (cycles);
C1 represents the pseudorange using C/A-code on L1 (meters);
P1 and P2 represent the pseudorange using P-code on L1 and L2 (meters);
D1 and D2 represent the Doppler frequency on L1 and L2 (Hertz).

The GPS time frame is used for the GPS files, while the UTC time frame is used for GLONASS files.

The header section may contain some optional records such as the leap seconds.

The last 20 characters of each record (i.e., columns 61 to 80) contain textual .END OF HEADER..

Figure 4.10 shows an example of a RINEX observation file for single-frequency data, which was created using the Ashtech Locus processor software.

The data section is divided into epochs; each contains
the time tag of the observation (the received-signal receiver time, in the GPS time frame for GPS files),
the number and list of satellites,
the various types of measurements in the same sequence as given in the header, and
the signal strength.

Other information, such as the loss of lock indicator, is also included in the data section. The data section may optionally contain the receiver clock offset in seconds (see Figure 5.1).

```
     2              OBSERVATION DATA    G (GPS)             RINEX VERSION / TYPE
ASHTORIN                                09 - APR - 01 17:27 PGM / RUN BY / DATE
                                                            COMMENT
TEST                                                        MARKER NAME
                                                            MARKER NUMBER
                                                            OBSERVER / AGENCY
                    LOCUS               L_42      UNKNOWN   REC # / TYPE / VERS
                                                            ANT # / TYPE
 -2687840.8300 -4301491.3200  3853858.0200                  APPROX POSITION XYZ
        0.0000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
     1     0                                                WAVELENGTH FACT L1/2
     3    L1    C1    D1                                    # / TYPES OF OBSERV
     10.0000                                                 INTERVAL
                                                            LEAP SECONDS
  1998     9    23    18    27   10.000000      GPS         TIME OF FIRST OBS
  1998     9    23    19     1   59.997000      GPS         TIME OF LAST OBS
                                                            END OF HEADER
 98  9 23 18 27 10.0000000  0  5G03G31G01G23G08                       0.000060824
   7877626.975 6  21949801.811          -48.022
   7858214.382 6  22175367.525         1996.393
   7842888.958 6  20376440.935         2817.693
   7874476.800 6  22485604.397          233.618
   7843609.590 6  22959447.916         3287.071
 98  9 23 18 27 20.0000000  0  6G03G31G01G23G08G09                    0.000047432
   7878091.833 6  21949887.017          -45.258
   7838246.804 6  22171573.369         1997.588
   7814702.570 6  20371080.421         2819.669
   7872108.827 6  22485156.722          239.992
   7810730.579 6  22953202.951         3289.061
     -1195.47216  24085463.326          937.326
                                           .
                                           .
                                           .
```

Fig. 4.10 Example of RINEX Observation file for single frequency data.

<u>Navigation File</u>
The navigation message file contains the satellite information.

In its header, the navigation message contains information such as the date of file creation, the agency name, and other relevant information.

Similar to the observation file, the last record in the header section of the navigation file must be .ENDOFHEADER..

Optionally, the header section may contain additional information such as the parameters of the ionospheric model for single-frequency users.

As well, almanac parameters relating GPS time and UTC and the leap seconds may optionally be included in the header section of the navigation message.

The first record in the data section contains the satellite PRN number, the time tag, and the satellite clock parameters (bias, drift, and drift rate).

The subsequent records contain information about the broadcast orbit of the satellite, the satellite health, the GPS week, and other relevant information (see Figure 4.11).

```
     2.10           N: GPS NAV DATA                         RINEX VERSION / TYPE
XXRINEXN V2.10      AIUB                3-SEP-99 15:22      PGM / RUN BY / DATE
EXAMPLE OF VERSION 2.10 FORMAT                              COMMENT
     .1676D-07   .2235D-07  -.1192D-06  -.1192D-06          ION ALPHA
     .1208D+06   .1310D+06  -.1310D+06  -.1966D+06          ION BETA
     .133179128170D-06  .107469588780D-12   552960     1025 DELTA-UTC: A0,A1,T,W
    13                                                      LEAP SECONDS
                                                            END OF HEADER
 6 99  9  2 17 51 44.0 -.839701388031D-03 -.165982783074D-10  .000000000000D+00
     .910000000000D+02  .934062500000D+02  .116040547840D-08  .162092304801D+00
     .484101474285D-05  .626740418375D-02  .652112066746D-05  .515365489006D+04
     .409904000000D+06 -.242143869400D-07  .329237003460D+00 -.596046447754D-07
     .111541663136D+01  .326593750000D+03  .206958726335D+01 -.638312302555D-08
     .307155651409D-09  .000000000000D+00  .102500000000D+04  .000000000000D+00
     .000000000000D+00  .000000000000D+00  .000000000000D+00  .910000000000D+02
     .406800000000D+06  .000000000000D+00
13 99  9  2 19  0  0.0  .490025617182D-03  .204636307899D-11  .000000000000D+00
     .133000000000D+03 -.963125000000D+02  .146970407622D-08  .292961152146D+01
    -.498816370964D-05  .200239347760D-02  .928156077862D-05  .515328476143D+04
     .414000000000D+06 -.279396772385D-07  .243031939942D+01 -.558793544769D-07
     .110192796930D+01  .271187500000D+03 -.232757915425D+01 -.619632953057D-08
    -.785747015231D-11  .000000000000D+00  .102500000000D+04  .000000000000D+00
     .000000000000D+00  .000000000000D+00  .000000000000D+00  .389000000000D+03
     .410400000000D+06  .000000000000D+00
                                          ,
                                          ,
                                          ,
```

* obtained from: ftp://ftp.unibe.ch/aiub/rinex/rinex210.txt

Figure 4.11 Example of RINEX Navigation file

Most GPS receiver manufacturers have developed post-processing software packages that accept GPS data in the RINEX format.

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