Chapter 6

GNSSs, Signals, and Receivers

Mohamed Tamazin, Malek Karaim and
Aboelmagd Noureldin

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.74677

Abstract

This chapter describes Global Navigation Satellite Systems (GNSSs) and their signal characteristics, beginning with an overview of Global Positioning System (GPS) architecture and describing its three primary segments: control, space, and user segments. After that, it addresses the GPS modernization program including the new civilian and military signals and their significance. It continues by outlining the GPS signal characteristics and the sources of GPS measurement error. GPS receivers as well are briefly described. Then, it gives an overview of the GLONASS and describes its modernization program. Additionally, it delves into many aspects the GLONASS, including GLONASS signal characteristics, the GLONASS radio frequency (RF) plan, pseudorandom (PR) ranging codes, and the intra-system interference navigation message. Finally, GPS and GLONASS are compared to highlight the advantages of combined GPS and GLONASS measurements over the GPS-only measurements.

Keywords: GNSS, GPS, GLONASS, signals, GNSS modernization

1. Introduction

Navigation solutions have become part of our daily life due to their widespread use in a range of applications including agriculture, navigation by land vehicles, and pedestrian navigation. A key navigation technology used in such applications is Global Navigation Satellite Systems (GNSSs), and several such systems currently provide this service. The US Global Positioning System (GPS) was this first such fully functional system. GLONASS, the Russian system, was the second to be active, and it also has global coverage. Similarly, the European Union satellite navigation system, Galileo, is scheduled to be fully operational in 2018.

While each of these systems has unique characteristics, all have major aspects in common. Each has a space segment, control segment, and user segment. What is more, all are based on transmitting radio frequency (RF) signals in a one-way fashion from satellites to receivers on and near the Earth's surface. Using measurements obtained from these signals, a GNSS receiver can find its position, velocity, and time (PVT) solution. Moreover, all GNSS systems use the notion of time-of-arrival (TOA) ranging. This requires measuring the signal transit time and the time interval the signal takes to travel between the satellite and the receiver to calculate the receiver-to-satellite range [1]. The transmitter-to-receiver distance can then be obtained by multiplying the signal transit time by the speed of light.

This chapter provides an overview of Global Positioning System (GPS) and GLONASS and their signals. First, it describes the system architecture in terms of the three main segments: control, space, and user. Then, it addresses the new civilian and military GPS signal characteristics, highlighting their significance. Following that, it briefly discusses the GPS measurement error sources. The chapter also covers essential aspects of the GLONASS system, including GLONASS signal characteristics, the GLONASS modernization program, the GLONASS Radio Frequency (RF) plan, pseudorandom (PR) ranging codes, and the intra-system interference navigation message. Finally, advantages of combining both GPS and GLONASS are listed to give the reader insight into the benefits of such integration.

2. Overview of GPS

GPS provides three-dimensional positioning and navigation services for both civilian and military users [2]. The GPS receivers use the TOA ranging to generate code pseudorange to determine the user's position. They also monitor changes in signal frequency to produce a rate of change of range measurements to determine velocity [3]. The time between the transmission of the signal and its arrival at the receiver is measured. The transmitter-to-receiver distance can then be obtained by scaling the signal transit time by the speed of light. Using the concept of trilateration, a GPS receiver can determine its position using the measured travel time along with the satellites' locations that are obtained from the navigation message carried by the signal. Though three satellites can be used to determine the user's position, at least four are required owing to an additional estimation of the receiver clock offset.

Figure 1 illustrates the concept of position fixing by trilateration by using the range to three satellites. Using four satellites to find the position improves the accuracy of the solution by eliminating the receiver clock offset. The first and second user-to-satellite range measurements define two spheres on two different satellites, and the intersection of these two spheres defines a circle of possible receiver positions. A third range measurement, intersecting with the first two, narrows those receiver positions to an ambiguous pair, while the fourth measurement resolves this ambiguity and determines the clock bias. The GPS positioning equations are found in [1–6]. Military GPS signals are more robust against interference and spoofing than civilian signals [3]; hence, the position determined by military signals is more precise than the position determined using civilian signals.

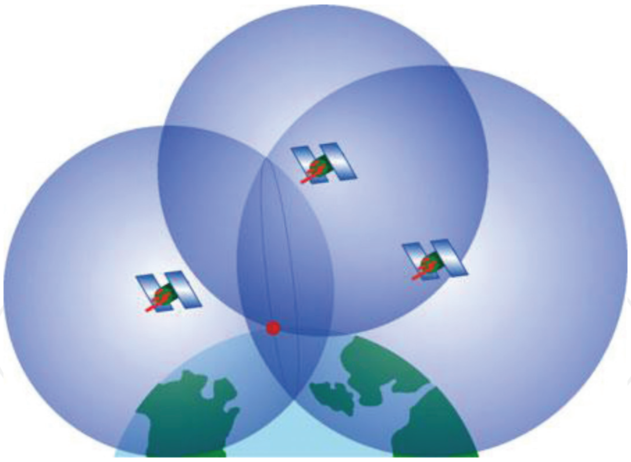


Figure 1. The concept of position fixing by trilateration using signals from three satellites. The user's position is indicated by the red dot [4].

3. The GPS structure

As mentioned earlier, the GPS is composite of three segments [7]: the space segment, a constellation of satellites orbiting the Earth at very high altitudes; the control segment, made up of a group of ground control stations; and the user segment, a user's equipment or simply the variety of military and civilian receivers. **Figure 2** illustrates the three segments, which are discussed in greater detail in this section.

3.1. The space segment

The GPS space segment is made up of a constellation of satellites that continuously broadcasts RF signals to users. In recent years, the US Air Force has operated 32 GPS satellites, of which 24 are available 95% of the time [4]. GPS satellites travel in medium Earth orbit (MEO) at an altitude of approximately 20,200 km, and each circles the Earth twice a day, meaning that the orbital period is approximately 12 h [7]. These satellites are distributed among six equally-spaced orbital planes, each having a target inclination of 55° [6], a satellite distribution that improves the visibility of satellites to GPS users across the globe, thereby enhancing navigation accuracy. GPS satellites broadcast RF signals containing coded information and navigation data, enabling a receiver to calculate pseudoranges and Doppler measurements to estimate position, velocity, and time.

In June 2011, the US Air Force successfully expanded its GPS constellation, known as the "Expandable 24" configuration [9]. Three of the 24 slots were upgraded, and six satellites were repositioned; thus, three additional satellites were added to the constellation. With a 27-slot constellation, GPS improved satellite visibility across the globe. **Table 1** summarizes the features of the current and future generations of GPS satellites, including Block IIA (second generation, "Advanced"), Block IIR ("Replenishment"), Block IIR (M) ('Modernized"), Block IIF ("Follow-on"), and GPS III [10].

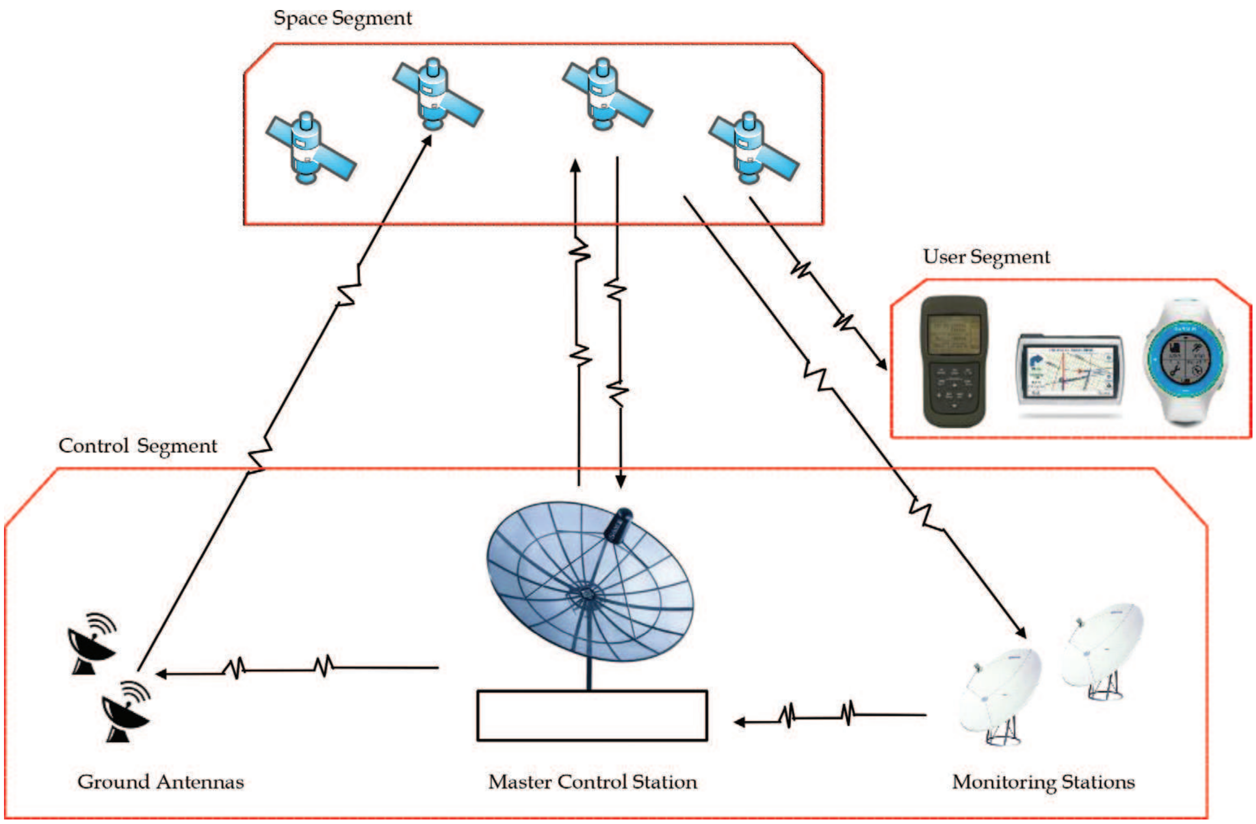


Figure 2. The GPS segments [8].

3.2. The control segment

Made up of a global network of ground facilities that track GPS satellites, the GPS control segment's main tasks are the control and maintenance of the system through monitoring and analyzing signal transmissions and sending commands and data updates to the GPS constellation.

Referring to [7], the current operational control segment includes a Master Control Station (MCS), an alternate master control station, 12 command and control antennas, and 16 monitoring sites. The locations of these facilities are shown in **Figure 3**.

3.3. The user segment

The user segment is represented by the wide array of types of GPS receivers. These capture and track satellite signals and process signals transmitted by GPS satellites, estimate the user-to-satellite ranges and range rates, and compute a PVT solution [12]. A GPS receiver had cost more than $100,000 in the mid-1980s; nowadays, an on-chip receiver is available in the market for less than $20, and it is estimated that more than 1 million receivers have been produced each year since 1997 [1]. As GPS is available at no direct charge to users, they can use receivers at any time and any place across the globe to determine their position [6].

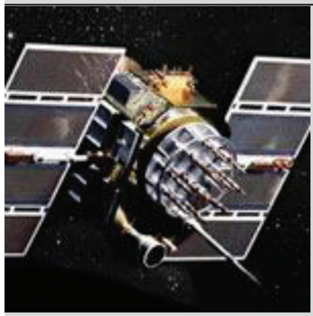
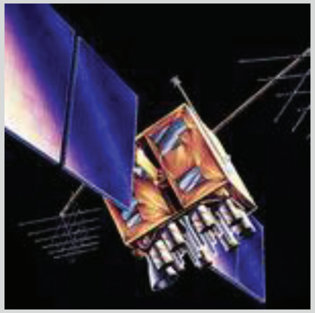
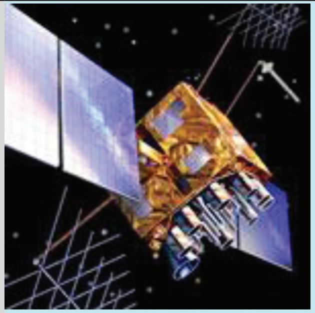
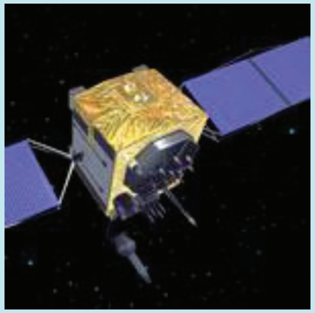
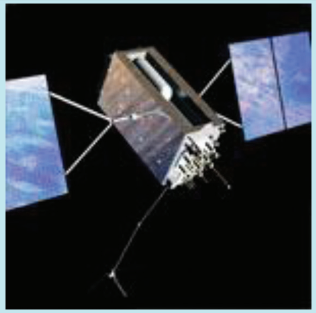
Legacy satellites		Modernized satellites		
				
Block IIA	Block IIR	Block IIR (M)	Block IIF	GPS III
6 Operational	12 Operational	7 Operational	6 Operational	Now in production
• Coarse acquisition (C/A) code on L1 frequency for civil users • Precise P(Y) code on L1 and L2 frequencies for military users • 7.5-year design lifespan • Launched in 1990–1997	• C/A code on L1 • P(Y) code on L1 and L2 • On-board clock monitoring • 7.5-year design lifespan • Launched in 1997–2004	• All legacy signals • Second civil signal on L2 (L2C) • New military M code signals for enhanced jam resistance • Flexible power levels for military signals • 7.5-year design lifespan • Launched in 2005–2009	• All Block IIR (M) signals • Third civil signal on L5 frequency (L5) • Advanced atomic clocks • Improved accuracy, signal strength, and quality • 12-year design lifespan • Launched since 2010	• All Block IIF signals • Fourth civil signal on L1 (L1C) • Enhanced signal reliability, accuracy, and integrity • No Selective Availability • Satellites 9+: laser reflectors; search and rescue payload • 15-year design lifespan • Begins launching in 2016

Table 1. The features of the current and future generations of GPS satellites [10].

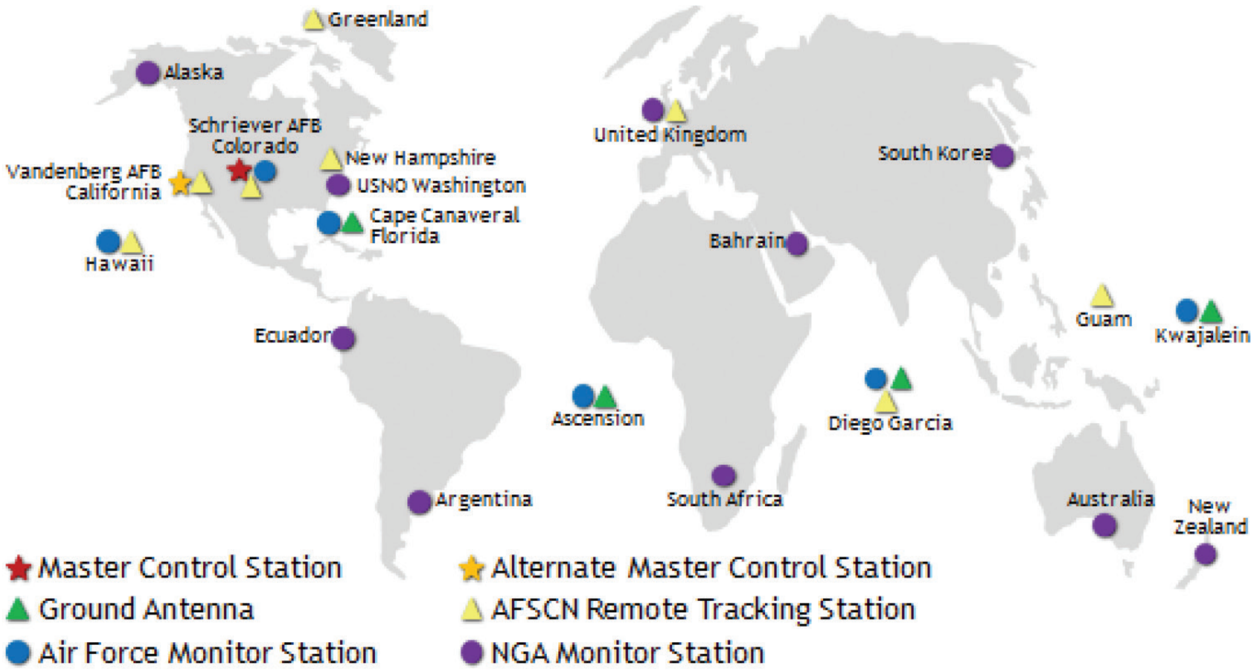


Figure 3. The locations of the GPS Master Control Station, an alternate Master Control Station, 12 command and control antennas, and 16 monitoring sites [11].

4. GPS signal characteristics

GPS satellites produce a central L-band frequency of 10.23 MHz using very stable clocks. Satellites then multiply this frequency by 154 and 120 to generate two carrier frequencies at L1 = 1575.42 MHz and L2 = 1227.60 MHz [13]. GPS signals consist of a carrier signal with frequency L1 or L2, a unique code assigned to each satellite, and a data message conveying information about satellite position, velocity, and clock bias. The two carrier frequencies are modulated by a combination of the data message and the unique code to carry required information to the user. The L1 frequency is modulated by two ranging code signals: the coarse/acquisition code (C/A) and the precise (P) code [2].

Each satellite has a unique C/A PRN code, and all these PRN codes are nearly orthogonal to each other, enabling a GPS receiver to differentiate among the satellites even though the satellites are broadcasting on the same two carrier frequencies, L1 and L2 [14]. Each C/A code repeats every millisecond and has a length of 1023 bit. The duration of each chip in a C/A code is about 1 ms, and the code rate is 1.023 MHz (or megachips/second (Mcps)) with a wavelength of about 300 m. The duration of the P code is about 7 days, and it modulates both L1 and L2. Used only by the military, this code has a rate of 10.23—10 times than that of a C/A code. The P code wavelength is about 30 m, making it much shorter and consequently much more precise than the C/A code [2].

The last key part of the GPS signal is the navigation message. It takes 12.5 min to receive the entire message, which is downloaded at a rate of 50 bit/s [6]. Its most important parts are the ephemeris, almanac data, and satellite clock bias parameters.

http://dx.doi.org/10.5772/intechopen.74677

To prepare the GPS signal for transmission by the satellite, first, an XOR operation is applied to combine the binary navigation message with the code. If the message bit and the code chip are the same, the result is 0; if they are different, the result is 1. Second, the combined signal is merged with the carrier using binary phase shift keying (BPSK) modulation: a "0" bit leaves the carrier signal intact, whereas a "1" bit causes the signal to be multiplied by −1 and shifts the carrier by 180°. **Figure 4** illustrates this process.

As mentioned above, the PRN code patterns are nearly orthogonal, an important property that makes the satellite identification process much easier [2]. Two codes are orthogonal when the sum of their term products shifted arbitrarily against each other is nearly zero. The cross correlation function for satellites m and n, with PRN codes $C^{(k)}$ and $C^{(l)}$, is expressed as

$$\sum_{1}^{1023} C^{(k)}(i) \cdot C^{(l)}(i+n) \approx 0, \textit{for all } k \neq l \tag{1}$$

This orthogonality makes the cross satellite interference small [14].

Another important property of PRN codes is that each PRN pattern is almost uncorrelated with itself:

$$\sum_{1}^{1023} C^{(k)}(i) \cdot C^{(k)}(i+n) \approx 0, \textit{for all } |n| \geq 1 \tag{2}$$

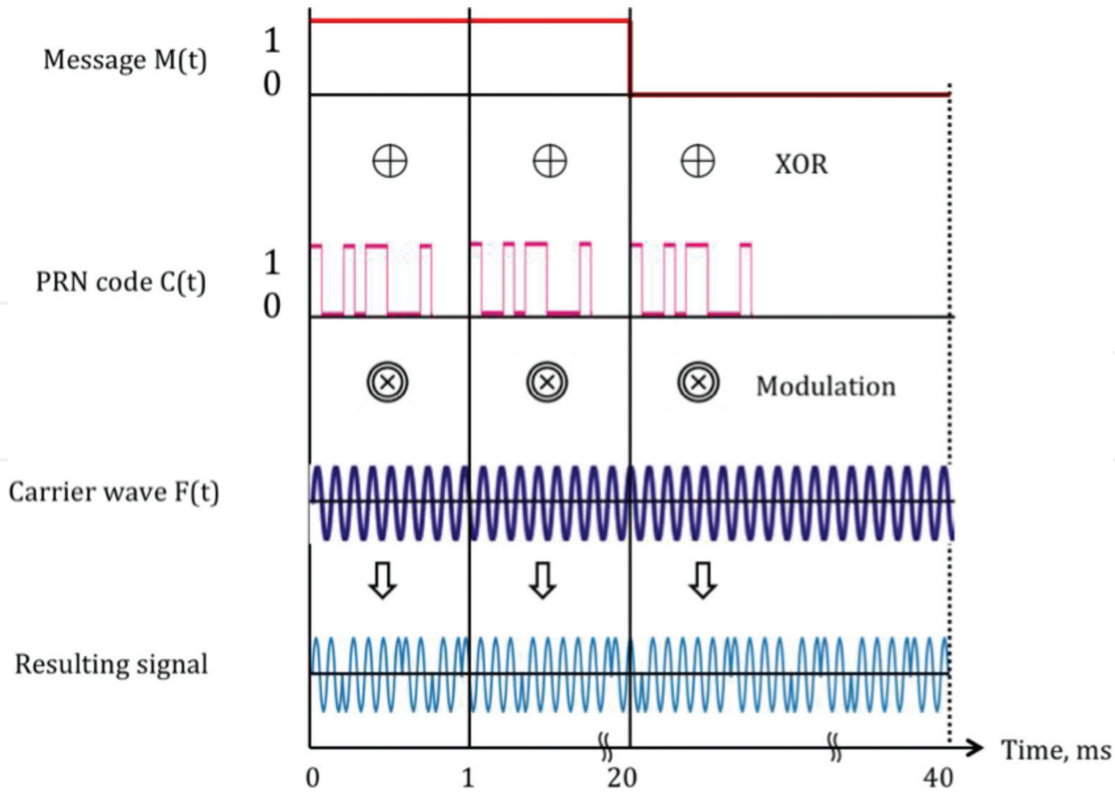


Figure 4. GPS signal structure [15].

Autocorrelation of a PRN pattern is nearly zero for any shift |n| ≥ 1. When n is zero, however, the function reaches a peak. Using this feature, the receiver compares the PRN code on the received signal against a locally generated replica of the same code to identify which satellite has generated the corresponding signal.

5. GPS receiver architecture

Figure 5 shows the high-level architecture of a GPS receiver. GPS receivers are made up of the antenna, RF front end, local oscillator, and navigation processor. The first element of the receiver architecture is the antenna, which must be able to receive right-hand circularly polarized (RHCP) signals because this is the type of signal transmitted by GPS satellites [1]. Also important is the antenna gain pattern, which indicates how well the antenna performs at various center frequencies, polarizations, and elevation angles.

The preamplifier is the first active component that comes after the antenna. It is often housed in the same enclosure as the antenna element. Because the antenna can receive multiple frequency bands, typically, there is one preamplifier per band; nonetheless, a single preamplifier may cover multiple bands. The main function of the preamplifier is to amplify the signal at the antenna's output [3]. Preamplifiers generally have three components: (1) a preselector filter that removes out-of-band interference and limits the noise bandwidth, (2) burnout protection that prevents possible high-power interference with the electronic components of the receiver, and (3) a low-noise amplifier (LNA). GPS signals are typically very weak, around −160 dBw or 10–6 W; thus, an LNA amplifies the signals by 20 to 35 dB to increase them to levels suitable for processing [17].

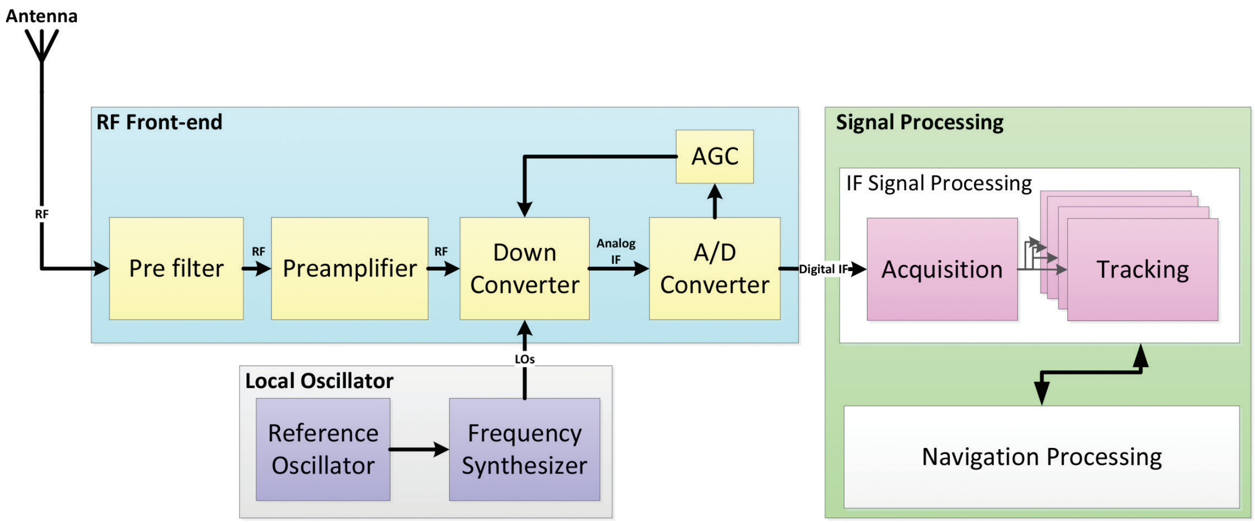


Figure 5. High-level architecture of GPS receivers [16].

After the antenna and LNA comes the RF front end. This unit generates a clean sampled signal for the signal-processing block [12]. Indeed, the front-end pre-filters amplify, downconvert, and digitize the received signal.

Filtering is crucial for several reasons: it rejects out-of-band signals, reduces noise in the received signal, and lessens the impact of aliasing. Wide bandwidth signals can provide high-resolution measurements in the time domain but demand higher sampling rates, causing the receiver to consume much more power [18]. A filter can mitigate this by allowing narrower band signals.

Down-conversion is the process performed by the front end to lower the RF signal frequency to either an intermediate frequency or directly to baseband [3]. This is necessary to facilitate the sampling and filtering processes. The down-conversion is often done using a mixer which multiplies the received signal by a locally generated replica and, then, filters the output signal to remove double-frequency terms [1], as depicted in **Figure 6**. The filtering and down-conversion of the signal frequencies are typically achieved in multiple, consecutive, stages due to the difficulty in implementing a stable band-pass filter with a high central frequency.

The last stage in the processing of the signal inside the RF front end is the conversion of the analogue signal to a digital signal. The band-pass sampling completes both discretization and down-conversion of the signal [12].

GPS receivers make their measurements using the estimates of the signal TOA and received carrier phase and frequency. A single local reference oscillator (see **Figure 4**) forms all frequency references in the receiver [19]. Because the oscillator is critical to receiver performance, particular attention needs to be given to its size, power consumption, stability (both short and long terms), and its temperature and vibration sensitivity [3]. In some cases, GPS receivers have multiple frequency references for down-conversion. In these instances, each mixer requires a precise reference frequency. The process of producing reference frequencies in the receiver from the local oscillator is called frequency synthesis, which uses a combination of integer and fractional frequency multiplications [20].

Figure 4 illustrates that the final stage of a GPS receiver is the navigation processor. This unit receives the conditioned signal (the output of the front end). This filtered and down-converted signal should contain all the necessary information carried by the signal when it

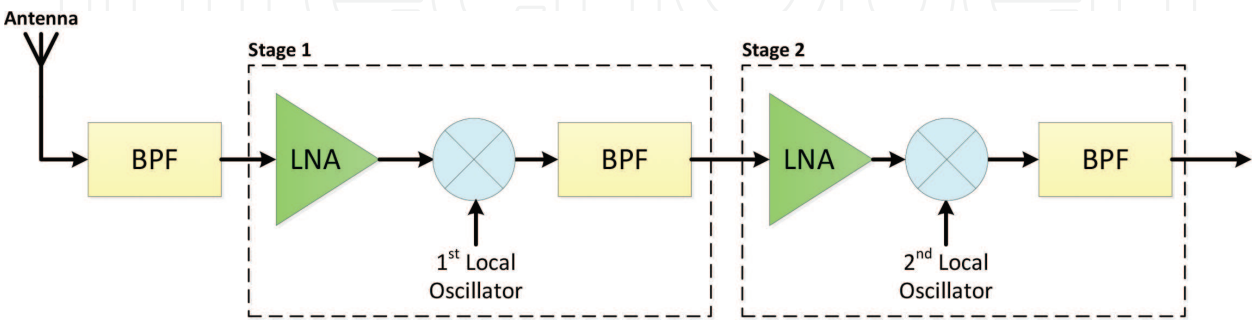


Figure 6. Block diagram of two-cascaded-stage down-conversion.

was received by the antenna. At the navigation-processing stage, the receiver extracts the measurements for pseudorange and rate-of-change of pseudorange to all satellites in view, and using these, it estimates the PVT solution for the antenna.

The navigation process usually happens in two stages: first, the pseudorange and pseudorange rates to each satellite are estimated; second, the user's position, velocity, and time information are estimated using these measurements. Signal processing at this level can be, in turn, divided into the following stages [12]:

- Signal acquisition: This involves detection of the signals from satellites in view and provides a rough estimation of the code delay and the Doppler frequency of the incoming signal from each satellite.
- Signal tracking: This is a recursive estimation process that continuously updates estimates of time-varying signal parameters.
- Signal monitoring: This is simultaneous with tracking and involves estimation of several parameters, including the carrier-to-noise ratio (C/N_0). The receiver uses signal monitoring to decide when loss of lock of signal occurs, for example.
- Navigation message extraction: This process, too, happens in parallel to signal tracking. The navigation message extraction includes satellite ephemerides' decoding.
- Measurement generation: Uses the tracking parameters to estimate ranges and range rate of change for all visible satellites.
- PVT solution: Uses the range and range rate of change estimates to compute the desired navigational solution.

6. GPS measurements

While tracking a satellite signal, a GPS receiver monitors three parameters: pseudoranges, carrier phase, and Doppler [7, 11]. A pseudorange is calculated by measuring the signal transit time from a satellite to the receiver and is described as "pseudo" ranges because these measurements are corrupted by satellite and receiver clock biases [6]. Carrier phase measurements track the difference between the carrier phases for the received and a locally generated replica of the signal. The Doppler measurement reflects the rate of change of the carrier phase [12].

7. GPS errors

GPS signals and measurements are prone to many disturbance factors commonly known as GPs errors. The first error source is due to the drift of both the satellite and receiver clocks.

http://dx.doi.org/10.5772/intechopen.74677

Despite their high level of accuracy, satellite clocks still drift slightly from GPS time. For affordability reasons and size, receiver clocks are usually much cheaper; consequently, they drift from GPS time rapidly. This drift translates into significant range errors in receiver measurements.

Once it departs the satellite antenna, the GPS signal needs to travel thousands of kilometers to reach to the receiver antenna and then the receiver circuitry. The first and longer part of this trip is by space where the signal maintains its characteristics. However, when the signal enters the atmosphere, this medium causes some unwanted effects. The two primary layers of the atmosphere, namely, ionosphere and troposphere, respectively, will add delays to the signal transit time and, hence, cause some errors in the measurements.

Once it nears the receiver antenna, the signal usually experiences reflections and echoes, i.e., it often bounces off objects near the receiver causing it to hit the antenna from different directions—a phenomenon known as multipath. Multipath is one of the major sources of errors, which harms GPS signals [6]. All aforementioned disturbances are a result of the nature of the signal or the propagation medium and are considered unintentional. Intentional signal degradation or replacement is, in many cases, a more problematic source of GPS errors. One major type of intentional errors is signal jamming. Signal jamming is deliberate interference caused by broadcasts of radio frequency (RF) signals around the receiver neighborhood with the aim of preventing the tracking of true GNSS signals.

8. Overview of GLONASS

Like GPS, GLONASS offers three-dimensional positioning and navigation services for both civilian and military users. In this system too, users determine their position and velocity using pseudorange and carrier phase measurements. Both systems use time-of-arrival (TOA) ranging to determine user position and velocity [21]. The GLONASS includes three components: a constellation of satellites (equivalent to the GPS space segment), ground control stations (also equivalent to the GPS control segment), and user's equipment (as well, equivalent to the GPS user segment) [22]. The ground segment consists of a master control station (MCS). The user segment consists of all the military and civilian receivers.

8.1. GLONASS space segment

The full GLONASS constellation consists of 24 satellites [21]. According to [23], 26 functional GLONASS-M satellites are in orbit, and 22 of them are in service, with four more having reserve status. With the launches of several GLONASS-M satellites and the GLONASS-K satellites, a full constellation of 24 satellites is now available.

GLONASS satellites circle the earth in three orbital planes evenly spaced by 120°. Each plane has eight satellites that are separated by an argument of latitude of 45°, and those satellites have a target inclination of 64.8°—considerably higher than that of GPS satellites. GLONASS orbits are highly circular with eccentricities smaller than those of GPS and closer to zero [24]. GLONASS satellites have a radius of 25,510 km, which gives an altitude of 19,130 km [22]. Compared to GPS, GLONASS has a shorter orbital period (11 h 15 min 40 s) due to its lower altitude. A comparison of the main differences between GLONASS and GPS is given in later sections.

8.2. GLONASS control segment

A key task of the GLONASS control station is to synchronize the satellite clocks with GLONASS time and calculate the time offset between GLONASS time and UTC [3]. It also uploads clock corrections, predicted ephemeris, and almanac data to GLONASS satellites. Moreover, this segment monitors the status of the current GLONASS constellation and corrects the orbital parameters accordingly. GLONASS uploads its navigation data to the satellites twice a day, while this is done once a day by the GPS [25].

GLONASS's ground control segment has two main parts: the system control center (SCC), located in Moscow, and a network of command tracking stations (CTS), located throughout the former Soviet Union (SU). The roles of the SCC and CTS are similar to those of the GPS Master Control Station and its monitoring stations [22].

8.3. GLONASS user segment

Like that for GPS, the GLONASS user segment contains the end user receiver equipment, which tracks and receives satellite signals. Similar to GPS receivers, these also process signals transmitted by the seen satellites, estimate pseudorange and rate of change of pseudorange from these signals, and calculate a position, velocity, and time (PVT) solution.

9. GLONASS modernization

The design of the GLONASS satellite has been improved several times, resulting in three satellite generations: the original GLONASS (started in 1982), GLONASS-M (started in 2003), and GLONASS-K (started in 2011). There are two types of GLONASS spacecraft in the constellation: the GLONASS-M satellite and GLONASS-K satellite. A brief description of each type is as follows.

9.1. First generation (GLONASS)

The first generation of GLONASS satellites (Uragan) was launched in 1982. Each satellite weighed approximately 1250 kg and was equipped with a basic propulsion system enabling it to relocate within its orbit [26]. Initially, GLONASS's main role was to control the formulation of the navigation signal and obtain the satellite ephemeris and almanac data. This generation is no longer in use.

http://dx.doi.org/10.5772/intechopen.74677

Satellite series	Launch	Current status	Clock error (s)
GLONASS	1982	Out of service	5×10^{-13}
GLONASS-M	2003	In service	1×10^{-13}
GLONASS-K1	2011	In service	5×10^{-14}
GLONASS-K2	2013	Design phase	1×10^{-14}

Table 2. Roadmap of GLONASS modernization.

9.2. Second generation (GLONASS-M)

GLONASS-M, the modernized version of the former constellation, was launched in 2003, boasting a longer design lifespan of about 7 years and a civil modulation to its L2 frequency band. These changes improved navigation performance, provided updated navigation radio signals, and increased the stability of those signals [27].

9.3. Third generation (GLONASS-K)

Significant improvements came in 2011 with the launch of the third generation, GLONASS-K. Among these changes was the increase of its satellites' lifespan to a decade and the reduction of their weight by half [22]. The accuracy was improved as well, with each satellite transmitting five navigation signals instead of two. These new satellites were intended to transmit four military signals on the L1 and L2 carriers and one civilian signal on the L3 frequency. The GLONASS-K satellites broadcast other signals; two of them are compatible with GPS/Galileo navigational signals. Adding the CDMA signals improved compatibility and enabled interoperability with services provided by other GNSSs, which paved the way for the production of receivers usable with all GNSSs [23]. **Table 2** shows how the system was upgraded over the years.

10. GLONASS signal characteristics

The GLONASS Interface Control Document (ICD) held by the Russian Institute of Space Device Engineering provides the detailed information about the structure of the GLONASS radio signals [22]. In contrast to GPS, GLONASS uses frequency division multiple access (FDMA) for signal modulation. This technique uses the same pseudorandom noise (PRN) code for all satellites to produce a spread spectrum signal. GPS, on the other hand, uses code-division multiple access (CDMA) to identify each individual satellite. FDMA provides better interference rejection for narrow-band interference signals compared to CDMA. In CDMA a single source of narrow-band interference source can disrupt all GPS satellite signals simultaneously, such interference only affects one FDMA GLONASS signal at a time. A shortcoming of FDMA, however, is that it requires more spectrum than CDMA systems. GLONASS uses L1 in the range of 1602.0–1615.5 MHz and L2 in the range of 1246.0–1256.5 MHz to transmit C/A code and P code.

10.1. GLONASS RF frequency plan

The nominal values of L1 and L2 carrier frequencies are expressed as [22]

$$f_{k1} = f_{01} + K\Delta f_1 \tag{3}$$

$$f_{k2} = f_{02} + K\Delta f_2 \tag{4}$$

where K is frequency channel number of the signals transmitted by GLONASS satellites in the L1 and L2 sub-bands:

$$f_{01} = 1602 \text{ MHz}; \Delta f_1 = 562.5 \text{ kHz, for sub} - \text{band L1}$$

$$f_{02} = 1246 \text{ MHz}; \Delta f_2 = 437.5 \text{ kHz, for sub} - \text{band L2}$$

Each satellite has a standard nominal frequency, with a value of 5.0 MHz that generates the carrier frequencies L1 and L2. The system uses 12 channels to switch among its 24 operational satellites. Antipodal satellites in the same orbit plane are separated by an argument of latitude of 180°, as illustrated in **Figure 7** [26].

10.2. GLONASS signal structure

GLONASS satellites, too, transmit two PRN codes: a coarse acquisition (C/A) code and a precise (P) code. The C/A code is transmitted only on the L1 frequency, while the P code is transmitted on both L1 and L2 frequencies. GLONASS uses bi-phase modulation to merge the carrier signal with a modulo-2 summation of the PRN code at a rate of 511 kHz, the navigation message at a rate of 50 bps, and a 100 Hz auxiliary meander sequence [21].

GLONASS-K satellites also broadcast new CDMA signals in the L3-band at a carrier frequency of 1202.025 MHz [23]. The chipping rate for the ranging code is 10.23 Mcps, and it repeats every 1 ms. The new signal, however, uses a quadrature phase shift keying (QPSK) technique with an in-phase channel dedicated for data and a quadrature channel for pilot information. This signal spectrum is depicted in **Figure 8**.

10.3. Standard accuracy ranging code (C/A code)

The C/A code is a 511-bit binary sequence that is modulated onto the carrier frequency at a chipping rate of 0.511 MHz and thus repeats every millisecond [3]. It is derived from the

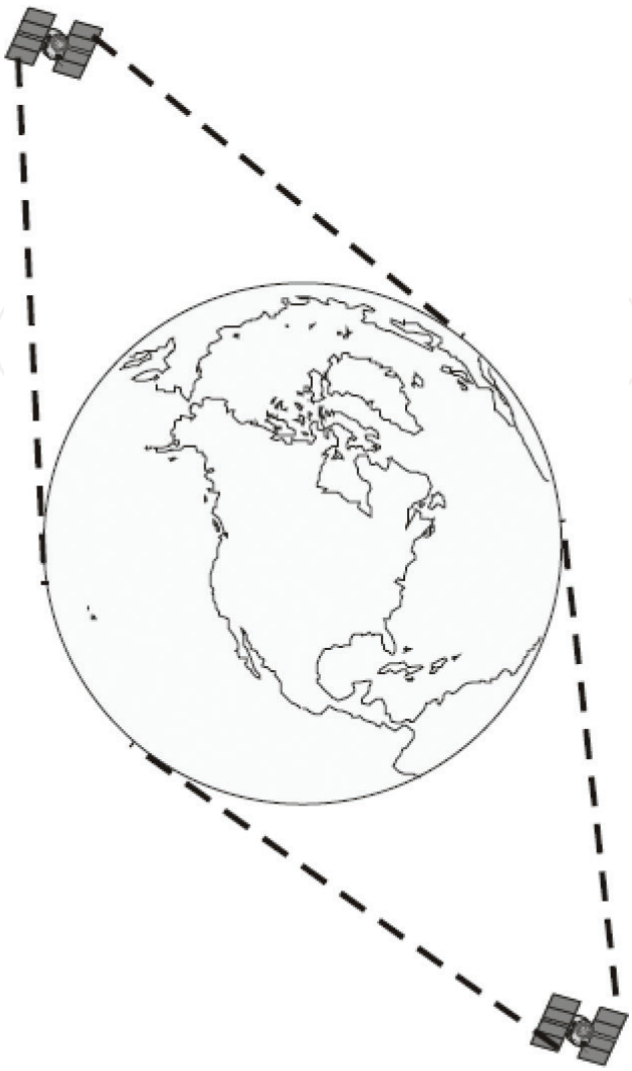


Figure 7. GLONASS antipodal satellites [3].

seventh bit of a nine-bit shift register. The code is described by the irreducible polynomial $1 + x^5 + x^7$. The initial state is defined as each bit containing the value "1" [22].

10.4. High accuracy ranging code (P code)

The GLONASS P code is a 5.11-million-bit-long binary sequence. It is modulated onto the carrier signal at a rate of 5.11 MHz and, hence, repeats every 1 s [3].

10.5. Intra-system interference

The intra-system interference in GLONASS is due to the intercorrelation properties of the ranging codes and the used FDMA technique [22]. The interference, indeed, happens inside the receiver between the signals transmitted on frequency channel K = n and signals transmitted on neighbor channels K = n + 1 and K = n − 1. In other words, this interference occurs when satellites with adjacent frequencies are visible at the same time.

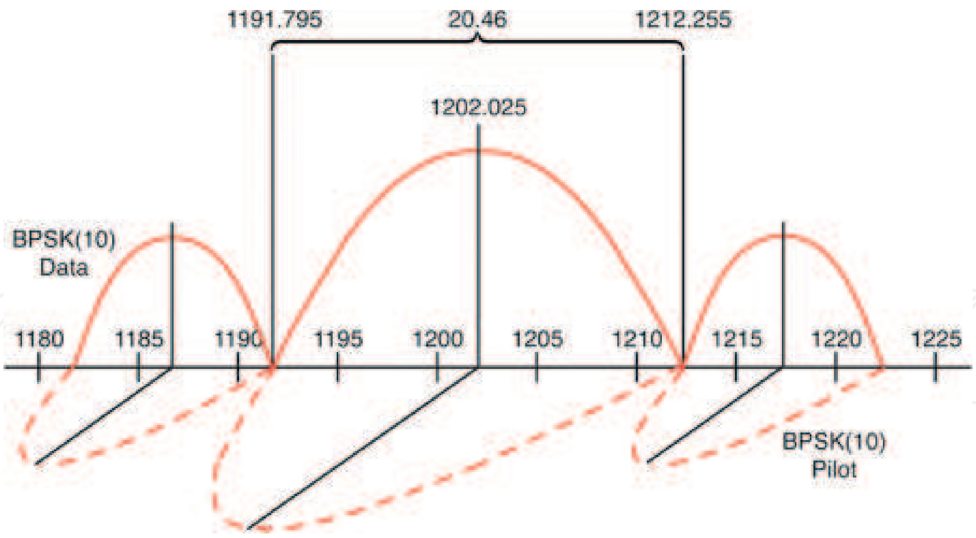


Figure 8. L3 CDMA signal spectrum [23].

10.6. GLONASS navigation message

The navigation message contains immediate and non-immediate data. It is broadcast from GLONASS satellites at a rate of 50 bps to provide users with necessary data for positioning, timing, and planning observations [22].

The immediate data contains information about GLONASS satellites. It is broadcast of a navigation signal which includes mainly the enumeration of the satellite time and the difference between the onboard time scale of the satellite and GLONASS time. The difference between the carrier frequency of the satellite signal and its nominal value is also included in this data along with ephemeris and other parameters.

The non-immediate data, on the other hand, contain information about almanac of the system. Almanac data provides information about the status of all satellites in the current constellation, coarse corrections of the onboard timescale for each satellite with respect to GLONASS time. Almanac data also have information about the orbital parameters of all satellites (orbit almanac) and correction to GLONASS time with respect to UTC (SU) and some other parameters [22].

11. Comparison between GPS and GLONASS

This section gives a brief comparison of GPS and GLONASS. It is essential to understand the similarities and differences between both GPS and GLONASS in particular when combining them in one navigation service or solution. Major differences between both systems are related to the constellation structure, the reference time system, the coordinates system, and the signal modulation or multiplexing technique. The following subsections briefly describe the GPS and GLONASS time and coordinate reference systems.

11.1. Time reference systems

Both GPS and GLONASS have their own time systems; thus, it is not straight forward to make time transformation from GLONASS time into GPS time or vice versa. The most important factor one must account for when processing data from a combined GPS and GLONASS is the difference between the two time scales.

11.2. GLONASS time system

As can be seen in **Table 2**, the daily satellite clock stability for GLONASS, GLONASS-M, and GLONASS-K is better than 5×10^{-13}, 1×10^{-13}, and 5×10^{-14}, respectively. The time shift between GLONASS time and the National Reference Time UTC (SU) is 3 h ICD (2008):

$$t_{GLONASS} = t_{UTC(SU)} + 03\text{h} \;\; 00\text{mins} \tag{5}$$

The following expression is used to align GLONASS satellite ephemeris at one instance with measurements given in UTC(SU):

$$t_{GLONASS} = t + \tau_c + \tau_n(t_b) - \gamma_n(t_b)(t - t_b) \tag{6}$$

where

t	time of transmission of the navigation signal in the onboard time scale,
τ_c	GLONASS time scale correction to UTC (SU) time,
t_b	index of a time interval within current day,
$\tau_n(t_b)$	correction to nth satellite time relative to GLONASS time at time t_b,
$\gamma_n(t_b)$	relative deviation of the predicted carrier frequency value of n-satellite from nominal value at time t_b.

GLONASS-M satellites transmit the difference between the GPS and GLONASS time scale (which is never more than 30 ns) [22].

11.3. Time transformation

GLONASS time could be transformed into GPS time using the following formula [27]:

$$t_{GPS} = t_{GLONASS} + \tau_c + \tau_u + \tau_g \tag{7}$$

where

$$\tau_c = \tau_{UTC(SU)} - t_{GLONASS} \tag{8}$$

		GLONASS	GPS
Constellation	Number of satellite	24	32
	Number of orbits	3	6
	Orbital inclination	64.8°	55°
	Orbital radius	25,510 km	26,560 km
	Orbital altitude	19,130 km	20,200 km
	Orbit period	11 h 15.8 min	11 h 58 min
Signal characteristics	Multiplexing	FDMA	CDMA
	Carrier frequencies	1602 + k × 0.5625 MHz 1246 + k × 0.4375 MHz	1575.42 MHz 1227.60 MHz
	Code frequencies	C/A code: 0.511 P code: 5.11	C/A code: 1.023 P code: 10.23
	Broadcast ephemerides	Position, velocity, acceleration	Keplerian elements
Coordinates system		PZ-90.02	WGS-84
Time system		GLONASS time	GPS time

Table 3. Comparison between GPS and GLONASS.

$$\tau_u = t_{UTC} - t_{UTC(SU)} \tag{9}$$

$$\tau_g = t_{GPS} - t_{UTC} \tag{10}$$

In combined GPS/GLONASS data processing, the differences between these time scales must be accounted for. Otherwise, systematic errors are introduced that will affect the combined positioning solution.

Table 3 summarizes vital parameters of GPS and GLONASS that must be considered when combining GPS/GLONASS data processing.

12. Advantages of combined GPS and GLONASS

In many cases, such as navigating in urban or mountainous areas, during aircraft high-dynamic scenario, or under the effect of interference, satellite visibility becomes an issue. In such situations, incorporating both GPS and GLONASS constellations in the navigation system may significantly improve the accuracy of the navigational solution. Merging both systems in one navigation solution provides the next significant advantages:

http://dx.doi.org/10.5772/intechopen.74677

- Increased satellite observability
- Remarkable increased spatial distribution of visible satellites
- Reduced horizontal and vertical dilution of precision (DOP) factors

On the other hand, the next considerations should be accounted for when combining GLONASS and GPS:

- The different aspects of the GLONASS and GPS navigation data
- The differences between the reference coordinate systems used in GLONASS and GPS
- The time scale offset between GLONASS and GPS

13. Conclusion

The demand for GNSS services and applications has been rapidly increasing. Luckily, we have more accessible GNSSs providing better functionality and broader coverage. Among these, GPS and GLONASS are fully functional at the time of writing. In this chapter, we gave a general overview of both systems, discussing the systems structure and signal characteristics, and provided an overview of the new features of GLONASS that intended to rectify the shortcomings of the GPS. The chapter is tailed with a short comparison between GLONASS and GPS highlighting advantages of combining both systems together.

Author details

Mohamed Tamazin[1], Malek Karaim[2]* and Aboelmagd Noureldin[2,3]

*Address all correspondence to: malek.karaim@queensu.ca

1 Electronics and Communications Engineering Department, Arab Academy for Science, Technology and Maritime Transport (AASTMT), Egypt

2 Electrical and Computer Engineering Department, Queen's University, Canada

3 Electrical and Computer Engineering Department, Royal Military College of Canada, Canada

References

[1] Bradford P, James S. Global Positioning System: Theory and Applications, Volume I. The American Institute of Aeronautics and Astronautics, Inc: Washington; 1996

[2] Pratap M, Per E. Global Positioning System: Signals, Measurements and Performance. 2nd ed. Massachusetts: Ganga-Jamuna Press; 2006

[3] Elliott K, Christopher H. Understanding GPS: Principles and Applications. 2nd ed. Artech House: Norwood; 2006

[4] Aboulmagd N, Tashfeen K, Jacques G. Fundamentals of Inertial Navigation, Satellite-Based Positioning and their Integration. Springer; 2013

[5] Kai B, Dennis A, Nicolaj B, Peter Ri, Søren J. A Software-defined GPS and Galileo Receiver: A Single-Frequency Approach. Birkhauser Boston: Springer; 2007

[6] Ahmed E. Introduction to GPS: The Global Positioning System. Artech House: Norwood; 2002

[7] ICD G. Navstar GPS Space Segment/Navigation User Interfaces, Interface Specification. IS-GPS-200E El Segundo, CA, USA2010

[8] Malek K. The Long Journey of a GPS Signal. Inside Signal Processing Newsletter. [Internet]. 2017. Available from: https://signalprocessingsociety.org/newsletter/2017/10/long-journey-gps-signal [Accessed: 2017-17-12]

[9] Camacho-Lara S. Current and Future GNSS and their Augmentation Systems in Handbook of Satellite Applications. New York: Springer; 2013. pp. 617-654

[10] USA Force. Space Segment [Internet]. Available from: http://www.gps.gov/systems/gps/space/ [Accessed: 2017-01-12]

[11] USA Force. Control Segment [Internet]. Available from: http://www.gps.gov/systems/gps/space/ [Accessed: 2017-01-12]

[12] Dan D. Fundamentals of GPS Receivers: A Hardware Approach. Springer; 2012

[13] Hofmann-Wellenhof B, Herbert L, James C. GPS Theory and Practice. New York: Springer; 1993

[14] Jay F. Aided Navigation GPS with High Rate Sensors. New York: McGraw-Hill; 2008

[15] Malek K. Real-Time Cycle-Slip Detection and Correction for Land Vehicle Navigation Using Inertial Aiding [Thesis]. Kingston: Queen's University; 2013

[16] Mohamed T. High Resolution Signal Processing Techniques for Enhancing GPS Receiver Performance [Thesis]. Kingston: Queen's University; 2015

[17] Sheffer DK, Lee TH. A 1.5-V, 1.5-GHz CMOS low noise amplifier. IEEE Journal of Solid-State Circuits. 1997;**32**:745-759. DOI: 10.1109/4.568846

[18] Jonas T, Per-Ludvig N, Christian S. A High-performance real-time GNSS software receiver and its role in evaluating various commercial front end ASICs. In: Proceedings of the 15th International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GPS 2002); 24 September 2002; Portland: ION;2002. p. 2554-2560

[19] Braasch MS and Van Dierendonck AJ. GPS Receiver Architectures and Measurements. In: Proceedings of the IEEE; January 1999. p. 48-64

[20] Ralph E, Arthur W. Dual down Conversion GPS Receiver with Single Local Oscillator. Google Patents (US5108334 A), 1992

[21] Lachapelle G. GPS Theory and Applications. ENGO 625 Course Lecture Notes. Department of Geomatics Engineering, University of Calgary, 2009

[22] GLONASS ICD [Internet]. 2008. Available from: http://www.GLONASS-ianc.rsa.ru [Accessed: 2011-20-04]

[23] Yuri U, Valeriy S, Grigory S, Vyacheslav D, Alexander P, Sergey K. GLONASS developing strategies for the future. In: GPS World Magazine. April 2011. p. 42-49

[24] Keong J. Determining Heading and Pitch Using a Single Difference GPS/GLONASS Approach. UCGE Reports No. 20134. Department of Geomatics Engineering, University of Calgary, 1999

[25] GPS ICD [Internet]. 2010. Available from: http://www.gps.gov/technical/icwg [Accessed: 2011-09-04]

[26] Abbasiannik S. Multichannel Dual Frequency GLONASS Software Receiver in Combination with GPS L1 C/A. UCGE Reports No. 20215. Department of Geomatics Engineering, University of Calgary, 2009

[27] Cai C. Precise Point Positioning Using Dual-Frequency GPS and GLONASS Measurements. UCGE Reports No. 20291. Department of Geomatics Engineering, University of Calgary, 2009