Module-4

-Kavita Guddad

- **PPS(Precise Positioning Signal)**
- The PPS is specified to provide a predictable accuracy of
  - ➢ at least 22m (2 drms, 95%) in the horizontal plane
  - ➢ 27.7m (95%) in the vertical plane.

The distance root mean square (drms) is a common measure used in navigation.

Twice the drms value, or 2 drms, is the radius of a circle that contains at least 95% of all possible fixes that can be obtained with a system (in this case, the PPS) at any one place.

- The PPS also provides
  - ➢ a UTC time transfer accuracy within 200 ns (95%) referenced to the time kept at the U.S. Naval Observatory (USNO) and is denoted as UTC (USNO)
  - ➢ Velocity measurement accuracy is specified as 0.2 m/s (95%)

SPS

The SPS is available to all users worldwide free of direct charges. There are no restrictions on SPS usage. This service is specified to provide accuracies of better than 13m (95%) in the horizontal plane and 22m (95%) in the vertical plane (global average; signal-in-space errors only).

UTC (USNO) time dissemination accuracy is specified to be better than 40 ns (95%).

SPS measured performance is typically much better than specification.

At the time of this writing, the SPS was the predominant satellite navigation service in use by millions throughout the world.

Antispoofing (AS) and Selective availability (SA)

The PPS is primarily intended for military and selected government agency users.
Civilian use is permitted, but only with special U.S. DOD approval.
Access to the aforementioned PPS position accuracies is controlled through two cryptographic features denoted as
Antispoofing (AS) and Selective availability (SA).

Antispoofing (AS)
AS is a mechanism intended to defeat deception jamming through encryption of the military signals. Deception jamming is a technique in which an adversary would replicate one or more of the satellite ranging codes, navigation data signal(s), and carrier frequency Doppler effects with the intent of deceiving a victim receiver.

Selective availability (SA)
SA had intentionally degraded SPS user accuracy by *dithering* the satellite's clock, thereby corrupting TOA measurement accuracy. Furthermore, SA could have introduced errors into the broadcast navigation data parameters. SA was discontinued on May 1, 2000 and per current U.S. government policy is to remain off. When it was activated, PPS users removed SA effects through cryptography.

Concept of Ranging Using TOA Measurements

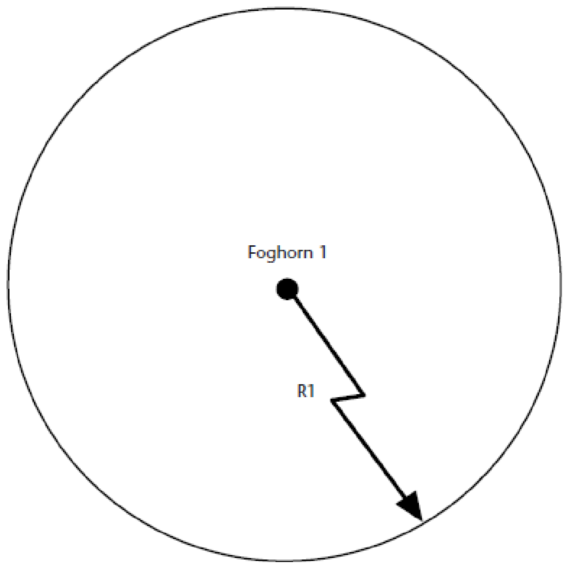


Figure 2.1 Range determination from a single source. (*After:* [1].)

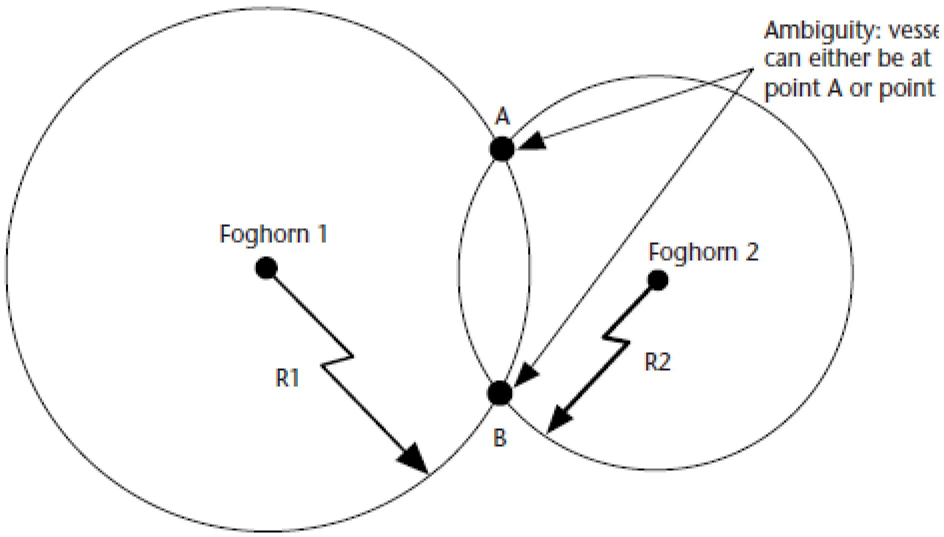


Figure 2.2 Ambiguity resulting from measurements to two sources. (*After:* [1].)

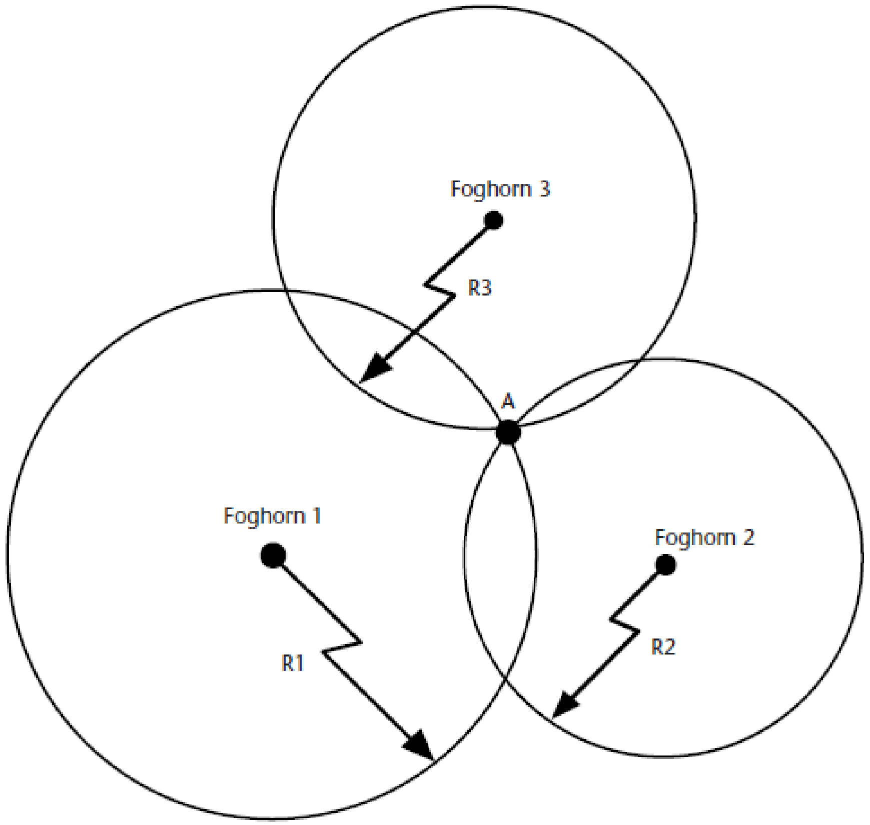


Figure 2.3 Position ambiguity removal by additional measurement. (*After:* [1].)

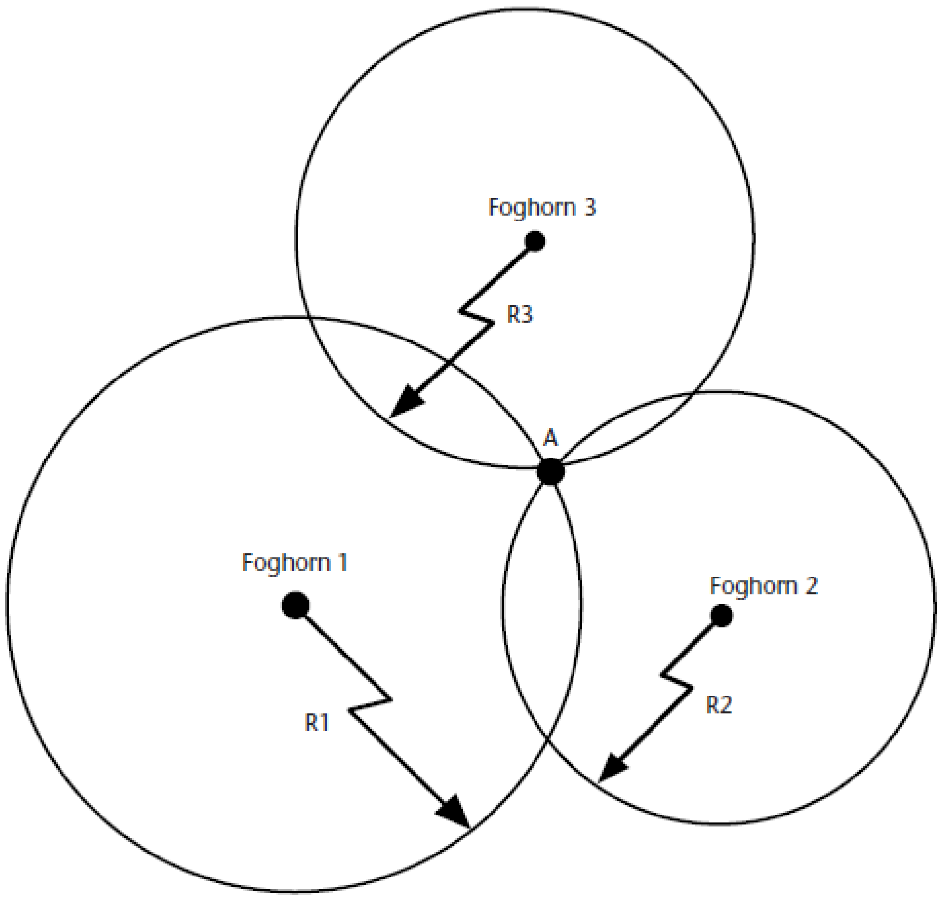


Figure 2.3 Position ambiguity removal by additional measurement. (*After:* [1].)

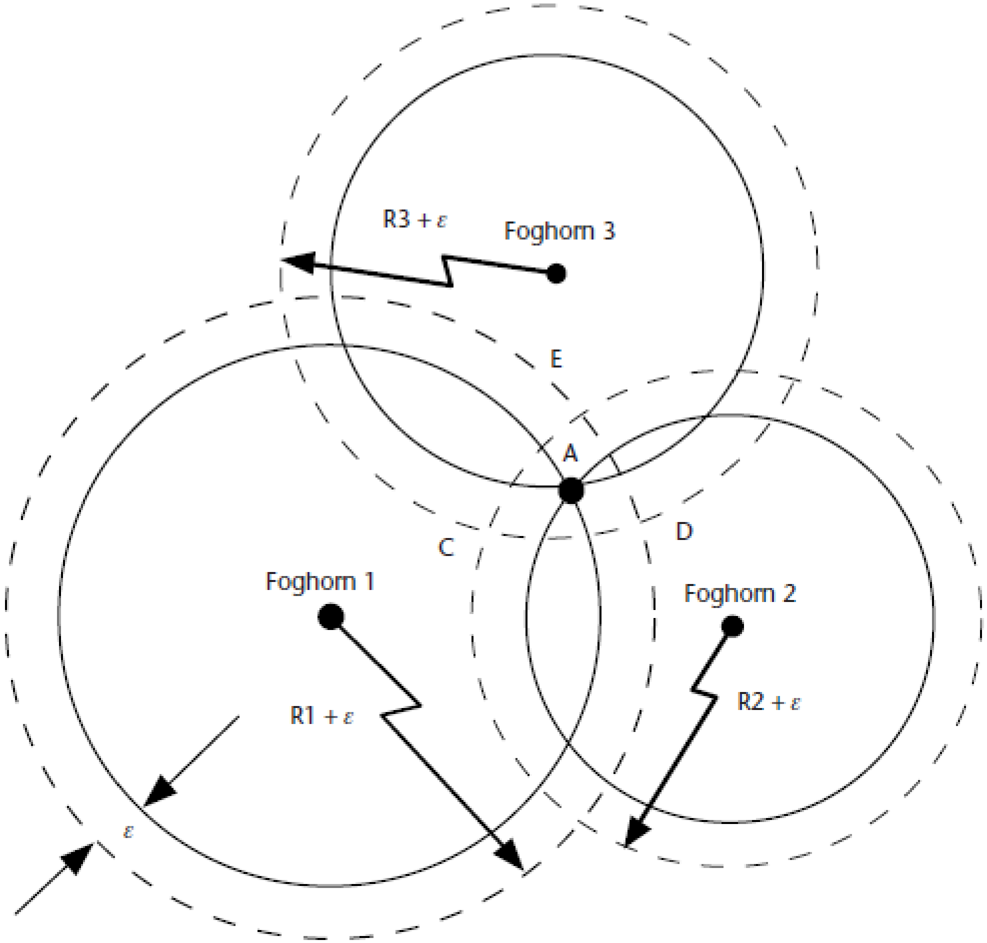


Figure 2.4 Effect of receiver clock offset on TOA measurements. (*After:* [1].)

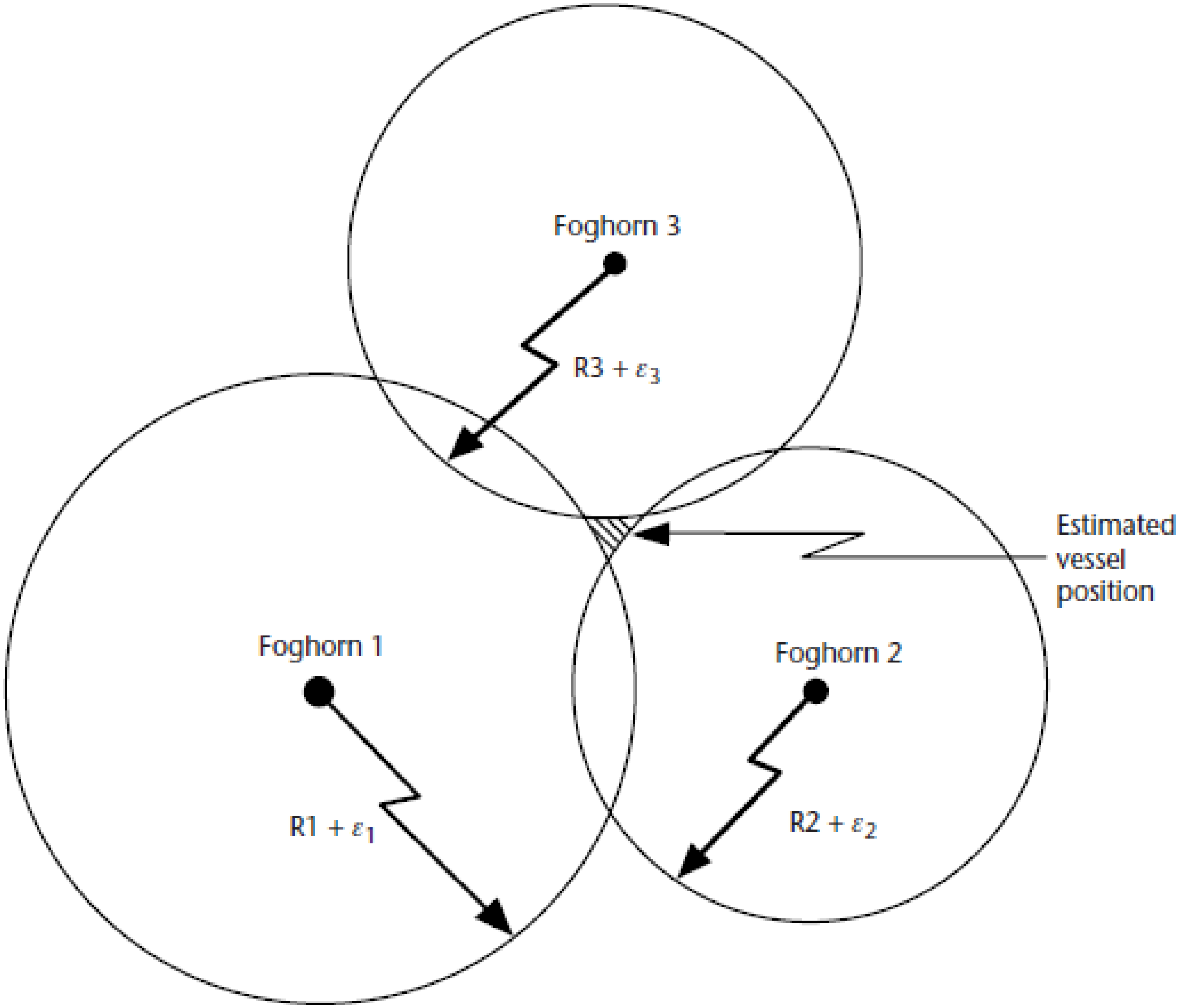


Figure 2.5 Effect of independent measurement errors on position certainty.

Principle of Position Determination Via Satellite-Generated Ranging Signals

GPS employs TOA ranging for user position determination. By making TOA measurements to multiple satellites, three-dimensional positioning is achieved.

satellite ranging signals travel at the speed of light, which is approximately 3 × 10^8 m/s. It is assumed that the satellite ephemerides are accurate (i.e., the satellite locations are precisely known).

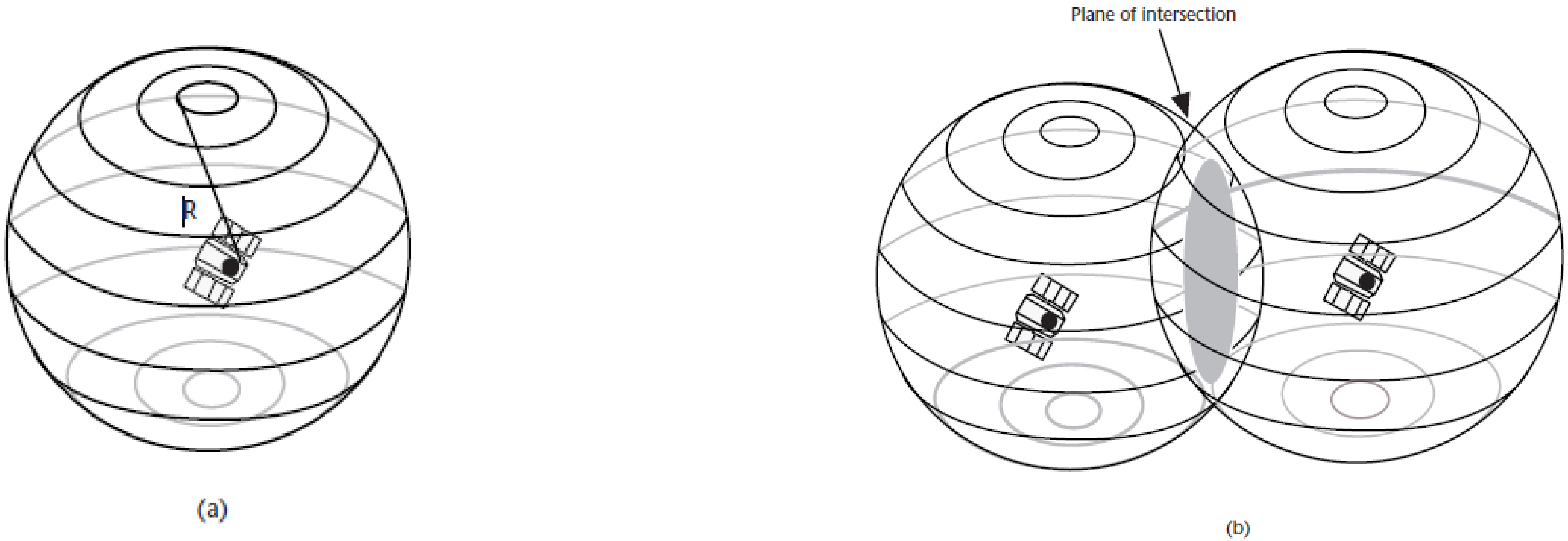
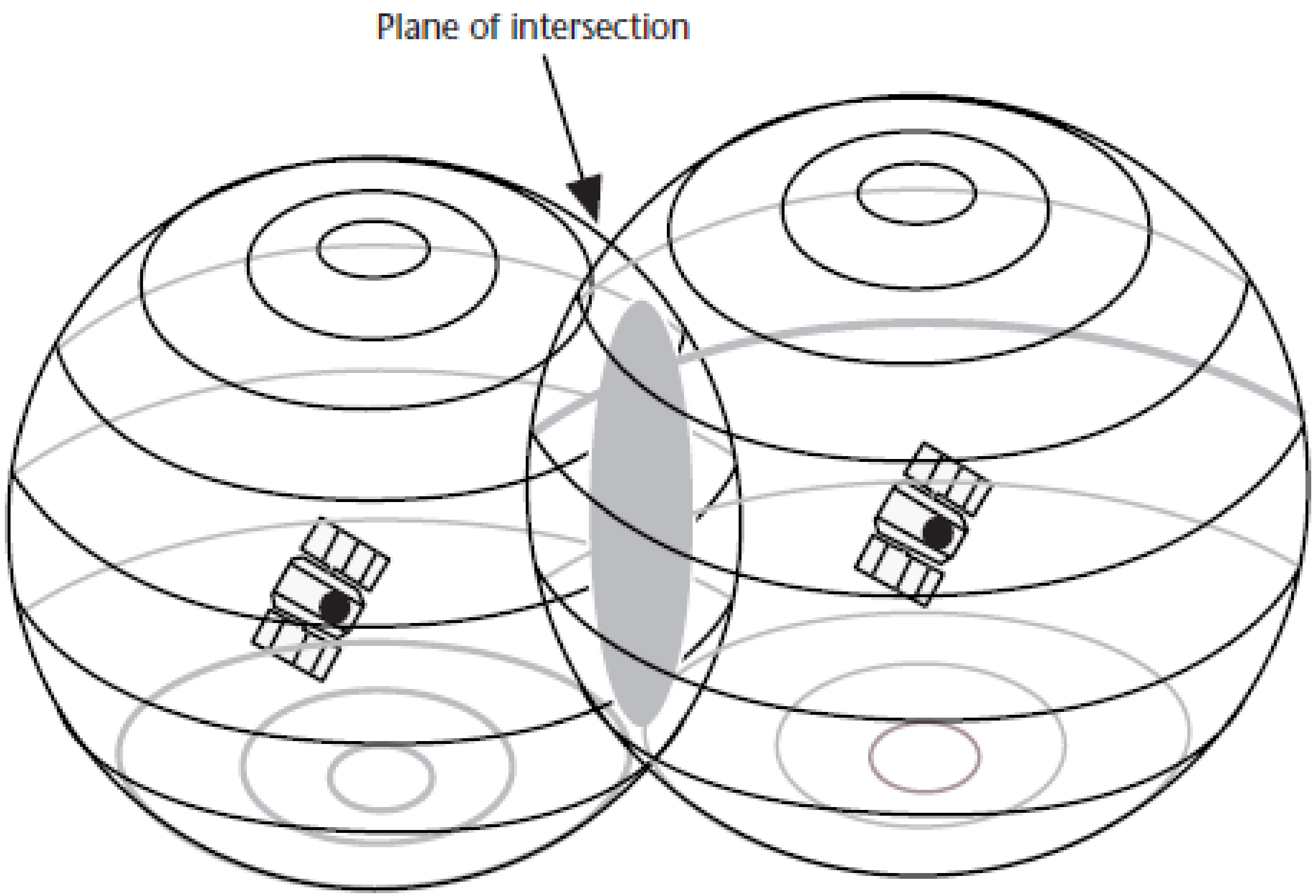


Figure 2.6 (a) User located on surface of sphere. (b) User located on perimeter of shaded circle. (*Source:* [2]. Reprinted with permission.) (c) Plane of intersection. (d) User located at one of two points on shaded circle. (*Source:* [2]. Reprinted with permission.) (e) User located at one of two



(b)

Figure 2.6 (a) User located on surface of sphere. (b) User located on perimeter of shaded circle. (*Source:* [2]. Reprinted with permission.) (c) Plane of intersection. (d) User located at one of two points on shaded circle. (*Source:* [2]. Reprinted with permission.) (e) User located at one of two points on circle perimeter.

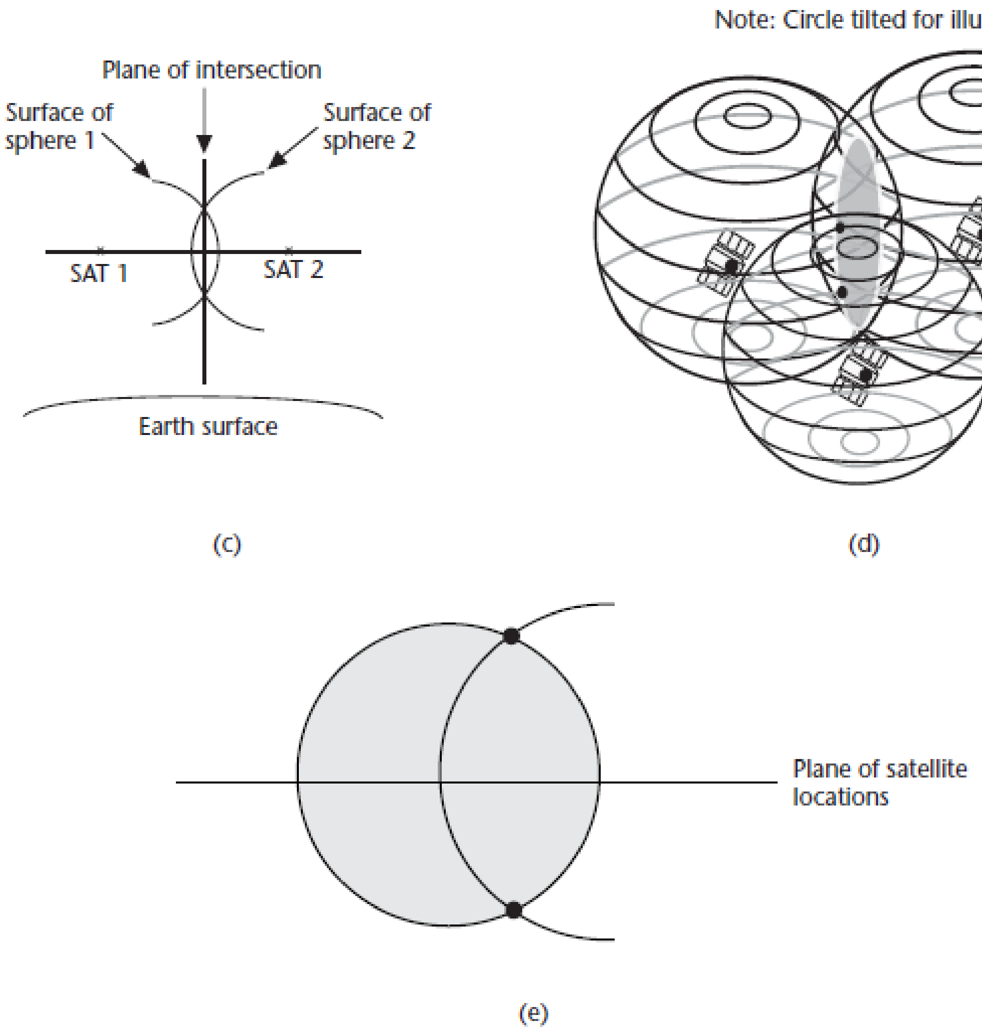


Figure 2.6 (continued.)

(*Source:* [2]. Reprinted with permission.) (c) Plane of intersection. (d) User located at one of two points on shaded circle. (*Source:* [2]. Reprinted with permission.) (e) User located at one of two points on circle perimeter.

Reference Coordinate Systems

- To formulate the mathematics of the satellite navigation problem, it is necessary to choose a reference coordinate system in which the states of both the satellite and the receiver can be represented. In this formulation, it is typical to describe satellite and receiver states in terms of position and velocity vectors measured in a Cartesian coordinate system.
- Two principal Cartesian coordinate systems are
  - ➢ Inertial Systems
  - ➢ Rotating Systems.

An overview of the coordinate systems used for GPS.

- ➢ Earth-Centered Inertial Coordinate System
- ➢ Earth-Centered Earth-Fixed Coordinate System

Earth-Centered Inertial Coordinate System

- For the purposes of measuring and determining the orbits of the GPS satellites, it is convenient to use an Earth-centered inertial (ECI) coordinate system
- In this system the origin is at the center of the mass of the Earth and whose axes are pointing in fixed directions with respect to the stars.
- A GPS satellite obeys Newton's laws of motion and gravitation in an ECI coordinate system
- **Determination and subsequent prediction of the GPS satellite orbits are carried out in an ECI coordinate system.**

- In typical ECI coordinate systems,
  - the *xy*-plane is taken to coincide with the Earth's equatorial plane,
  - the +*x*-axis is permanently fixed in a particular direction relative to the celestial sphere,
  - the +*z*-axis is taken normal to the *xy*-plane in the direction of the north pole
  - the +*y*-axis is chosen so as to form a right-handed coordinate system.

- One subtlety in the definition of an ECI coordinate system arises due to irregularities in the Earth's motion.
- The Earth's shape is oblate, and due largely to the gravitational pull of the Sun and the Moon on the Earth's equatorial bulge, the equatorial plane moves with respect to the celestial sphere.
- Because the *x*-axis is defined relative to the celestial sphere and the *z*-axis is defined relative to the equatorial plane, the irregularities in the Earth's motion would cause the ECI frame as defined earlier not to be truly inertial.
- The solution to this problem is to define the orientation of the axes at a particular instant in time, or *epoch*.
- The GPS ECI coordinate system uses the orientation of the equatorial plane at 1200 hours UTC (USNO) on

  January 1, 2000, denoted as the J2000 system.

  the +*x*-axis is taken to point from the center of the mass of the Earth to the direction of vernal equinox,

  the *y*- and *z*-axes are defined as described previously, all at the aforementioned epoch.

Since the orientation of the axes remains fixed, the ECI coordinate system defined in this way can be considered inertial for GPS purposes.

Earth-Centered Earth-Fixed Coordinate (ECEF) System

- For the purpose of computing the position of a GPS receiver, it is more convenient to use a coordinate system that rotates with the Earth, known as an Earth-centered Earth-fixed (ECEF) system.
- In such a coordinate system, it is easier to compute the latitude, longitude, and height parameters that the receiver displays.
- As with the ECI coordinate system, the ECEF coordinate system used for GPS has its

  xy-plane coincident with the Earth's equatorial plane.

  However, in the ECEF system,

  the +*x*-axis points in the direction of 0° longitude

  the +*y*-axis points in the direction of 90°E longitude.

  the z-axis is chosen to be normal to the equatorial plane in the direction of the geographical

  North Pole
- The *x*-, *y*-, and *z*-axes therefore rotate with the Earth and no longer describe fixed directions in inertial space. In this ECEF system, (i.e., where the lines of longitude meet in the northern hemisphere), thereby completing the right-handed coordinate system.

- GPS orbit computation software includes the transformations between the ECI and the ECEF coordinate systems.
- Such transformations are accomplished by the application of rotation matrices to the satellite position and velocity vectors in the ECI coordinate system.

(The broadcast orbit computation procedure described in [4] and in Section 2.3 generates satellite position and velocity in the ECEF frame.)

- Precise orbits from numerous computation centers also express GPS position and velocity in ECEF.

Position Determination Using PRN Codes

- GPS satellite transmissions utilize direct sequence spread spectrum (DSSS) modulation
- DSSS provides the structure for the transmission of ranging signals and essential navigation data, such as satellite ephemerides and satellite health.
- The ranging signals are PRN codes that binary phase shift key (BPSK) modulate the satellite carrier frequencies.
- These codes look like and have spectral properties similar to random binary sequences but are actually deterministic.
- A simple example of a short PRN code sequence is shown in Figure 2.14. These codes have a predictable pattern, which is periodic and can be replicated by a suitably equipped receiver.

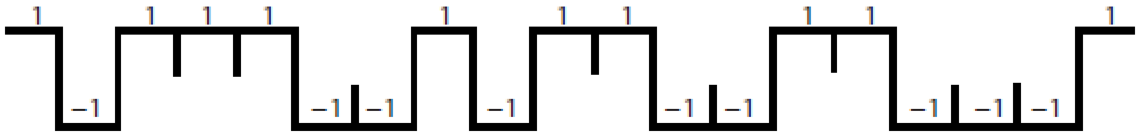


Figure 2.14 PRN ranging code.

- Each GPS satellite(at the time of this writing,) broadcasted two types of PRN ranging codes:
  - a “short” coarse/acquisition (C/A)-code
  - a “long” precision (P)-code.

  (Additional signals are planned to be broadcast. They are described in Chapter 4.)

- The C/A code has a 1-ms period and repeats constantly, whereas the P-code satellite transmission is a 7-day sequence that repeats approximately every Saturday/Sunday midnight.

- Presently, the P-code is encrypted.

This encrypted code is denoted as the Y-code. The Y-code is accessible only to PPS users through cryptography. (Further details regarding PRN code properties, frequency generation, and associated modulation processes
are contained in Chapter 4.)

Determining Satellite-to-User Range

- We examined the theoretical aspects of using satellite ranging signals and multiple spheres to solve for user position in three dimensions.
- That example was predicated on the assumption that the receiver clock was perfectly synchronized to system time.
- actuality, this is generally not the case. Prior to solving for three-dimensional user position, we will examine the fundamental concepts involving satellite-to-user range determination with nonsynchronized clocks and PRN codes.
- There are a number of error sources that affect range measurement accuracy (e.g., measurement noise and propagation delays) however, these can generally be considered negligible when compared to the errors experienced from nonsynchronized clocks.
- Therefore, in our development of basic concepts, errors other than clock offset are omitted.

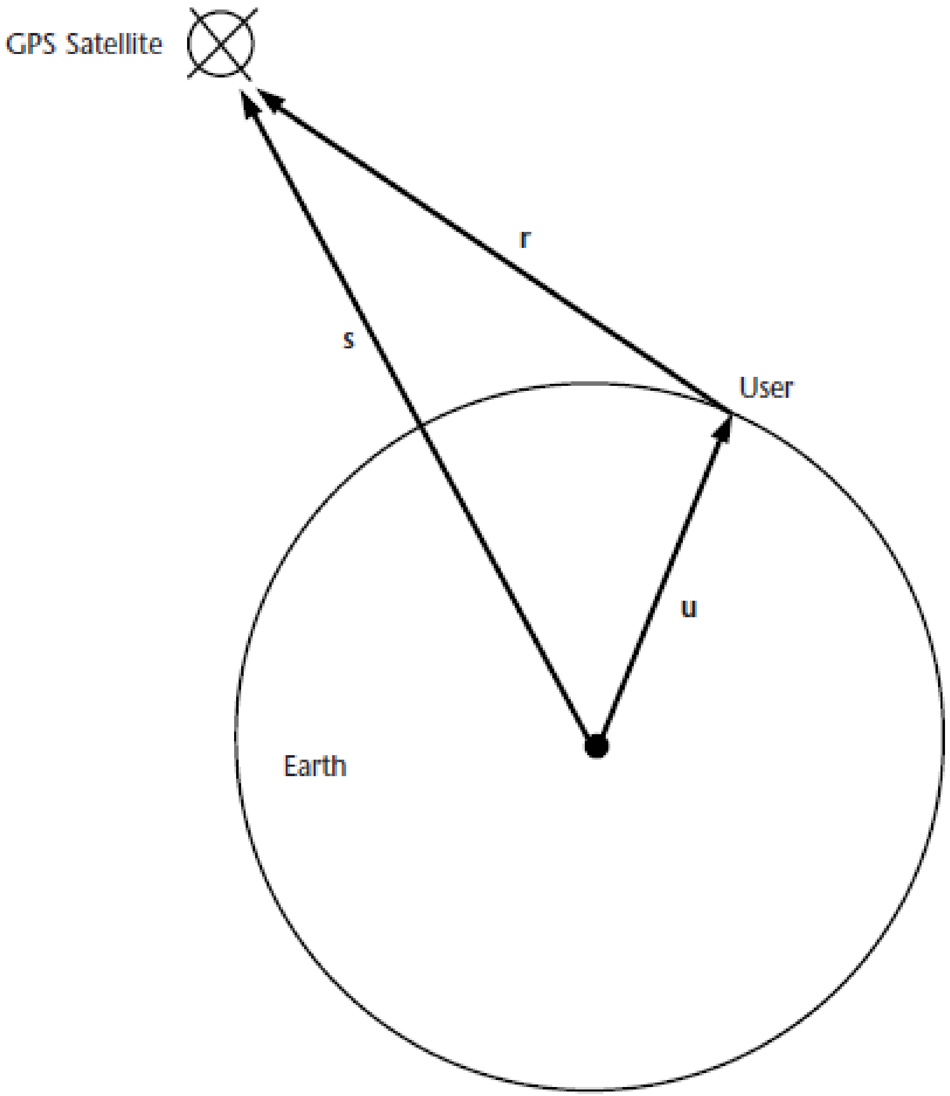


Figure 2.15 User position vector representation.

- In Figure 2.15, we wish to determine vector **u**, which represents a user receiver's position with respect to the ECEF coordinate system origin.
- The user's position coordinates x_u, y_u, z_u are considered unknown.
- Vector **r** represents the vector offset from the user to the satellite.
- The satellite is located at coordinates x_s, y_s, z_s within the ECEF Cartesian coordinate system.
- Vector **s** represents the position of the satellite relative to the coordinate origin.
- Vector **s** is computed using ephemeris data broadcast by the satellite.

- The satellite-to-user vector **r** is $\quad \mathbf{r} = \mathbf{s} - \mathbf{u}$

- The magnitude of vector **r** is $\quad r = \|\mathbf{s} - \mathbf{u}\|$

Let *r* represent the magnitude of **r** $\quad r = \|\mathbf{s} - \mathbf{u}\|$

- The distance *r* is computed by measuring the propagation time required for a satellite-generated ranging code to transit from the satellite to the user receiver antenna.
- The propagation time measurement process is illustrated in Figure 2.16.

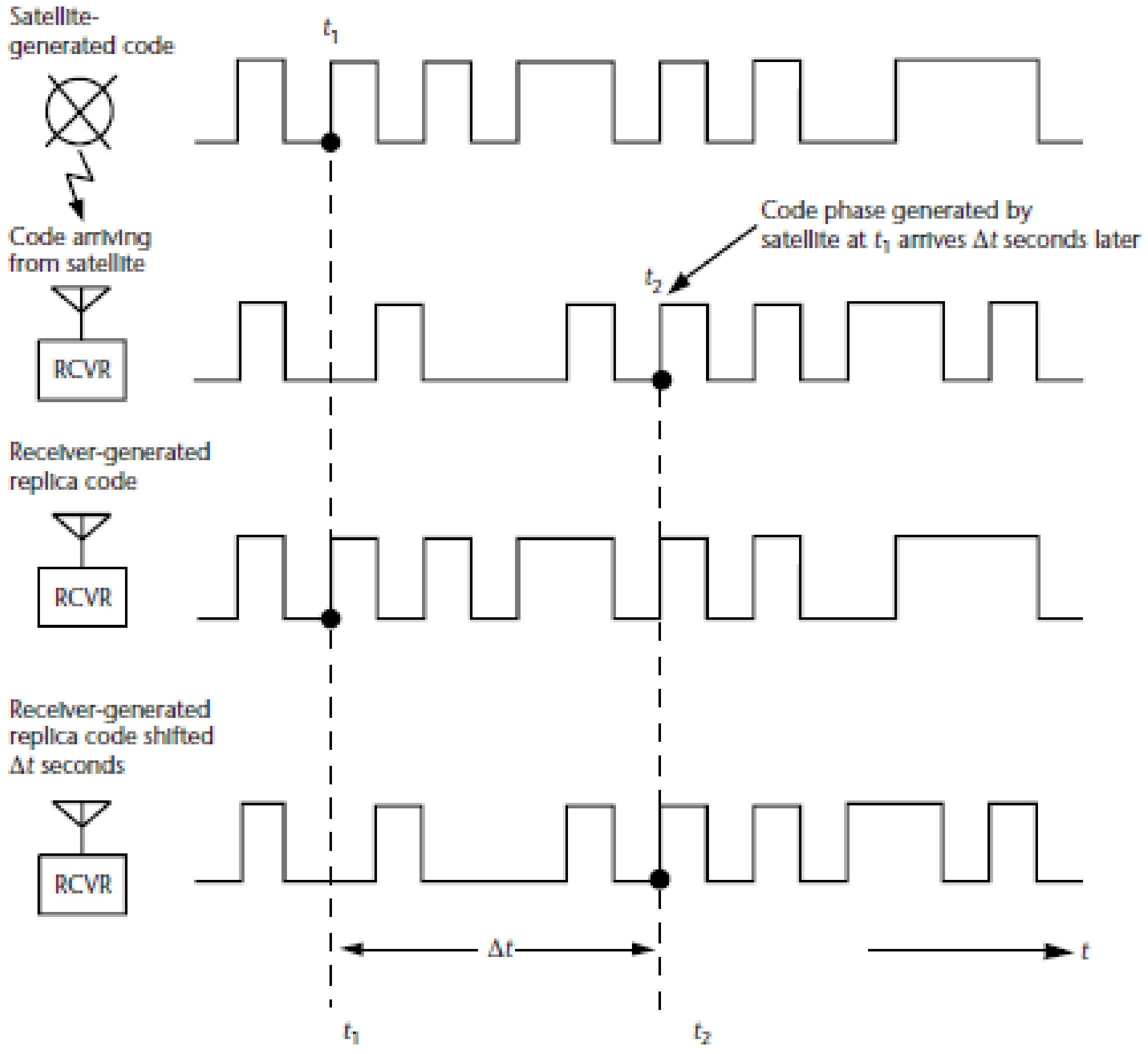


Figure 2.16 Use of replica code to determine satellite code transmission time.

- As an example, a specific code phase generated by the satellite at t1 arrives at the receiver at t2.
- The propagation time is represented by Δt.
- Within the receiver, an identical coded ranging signal is generated at t, with respect to the receiver clock.
- This replica code is shifted in time until it achieves correlation with the received satellite-generated ranging code.
- If the satellite clock and the receiver clock were perfectly synchronized, the correlation process would yield the true propagation time.
- By multiplying this propagation time, Δt, by the speed of light, the true (i.e., geometric) satellite-to-user distance can be computed.
- However, the satellite and receiver clocks are generally not synchronized. The receiver clock will generally have a bias error from system time.
- Further, satellite frequency generation and timing is based on a highly accurate free running cesium or rubidium atomic clock, which is typically offset from system time.

- Thus, the range determined by the correlation process is denoted as the pseudorange . The measurement is called *pseudorange* because it is the range determined by multiplying the signal propagation velocity, ***c***, by the time difference between two non-synchronized clocks (the satellite clock and the receiver clock).
- The measurement contains
  (1) the geometric satellite-to-user range,
  (2) an offset attributed to the difference between system time and the user clock,
  (3) an offset between system time and the satellite clock.
- The timing relationships are shown in Figure 2.17, where:
  Ts = System time at which the signal left the satellite
  Tu = System time at which the signal reached the user receiver
  t = Offset of the satellite clock from system time
  [advance is positive;retardation (delay) is negative]
  tu = Offset of the receiver clock from system time
  Ts + *t* = Satellite clock reading at the time that the signal left the satellite
  Tu + *tu* = User receiver clock reading at the time the signal reached the user receiver
  c = speed of light

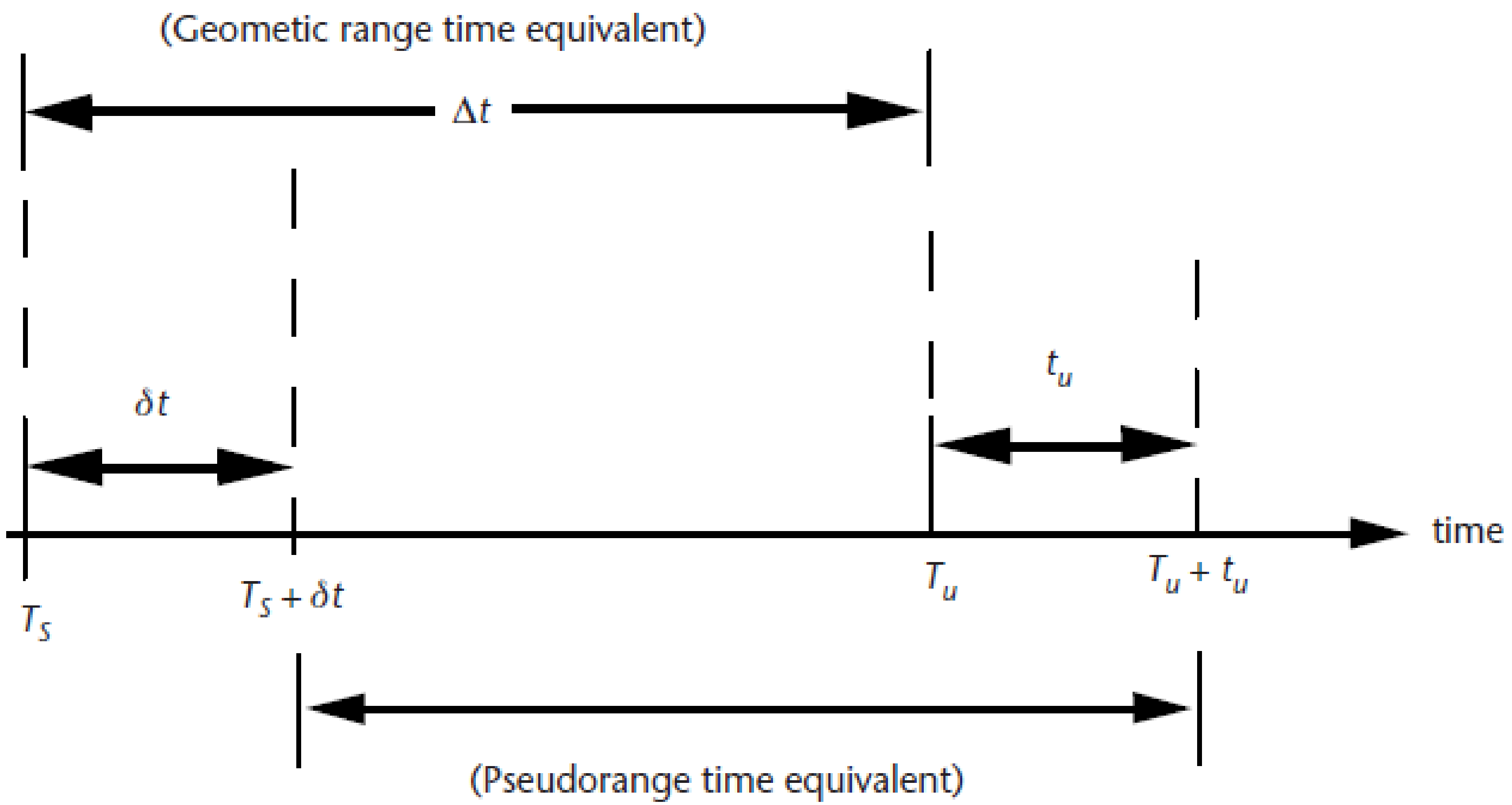


Figure 2.17 Range measurement timing relationships.

- Need to add few slides for user position

GPS User Segment:

- The user receiving equipment, typically referred to as a **GPS receiver**,
- IT processes the L-band signals transmitted from the satellites to determine 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 such as cellular telephones, PDAs, and automobiles.
- These first receivers were primarily analog devices for military applications and were large, bulky, and heavy.
- Today, receivers take on many form factors, including chipsets, handheld units, and Industry Standard Architecture (ISA) compatible cards. In fact, there are many single- chip GPS receivers that have leveraged low-voltage bipolar complementary metal oxide semiconductor (BiCMOS) processes and power-management techniques to meet the need for small size and low battery drain of handheld devices.
- Selection of a GPS receiver depends on the user's application

  (e.g., civilian versus military, platform dynamics, and shock and vibration environment).
- Following a description of a typical receiver's components, selection criteria are addressed.

GPS Set (receiver set)Characteristics

- A block diagram of a GPS receiving set is shown in Figure 3.23.
- The GPS set consists of five principal components:
  antenna, receiver, processor, input/output (I/O) device such as a control display unit (CDU), and a power supply.

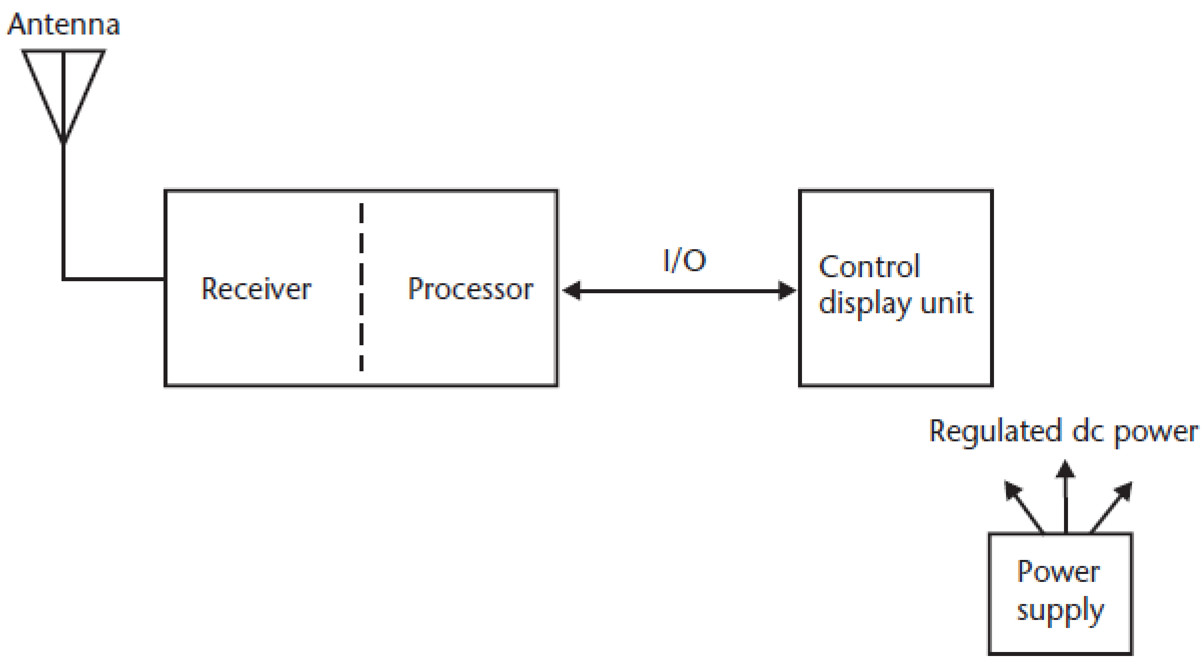


Figure 3.23 Principal GPS receiver components.

Antenna

- Satellite signals are received via the antenna, which is right-hand circularly polarized (RHCP) and provides near hemispherical coverage.
- Typical coverage is 160° with gain variations from about 2.5 dBic at zenith to near unity at an elevation angle of 15°.
- The RHCP antenna unity gain also can be expressed as 0 dBic = 0 dB with respect to an isotropic circularly polarized antenna.). Below 15°, the gain is usually negative.
- An example antenna pattern is shown in Figure 3.24. This pattern was produced by a stacked-patch antenna element embedded in a dielectric substrate

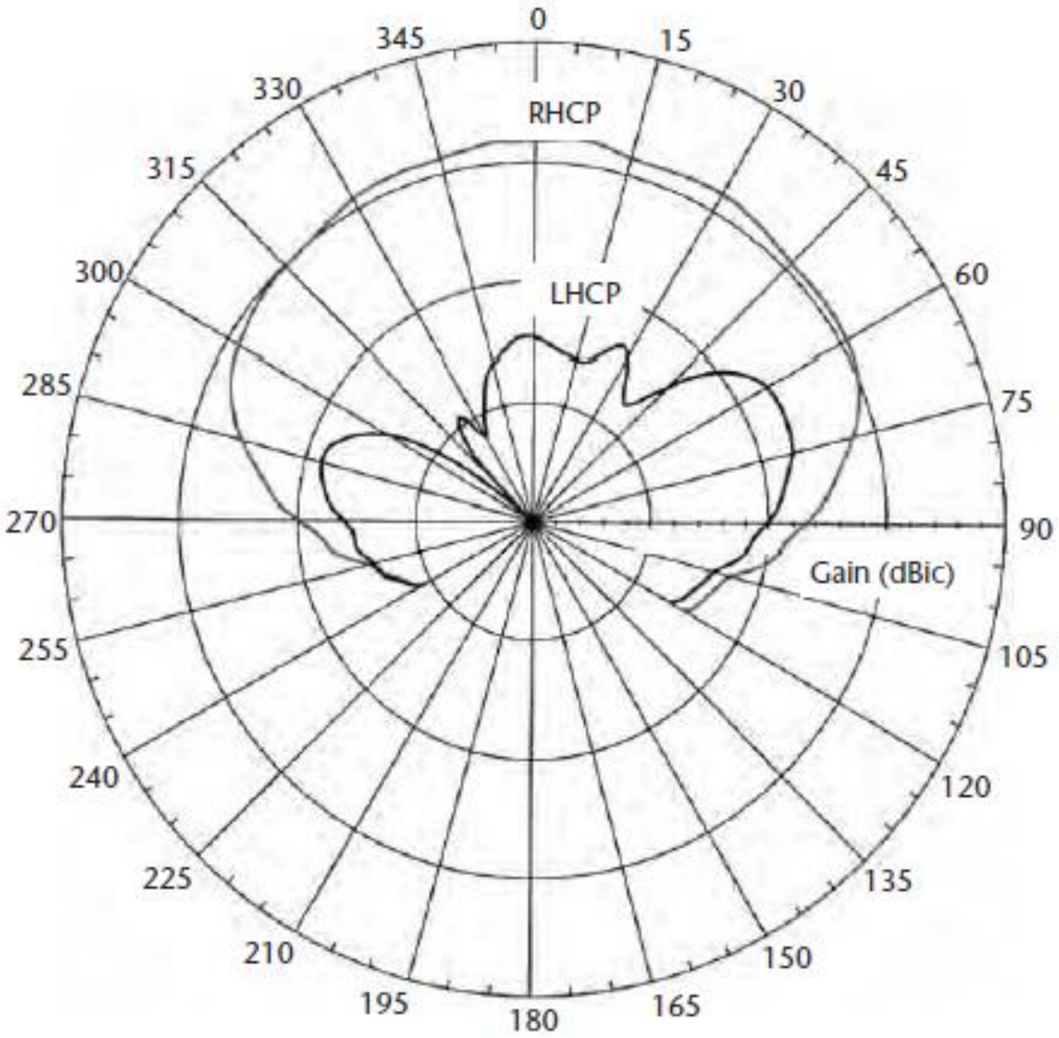


Figure 3.24 Example of RHCP hemispherical antenna pattern.

Receiver

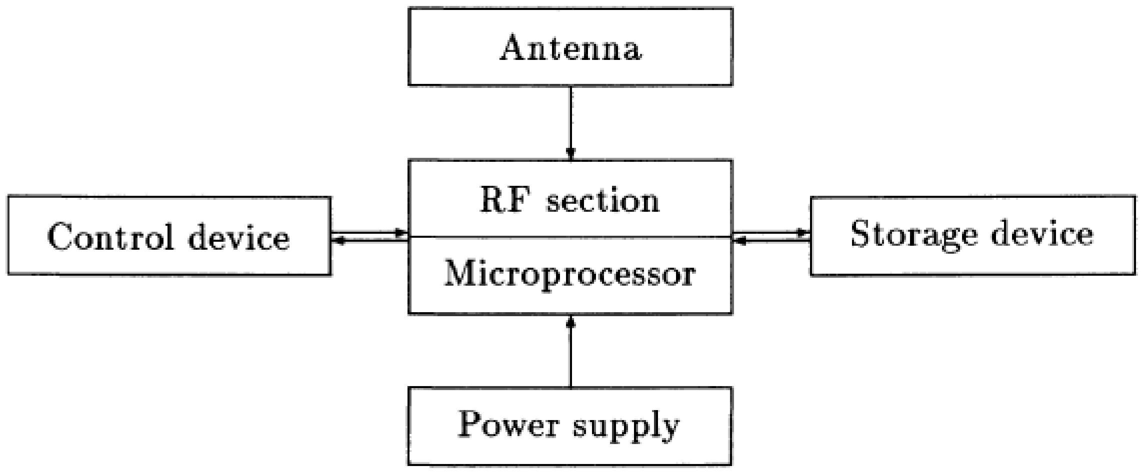


Fig. 5.5. Basic concept of a receiver unit

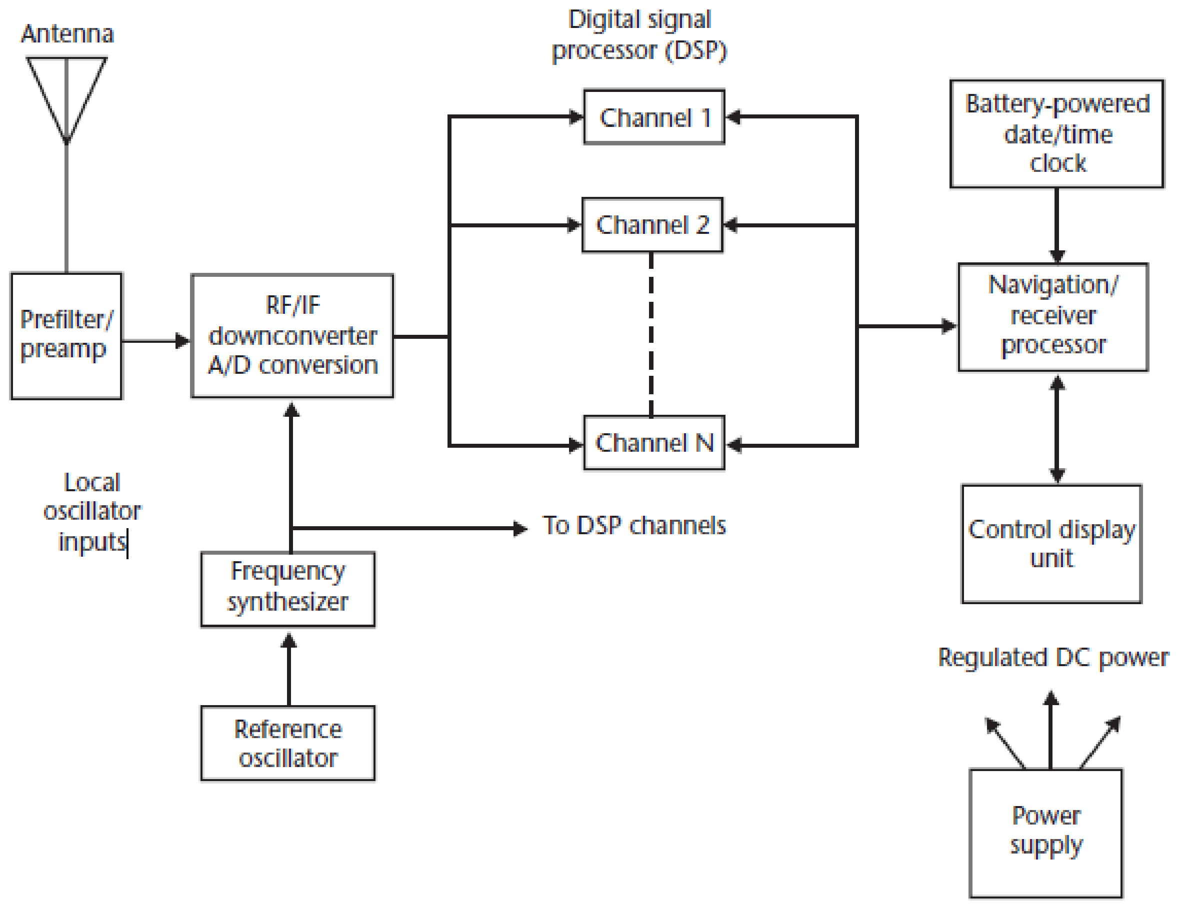


Figure 3.25 Generic SPS receiver.

- Legacy PPS users generally employ sets that track P(Y) code on both L1 and L2.
- These sets initiate operation with receivers tracking C/A code on L1 and then transition to tracking P(Y) code on both L1 and L2.
- Y-code tracking occurs only with the aid of cryptographic equipment. (If the satellite signal is encrypted and the receiver does not have the proper cryptographic equipment, the receiver generally defaults to tracking C/A code on L1.)
- It is anticipated that the forthcoming YMCA receivers will perform a direct acquisition of the M code signal.
- Following M code acquisition, the receivers will then track Mcode on both L1 and L2 if the receiver is capable of dual-frequency operation. Otherwise, it will operate on either L1 or L2.

- A block diagram that is representative of the SV signal structure for L1 ($154f_0$) and

L2 ($120f_0$) is shown in Figure 4.5 (where f_0 is the fundamental frequency: 10.23 MHz).

- As shown in Figure 4.5, the L1 frequency ($154f_0$) is modulated by two PRN codes (plus the navigation message data), the C/A code, and the P code.
- The L2 frequency ($120f_0$) is modulated by only one PRN code at a time.
- One of the P code modes has no data modulation. The nominal reference frequency, f_0, as it appears to an observer on the ground, is 10.23 MHz.
- To compensate for relativistic effects, the output of the SV's frequency standard (as it appears from the SV) is 10.23 MHz offset by a $\delta f/f$ of 4.467 · 10^-10.

  This results in a δf of 4.57 · 10KHz and $f_0 = 10.22999999543$ MHz To the GPS receiver on the ground, the C/A

- code has a chipping rate of 1.023 · 10M chips/s ($f_0/10 = 1.023$ MHz) and the P code
- has a chipping rate of 10.23 · 10_Mchips/s ($f_0 = 10.23$ MHz). Using the notation
- introduced in Section 4.2.3, the C/A code signal uses a BPSK-R(1) modulation and
- the P code uses a BPSK-R(10) modulation. The P code is available to PPS users but
- not to SPS users since the CS normally configures an AS mode in the SV. When AS is

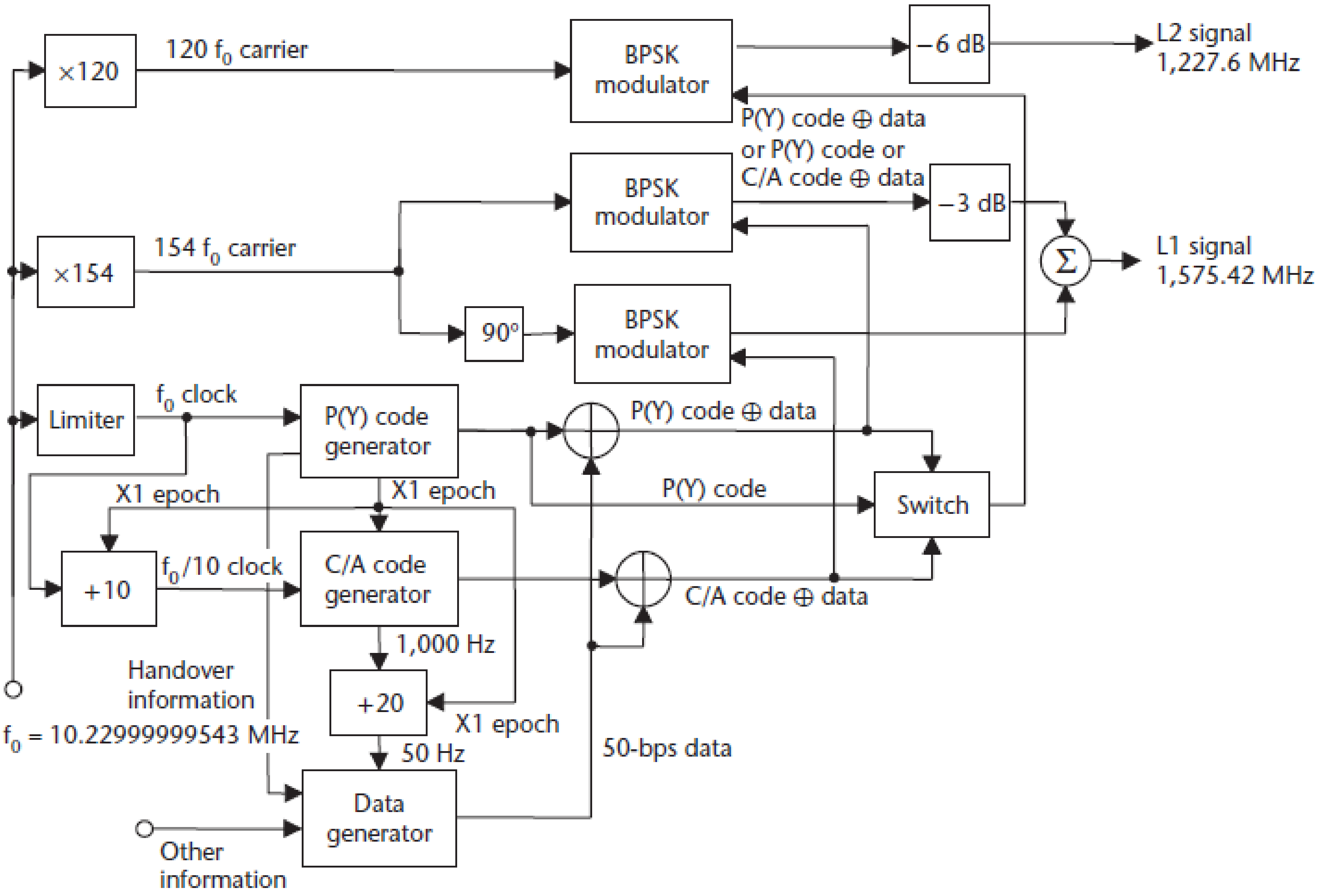


Figure 4.5 Legacy GPS satellite signal structure.

Navigation Message Format

- GPS satellites generate data at 50bps.I transmits 1500 bits of data in to 5 subframes of 300 bits each
- This data provides the user with the information necessary to compute the precise locations of each visible satellite and time of transmission for each navigation signal.
- The data also includes a significant set of auxiliary information that may be used, for example, to assist the equipment in acquiring new satellites, to translate from GPS system time to UTC, and to correct for a number of errors that affect the range measurements.
- The GPS navigation message is transmitted in five 300-bit subframes, as shown in Figure 4.19. Each subframe is itself composed of ten 30-bit words. The last 6 bits in each word of the navigation message are used for parity checking to provide the user equipment with a capability to detect bit errors during demodulation.
- A (32,26) Hamming code is employed. The five subframes are transmitted in order beginning with subframe 1. Subframes 4 and 5 consist of 25 pages each, so that the first time through the five subframes, page 1 of subframes 4 and 5 are broadcast.
- In the next cycle through the five subframes, page 2 of subframes 4 and 5 are broadcast and so on.

	Number of bits	Transmission time
Total message	1 500	30 seconds
Subframe (1–5)	300	6 seconds
Word (1–10)	30	0.6 seconds

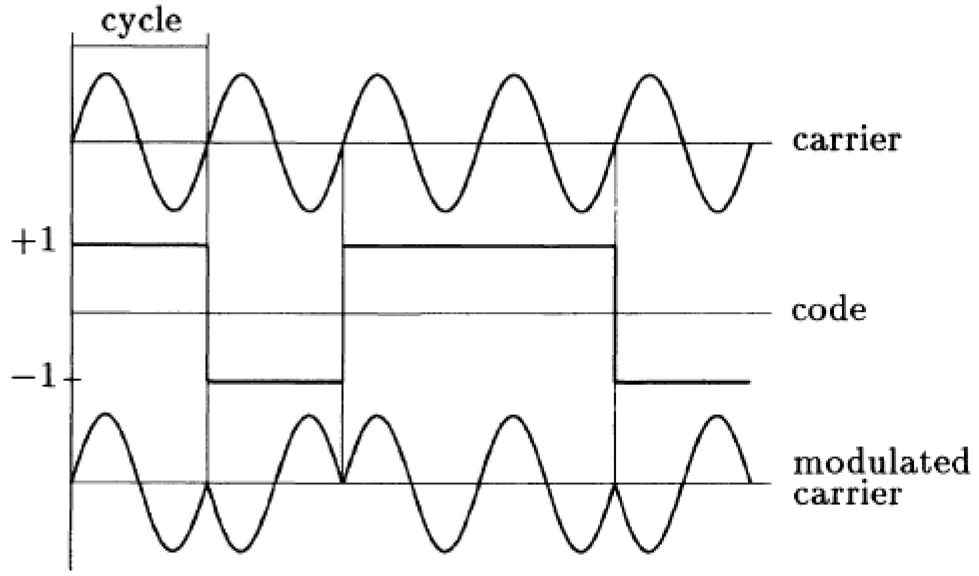


Fig. 5.1. Biphase modulation of carrier wave

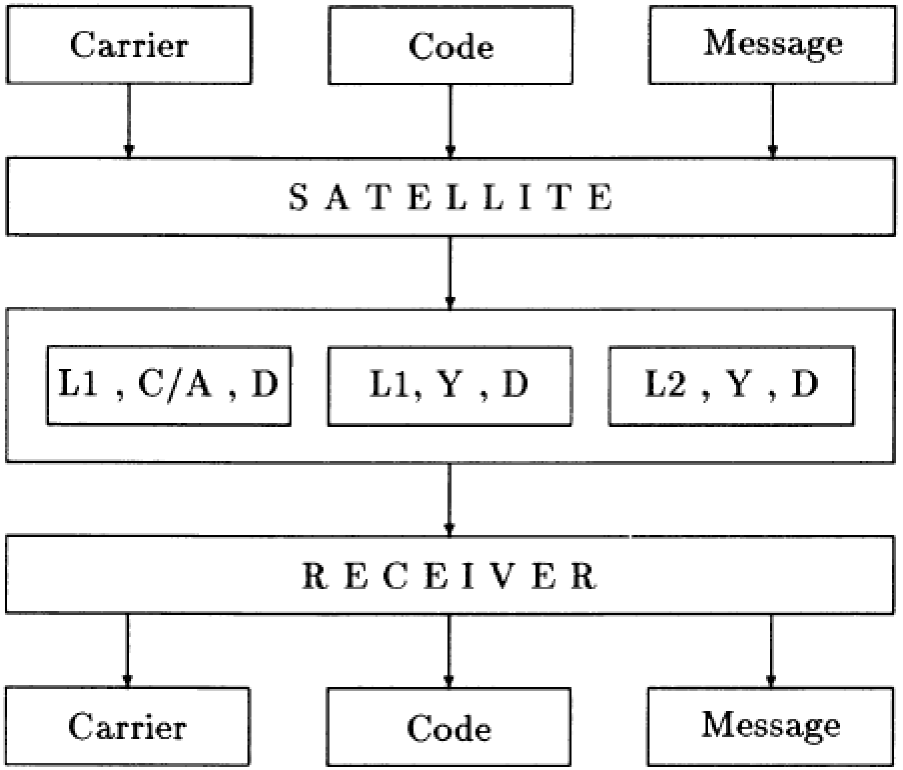


Fig. 5.4. Principle of signal processing

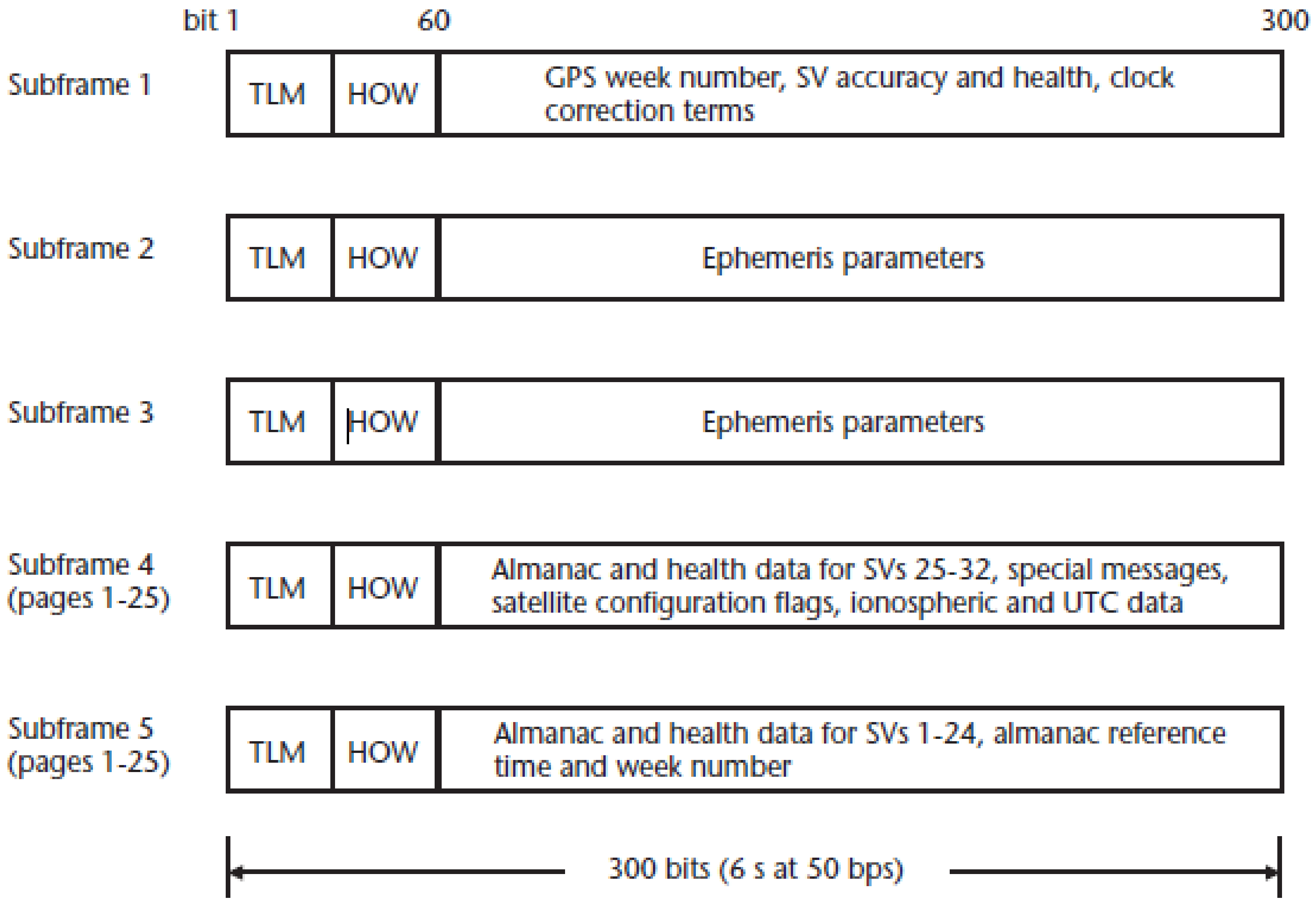


Figure 4.19 Navigation message format.

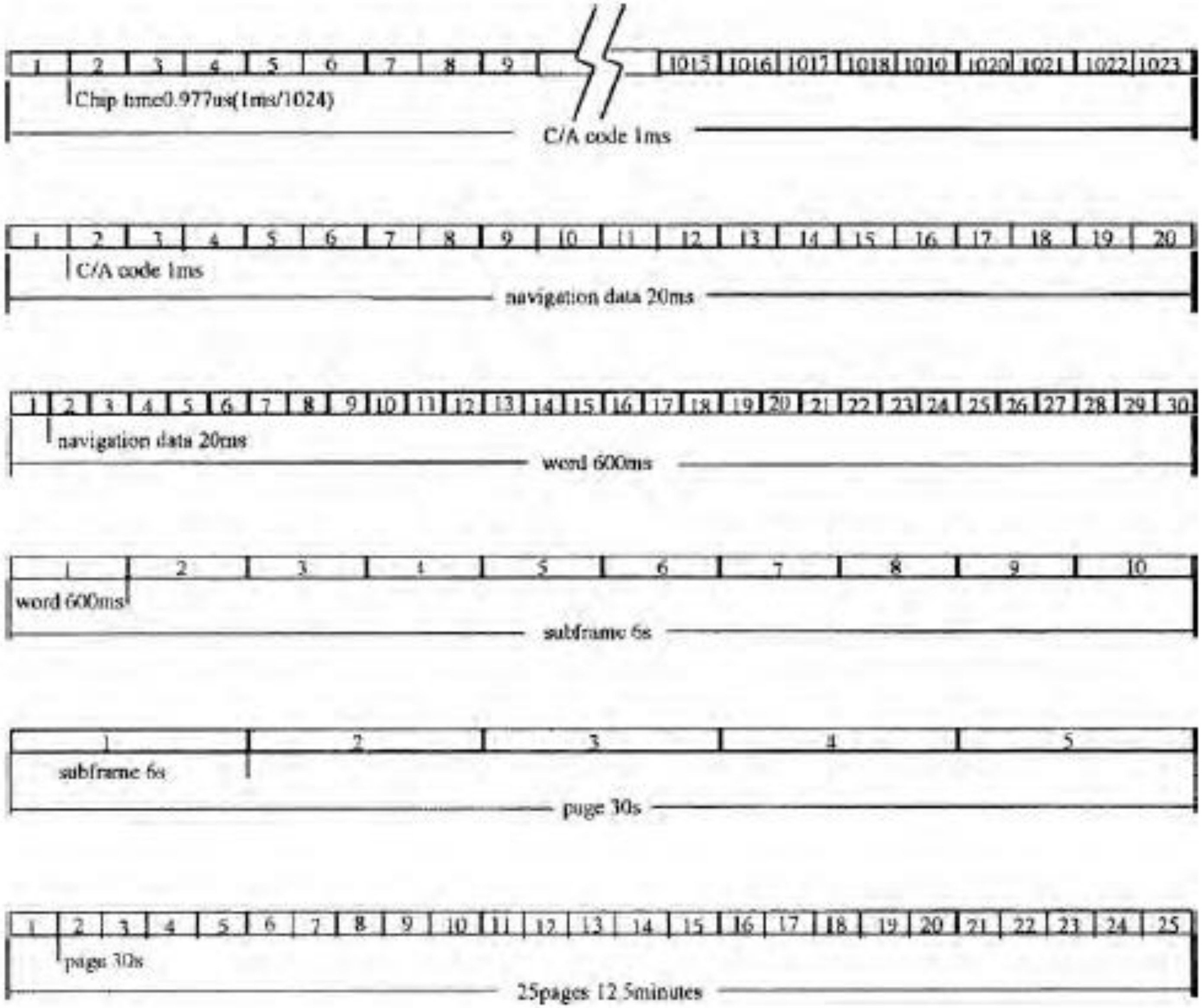


FIGURE 5.3 GPS data format.

- Although there are provisions for a loss of ground contact, normally the control segment uploads critical navigation data elements once or twice per day per satellite.
- In this nominal mode of operation, the same critical navigation data elements (e.g., satellite ephemeris and clock correction data) are broadcast repeatedly over 2-hour time spans (except if an upload occurs during this interval).
- On 2-hour boundaries, each satellite switches to broadcasting a different set of these critical elements, which are stored in tables in the satellite's RAM.
- The control segment generates these message elements based upon its current estimates of each satellite's position and clock error and prediction algorithms on how these parameters will change over time.
- The first two words of each subframe (bits 1–60) contain telemetry (TLM) data and a handover word (HOW).
- The TLM word is the first of the 10 words in each subframe and includes a fixed preamble, a fixed 8-bit pattern 10001011 that never changes.
- This pattern is included to assist the user equipment in locating the beginning of each subframe.

- Each TLM word also includes 14 bits of data that are only meaningful to authorized users.
- The HOW, so-named because it allows the user equipment to “handover” from C/A code tracking to P(Y) code tracking, provides the GPS time-of-week (TOW) modulo 6 seconds corresponding to the leading edge of the following subframe.
- The HOW also provides two flag bits, one that indicates whether antispoofing is activated (see Section 4.3.1), and one that serves as an alert indicator.
- If the alert flag is set, it indicates that the signal accuracy may be poor and should be processed at the user’s own risk.
- Finally, the HOW provides the subframe number (1–5).

- The first two words of all the subframes are the telemetry (TLM) and hand over word (HOW). Each word contains 30 bits and the message is transmitted from bit 1 to bit 30.
- These two words are shown in Figure 5.7.
- The TLM word begins with an 8-bit preamble, followed by 16 reserved bits and 6 parity bits. The bit pattern of the preamble is shown in this figure.
- The bit pattern of the preamble will be used to match the navigation data to detect the beginning of a subframe.
- The HOW word can be divided into four parts.

1. The first 17 bits (1–17) are the truncated time of week (TOW) count that provides the time of the week in units of 6 seconds.
2. The next two bits (18, 19) are flag bits. For satellite configuration 001 (block II satellite) bit 18 is an alert bit and bit 19 is antispoof.

   Satellites are procured in blocks. Most block I satellites are experimental ones and all the satellites in orbit are

   from block II. When bit 18 = 1, it indicates that the satellite user range accuracy may be worse than indicated in subframe1 and the

   user uses the satellite at the user's own risk. Bit 19 = 1 indicates the antispoof mode is on.
3. The following three bits (20–22) are the subframe ID and their values are 1, 2, 3, 4, and 5 or (001, 010, 011, 100, and 101) to identify

   one of the five subframes. These data will be used for subframe matching.
4. The last 8 bits (23–30) are used for parity bits

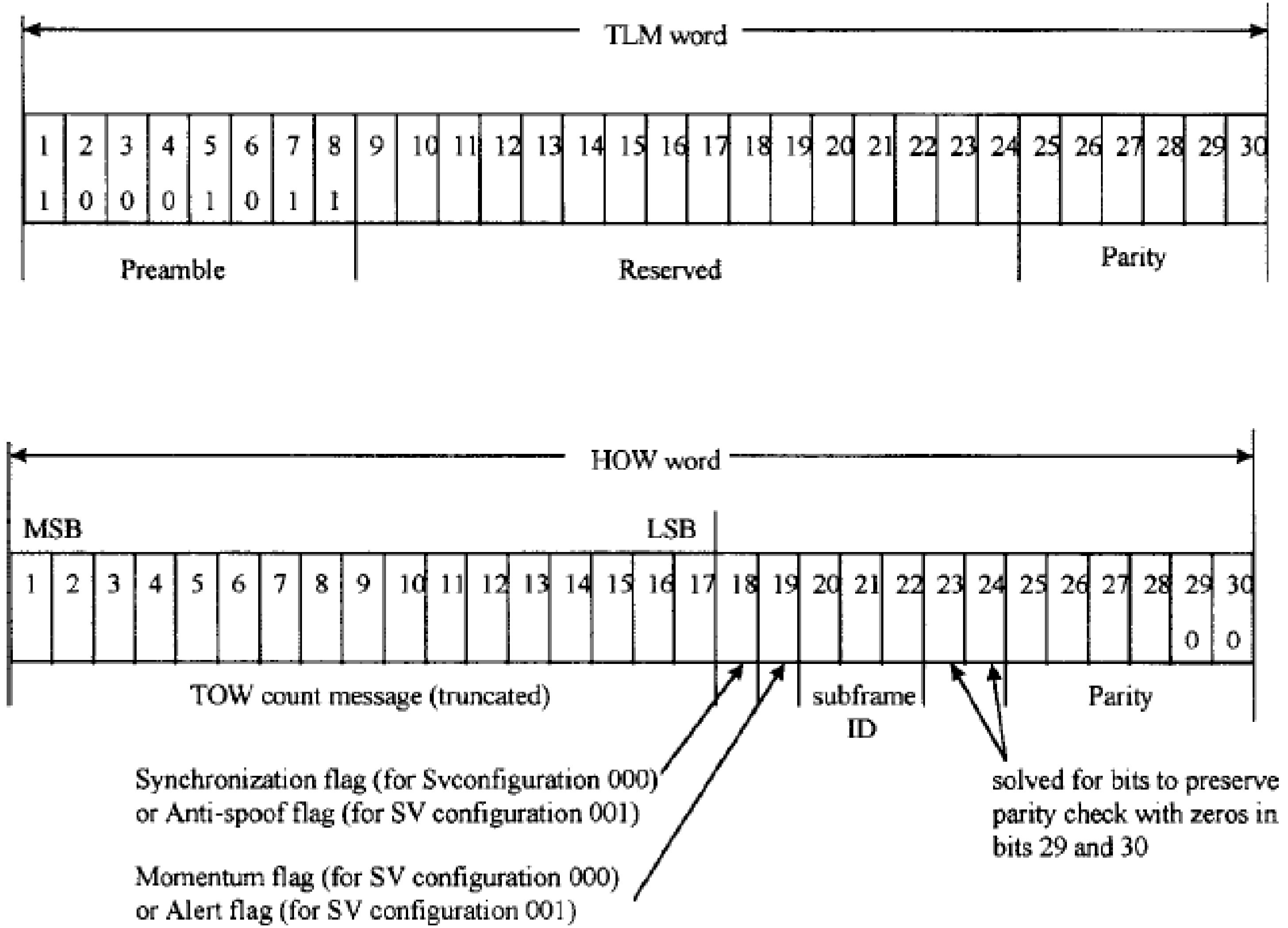


FIGURE 5.7 TLM and HOW words.

Subframe 1

- Subframe 1 provides the GPS transmission week number, which is the number of weeks modulo 1,024 that have elapsed since January 5, 1980.
- The first rollover of the GPS week number occurred on August 22, 1999. The next rollover will occur in April 2019.
- It is prudent that the GPS receiver designer keep track of these rare but inevitable rollover epochs in nonvolatile memory.
- Subframe 1 also provides the following satellite clock correction terms:

a_{f0}, a_{f1}, a_{f2}, and time of clock, t_{oc}, which are extremely important for precise ranging, since they account for the lack of perfect synchronization between the timing of the SV broadcast signals and GPS system time.

- A 10-bit number referred to as issue of data, clock (IODC) is included in subframe 1 to uniquely identify the current set of navigation data.
- User equipment can monitor the IODC field to detect changes to the navigation data.
- The current IODC is different from IODCs used over the past seven days. .

- Subframe 1 also includes a group delay correction, T_{gd}, a user range accuracy (URA) indicator, a SV health indicator, an L2 code indicator, and an L2 P data flag.

➢ T_{gd} is needed by single- frequency (L1- or L2-only) users since the clock correction parameters refer to the timing of the P(Y) code on L1 and L2, as apparent to a user that is using a linear combination of dual-frequency L1/L2 P(Y) code measurements to mitigate ionospheric errors.

➢ The URA indicator provides the user with an estimate of the 1-sigma range errors to the satellite due to satellite and control segment errors (and is fully applicable only for L1/L2 P-code users).

➢ The SV health indicator is a 6-bit field that indicates whether the satellite is operating normally or whether components of the signal or navigation data are suspected to be erroneous.

➢ The L2 code indicator field indicates whether the P(Y) code or C/A code is active on L2.

➢ Finally, the L2 P data flag indicates whether navigation data is being modulated on to the L2 P(Y) code

Subframes 2 and 3

- Subframes 2 and 3 include the osculating Keplerian orbital elements that allow the user equipment to precisely determine the location of the satellite.
- Subframe 2 also includes a fit interval flag and an age of data offset (AODO) term.
  - The fit interval flag indicates whether the orbital elements are based upon a nominal 4-hour curve fit (that corresponds to the 2-hour nominal data transmission interval described earlier) or a longer interval.
  - The AODO term provides an indication of the age of the elements based on a navigation message correction table (NMCT) that has been included in the GPS navigation data since 1995.
- Both subframes 2 and 3 also include an issue of data ephemeris (IODE) field.
- IODE consists of the 8 least significant bits (LSBs) of IODC and may be used by the user equipment to detect changes in the broadcast orbital elements.

- Pages 2–5 and 7–10 of subframe 4 and pages 1–24 of subframe 5 contain almanac data (coarse orbital elements that allow the user equipment to determine approximate positions of other satellites to assist acquisition) for SVs 1–32.
- Page 13 of subframe 4 includes the NMCT range corrections. Page 18 of subframe 4 includes ionospheric correction parameters for single-frequency users and parameters so that user equipment can relate UTC to GPS system time.
- Page 25 of subframes 4 and 5 provide configuration and health flags for SVs 1–32.
- The data payloads of the remaining pages of subframes 4 and 5 are currently reserved.

Modernized GPS Signals

- C/A at L1 and P(Y) at L1,L2 are known as Legacy GPS signals.
- Three additional signals are broadcast by GPS satellites (from 2006) as illustrated in Figure 4.20.
- These include two new civil signals,
  - an L2 civil (L2C) signal
  - a signal at 1,176.45 MHz (115 $f0$) referred to as L5 .
  - a new military signal, M code, at L1 and L2 frequency

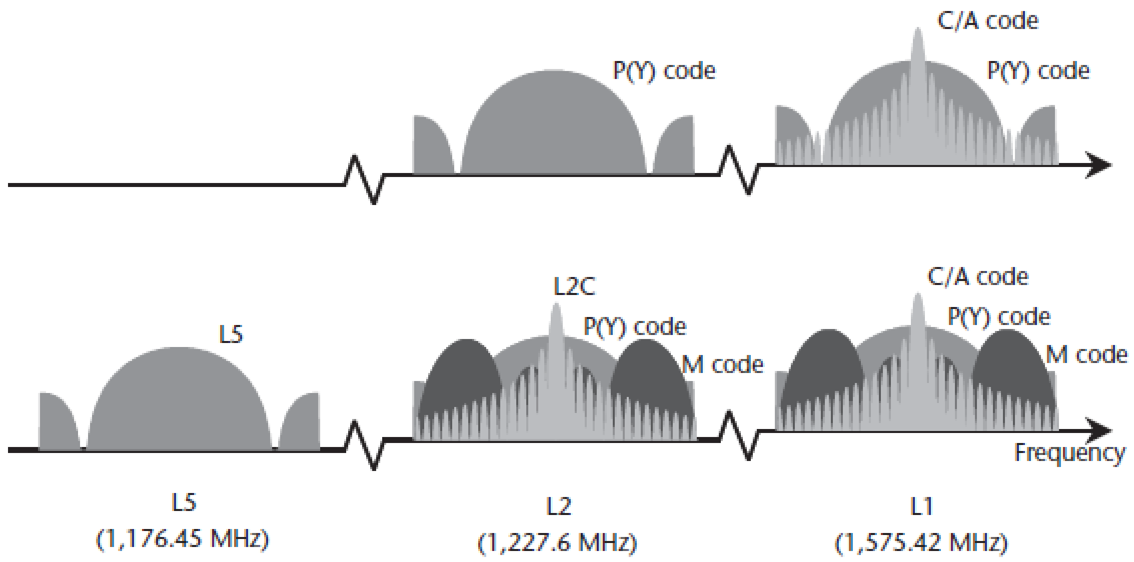


Figure 4.20 Legacy (top) and modernized GPS signals (bottom).

L2 Civil Signal

- The L2 civil (L2C) signal has a similar power spectrum (i.e., 2.046 MHz null-to-null bandwidth) to the C/A code.
- L2C is different from the C/A code in following ways,

1. First, L2C uses two different PRN codes per satellite.
   - The first PRN code is referred to as the civil moderate (CM) code because it employs a sequence that repeats every 10,230 chips, which is considered to be of moderate length.
   - The second code, the civil long (CL) code, is extremely long with a length of 767,250 chips.
   - As shown in Figure 4.21, these two codes are generated, each at a 511.5-kchip/s rate, and are used in the following manner to generate the overall L2C signal.
   - First, the CM code is modulated by a 25-bps navigation data stream after the data is encoded

   into a 50-baud stream with a rate one-half constraint-length 7 FEC code.
2. The 25-bps data rate is one-half the rate of the navigation data on the C/A code and P(Y) code

   signals and was chosen so that the data on the L2C signal can be demodulated in challenged

   environments (e.g., indoors or under heavy foliage) where 50-bps data could not be.
3. The baseband L2C signal is formed by the chip-by-chip multiplexing of the CM (with data) and CL codes.

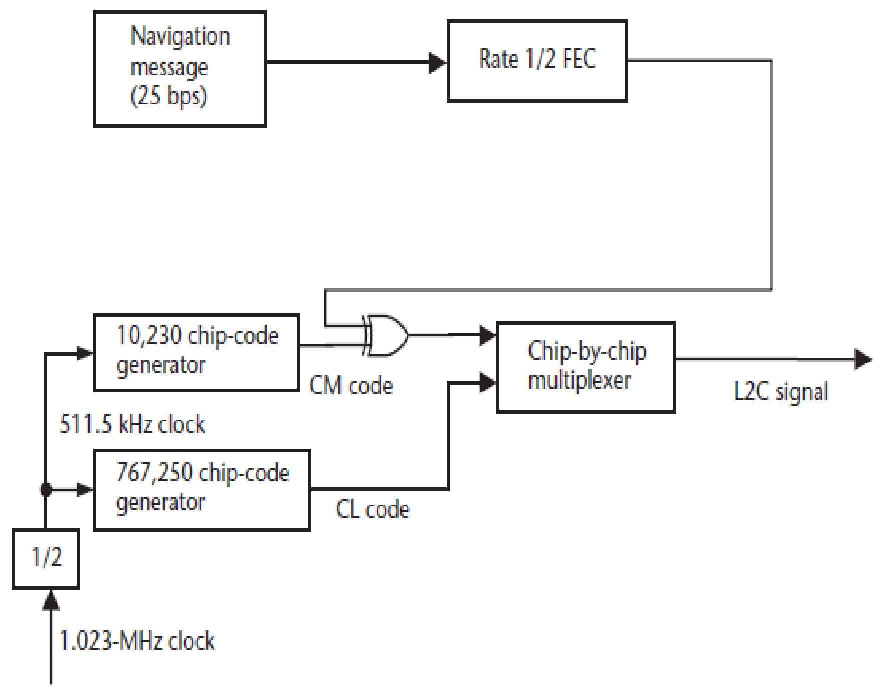


Figure 4.21 Baseband L2C signal generator.

- The rate one-half constraint-length FEC scheme used to encode the 25-bps L2C navigation data into a 50-baud bit stream is shown in Figure 4.23.

- The minimum specified received L2C power level for signals broadcast from the Block IIR-M and IIF satellites is −160 dBW

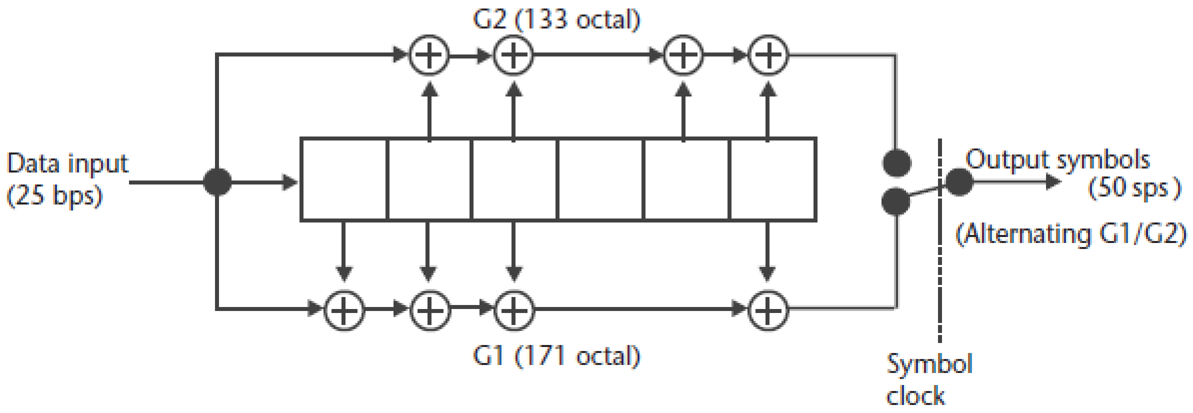


Figure 4.23 L2C data convolution encoder.

L5 Signal

- The GPS L5 signal is generated as shown in Figure 4.24.
- QPSK is used to combine an in-phase signal component (I5) and a quadrature phase signal component (Q5).
- Different length-10,230 PRN codes are used for I5 and Q5.
- I5 is modulated by 50-bps navigation data that, after the use of FEC using the same convolutional encoding as L2C, results in an overall symbol rate of 100 baud.
- A 10.23-MHz chipping rate is employed for both the I5 and Q5 PRN codes resulting in a 1-ms code repetition period.

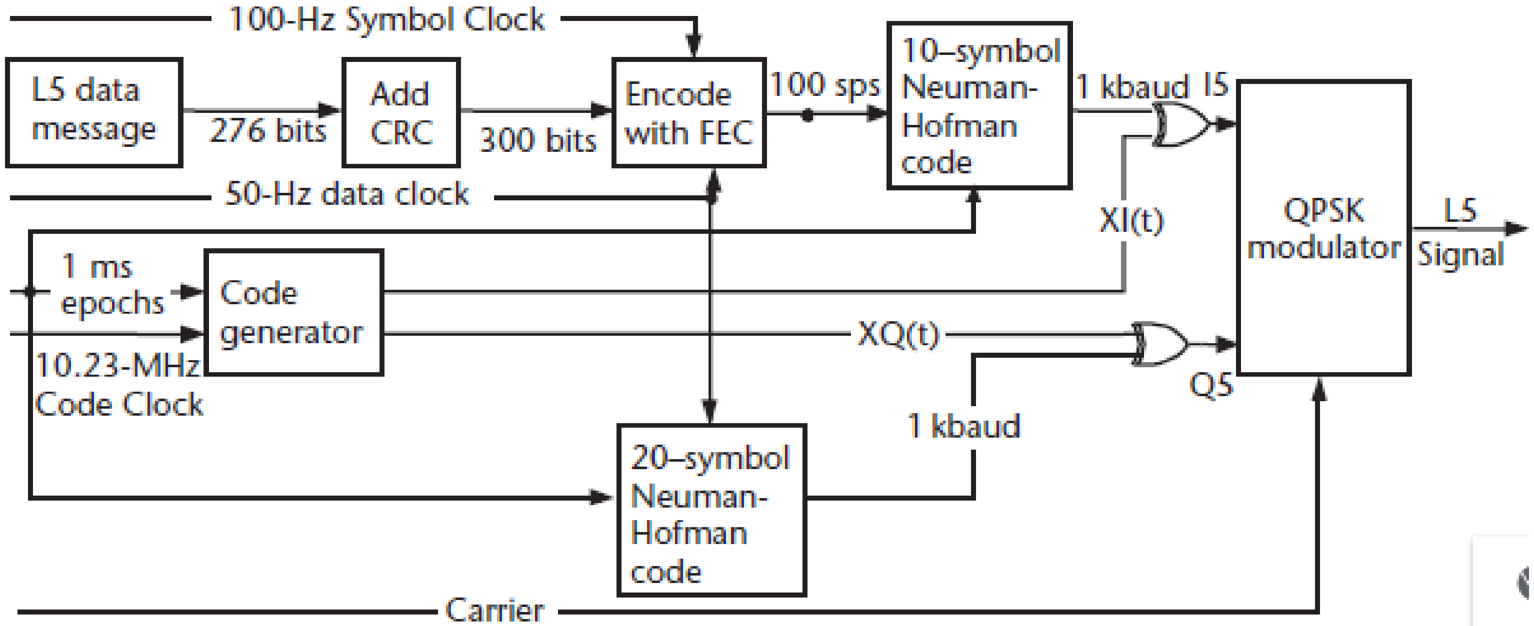


Figure 4.24 L5 signal generation.

M Code

- The modernized military signal (M code) is designed exclusively for military use and is intended to eventually replace the P(Y) code.
- During the transition period of replacing the GPS constellation with modernized SVs, the military user equipment will combine P(Y) code, M code, and C/A code operation in the so-called YMCA receiver.
- To accomplish the spectral separation shown in Figure 4.20, the new M-code employs BOC modulation. Specifically, M-code is a BOCs (10,5) signal.
- The first parameter denotes the frequency of an underlying square wave subcarrier, which is 10 × 1.023 MHz, and the second parameter denotes the underlying M-code generator Code chipping rate, which is 5 × 1.023 Mchip/s.
- Figure 4.26 depicts a very high level block diagram of the M code generator. It illustrates the BOC square wave modulation of the underlying M code generator that results in the split spectrum signals of Figure 4.20.

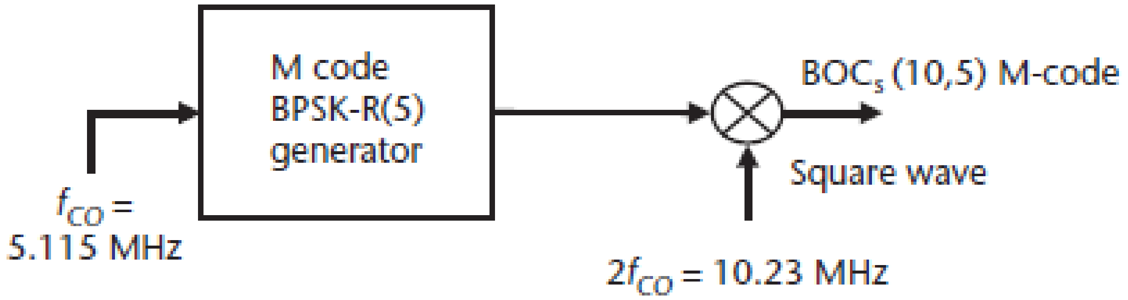


Figure 4.26 M code signal generation.

The primary military benefits that M code

- Improved security plus spectral isolation from the civil signals to permit noninterfering higher power M code modes that support antijam resistance.
- Enhanced tracking and data demodulation performance, robust acquisition, and compatibility with C/A code and P(Y) code.

It accomplishes these objectives within the existing GPS L1 (1,575.42 MHz) and L2 (1,227.60 MHz) frequency bands.