Satellite Communications in Shipping

Global Navigation Satellite Systems – GNSS

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ABSTRACT

This paper, titled "Global GNSS Navigation Satellite Systems in Shipping" was devised for the course in Shipping Informatics of the Interdepartmental of Postgraduate Studies Program entitled: "Informatics and Computational Biomedicine" of the flow: "Informatics", at the University of Thessaly. Writing was done according to the IEEE design principles. The thematic section presents the general principles of operation of the GNSS satellite navigation systems, a brief description of the major satellite navigation systems followed by satellite GPS receivers and finally the maritime uses of GNSS systems, its prospects and capabilities.

Keywords:

GNSS, GPS, Glonass, BeiDou, Galileo.

I. *INTRODUCTION*

The range of technologies included in satellite communications is quite large and starts from the track engineering for the movement of satellites, as well as the study of the phenomena of propagation and transmission of satellite signals. Our work aspires to introduce the reader to the basic principles of operation of modern GNSS satellite navigation systems, their description and study, their structure, their possibilities, and how they can be developed in terms of their needs in shipping. It also aims to illustrate this modern piece of global communications in a simple and comprehensible way.

II. *CHAPTER FIRST: GENERAL PRINCIPLES OF OPERATION OF THE GNSS SATELLITE NAVIGATION SYSTEMS*

A. Historical evolution, current situation and prospects of satellite navigation systems.

1. The creation of the first satellite navigation systems (1960-1970).

The creation of the first satellite navigation systems dates back to the end of the 1950's and, in particular, in 1957, with the launch of the first artificial satellite Sputnik-1 by the Soviet Union. Competition between the two superpowers of the era (the US and the Soviet Union) led to the creation of scientific and defense programs aimed at exploiting space applications. Based on the results of US satellite tracking studies, it turned out that it was possible to calculate the parameters defining the elliptical trajectory of an artificial satellite and then to determine its position at any time. This has led to the exploration of the possibility of creating a highly accurate positioning satellite system for US Navy operational requirements.

The first satellite navigation systems were developed in the 1960's by the US and the Soviet Union (US Navsat / Transit System and Tsikada System of the Soviet Union) for military first-time uses, providing global coverage regardless of the prevailing visibility conditions. Despite the fact that these first satellite systems were designed for military use, after their full development, they were also used for various civilian uses (navigation, aviation, geodesy, etc.), remaining in use around the end of the 1990's.

1) US Navsat / Transit satellite system.

In 1959, the US Navy commissioned John Hopkins University's Applied Physics Laboratory to set up a satellite navigation system to support its nuclear submarines, in particular to provide high precision stigma. This system was completed in 1963, under the name Navsat / Transit. During its use, it was found that the system did not provide the desired positioning accuracy and thus in 1967 it was released for commercial use. In addition to navigation, Navsat / Transit was also used in applications such as aviation and geodesy.

This system was designed to operate with 5 or 6 satellites, traveling in polar orbits and 1100 km high above the Earth's surface, with a 106-minute stretch. The orbital planes of the system's satellites were designed to intersect the earth's axis of rotation and form equidistant angular distances. However, over time these levels deviated from their original position and the respective satellites have begun to be replaced by new satellites. With the above arrangement and rotation of the satellites, each point of the Earth's surface, due to the rotation of the latter around its axis, passed successively under the orbit of each satellite and the determination of the maritime position was possible only when there was a satellite crossing above the horizon, which happened every 90 min on average (depending on the latitude). The accuracy of the shipping position was of the order of one tenth of the nautical mile (about 180 m).

To accurately determine the actual track and exact location of each satellite in the system, there were four ground monitoring stations that recorded the frequency change of the satellite signals and then forwarded this information to the computing center for further processing. This information (satellite newspapers and satellite almanac) was transmitted every 12 hours to each satellite of the system, which would store them in its memory and then broadcast it every 2 minutes to shipping message, for the use of satellite receivers and the extraction of the maritime position. Despite the fact that the Navsat / Transit system provided position accuracy very satisfactory for the data of that time (200 m), it was characterized by the inherent weakness of its non-sustained availability. In determining the next ship's position, long intervals, which in some cases exceeded one hour, were mediated.

2) The Soviet satellite navigation system Tsikada.

Studies on the creation of the first Soviet satellite navigation system began in the late 1950’s and the system development program began officially in 1962. The first satellite of the system was put into orbit in 1967 while the system was put into operational use 1979. Since the mid-70s, the original satellites of the Tsikada system (type Tsyclon and Zaliv) began to be replaced by younger (Parus type), who supported multiple military and civilian uses such as:

a) Determination of precision position and communication of Soviet submarines (Tsikada military system).

b) Navigation of Soviet merchant ships (Tsikada commercial system).

c) Support for Search and Rescue-SAR by incorporating on the satellites a suitable device for receiving the rescue beacon emission.

2. *The evolution of satellite navigation systems since in the 1980s.*

Since the late 1970’s and especially in the 1980’s, US and Soviet Union programs have been launched to create the second-generation satellite navigation systems: GPS (US) and Glonass (the Soviet Union). These systems cover a wide range of military and civilian positioning, navigation, and exact time reporting applications, and for this reason they are also known as Position, Navigation and Time Systems (PNT).

The main advantages of these systems with respect to the previous satellite systems of the period 1960-1970 are:

1) Positioning is provided:

a) At any point on or near the surface of the Earth, for ships, vehicles, aircrafts and a variety of other applications (geodesy, cadastre, emergency response, etc.).

b) Continuously, without the long intervals between successive moments of the earlier satellite systems of the period 1960-1970.

c) Autonomous, without requiring registration by the user.

d) Use of small size and weight receptors.

e) Two different levels of precision for military and civilian use respectively.

2) In addition to positioning, the GPS and Glonass satellite systems also provide the following information:

a) Speed and course of the vessel in which the satellite receiver is installed.

b) International Reference Time, to meet the needs of synchronization and coordination of telecommunication and other systems.

3) The GPS or Glonass satellite orbits are designed in such a way that signals from at least 4 to 7 satellites are received at any point on the Earth's surface and at any time. For securing this possibility, use 24 - 30 satellites, compared to the 5 to 6 satellites of the previous satellite systems for the period 1960-1970. The satellites of the GPS and Glonass systems are rotating at about 20,000 km in six orbital levels in the GPS system and three orbital planes in the Glonass system versus the lower 1,100 km of the previous satellite systems in the 1960-1970.

In GPS and Glonass systems, positioning is based on measuring receiver distances from at least four satellites. In this way, the position of the receiver is determined in the intersection of four spherical surfaces, which have centers of the positions of the satellites and the radii measured at all times by the receiver (Fig.1).

The first GPS experimental satellite was launched in 1978. In 1994, the expected number of 24 satellites was completed and officially announced by the United States of its completion and full operational capability. The development of the Glonass system began in 1982, with the launch of the first satellite. The Glonass system was placed in limited operational use with fewer than the foreseen 24 satellites in 1995 and was then completed and operated and supported by the Russian Federation.

In addition to the above-mentioned second-generation navigation satellite systems (GPS and Glonass), which have worldwide coverage, various satellite positioning, navigation and time satellite systems have been or are in the process of being implemented which provide global or regional (local) geographic cover. These systems can be classified into different categories, such as the main ones being:

1) Global Navigation Satellite Systems (GNSS), operating with approximately 24 - 30 satellites, with features similar to GPS and Glonass. Systems in this category are Galileo's European Space Company under development, and China's Beidou system under development.

2) Regional Navigational Satellite Systems (RNSS), operating with a limited number of satellites (less than 10) to cover an extended geographical area and not the whole of the Subway. Systems of this category are Japan's QZSS system and India's IRNSS system.

3) Satellite Based Augmentation Systems (SBAS), which operate by receiving signals from the satellites of one or more global satellite navigation systems, as well as additional signals from geostationary satellites, in order to enhance their capabilities in a broad geographic region, such as Europe, North America etc . Indicative systems of this category are the European EGNOS system, the system WAAAS for the US-Canada region, MSAS for Japan and the GAGAN system for India.

China's Beidou system was originally designed as a regional system to cover Asia, but was then redesigned as a global system.

Determination of maritime position in GPS and Glonass systems

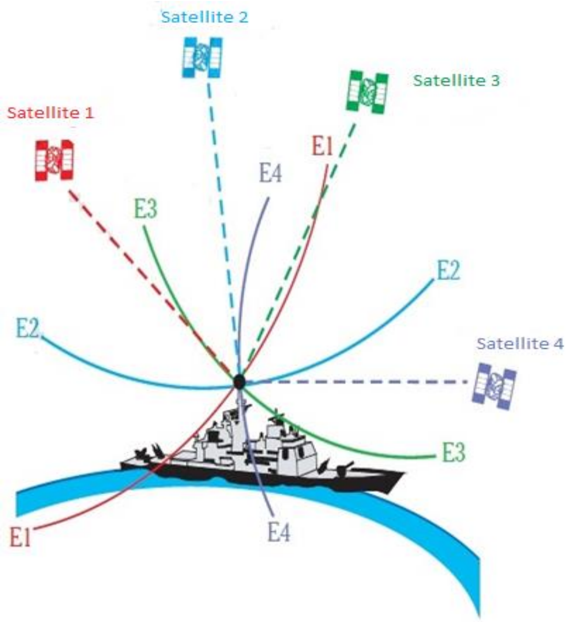

Fig.1. Determination of maritime position in GPS and Glonass systems.

B. Basic principles of operation of the modern GNSS satellite navigation systems

The basic positioning principle with a modern Global Navigation Satellite System (GNSS) is in principle very simple:

"If the distances of the satellite receiver of a GNSS system from at least three satellites and the positions of these satellites are known, then the position of the receiver is determined at the intersection of the spherical surfaces, which have centers of the positions of the satellites and rays equal to measured satellite-receiver distances " (Fig.1).

However, in practice the application of the above simple general positioning principle is implemented by a series of complex processes and functions by measuring receiver distances from more than three satellites. The main of these processes are summarized as follows:

1) The position of the satellite receiver on the Earth's surface (eg ship's position) or near the Earth's surface (eg aircraft position) is determined by the locations of the satellites of the used GNSS systems (GPS, Glonass, Galileo, etc.).

2) In GNSS satellite navigation systems, satellite positions are not stable, but they change at any time due to their movement to elliptical trajectories. However, the exact locations of the satellites at any time, and therefore at the time of determining the location of the satellite receiver, can be accurately determined according to the Kepler's Laws.

3) Each satellite of a GNSS system (GPS, Galileo, Glonass, etc.) emits a complex pulsed encoded satellite signal associated with its transmission time. The satellite signals provide the receiver with all the information needed to determine the location, such as the exact positions of the satellites (satellite newspapers), etc.

4) Receiver distances from the satellites result from the measurement of the propagation time of the satellite signals and their multiplication by the propagation velocity of the electromagnetic waves. Distances measured in this way contain some errors and are called pseudo distances.

5) The errors of the measured pseudo distances are mainly due to the fact that the timers of the satellite receivers are not as accurate as the satellite timers, as well as the change in the propagation velocity of the satellite signals in the ionosphere and the troposphere.

6) To correct the total error of pseudo distances, it is required to simultaneously receive signals from at least four satellites instead of three that would normally be required (for measuring the receiver distances from three satellites and determining the position of the receiver at the intersection of three spherical surfaces).

7) For calculating the receiver's distances from the satellites, apart from the aforementioned basic method of measuring the propagation time of satellite signals, the phase comparison method, which provides much more precision, is also used.

8) The phase comparison method is mainly used in geodetic applications, such as the Real Time Kinematic Positioning (RTK) method.

9) For the precise determination of the location of the satellites, the GNSS systems have a ground monitoring and control section, which consists of:

a) Network of ground monitoring stations.

b) Main control station.

c) Ground stations for the transmission (power supply) of the processed components of the main control station to the satellites for further retransmission to the satellite maritime receivers.

10) In order to perform the calculations required for determining the receiver location, both the position of the satellite receiver and the positions of the satellites must be referenced in a common reference system. The common reporting system, which identifies both the location of the satellite receiver and the positions of the satellites for different satellite positioning systems, is a different Geodetic Reference System (Geodetic Datum) such as:

a) The WGS-84 reference geodetic system which is used in the GPS system.

b) The PZ-90 reference geodetic system, which is used in the Glonass system

11) Regardless of the geodetic reference system which is used to calculate the coordinates of the receiver location, GNSS receivers may convert these coordinates into several reference geodetic systems (ED-50, Tokyo datum etc.), depending on the user's choices.

C. Basic parts of a global GNSS satellite navigation system

Every GNSS global satellite navigation system, such as GPS, Glonass, Galileo, etc., can be considered as comprising the next three main sections:

1) The satellite segment, which consists of the system's satellites.

2) The control department, which consists of a network of earth stations.

3) The user segment, which consists of all system receivers that are used in a wide range of civilian and military applications.

1. GNSS satellite systems

In order to determine the location of the satellite receiver, GNSS satellite navigation systems have a network of satellites that emits coded signals containing information. This information is used by the maritime receivers to determine the position (stigma) of the ship.

The satellite configuration of a GNSS system typically consists of 24 to 30 Medium Earth Orbit (MEO) satellites. These satellites (Fig.2) revolve around the Earth at an altitude of about 22,000 km above its surface and are distributed in orbital planes, which are inclined about 55° - 65° to the plane of the equator. With this form of satellite formation it is ensured that at any point on Earth at least 5-6 satellites are visible to determine the location of the receiver by taking satellite signals from the most suitable satellites. The satellite format of China's BeiDou (Compass) system consists of a combination of Medium Earth Orbit (MEO), Geostationary Orbit (GED) and Inclined Geosynchronous Orbit (IGSO) satellites.

The signals emitted by the GNSS satellites are designed so that at all times they provide the receivers with all the information necessary for precise positioning, such as exact positions of the satellites, satellite timer errors, etc.

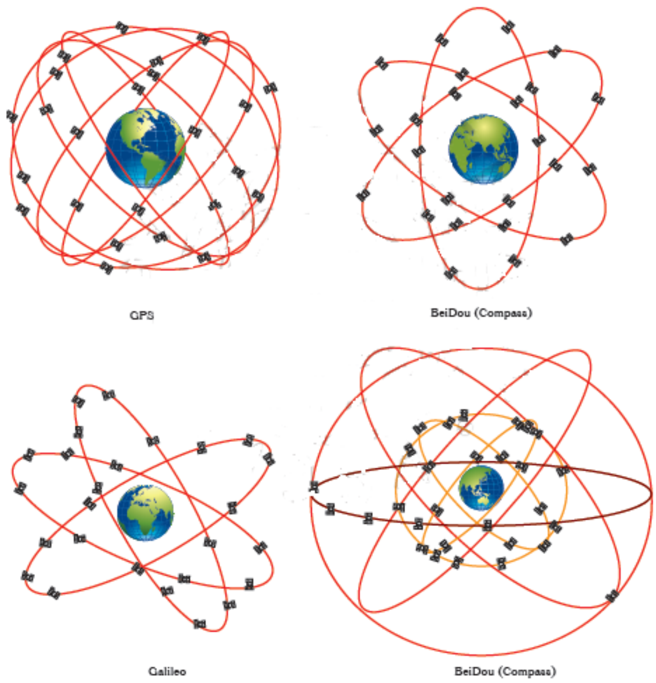

Fig.2. Comparison of satellite formats of modern GNSS systems.

2. Terrestrial GNSS systems

The Ground Segment of a typical GNSS system, such as GPS, Glonass, etc., in its simple generalized format consists of:

1) One or more control stations.

2) A network of stations monitoring and recording of satellite signals

3) A number of transmitting stations of processed data to the satellites.

The stations that monitor and record the satellite signals, make a record of satellite signals transmitted by the satellites and send them to the main control station for processing.

The control station (Fig.3) processes the received satellite signals from the monitoring and recording stations to determine and / or predict their various components, such as:

1) Satellite positions (satellite almanac and satellite newspapers).

2) Satellite status and satellite timer errors.

3) Atmospheric conditions for satellite signal propagation models.

The data identified at the control station is sent to the power stations, which re-transmit them to the satellites. The satellites store the data they receive from the power stations to continuously update the information of the satellite signals emitted to the receivers.

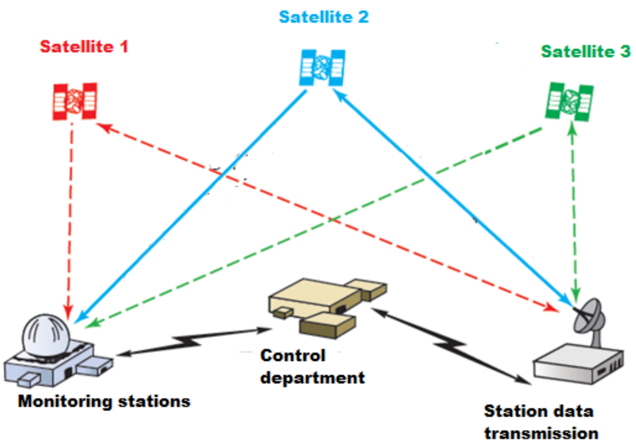

Fig.3. Function of a GNSS system control station (GPS, Glonass etc.).

3. GNSS system users section

The GNSS user segment consists of satellite receivers that receive and process satellite signals in various applications such as: precise positioning of a moving or stationary receiver for navigating ships, aircrafts and vehicles to provide accurate reporting time etc. These applications cover a wide range of activities, such as: navigation, aviation, public safety, remote control of aircrafts and vehicles, research and rescue, etc. From the number of these applications, this work mainly describes the applications of GNSS systems in navigation.

D. Geometry of satellite positioning

Determination of the location of a point on or near the surface of the Earth with the help of satellites can be done by various geometrical methods, such as:

1) Measurement of satellite-receiver distances.

2) Address measurement.

3) Measure distance differences.

All of the above methods have occasionally been used by various satellite systems in various applications. However, the method ultimately prevalent in modern GNSS satellite systems (GPS, Glonass, Galileo, etc.) is the measurement of satellite-receiver distances.

In order to determine the location of the satellite receiver, the measurement of receiver distances from satellites is performed by two basic methods of processing the received satellite signals:

1) Distance measurement with pseudo-random sequence code.

2) Distance measurement with phase difference.

E. Classification of satellite positioning methods

The general principle of positioning in GNSS systems is implemented with different variations, depending on the uses of the system (maritime, geodetic, etc.). The main methods of positioning GNSS systems are:

1) Maritime (kinematic) positioning. In the Maritime Positioning, the receiver is in motion (ship, aircraft, car, etc.) and the processing of the measurements is done in real time to provide the coordinates of the position at any time. The location accuracy of the satellite receiver provided by the maritime positioning method can be greatly increased by applying the differential positioning method.

2) Static positioning. In Static Positioning, which used in geodetic applications, the receiver remains stationary at the point of the earth surface to which the position is to be determined. In geodetic applications the required positioning accuracy is much higher than in shipping applications. Typical geodetic applications require and achieve precision of the order of a few centimeters of the meter, while in special applications it is possible to achieve a millimeter precision (of the order of millimeters).

3) Differential positioning. With the Differential Positioning method, better positioning of the satellite receiver is achieved by receiving signals from both the satellites of the GNSS system used and ground reference stations (differential stations).

4) Real time Kinematic determination of centimeter accuracy (RTK). The real time kinematic determination method is a specific differential positioning technique in which the measurement of receiver distances by satellites is based on the monitoring measurement of the phase of received satellite signals in the receiver instead of the time difference measurement used in the conventional satellite differential positioning.

5) Determination of real-time centimeter precision position (Wide Area RTK - WARTK). It was developed to increase the range of RTK (range of hundreds of kilometers, compared to 20-40 km of the RTK method). The WARTK method employs sophisticated techniques for identifying and transmitting differential corrections first by using a network of reference stations in broad geographical areas such as the wide area of western-central and southern Europe and secondly by transmitting differential corrections by satellite telecommunication links.

F. GNSS satellite signals

The satellites of the GNSS systems continuously transmit coded radio signals, which are received and processed on the satellite receivers for the calculation: first of the time $\Delta_t\Delta_i$ of the distribution of satellite signals from the satellite to the receiver, and second of the coordinates of the position of the satellites at any time.

The satellite signals emitted by a GNSS system (GPS, Glonass, etc.) are a synthesis of the following three signals:

1) A continuous sinusoidal signal called a carrier wave because it is used as a vehicle for transporting the two other signals.

2) A pseudo-random sequence digital signal consisting of successive positive and negative chips and used to identify the receiver the satellite from which the signal is transmitted and to determine the satellite-receiver distance.

3) A digital signal, known as a Maritime Message, which consists of successive positive and negative pulses (bits) and is used to transmit basic information to the receivers, such as: the exact transmission time of the satellite signal, the exact

coordinates of its position the satellite from which the satellite signal is received (satellite newspapers) and the state of the satellite (the receiver will not receive data from an unhealthy satellite).

GNSS satellites (GPS, Glonass, Galileo, etc.) emit signals at different frequencies, such as L1 = 1575,42 Mhz and L2 = 1227,6 Mhz of the GPS, L1 = 1620 MHz and L2 = 12046 Mhz of the Glonass system. Even in a particular GNSS system, e.g. in the GPS, its operational satellites, depending on their launch date, emit at two or more of the aforementioned frequencies. In addition, the structure and characteristics of the satellite signals of most GNSS systems are improved by launching new satellites, replacing older ones after their end-of-life. Advanced satellite signals from satellites modern technology taxes, being more durable, can be taken and decoded even in the most unfavorable operating environments, such as during storms or when moving vehicles in urban environments with numerous and high-rise buildings. Increased accuracy and durability of satellite signals allows the construction of small antenna-receivers, which can operate even in the closed area of the bridge, in the form of USB to a computer instead of externally, operating extremely satisfactorily.

Also, new satellite signals cannot be used by older receivers that were built to receive and process older satellite signals, with the result that these older receivers have reduced capabilities. Some modern receivers have the ability to receive and process satellite signals from more than one GNSS satellite system, e.g. both from the satellites of the GPS system and from the satellites of the Galileo system. These composite receivers offer enhanced capabilities and reliability over the receivers of a single system (GPS, Glonass). The tendency of manufacturers is to market more complex satellite receivers to receive satellite signals from several or all of the individual GNSS systems.

This broadens the commercial flexibility to develop a wide variety of products, from simpler and more accessible to the public, to the most demanding and confidential for government use.

Consequently, modern GNSS has unprecedented reliability and performance, capable of rendering them indispensable tools in any application or system related to imprinting, the visual representation and control of the position and movement of an individual ship or group of ships in the context of the hazards and limitations of each shipping environment.

G. Satellite trajectories of GNSS systems

1. Basic principles of satellite tracking and forecasting the position of the satellites

The calculation of the location coordinates of the satellite receiver of a GNSS system is based on the knowledge of the location of the satellites from which the satellite signals received by the receiver.

The determination of the location of the satellites is based on the three Kepler Laws. According to these Laws, satellites move on orbit-shaped orbits in which one focal point is the Earth's mass center. However, in reality the normal elliptical trajectory of a satellite is disturbed due to the effect of the Earth's shape, of the atmospheric friction, of the pressure of solar radiation, of the pulling forces of the Moon, of the Sun, of the planets and other forces.

For the above reasons, actual satellite orbits slightly deviate from the ideal elliptical or circular caterpillars.

Deviations of actual satellite trajectories from the ideal elliptical or circular caterpillars are provided in satellite newspapers. These deviations are calculated in the GNSS ground control section.

The data of the estimated satellite newspaper control ground is transmitted to the satellites for the continuous updating of the relevant information transmitted by satellite signals to the satellite receivers.

2. The Kepler laws

The basic principles of satellite movement in their orbit were formulated by Johannes Kepler (1571-1630) in the 16th century with the corresponding description of the orbital motions of the planets and then explained and completed by Isaac Newton (1643-1727).

The three Kepler Laws, as complemented by Newton, are expressed by the celestial mechanics equations, which are based on the assumption that the satellite is moving under the following conditions:

1) The Earth is completely spherical, with its mass centered in its center.

2) The mass of the satellite is considered negligible in relation to the mass of the Earth.

3) The satellite moves in the vacuum without friction.

4) There are no forces exerted on the satellite due to the influence of the Sun, the Moon or planets, etc.

According to Kepler's Laws, satellites move on elliptical trajectories and the position of each satellite can be determined by means of six parameters, known as Kepler's elements. These trajectories are called Kepler's trajectories.

3. Satellite position prediction.

i. Positioning of satellites

The Kepler's elements of the satellite track provide an excellent basis for predicting the position of the satellite. However, because the satellite effects other forces (other than the Earth's attractive force) that disrupt its orbit, for accurate prediction it is necessary to analyze these disturbances and to determine their effects on the Kepler's elements. By analyzing the Kepler's elements disorders, precise satellite based newspaper data are identified which allow the satellite to be predicted at a specific time on the actual satellite track.

ii. Satellite newspapers and satellite almanac

For the precise determination of the position of the satellites, satellite newspapers are used, which provide all the parameters for accurately determining the satellite orbit. The satellite news items required to determine the location of the satellite receiver are determined by continuous monitoring and analysis of the satellite movement from the GNSS ground control section. Satellite newspapers are sent to satellites and then transmitted to satellite receivers via the relevant shipping messages emitted by satellite signals.

In addition to determining the position of the satellite receiver, knowing the satellite orbit and predicting its position is necessary in other cases, for example as ancillary information in receivers for the rapid detection of satellite signals. In this case, approximate orbitals of lesser accuracy than the high precision trajectories required to determine the location of the satellite receiver are sufficient. The data of these approximate orbits are provided in the form of simple Kepler's data items in the "Satellite Almanac", which is usually emitted along with the satellite newspaper of the maritime message of the satellite signals.

In a typical GNSS, the shipping signal of the signal emitted by each satellite includes, among other things, the data of satellite newspaper of the specific satellite and the satellite almanac of all GNSS satellites of the specific satellite (GPS, Glonass, etc.).

The satellite newspaper and satellite almanac information transmitted by each satellite's shipping message is received at the satellite receivers and used as follows:

1) The satellite almanac data is used by the receiver to identify the approximate positions of all satellites in order to speed up the process of identifying and selecting the most suitable satellites to determine the location of the receiver.

2) Each satellite's satellite newspaper data is used by the receiver to determine the exact positions of the satellites used to determine the position.

4. Types of satellite orbits

In order to understand and thoroughly study the operating principles of satellite navigation systems and to more effectively assess their accuracy and reliability, it is useful to classify the GNSS satellite trajectories into groups with common features related to: first the track height, second the angle of inclination of the orbital plane to the plane of Ecuador, third the shape of the track (circular or elliptical) and fourth the period of rotation.

Depending on the height of the track, we distinguish the following categories of satellite orbits:

1) Low Earth Orbits (LEO) or simply Low Tracks at a height of 180 to 2,000 km.

2) Medium Earth Orbits (MEO) or just Medium Tracks at altitudes above 2,000 and less than 35,780 km.

3) Geosynchronous Orbits (GSO), at a height of 35,780 km, to which the Geostationary Orbit (GEO) belongs.

4) High Earth Orbits (HEO) or Simple High Orbits with orbital heights greater than 35,780 km.

The height of the track is the distance of the satellite from the surface of the Earth in the direction of the passenger radius and is different from the distance of the satellite from the center of the Earth.

The period of the satellite track, that is, the time the satellite completes a complete rotation around the Earth, depends on the height of the satellite track. According to Kepler's Laws, the height of a satellite's track determines the speed of its motion and the time it takes to complete its rotation around the Earth. The speed of the satellite is higher at lower altitudes than at higher and thus the time required for a satellite to rotate around the Earth is lower for satellites on low orbits than the time of satellites on medium and high orbits. Due to the interdependence of the period and the height of the orbit, at some orbital heights the satellite orbits exhibit special features, such as geosynchronous and geostationary trajectories.

Geosynchronous orbits, the satellites move at a height of 35,780 km and complete a full turn around the Earth in one day (23 hours, 56 minutes and 4 seconds). A special category of geosynchronous satellite trajectories are, geostationary orbits. In the geostationary trajectories, satellites move in circular orbits above Ecuador at a height of 35,780 km and always remain above the same point in Ecuador, following the rotation of the Earth.

Low Earth orbit satellites (LEO) complete a complete rotation around the Earth in a time ranging from 90 minutes to a few hours. Middle Earth orbit satellites (MEO) complete a complete rotation around the Earth in a few hours.

High Orbit Satellites (HEO), that is, at a height of more than 35,780 km, complete a complete rotation around the Earth in more than one day. For example, the moon's rotation time around the Earth at a distance (orbital height) of approximately 384,000 km is about 28 days (Lunar month).

III. *CHAPTER SECOND: A BRIEF DESCRIPTION OF THE MAJOR SATELLITE NAVIGATION SYSTEMS*

A. Categories of satellite navigation systems

1. Global and regional systems of satellite shipping

Satellite navigation systems can be classified initially into the following two categories:

1) Global Navigation Satellite Systems (GNSS) have been developed or developed by a number of major countries such as: the US’s GPS system, Russia's Glonass system, China's Beidou system or a coalition of countries, such as the European Galileo system. These systems are designed to operate by receiving signals from a satellite formation, usually consisting of 24 to 30 satellites (Fig.2). This satellite formation achieves satisfactory global coverage because it ensures that at any point on the surface of the earth it will be possible at any time to receive signals from four satellites to determine the location of the receiver.

2) Regional Navigation Satellite Systems (RNSS) developed or developed by certain countries, to provide high-precision positioning and time information, to users within their territory but also to neighboring areas. These systems operate by receiving signals from a satellite formation usually consisting of a limited number of satellites to ensure that the desired geographic area is covered. The satellite format of RNSS systems consists of fewer than 10 satellites (compared to about 30 satellites of a global GNSS system). These satellites follow special satellite trajectories that ensure that in the geographical coverage area of a particular RNSS system it will be possible at any time to receive signals from four

satellites to determine the location of the receiver. Indicative examples of RNSS systems include Japan's QZSS system, India's IRNSS system, and China's BeiDou system. China's BeiDou system was initially designed and developed as a regional system with a limited number of satellites to cover the area of China, but then developed in global by completing the original satellite formation with several additional satellites to reach global coverage.

2. Satellite and terrestrial enhancement systems

Both global and regional satellite navigation systems can operate either autonomously with their basic functions and capabilities, either as systems for enhancing the capabilities of basic satellite navigation systems, as follows:

1) In autonomously systems the determination of the receiver's location results from the reception of signals only from the satellites of a system.

2) In augmentation systems, receiver location determination results from receiving signals from the satellites of a satellite navigation system, as well as other additional signals emitted from other sources, such as: supplementary satellites or / and ground station networks, in order to achieve increase the accuracy and reliability of a system.

Enhancement systems can be distinguished in:

1) Satellite based Augmentation Systems (SBAS) determine the location of the receiver by receiving signals from the satellites of one or more of the world or regional satellite navigation systems, as well as additional signals emitted by complementary satellites, the who are usually in geostationary trajectories above a certain point in Ecuador to cover a wide geographical area such as the Region of Europe, the North American region etc.

The general principles of operation of SBAS systems (with minor variants) are as follows:

a) A network of ground reference stations is used, with a central control station for calculating the corrections of satellite signals in an extended geographical area, e.g. North America (USA and Canada), Western and Eastern Europe etc.

b) Terrestrial reference stations continuously carry out distance measurements and transmit them to the central control stations for further processing. Corrections for satellite orbits, timer errors and the effect of the ionosphere are calculated there. These corrections are referred to as Wide Area Differential Corrections (WAD).

c) The main stations continuously perform tests relevant to the operational status of the satellites and detect any abnormal behavior.

d) Next, both the corrections and the information related to the operational status of the GNSS systems are sent to certain geostationary satellites. These geostationary satellites transmit these corrections and information to the receivers of the area covered by the SBAS system.

e) With the above procedure, the receivers receive in real time from geostationary satellites differential corrections of high precision for the near geographical area of the nearest terrestrial reference station.

The benefit resulting from augmented SBAS systems is multiple. First of all, the corrections provided drastically improve location accuracy. In addition, the signal emitted by the geostationary satellites, is compatible with the satellite signals of the basic GNSS and RNSS satellite navigation systems (GPS, Glonass, Galileo, IRNSS, etc.). So these geostationary satellites can be used, in addition to transmitting differential corrections, and as additional satellites of these systems, providing in this way further improving location accuracy. Finally, information related to the operational status and suitability of the satellites, ensure that in any case of abnormal operation of the satellite systems, the user is informed about the problem in a few seconds.

Representative examples of SBAS systems are the European EGNOS system, the US's WAAS system, the MSAS system in Japan and the GAGAN system in India.

2) Ground Based Augmentation Systems (GBAS), essentially consist of sophisticated D-GNSS Differential Satellite Navigation Systems, operating on terrestrial networks of different stations, instead of a single differential station. GBAS systems are designed, to cover exacting requirements shipping-navigation in an approximation region of a port or airport. They use a reference station network (4, 5 or 10 approximately stations). These stations carry out distance measurements with the help of all available GNSS satellites. Then, they export differential corrections as well as information related to the correct functioning of GNSS systems. All of these data are transmitted to users via telecommunication links, usually in the frequency zone VHF. Indicative systems of this category are the National System of Differential GPS (NDGPS) in the US, which covers users all over the US and US coastal areas and the LAAS system (Local Area Augmentation System). LAAS is an aircraft landing system for all weather, through which the approaching aircraft perform very high precision position air navigation at many airports in Europe and the USA.

B. The US global positioning system

1. General description of the GPS system

The Global Positioning System (GPS) was designed by the US Department of Defense in the 1970's for military use and secondarily for civilian use. The system was developed and made available for initial testing since the second half of the 1980's. At the end of the trial period, the system became fully operational availability during the 1990's. The GPS system has gone through several phases of development, during which it was abolished gradually some initial limitations of the position accuracy provided for political users, and advanced satellite signals were added for both military and civilian uses.

Despite the fact that the GPS system was created for mainly military uses, today GPS receivers used for civil uses account for 95% of all system users. The political uses of the GPS system cover a wide range of applications for both business purposes (navigation, aviation, geodesy, land registry, public safety, etc.) as well as simple daily needs (integration of GPS receivers on mobile phones, electronic private cars navigation systems, taxis, etc.).

According to the original design, to determine the position of the satellite receiver, the GPS satellites emit the following three coded signals:

1) Pseudo-random sequence code of common precision (Coarse Acquisition Code, C / A) for the identification of satellites and the determination of receiver distances from satellites to political users.

2) Pseudo-random sequence code of high precision (Precision Code, P) to determine the receiver's distances from the satellites for military users.

3) Data code (Code, D) or a maritime message to determine the position of the satellites with the forecasts elements of their tracks (satellite newspapers) and the exact time information it contains.

The extensive use of GNSS satellite navigation systems in a wide range of applications, the need for more accurate and reliable services and the feasibility of interoperability between different systems (GPS, Glonass, Gallileo, BeiDou etc.), have highlighted the need to create new satellite signals, which, according to the GPS system modernization program, are projected to be transmitted by modern technology satellites, which are gradually replacing older system satellites. The program for the modernization of the GPS system is scheduled to be completed in 2025.

The new GPS satellite signals are:

1) The new military signal M (high precision code), which will form both frequencies L1 and L2.

2) The new political signal L1C (common precision code), analogous to the C / A code, which will modulate the L1 frequency.

3) The new L2C political signal (common precision code), analogous to the C / A code, which will modulate the L2 frequency.

4) The new political signal for the provision of human security services at the new carrier frequency L5 = 1176,45 MHz.

2. Space segment of GPS

The GPS system was designed to operate with 27 satellites in total (24 basics and 3 backup) distributed over 6 orbital planes, tilted at 55° with the Ecuador level, which intersect at points with a difference of 60° longitude [Fig.2]. The beam range of the transmitting antenna of each satellite is 45°, so that every satellite broadcast is covered with the maximum surface area of the earth. The GPS satellites follow approximately circular tracks at a height of 20,200 km above the Earth's surface. With these satellite trajectories, a uniform global coverage is achieved, ensuring that at any time of the day, anywhere on the Earth, a signal from 4 to 8 satellites at an angle of elevation greater than 15° is simultaneously taken. For an elevation angle of 10°, the number of available satellites is increased to 10 and for angle 5° the "visible-available" satellites are 12.

Depending on their launch time, GPS satellites belong to different categories or generations. The latest GPS satellites use an extra L5 frequency and three additional codes (M, L1C, L2C codes) to provide higher accuracy and reliability services.

3. GPS ground control

The ground control of the GPS system consists of:

1) A primary control station, located on the Falcon Schriever air base in the State of Colorado Springs, USA (Fig.4) and

2) Five additional ground monitoring stations (Fig.4), which are in the following positions: a) Cape Canaveral of USA, b) Pacific Island of Hawaii, c) Pacific Kwajalein Island, d) Diego Garcia Island of the Indian, e) Ascension Island of the Atlantic. Of these five stations, the three stations on the Atlantic, Indian and Pacific Ocean islands, in addition to receiving the signals emitted by the satellites, transmit to the satellites useful information coming from the main control station (Colorado Springs) (Fig.3). Then, this information is transmitted by the satellites to the users (satellite receivers) for positioning.

In order to better monitor the satellites, the ground monitoring and control stations of the GPS system are uniformly dispersed on the Earth's surface in locations with a difference of approximately 60° longitude and small or medium latitudes on either side of the Equator.

The main monitoring stations perform pseudo spacing measurements every 1.5 seconds. These measurements combine them with ionospheric and meteorological data, generating data packets that are transmitted to the main control station every 15 minutes.

The master control station collects and processes the data emitted by the monitoring stations to identify or / and predict various elements such as:

1) Satellite positions (satellite almanac and satellite newspapers).

2) Satellite status and satellite timer errors.

3) Atmospheric conditions for satellite signal propagation models.

The above parts of the control section are sent from three terrestrial stations to the satellites in which they are stored for further transmission to the users.

The core network of 6 ground control stations (Fig.4), has been interfaced with other terrestrial networks to improve the reliability and accuracy of GPS, such as the International GNSS Service (IGS).

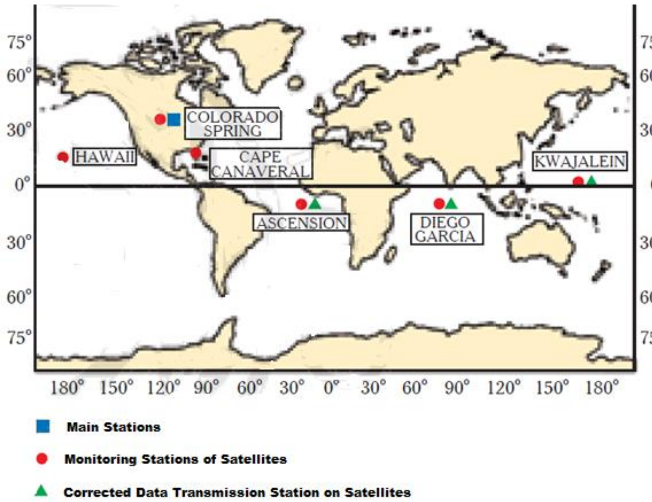

Fig.4. Locations of the GPS ground control stations.

4. GPS system users - services provided

1) Basic uses of GPS.

The GPS user segment consists of all system receivers that are used in a wide range of civilian and military applications. The main political uses of the GPS system are as follows:

a) Immediate and continuous determination of the location of any point on or near the surface of the Earth such as position (stigma) of ships and small navigable means, aircrafts, land vehicles (cars, trains, etc.), as well as individuals people (climbers, cyclists, walkers, etc.).

b) Exact navigation of ships, aircrafts and other vehicles to arrive at the desired point of destination.

c) Precise positioning and movement of vessels by interfacing GPS receivers with AIS systems and systems maritime traffic control.

d) Precise positioning and movement of aircrafts by air traffic control centers.

e) Accurate depiction of the position and movement of various categories of vehicles, such as ambulances, fire brigades, police officers, etc., for more efficient management of their operational exploitation.

f) Geodetic, topographic, hydrographic and cartographic work for the direct determination of the geodetic coordinates of the Earth's surface with an accuracy of up to 2 cm and for the more accurate mapping of various areas of the Earth in a single Geodetic Reference System (Geodetic Date).

g) Providing accurate reporting time for synchronization of telecommunication systems.

2) Levels of GPS provided services.

The GPS system is designed to prevent unauthorized political users from taking full advantage of their capabilities by providing the following service categories:

3) Standard Positioning Service (SPS).

This service is freely available to all users at the carrier frequency L1, which is configured with the C / A code. In theory, the average position error that the service ensures is less than 13 m in the horizontal direction and 122 m in the vertical direction. Practically, the accuracy achieved is greater, with a maximum error value of approximately 10 m.

4) Precise Positioning Service (PPS).

This service is provided to military / government users, in appropriately configured signals for L1 and L2 frequencies, configured with pseudo-random sequence secret codes. While the common precision positioning service is vulnerable to deception and jamming techniques, the same is not the case for precision positioning service, which has excellent resistance to these techniques. The accuracy of the stigma is of the order of magnitude.

5) Air Navigation Service (this service is provided via the new carrier frequency L5).

According to the GPS system upgrade, provision of upgraded SPS precision services and high-precision PPS with the transmission of the new L1C, L2C and M satellite signals will be provided only by the latest technology receivers.

6) Standard Positioning Service (SPS) and selective availability.

The Common Positioning SPS function of the GPS system is available without any limitation to all interested system users in any area of the Earth. Common positioning of SPS is achieved by obtaining the low-precision code (C / A code) of satellite signals with common GPS receivers, which are freely available on the market. These receivers provide position accuracy less than that provided to the PPS positioning service requiring the use of special receivers capable of receiving both of the C / A code and the high precision P code of the satellite signals.

According to the original design of the GPS system, the position accuracy (95% probability) that would provide the system in the normal SPS positioning mode for unauthorized users would be 100 m. However, as proven during the first system tests, the SPS accuracy is actually 30 m and does not differ significantly from the PPS position accuracy, which is 22 m. Following this finding, the US Department of Defense decided for military security reasons to artificially degrade the SPS accuracy from 30 m to 100 m by using data accuracy limiting techniques of the C / A Code, in order to prevent the use of the system for military use by enemy forces.

This deliberate degradation of GPS accuracy in SPS mode is known as selective availability or controlled availability (S.A.) and was first applied in 1991.

With the application of selective availability, the accuracy (with 95% probability) provided by the GPS system in the normal SPS positioning mode is:

a) 100 m in the determination of the horizontal position,

b) 156 m in altitude determination,

c) 340 ns in time determination.

The above limitations on the accuracy of GPS services provided by the policy of selective availability were applied until 2000, so according to a decision of the US President a selective availability application was abolished and the system now provides a 30 - meter position accuracy (95% probability) to the normal positioning SPS function.

However, as stated in the above-mentioned decision, if US national security reasons so require, it is possible to re-apply the policy of selective availability and the accuracy provided of positioning of the GPS system (with 95% probability) is limited to 100 m again.

7) High Precision Positioning (PPS) and anti-deception.

As mentioned above, provision of high-precision positioning (PPS) services is in principle available only for US military uses and some other states that have a special agreement with the US Department of Defense. Accurate positioning is achieved by using special military GPS receivers, which are capable of receiving and decoding the encrypted P(Y) code data of the satellite signals.

For accurate PPS position determination, GPS receivers use the high precision (P) code of the satellite signals. The P code is not usually available for free use but is incorporated into the satellite signals in an encrypted form as a P (Y) code resulting from the combination of the P code with a secret W code. Recovering the P code into the receiver is only possible if the secret code W is known. However, despite these constraints, the technology developed by some receiver manufacturers now makes it possible to recover the P code without the knowledge of the secret code "Key" W.

Encryption of the P code and its transformation into W code is a deliberate degradation method for PPS accuracy, known as anti - deception or disorientation (Antispoofing - AS).

Another reason for activating anti- deception, perhaps more important than obstructing the use of the P code by hostile forces, is the deprivation of the enemy's ability to take electronic maritime war measures against the effectiveness of GPS / PPS, such as by emitting a disorienting or deceiving signal of the receiver with features corresponding to the P code but with incorrect data.

C. The global navigation satellite system Glonass of Russia

1. General description of Glonass

The Glonass (Global Navigation Satellite System) system is the equivalent of the US GPS system, Russian navigation and time positioning system and designed with technical features, operational capabilities and operating principles similar to the GPS system. Its design and development date back to at least the early 1980's and is at the time the Soviet Union's response to the US GPS system. The first Glonass system was launched in 1982 and the system was put into operation in 1995. Glonass services were made available to political users much later in 2007.

The Glonass satellite signals consist of carrier frequencies configured with pseudo-random sequence codes and a maritime message as in GPS. In particular, the carrier frequencies G1 (1602 MHz), G2 (1246 MHZ) and G3 (1204, 704 MHz) and the C / A code and series pseudo-random P code are used. The G1 frequency is exclusively formed by the C / A standard code and is intended for civil use. Frequency G2 is furthermore shaped by high precision code P and is intended for military use. The new G3 frequency available to the Glonass K satellite is modeled with new codes, the C / A2 standard code for civil use and the P2 code for military use. This frequency will additionally cover search and rescue and security services for human life.

However, in contrast GPS signals, where multiple satellite signals are emitted on the same carrier frequency as the CDMA technique in the Glonass system, each satellite uses a separate transmit frequency. This technology is an older generation and is expected to be replaced in the near future by the one used in GPS.

The Glonass geodetic reference system (PZ-90) is different from the GPS geodetic reference system (WGS-84). Consequently, a receiver operating simultaneously with both GNSS systems must have the appropriate coordinate conversion software from one system to another.

According to the modernization program of Glonass, it is planned to gradually replace its original satellites with corresponding newer technology (Glonass-M and Glonass-K). The system will then be able to provide upgraded civil and military services similar to the Galileo system and the future upgraded GPS-III system.

2. Space segment of Glonass

The space segment of the Glonass system is designed to operate with 24 satellites in total, 21 main and 3 backup. These satellites [Fig.2], rotate at approximately 19,100 km (slightly lower the height of the GPS satellites), divided into three orbital levels instead of the six orbital levels of the GPS system, with a period of 11 hours, 15 minutes and 45 seconds. The three orbital levels of the Glonass system [Fig.2] have an inclination of 55° to the plane of the equator and form an angle of 120° between them. The neighboring satellites of each orbital plane have a 45° angular distance. At each orbital plane there are seven basic satellites and one spare. On the antennas of the new Glonass-M satellites of the system, the innovation of the beam range available not only for broadcast to terrestrial users but also for space crafts is applied.

3. Glonass ground control section

On the ground section of Glonass performs extremely accurate measurement of time and phase errors of received satellite signals. Subsequently, the data to be exported is transmitted to the system satellites, which appropriately correct their emissions to users. In order to measure these two errors as accurately as possible, Glonass has a central control station, which is subdivided into two functional sections: the central synchronizer and the phase control system. Through these two segments, a continuous measurement of the distance of the satellites from the ground is performed by Radar techniques. At the same time, laser distance measurement is performed to increase the measurement accuracy from 2-3 m to a few centimeters. These measurements are compared to the pseudo-distances measured by the usual method of extracting the position from the satellites. The pseudo-distances are measured by 4 monitoring, control and telemetry stations located in St. Petersburg, Schelkovo (in the Moscow region), Yenisseysk (Siberian region) and Komsomolskna-Amure, (in Russia). These stations perform pseudo- distances measurements creating digital data packets, which are transmitted to the main control station every 10-15 min.

By combining all the data it collects, the Glonass central control station identifies and predicts the satellite orbits and time elements, then transmitting to the satellites the maritime message. In addition, it synchronizes the time reference of the satellites and controls the time difference between Glonass and UTC (Coordinated Universal Time).

4. Glonass system users - services provided

The Glonass system provides two different levels of service for both military and civilian use, as is the GPS system. The services and applications provided are similar to those of the GPS system.

D. The Galileo global system of the European Union

1. General description of Galileo

The Galileo system is the currently under development civil – autonomous - global navigation satellite system of the European Union and the European Space Agency (ESA), launched for the first time in 1999. The Galileo system is a technological breakthrough for the strategic objectives of the European Union (EU). The EU realized on time that the technical and operational autonomy provided by its own satellite positioning system is a prerequisite for the further development of transport networks, communications networks, energy infrastructure, and the establishment of a common defense and security policy.

Unlike the prehistory of GPS and Glonass systems, the Galileo system has been designed from the outset with the primary purpose of exploiting it in political applications and thus military / governmental. For this reason, both the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) participated in the initial development phases of the system. In addition, the development of the system has not only begun influenced by the technological basis of GPS but continues to be determined by the compatibility and interoperability between the two systems. At this point, it should be stressed that the Galileo system is compatible with the GPS but fully independent of it.

The Galileo reference geodetic system is identical to the international reference system as defined by the International Earth Rotation Service (IERS).

Four satellites have been put into orbit, moving on two orbital planes, enabling the location of a very high accuracy location in Europe (greater than GPS) (Fig.5a). Several manufacturers, following successful tests to assess the accuracy and reliability of the Galileo system with laboratory receivers, have already announced the construction and disposal of the first commercial receivers since 2015. Given that Galileo is interoperable with existing GPS, Glonass and BeiDou systems, the commercial system receivers (as well as several tested laboratory receivers) will be capable of positioning by simultaneously receiving satellite signals from all GNSS systems.

Galileo satellite signals are transmitted over a wider range of frequencies than GPS and other GNSS systems. This practice is used to increase the reliability of the system, to better serve the many applications-services, provided to its users, but also to ensure maximum compatibility and interoperability with other GNSS systems. Galileo satellite signals are emitted at different carrier frequencies, configured as in the case of GPS and Glonass systems with pseudo-random sequence codes and maritime message. The Galileo system makes extensive use of new formatting and coding techniques to increase its accuracy, reliability and resistance to electromagnetic interference.

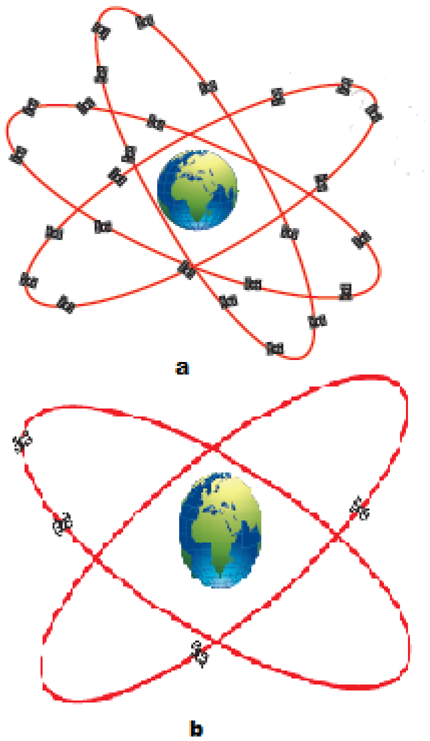

Fig.5. (a) Galileo satellite formation in full development and (b) its present status.

2. Space segment of Galileo

The space segment of the Galileo system, when completed (2020), is expected to include 30 satellites in total, which will be divided into three orbital planes in Medium Earth Orbit (MEO), with 10 satellites at each orbital plane. A satellite on each track will act as a back-up, available to cover any malfunction of another satellite on the same track. Thus, the availability of back-up satellites ensures that the loss of a satellite will not adversely affect the users, as the satellite formation will be immediately restored with the launch of the back-up satellite to replace the lost or problematic.

The height of the track of Galileo satellites is 23,222 km, and their rotation period is 14 hours and 4 minutes. The three orbital levels are 56° tilted to the plane of the equator. The flight height and slope of the tracks were chosen to ensure good coverage of the polar latitudes, which are not adequately served by the GPS. The aforementioned satellite distribution in orbits guarantees global coverage for users, with at least six satellites available at the same time, for an elevation angle of more than 10^{o} at any time of the day.

3. Galileo ground control section

This section does not differ in design philosophy from GPS and Glonass, except that it has a much larger number of stations. Moreover, because it is essentially a political system, almost every detail of its infrastructure is known. Analysis of this infrastructure is beneficial for understanding not only the particular system but, more generally, any modern GNSS system.

The ground control system of the Galileo system is subdivided into the following two functional centers.

1) The Galileo Control System (GCS), which is responsible for the control and telemetry functions of all Galileo satellites. For this purpose, it has a network of five Telemetry Tracking and Control (TT & C) stations. At the heart of the system are two Ground Control Centers (GCCs), which exercise a central control over all Galileo functions.

2) The Galileo Mission System (GMS), which is responsible for identifying and transmitting to the satellites the signals needed to provide services UTC shipping and time. For this purpose, GMS uses a global network of 40 Galileo Sensor Stations (GSS). These stations continuously monitor satellite signals while communicating with each other via both radio and satellite wireless telecommunication. The GMS communicates with Galileo satellites through a global five satellite broadcasting Mission Up-Link stations (ULS) network. Through the GSS network, time and trajectory errors, which are then transmitted to the satellites via ULS, are identified. The ULS, GSS and TT & C stations are interconnected with the two GCC stations via multiple wireless and radio data exchange telecommunication networks to ensure continuous and uninterrupted communication between them.

4. Galileo system users - services provided

Galileo receivers will provide high-precision positioning services of one meter to all political users without restrictions. Galileo is designed to be interoperable with GPS, Glonass and BeiDou systems. The system receivers will determine the location of their carrier by receiving satellite signals from any combination of satellites of all GNSS.

Unlike GPS and Glonass, Galileo has been designed from the outset with a view to its political use. For this reason, it has a number of upgraded civilian services, while services intended exclusively for military / government use are provided. In particular, in addition to positioning services, Galileo provides upgraded and original Search and Rescue (SAR) services based on the Cospas-Sarsat system. For this purpose, the satellites of the Galileo system have a separate unit, which relay the danger signal received from a user's transmitter, to the coordinating center, which will then activate the rescue procedures. At the same time, Galileo will transmit to the user in danger a suitable signal with the information that the rescue procedure has been activated, which is not currently available for other GNSS. The services provided by the system are as follows:

1) Open Service (OS), which is free of charge for every possible user, as is currently the case for the corresponding political uses of GPS. In practice, the open access service enables each user to combine a number of Galileo and GPS signals into a common receiver, in order to achieve drastic improvement the accuracy of position in adverse conditions of reception of satellite signals, such as the urban environment and dense vegetation. This service is covered by signals in the carrier frequencies E2, L1 and E1.

2) Commercial Service (CS) intended for the development of professional applications. This service has high guarantees of availability / uninterrupted supply to users. In addition, the shipping message for this service is transmitted at a higher transmission rate of 500 bps. It is available through provider billing, so the system is also cost-effective. Its coverage is ensured by signals in the carrier frequencies E2, L1, E1, E5b and E6. In addition, this service can be covered by cryptoscopic signals on the carrier frequency L1.

3) Safety of Life (SoL) for applications such as aviation, navigation and railways where there is a high requirement for positioning and movement accuracy of the carrier - receiver. This service is available in multiple satellite signals simultaneous demodulation receivers. SoL is applied to the radio frequency zones, defined for aeronautical radio navigation services (L1 and E5).

4) Search and Rescue (SAR) services aimed at significantly improving existing emergency and rescue aid systems. Galileo satellites have the ability to receive signals from emergency transmitters on ships and aircrafts or from individuals and then relay them to international rescue centers. The signals of this service will be received in the frequency band 406.0 - 406.1 MHz and will re-transmit this information to the appropriate centers on the ground via the L6 frequency.

5) Public Regulated Services (PRS). These services are for government use, they use encrypted pseudo-random sequence codes, have high interference features and are primarily used for the needs of public agencies and European security. These services are covered by signals in the carrier frequencies E6 and E1.

E. China's BeiDou (Compass) global system

1. General description of BeiDou

For reasons analogous to competition between GPS and Galileo, China's strategic pursuits could not be lacking in the development of an intimate satellite positioning system, global coverage. Originally called Beidou-1, it was developed as a regional satellite navigation system to cover users in the broader geographical area of Asia and the Pacific Ocean. Today, BeiDou-2 or BeiDou (also known as Compass) seeks to serve users on a global scale, alongside interoperability with the other GNSS available. The first satellite of the system was launched in 2009 while the system will be fully operational in 2020. At present, only 14 of the 35 satellites are operational and are in orbit around the Earth (Fig.6). BeiDou-2 is expected to provide complete global satellite navigation services in 2020, similar to GPS, Glonass and Galileo.

BeiDou satellite signals are transmitted to users in six different carrier frequencies. These signals are configured with pseudo-random sequence and maritime message codes. From broadcasting frequencies, B1, B2 and L5 coincide with Galileo's E1, E2, E5B and E6 frequencies. Overlapping may be beneficial for users internationally, provided that issues of mutual interference are addressed, especially in the E1 and E2 frequency bands, which are available for the free Galileo service.

The Geodetic Reference System of the BeiDou-2 system is the China Geodetic Coordinate System 2000 (CGCS2000), coinciding with the ITRS International Terrestrial Reference System.

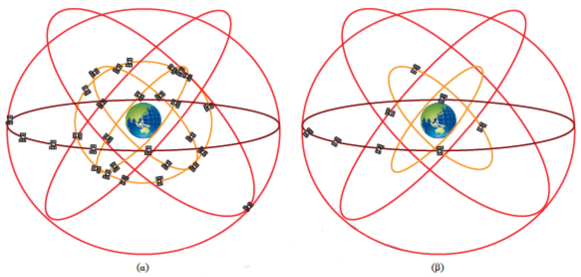

Fig.6. (a) BeiDou's complete satellite format and (b) its current status.

2. *Space segment of BeiDou*

BeiDou's space segment will comprise a total of 35 satellites. Of these, 5 will be in geostationary orbit (GEO), 27 will move at mean track height (MEO) and the other 3 will be in inclined geosynchronous orbit (IGSO). The number of IGSO tracks is 3, with one satellite per track. In three tracks the other 27 non geostationary satellites will move. The medium altitude satellites will rotate at a height of 21,500 km, while geosynchronous at a height of 35,785 km.

3. *BeiDou ground control section*

The Compass Ground Segment consists of the Master Control Station, Upload Stations, and Monitor Stations. The main control station is responsible for controlling the satellite formation and for processing the measurements received from the monitoring stations to generate the maritime message. Power stations are responsible for the transmission of the orbital corrections and the maritime message to the satellites. The tracking stations collect all data from the BeiDou satellites that are visible from where they are located. In the current situation, BeiDou's ground section consists of a main control station, two power stations and 30 main monitoring stations.

4. *BeiDou system users - services provided*

The Compass User Segment consists of the receivers that receive the messages emitted by the system satellites, identify the pseudo distances and solve the equations in order to extract the user's position, speed and exact time (PVT). The BeiDou system provides two kinds of services to users: Open Service and Authorized Service. The open access service provides each user with no charge location, speed and time information, with a positioning accuracy of better than 10 m, speed determination accuracy better than 0.2 m / s and a timing accuracy better than 20ns. The above data is much improved for the authorized access service, which also provides system correct operation (integrity) control services.

IV. *CHAPTER THIRD: GPS SATELLITE RECEIVERS*

A. *Historical development and current status of GPS / GNSS receivers*

The evolution of GNSS receiver technology over the last two decades has been similar to that of portable electronic devices such as mobile phones and computers. With the evolution of electronics, GNSS receivers are increasingly smaller in weight and dimensions they occupy less volume, cost less, require less electrical power for their operation, are more reliable and can perform more functions. Due to the shrinkage of electronic components and circuits, GNSS receivers require fewer and smaller electronic units to manufacture them. Today, a GNSS receiver can practically consist of a limited number of integrated circuits and have very small dimensions and weight, unlike the very bulky satellite navigation receivers of the first satellite navigation systems of the 1960’s.

Modern common digital technology also unveils inexhaustible combinations of different devices and systems into a single device, such as:

1) Simple, cost effective and easy to use integrated shipping systems, for example a system in which they are combined in a device of small dimensions and weight, such as a flat screen computer or 21" TV, the following four nautical electronic instruments and systems: a) Digital Maritime Radars, b) GNSS satellite receiver, c) AIS Ship Identification System and d) ECS Electronic Chart System.

2) Mobile phones with embedded GNSS satellite receiver capable of displaying the receiver's location on an electronic map on the screen of the mobile phone.

B. *Operating cycle of a satellite positioning receiver*

The GNSS receiver performs the following procedures in sequence in each operating cycle:

1) Recognizing satellites in its area, measuring distances and synchronizing with them.

2) Receiving a maritime message and calculating exact position of satellites.

3) Use distances (at least four) of known satellite positions to calculate the receiver location and we calculate the speed of the receiver by exploiting the Doppler phenomenon.

4) Converting the calculated position of the receiver to longitude, width and height based on a geodetic reference system (usually WGS 84).

C. Basic units of a GNSS receiver

A GNSS receiver consists of the following basic units:

1) Preamplified antenna.

The purpose of the antenna is to convert the satellite signals that result in it, in the form of an electromagnetic wave, to the appropriate electrical signals that can then be processed by the receiver. The size and shape of the antenna determine its ability to receive and then route to the receiver circuits, even the weakest satellite signals. The antennas of the GNSS systems have a preamplifier, so that even the weakest signals can be received. In order to receive satellite signals, the antenna of the GNSS receivers is always multi directional so that the reception is not limited to a single address but covers all the points on the horizon. Depending on the applications for which the GNSS receiver is limited, the antenna used is capable of receiving satellite signals, either exclusively at a basic L1 frequency or at more frequencies (e.g. L1, L5 and E5).

The antennas used in GNSS receivers are classified in the following categories:

a) Monopole: Antennas of this category are only capable of receiving one frequency, are small and simple in their construction but require a flat base to limit multi-branch interference.

b) Quadrifilar: The antennas in this category are capable of receiving only one frequency L1, consist of a more complex than the monopolar antenna construction, but they have very good reception.

c) Microstrip: Antennas of this category are capable of receiving multi frequency satellite signals and are used in aircraft receivers.

d) Spiral: Antennas of this category are capable of receiving satellite signals of multiple frequencies, provide very good reception and are used in many categories of receivers.

2) Unit for converting the received radio frequency to the intermediate frequency (RF / IF unit).

As with telecommunication receivers, a GNSS receiver has a unit which, without changing the configuration of received signals, converts their carrier radio frequency (RF) to a lower frequency, called intermediate frequency (IF). While high radio frequency RF is chosen to be more suitable for the distribution of satellite signals, in the reception phase a much lower frequency is the most suitable for the receiver's electronic circuits. This unit is therefore charged with the task of converting the frequency from one price to another. This conversion is performed on the receiver by means of a local oscillator, a mixer and a bandpass filter, which allows the passage of signals of a particular frequency band. The local oscillators used in the GNSS receivers are of high precision to produce an extremely stable frequency without introducing errors in the received signal. The resulting signal at the output of this unit has an intermediate frequency equal to the difference of the RF frequency and that of the local oscillator.

3) Digital signal processing unit or digital correlation unit.

The digital signal processing unit performs two functions, having respective subsystems-circuits: It detects, retrieves and monitors the satellite signals with the digital correlation unit, while processing the satellite signals, controls the receiver and performs calculations with the micro-controller. In addition, the GNSS receiver has the necessary power supply and that means (digital memory) that allows it to store the data it receives and calculates, as well as orders to him. In modern receivers, the above mentioned units refer to two integrated circuits, one for the RF / IF unit, and one for the digital signal processing unit. There are also receivers in which the two units are combined into a single integrated circuit.

The technology of manufacturing accordingly integrated circuits (chips) is referred to as Application Specific Integrated Circuit (ASIC), that is, Integrated Circuit for the Requested Application. The construction of two different integrated circuits or an exclusive one that performs all the functions of the satellite receiver drastically simplifies the process and time of production while minimizing its cost. From a technical point of view, the use of integrated circuits revolutionized GNSS receivers, since within the integrated circuit hundreds or thousands of digital correlations can be performed at the same time. This technology is therefore responsible for the abolition of the sequential digital correlation method performed by the first GNSS receivers, which was particularly time consuming.

D. GNSS software receivers

The development of microprocessors and, by extension, computers, makes it possible to introduce new innovative applications such as the GNSS software receiver. In this application, in place of the integrated circuit of the digital signal processing unit, a microprocessor is placed in which the appropriate software program is loaded. The individual components of the digital signal processing unit (microprocessor, central processing unit, digital association filter bank, digital clock) are replaced by a single programmable microprocessor, whose software commands perform all the functions mentioned in the previous paragraph.

This microprocessor is powered by the binary symbols (bits) provided by the analog signal converter to a digital, of the integrated RF/IF circuit. It goes without saying that in place of the programmable microprocessor we can use a complete computer, equipped with the appropriate software. In this case the antenna and the RF/IF unit can be a simple USB key. The application of the GNSS software receiver is highly flexible and multiplies its capabilities. Complete independence of the digital signal processing unit from the RF/IF unit, maximizes the frequency range at which the RF/IF unit can operate. Thus, a common GNSS receiver can operate in the frequency range that simultaneously covers all available GNSS.

In addition, any change in the transmission characteristics of the satellite signal of a GNSS (e.g. adding a new signal to another frequency, changing the configuration techniques or parameters, etc.) does not require new equipment, specifically software intervention (redesign of the chip), but a simple update of the microprocessor program.

E. Categories of GNSS receivers

For more effective consideration of their technical features and operational capabilities, GNSS receivers (GPS, Glonass, etc.) can be categorized into different categories. These categories concern the following classification criteria.

1) Depending on the reception and processing capabilities of satellite signals, GNSS receivers can be classified into the following categories:

a) Receivers of a frequency policy, e.g. L1 or E1 pseudo distance measurements with the C / A code. This category includes typical shipping receivers.

b) Receivers of a frequency policy, e.g. L1 or E1, with C / A code pseudo distance measurements and the phase comparison method. This category includes typical geodetic receivers.

c) Two frequency receivers, for example L1, L2 or E1, E5.

d) Pseudo distance measurement receivers with encrypted M code. This category includes standard military receivers.

e) GNSS differential receivers. Receivers of this category are able to receive a signal from a differential station to improve position accuracy provided by common maritime receivers.

f) RTK (Real Time Kinematic) Accuracy Receivers. Receivers of this category can simultaneously receive signals from 4 to 5 differential stations to provide real time position accuracy.

g) Receivers for simultaneous reception of signals from 1-2 different GNSS systems, e.g. GPS, Galileo and Glonass.

2) Depending on the number of satellite signal reception and processing channels, this depending on the receiver category usually ranges from 12 to 40 channels.

Most GPS receivers currently on the market have at least 12 channels, while multiple composite receivers capable of receiving satellite signals from multiple systems (GNSS at the same time MTSS etc.), the number of channels can also reach 120. A good GNSS receiver must be multichannel and have a separate channel to receive and process the satellite signal from each satellite. The older GPS receivers had a smaller number of satellite signal reception and processing channels, depending on which of them belonged to one of the following categories:

a) Continuous or multichannel receivers: The receivers have four or more channels and corresponding processing units. Each channel was used to continuously measure a single satellite signal. In this way, there were simultaneous reception and processing of signals with at least four satellites and the resulting stigma is very accurate.

b) Multiplex receivers: The receivers have one or two channels and several processing units. Receiving satellite signals (one or two channels) alternated from satellite to satellite in a very short time (at one second time a multiplexer receiver receives sequentially data from five different satellites). In this way the processing of the signals in the respective software units was done without interruption. The multiplexed receivers have had similar advantages to multi channels, as they observed almost simultaneously several satellites.

c) Sequential receivers: These receivers only had one channel and one processing unit, which were used for sequential reception and processing of signals from different satellites but with a recycling time much greater than that of the multiplexer (1 second to one hour).

3) Depending on their intended use, GNSS receivers are classified into the following categories:

a) GNSS portable and general purpose ship receivers. The receivers of this category have very small dimensions and weight. Most of these receivers have the shape and dimensions of a mobile phone, while others have the shape and dimensions of a wristwatch. Several of the receivers in this category have a small screen that provides the ability to display an electronic map with real time receiver location.

b) GNSS Maritime Receivers for permanent installation on ships. Some of the receivers in this category have a small screen that provides the ability to depict an electronic map with the position and course of the vessel in real time.

c) Differential positioning maritime receivers (D-GNSS). The GNSS differential maritime receivers are in the form of the GNSS common navigation receivers.

d) Receivers for connection to a PC. In this case, the receiver is limited to a small unit of material, which has neither a screen nor a control key, and its operation is controlled by a PC with which it is connected to its usual serial port or to the USB port, but also with a wireless Bluetooth interface.

e) Receivers for incorporation into other systems and devices. In addition to the above-mentioned GNSS receivers for computer connection, technological developments have made the mass construction of GNSS receivers of very small dimensions, a single microchip, for integration into other systems and devices, such as: 1) mobile phones, 2) various electronic instruments and devices.

f) Geodetic receivers. These receivers are used for geodetic applications, requiring location accuracy of the order of a few centimeters (2-3 cm), which is much higher than in maritime applications. The basic categories of GNSS geodetic receivers are:

- Positioning static geodetic receivers. These receivers operate at the principle of differential positioning, which requires the use of at least two receivers. They are placed and remain stationary both at the station and at the point where the position is taken, where satellite signals are continuously received and recorded over a long period of time (usually over 3-4 hours). Subsequent determination of the position results from the post processing of the satellite computer data.

- Real time positioning geodetic, hydrographic and industrial kinematic receivers. These receivers provide the ability to determine centimeter accuracy (2 - 3 cm) in real time (no stop at positioning point required) and used:

- In geodetic / topographic applications without requiring any receiver attitude to receive satellite signals.
- In special hydrographic surveys of high precision positioning requirements.
- In special precision constructions, such as the construction of railway tracks, bridges, etc.

g) Composite satellite GNSS receivers (GPS, Glonass, EGNOS, WAAS etc.). The receivers of this category have the same form as the common GNSS receivers. Their difference from their respective common GNSS receivers is the ability to receive and process signals from others except GPS, satellites from corresponding additional internal receiving channels and corresponding processing units.

V. *CHAPTER FOURTH: MARITIME USES OF GNSS SYSTEMS*

A. Navigation with the GPS system

The creation of GPS is one of the most important developments in the improvement of navigation methods, since with the help of a simple satellite receiver of very small dimensions and weight it is possible to immediately and continuously determine the position of the ship in real time with precision inconceivable for the traditional methods navigation. However, the effect of the capabilities of a GPS / GNSS navigation receiver on navigation methods is not limited to its basic ability to directly, constantly and reliably determine the position of the ship but also offers a number of very useful precision navigation services such as:

1) The registration on the receiver of several shipping routes, defined by successive change of course points or way points.

2) The provision during the voyage of indications of distance from a way point and the course to be observed for arrival at that point.

Navigation support capabilities with GPS are increasing rapidly when the GPS receiver is used for its net-centered connection with other electronic naval instruments and systems, such as ECDIS and AIS, the Marine Radar / ARPA, the sonar device, the log and the integrated navigation systems and the integrated bridge systems.

The capabilities of modern digital technology have made it possible to build GPS / GNSS receivers in micro-integrated circuits for integration into both of Integrated Navigation Systems (INS) and Integrated Bridge Systems (IBS), as well as other electronic nautical instruments and systems.

On modern ships, GPS / GNSS receivers of very high capabilities can now be installed in the form of an integrated circuit, which is integrated into a single receiver satellite antenna unit (Fig.7). These receivers are not directly accessible but are handled by:

1) Autonomous "display and control" units (Fig.8).

2) An INS system.

3) An IBS system console.

This chapter describes the most important uses and capabilities of a typical GPS maritime receiver when it is used autonomously without its interfacing with other marine instruments and devices.

Fig.7. GNSS Maritime Receiver (GPS, Glonass, Galileo, BeiDou, WASS, EGNOS), in which antenna and satellite receiver are integrated into one unit.

Fig.8. Naval Electronic Instrument displaying and Control Unit for interfacing with: GNSS receivers, satellite compasses, routers etc.

B. Basic capabilities of a typical GPS maritime receiver

The basic capabilities of a simple GPS maritime receiver etc. are the following:

1) Continuous real time indication of the position coordinates (stigma) of the ship according to the following basic user options:

a) Selection of the geodetic reference system (WGS-84, ED-50 etc.), in which the coordinates of the position are referenced.

b) Selection of positioning with geodetic ellipsoidal coordinates (φ, λ, h) or UTM (X, Y) cartesian coordinates.

2) Recording the coordinates of different way points (WP) in receiver memory, which are utilized in many applications, such as:

a) Designing a shipping route with successive change of course points (Fig.9).

b) Storage of critical way points for future use, such as entry points on a channel or port, shunting points in a channel or in restricted waters etc.

c) Anchorage safety.

d) Observation of safety distances from specific shipping risks during the voyage.

e) Activation of human procedures at sea.

f) Calculation of the vessel's actual course and speed.

g) Calculation of the direction and intensity of the sea current.

h) Calculation of router error.

i) Using the GPS receiver (even simple amateur receivers) to convert one point coordinates from one geodetic reference system to another and to convert geodetic ellipsoidal coordinates (φ, λ, h) to UTM (X, Y, Z) cartesian coordinates and vice versa.

We can say that the basic core of the widest and most inexhaustible range of maritime capabilities and GPS applications is the recording of way points in the receiver's memory for future use, which is usually done in the following ways:

1) At the stage of preparation of the voyage: Way points are entered by typing their coordinates for later use in various applications, such as:

a) To define the route as successive change of course points.

b) As reference points for observing safety distances from specific shipping risks during the voyage.

2) During the voyage: Way points can be entered, except by typing their coordinates and in a direct way, usually by pressing a button to automatically record the coordinates of the position (stigma) of the ship as a way point. The way points registered in this way are utilized in many applications such as anchorage safety, activation of human procedures at sea, for the storage of critical way points for future use, such as entry points in a channel or port etc.

From the above it results that the capabilities of GPS navigation receivers, even the most amateur ones, are not only limited to automatic and continuous real time positioning but cover a wide range of shipping applications, some of which are just mentioned above. These applications of GPS navigation receivers are based on the automatic resolution by the receiver of the two major shipping problems (straight and loxodromic problem). This solution computes:

1) The distance and bearing of a way point (B) from another way point (A) (reverse loxodromic problem).

2) The coordinates of the position of a point, which is at a given distance and bearing by another (straight loxodromic problem).

For the needs of navigation it is more common to solve the reverse loxodromic problem for:

1) The calculation of the bearing (route to be followed) to arrive at the next change of course point.

2) The calculation of the distance of the present position of the ship from the next change of course point or from a specific way point.

3) The execution of anchorage safety.

4) Activating and executing procedures for locating and rescuing human beings at sea.

5) Keeping safety distances during sailing.

The solving of the above shipping problems is not directly perceived by the user, because these calculations are automatically made by the receiver without his direct intervention in the calculation procedures.

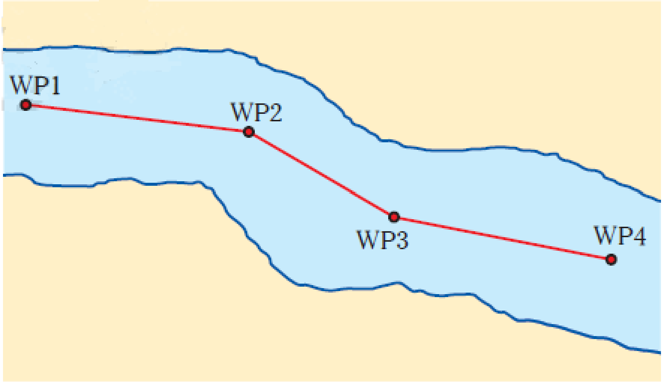

Fig.9. Route design with successive change course points. The way points are usually denoted by WP (Way Point) characters and a serial number e.g. WP1, WP2 and so on.

C. Additional features of professional GPS maritime receivers

In addition to the above capabilities provided by all GPS navigation receivers (even from the portable ones, which as we have said are in the form of a portable phone or wristwatch) and therefore can be used in addition to identifying positioning of ships and in a variety of other applications, professional maritime receivers also offer other possibilities such as:

1) Transfer of way points from computer to receiver and vice versa.

2) Connection to other nautical electronic instruments and systems (ECDIS, AIS, Radar / ARPA, sonar device, log etc.).

3) Warning that the boat is out of the planned route at a distance greater than the user defined maximum allowable deviation (off track limit).

4) Warning that the boat is approaching the next change or destination point depending on the user defined distance from that point.

5) Anchorage safety warning when the vessel has been dropped from the anchoring position at a distance greater than that specified by the user.

6) Identification / avoidance of individual hazards (warning when the position of the vessel is less than the user defined safety distance from a way point).

7) Indications of reliability and provided stigma accuracy, usually with the Geometric Dilution of Precision GDOP, PDOP, HDOP, and VDOP parameters.

8) Selection of satellites to be used or not to be taken into account for the determination of the position.

D. Basic marine GPS receiver settings

The basic elements that the user must observe to ensure the highest possible accuracy, minimize possible errors and assess the accuracy of the stigma provided by the receiver he uses, are the following:

1) Setting the receiver's basic operating parameters, such as:

a) Selection of the geodetic reference system (WGS-84, ED-50, etc.), in which the coordinates of the position are referenced. This setting is very decisive in achieving the position accuracy provided by the satellite system. Note that choosing the receiver of a different reference geodetic system from the nautical map system used may result in position errors in the order of 1 km.

b) Selection of positioning with geodetic ellipsoidal coordinates (φ, λ, h) or UTM (X, Y) cartesian coordinates.

c) Registration of the estimated position (with a very wholesale accuracy of 200 nm) or selection of the broader area where the receiver is located, as well as the date and time in order to exploit the satellite almanac data, so as to reduce the time required to determine the first position after activation of the receiver.

d) Selection of displaying units of coordinates, distances, angles etc., such as:

- Displaying of geographic coordinates (φ, λ) in degrees, first and second minutes, e.g. N 12° 34' 56.78", W 013° 24' 39.28".
- Displaying of geographic coordinates (φ, λ) in degrees and first minutes in decimal format, e.g. N 35° 15.678', E 022° 36.287'.
- Display elevations in meters or feet.
- Display of distances in nautical miles, kilometers or miles of land.
- Display of a speed determined by the receiver at nodes or kilometers per hour.

2) Checking the geometry of the satellites as well as the provided position accuracy (usually with the GDOP, HDOP, VDOP parameters) and if necessary defining the satellites that should not be taken into account in the determination of the position.

3) Checking the ability to determine position three dimensional or recording the elements required to define a two dimensional position.

4) Check the age of the satellite almanac and if it is old, renew it to reduce the time required to determine the first position after activating the receiver.

E. Examples of capabilities utilization of GPS maritime receivers

The practical shipping applications of the GPS are numerous. Below are two examples that are only indicative of its overall capabilities, which, in addition to precise positioning, cover a very wide range of practices maritime applications.

1) Anchorage safety.

The anchorage safety control process with a typical GPS maritime receiver is as follows:

When anchoring is carried out, the mooring position as a way point is stored in the receiver's memory. This point (point A) must correspond to the actual position of the anchor, specifically at the mooring position of the anchor and not in the position of the bridge immediately after anchorage (point B).

After the anchorage is completed, the ability of the receiver to automatically calculate the bearing and the distance of its position from the way point corresponding to the actual mooring position (point A) is activated. This ability is provided by the automatic solution of the inverse loxodromic problem by the receiver. To solve this problem, the microprocessor embedded in each maritime receiver uses:

1) The coordinates of each position (stigma) of the ship (point B) as the starting point.

2) The coordinates of the actual anchorage point to the end point (point A).

Then, based on the above data, the receiver continually calculates and displays on the screen the distance of the second point (actual anchorage - mooring point of the anchor) from the each actual position of the ship (bridge position). At this distance, the estimated GPS position error should be added for security reasons.

The above procedure can be done with any portable simple GPS receiver. Professional shipping receivers (whether portable or not) provide the additional ability to enter into the memory of the receiver of a particular security distance from the way point, which is used as a real anchorage point. By registering the above security distance to a professional maritime receiver, an audible alert is automatically provided, when the ship's estimated distance from the receiver from the actual anchorage point is greater than the determined distance (when the vessel has fallen from the mooring position at a distance greater than the user defined safety distance of anchorage).

2) Observation of safety distances from specific shipping risks during the voyage.

The procedure keeping of safety distance from a shipping hazard, e.g. from the rocks of the following map (Fig.10), with a common amateur GPS receiver is as follows:

At the stage of the preparation of the voyage or even during the voyage, a way point is registered in the memory of the receiver, which is selected at the geometric center of the maritime risks area [way point A]. The registration is done by typing in the receiver the geographical (geodetic) coordinates (φ, λ) of point A, as they result from the paper map, taking into account the map coordinate system (geodetic reference system).

During the voyage in the area of the aforementioned shipping hazards, even with a course of zλ = 320o the receiver's ability to automatically calculate the bearing and the distance of its position from the above way point is activated. This feature is provided to all maritime receivers, even in amateur and is implemented by automatically solving by the receiver the reverse loxodromic problem. To solve this problem, the microprocessor embedded in each maritime receiver uses:

1) The coordinates of each position (stigma) of the ship (Π1, Π2, Π3 .....) as the starting point of the rhumb line.

2) The coordinates of the selected for the position of shipping risks way point A, as the point of destination for the rhumb line.

Then, on the basis of the above data, the receiver calculates and displays on the screen the distance and the bearing of the second point A (center of the maritime risks area) from the actual position (stigma) of the ship.

The above procedure can be done with any portable GPS amateur receiver. Professional shipping receivers (portable or non-portable) provide additional storage capability in the memory of the receiver of a particular security distance from way points, which are used as reference points for measuring safety distance. In our example as a safety distance from the (WPA) rocks, the distance is 0.5 nm. By registering the above security distance to a professional maritime receiver, an audible alert is automatically provided, when the ship's estimated distance by the receiver from point A is less than the safety distance (0.5 nm).

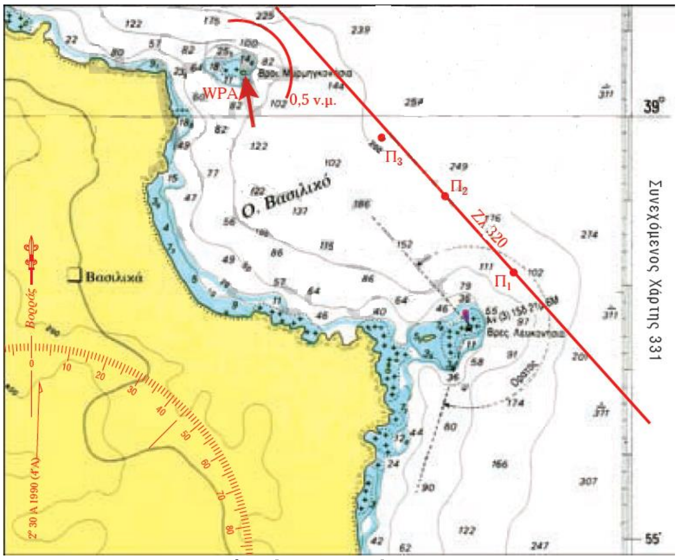

Fig.10. Keeping safety distances with GPS receiver.

REFERENCES

[1] http://artemis.cslab.ntua.gr/el_thesis/artemis.ntua.ece/DT2012-0122/DT2012-0122.pdf

[2] https://el.wikipedia.org/wiki/Global_Positioning_System

[3] http://erodios.it.teithe.gr/BlindNav/GPS/GPS.htm

[4] https://www.gps.gov/systems/gps/modernization/

[5] Aerospace Corporation, (2003). GPS Primer: A Student Guide to the Global Positioning System. Los Angeles, USA. Available at : https://florida.theorangegrove.org/og/file/9129db88-b76c-0c3b-2149-344ce701f190/1/GPS-Primer.pdf

[6] Betz, J. W. (2002). Binary offset carrier modulation for radio navigation. Navigation, 48 (4): 227-246. doi: 10.1002/j.2161-4296.2001.tb00247.x

[7] Feng, Y (2003), Combined Galileo and GPS: A Technical Perspective. Journal of Global Positioning Systems, 2 (1): 67-72.

[8] https://eclass.teicrete.gr/modules/document/file.php/TD103/%CE%A0%CE%95%CE%A1%CE%99%CE%95%CE%A7%CE%9F%CE%9C%CE%95%CE%9D%CE%9F/%CE%A3%CE%97%CE%9C%CE%95%CE%99%CE%A9%CE%A3%CE%95%CE%99%CE%A3/K.7-/7.pdf

[9] http://users.sch.gr/mppapado/downloads/GPS.pdf

[10] https://www.princeton.edu/~alaink/Orf467F07/GNSS.pdf

[11] http://multimedia.biol.uoa.gr/MDE-AKTINOBOLIES/FEK399-syxnothtes%20genika.pdf

[12] GLONASS-ICD (2008). GLONASS Interface Control Document. Version 5.1, 2008, available from: http://gauss.gge.unb.ca/GLONASS.ICD.pdf

[13] Cojocaru.S. et. al. (2009). “GPS-Glonass-Galileo: A Dynamical Comparison”. Journal of Navigation, 62, pp 135-150. doi:10.1017/S0373463308004980.

[14] Euler H. J. (2005): Reference Station Network Information Distribution, IAG Working Group 4.5.1: Network RTK. Available at: http://www.wasoft.de/e/iagwg451/euler/euler.html

[15] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4321187/

[16] Commission of the European Communities, The World Radiocommunication Conference 2003 (WRC-03), Brussels. Available at:http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2003:0183:FIN:EN:PDF

[17] https://repository.kallipos.gr/bitstream/11419/2712/5/00_master_document.pdf

[18] Hofmann-Wellenhof, B., Lichtenegger, H. and Wasle, E. (2008). GNSS-global navigation satellite systems. Wien: Springer. Available at: .https://nguyenduyliemgis.files.wordpress.com/2014/09/gnss-global-navigation-satellite-systems-gps-glonass-galileo-and-more-2008.pdf

[19] Januszewski, J. (2014). “GNSS Receivers, Their Features, User Environment And Applications”. Annual of Navigation,21(1). Available at: yadda.icm.edu.pl/.../Annual_Januszewski_21.pdf

[20] http://w3.uch.edu.tw/ccchang50/ebook_introduction%20to%20gps.pdf

[21] http://www.navipedia.net/index.php/Main_Page

[22] http://hmga.gr/storehouse/word-acrobat/GPS.pdf