

## **TIME: A CRITICAL PARAMETER IN SATELLITE NAVIGATION AND POSITIONING INFRASTRUCTURE**

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### **ABSTRACT**

The applications of space-borne satellites are increasing in many aspects of human endeavours; the most among them being the provision of guaranteed access to users of precise time and location services. An investigation was therefore carried out through a review process mechanism to determine the orbit parameter that has great influence on a satellite for ensured performance and accuracy. This was approached through the consideration of the role of time in satellite navigation and positioning, with reference to some satellites' principal characteristics: satellite segments, satellite orbit, satellite position fixing, and some error sources in satellite systems. It was found that these characteristics are intrinsically or extrinsically highly time dependent and related in satellite operations. In addition efforts were made to highlight the design and development of atomic clocks for accurate time keeping in satellite navigation and ranging. Consequently, it was observed that without time, satellite navigation and positioning infrastructural provision would not be possible; thus, concluding that time is a critical parameter in services rendered through the satellite initiatives.

**Keywords: time, atomic clock, satellite segments, performance, accuracy**

### **INTRODUCTION**

Satellite positioning, and navigation systems, developed by the United States of America (GPS), the Russian Global Navigation Satellite System (GLONASS), and their European counterpart (Galileo), are both military and civilian systems. Aside the continuous availability of these systems to civilian position-fixing tasks, such as navigation and surveys, they have completely changed the former working methods (e.g. triangulation, traversing, trilateration, etc), by making the system more user friendly. Low-cost, hand-held receivers have the capability of giving coordinates at any point on the earth's surface to an accuracy of around 10 metres, while more sophisticated survey units can give relative position to within a few millimetres (Bannister et al, 1998). One of the particular advantages of these satellite positioning systems is that a clear line of sight is not required between observation points, and the equipment can work day or night, in all weathers, being unaffected by rain, fog or snow. This attribute has made satellite applications invaluable in many aspects of environmental, socio-economic development of many nations.

As a result, researches are continuously being carried out in satellite technology and its applications in many areas of human initiatives. Robins (1962) outlined the activities of the British space research agency. His study considered the general organization of civil space research in the United Kingdom, and its relations with international organizations. A brief summary of the characteristics of the Skylark rocket was given in addition to the optical and radio tracking methods used at the British-controlled stations for tracking of satellites and space probes. The general plans for the instrumentation of United States Scout satellites with British equipment were highlighted as well as the technical and organizational problems which have to be

solved in this type of enterprise and of the capabilities results. Ring (1962) observed that the removal of atmospheric absorption enables the astronomer to extend his observations to much shorter wavelengths and many new astrophysical problems can be tackled. This was in relation to the difficulties of instrumenting an astronomical satellite for ultra-violet observation. A summary of the various astro-physical problems that are to be investigated in this way, he pointed out, shows the limitation of the technique both instrumentally and astronomically. Pressey (1962) studied ground equipment for radio observations on artificial satellites, and gave an indication of the way in which the observations might be used to study wave propagation. McLauchlan, and Walters (1962) described an equipment for the reduction of Time-Multiplexed telemetry data, and disclosed that this equipment accepts a magnetic tape input. After analogue processing, it produces outputs in the form of film and punch cards.

Hurden (1962) carried out a design of rocket engines burning hydrogen as fuel. An analysis was made of problems likely to arise in the design and development of a liquid hydrogen/liquid oxygen rocket engine and attention was drawn to those aspects where departure from normal practice was likely. It was concluded that there were no formidable difficulties to be overcome in the construction of such an engine. Hunt and White (1962) highlighted on a general study made of the processes required to arrive at an optimum stage design for a satellite launching vehicle, and stressed that to achieve the best performance, attention must be kept focused on payload. Bailey et al (1962) considered the important factors which influence the design of a liquid oxygen/hydrogen propulsion system for the third stage of a satellite launching vehicle. The payload capabilities of such a system were examined for missions ranging from a close circular satellite orbit to a soft-landing on the moon. In a related research approach, Stewart (1962) proposals for the use of liquid hydrogen as a working fluid in advanced propulsion systems other than nuclear rockets were reviewed, Zwicky's morphological analysis first being employed to determine the range of possible systems. Particular attention was paid to free radical propulsion which includes: heating jet, the solar heating jet, the photon rocket, and interstellar propulsion. Likely applications were the establishment of satellites and for propulsion on heliocentric missions. Also studied was the use of hydrogen in fuel cells and in hydrogen/oxygen motors for generating auxiliary power.

Aside from the review of the design and mechanical aspect of the satellite instrumentation, some applications of these systems in resource management have been carried out. Lemmens (2003) provided some brief information for readers in positioning for mobile GIS applications. With the listed GPS receivers, he pointed out; the surveyor is able to determine positions at the centimeter level. Some other authors have also carried out studies in satellite technology and applications, among whom are: Lemmens (2003); Sipkes (2003); Nwadior (2004a, b); and Fitch (2004).

However, these research initiatives notwithstanding, the present author observed that little or no attempt had been made to analyze some essential mathematical orbit parameters that influence satellite performance and accuracy. It is in recognition of this that the paper attempted to fill this gap by critically studying this aspect for sustainable navigation and position fixing through the satellite tracking and ranging techniques. Furthermore, it is envisaged that this review would open an avenue for future investigation on this work empirically, as an input in satellite systems development and applications.

## MEASUREMENT OF TIME IN SATELLITE NAVIGATION

Measurement of time in precise works like those of the satellite system, is done using the atomic clocks. Without atomic clocks, satellites (GPS, GLONASS, GALILEO, etc) would not be possible. According to Lemmens (2005), three main types of atomic clock can be distinguished depending on the elements used: caesium, hydrogen or rubidium. The caesium-133 atom is most commonly used. Atomic clocks do not rely on atomic decay and they are not radioactive. The adjective "atom" refers to the characteristic oscillation frequencies of atoms. The measurement of vibrations is the principle of all atomic clocks. The major difference concerns, in addition to the element chosen, the way of detecting the change in energy level: caesium clocks separate atoms of different energy levels by magnetic field; hydrogen clocks maintain hydrogen atoms at the required energy level in a container of a special material so that the atoms do not lose their higher energy state too fast, and rubidium atomic clocks, which are the simplest and most compact, use a glass cell of rubidium gas that changes its absorption of light at the optical rubidium frequency when the microwave frequency is just right.

## THE MASTER CLOCK

Atomic clocks keep time better than any other clock, they are even more steady than the Earth's rotation. (Lemmens, 2005). The caesium atomic clock is the most accurate in the long term: better than one second per 1 million years. Hydrogen atomic clocks show a better accuracy in the short term (1 week): about 10 times the accuracy of caesium clocks. The hydrogen master oscillator provides fractional frequency stability of about 1 part in  $10^{18}$  for intervals of a few hours to a day. The maser's high frequency stability is ideally for a variety of space applications such as very Long Baseline Interferometry (VLBI) from space, precision measurements of relativistic and gravitational effects and GPS as well as Galileo and GLONASS.

As a result of the extremely high accuracy of atomic clocks, the world's time-keeping system lost its astronomical basis in 1967. Then, the 13<sup>th</sup> General Conference on Weights and Measures derived the SI second from vibrations of the caesium atom, which is now internationally agreed as the interval taken to complete, 9,192,631,770 oscillations of the caesium – 133 atom, exposed to a suitable excitation.

## SATELLITES: POSITION, TIME AND DISTANCE

The determination of these satellite parameters of position, time and distance would be illustrated using GPS as example. Receiver position is calculated from the position of satellites and the distances to them. Distance is calculated from the time a radio signal travels between satellite and receiver. But how is the satellite's position known, and how is traveling time determined.

Basically, satellite positioning is a trilateration problem (Key and Lemmens, 2005). From the known position of three satellites and the measured distances between them and the receiver, coordinates of receiver position can be calculated. Position can also be determined through resection to three or more satellites. The distances are determined by multiplying the traveling time of the radio signals by the speed of light. But how is a continual check to be kept on the positions of satellites.

Their orbits are not completely deterministic but fluctuate due to celestial gravity forces. Since radio signals travel at a speed of 300,000km per second, an inaccuracy in time measurement of one-nanosecond (one billion part of a second or  $10^{-9}$  second)

induces a distance error of 30cm, whilst with geodetic receivers, an accuracy at the centimetre level can be achieved.

## **POSITION AND TIME**

The ground segment monitors and controls the position of GPS satellites. For two daily windows lasting one-and-a-half hours, each satellite is out of contact with the ground stations. The main station acts as data processing centre for all information, including that collected at the remote station. Orbit coordinates are continuously determined by triangulation. Comparing the time of the satellites' four atomic clocks with similar devices on the ground provides information on time errors. When a satellite drifts slightly out of orbit, repositioning is undertaken. The clocks may also be readjusted, but more usually information on time errors is attached to GPS signals as correction factors. The computed corrections, time readjustments and repositioning information are transmitted to the satellites via three up-link stations co-located with the downlink monitoring stations. In this way, all the GPS satellites are able to continuously attach corrections to the parameters they send out, which include ephemeris data, almanac data, satellite health information and clock correction data.

## **TIME AS AN ESSENTIAL PARAMETER IN SATELLITE NAVIGATION**

The role of time in satellite navigation can be invariably considered with reference to the following: satellite segments, satellite orbit, basic principle of position fixing, and some error sources in satellite systems.

## **SPACE SEGMENT**

The satellite positioning systems consist of three segments; the space segment, control segment and the user segment. In the GPS system, the space segment is composed of satellites weighing about 400 kg and powered by means of two solar panels with three back-up, nickel-cadmium batteries. The first NAVSTAR satellite for the GPS system, for example, has a total of 28 GPS satellites in orbit about the earth. The satellites were at an altitude of 20200 km above the earth, with an orbit time of 12 hours (11h: 58 min). At least four satellites are always in view from any point on the earth. The GLONASS system consists of 24 operational satellites, with each satellite orbiting the earth every 11 hr., 15 min., and has a life span of at least five years.

In the GPS, each satellite has a fundamental frequency of 10.23 MHz and transmits two L-band radio signals. Signal L<sub>1</sub> has a frequency of 1575.42 MHz (10.23 X 154) and L<sub>2</sub> a frequency of 1227.60MHz (10.23 X 120). Modulated onto these signals are a Coarse Acquisition (C/A) code-referred to as the Standard S-code, and a Precise P-code. These codes are in effect time marked linked to ultra-accurate clocks (oscillators) on board the satellites. Each satellite carries three rubidium or caesium clocks having a precision in the region of 10<sup>-13</sup> seconds. In addition, both the L<sub>1</sub> and L<sub>2</sub> carry a formatted data message, transmitted at a rate of 50 bits per second, containing satellite identification, satellite ephemeris, clock information, ionospheric data. etc.

Like the GPS, the GLONASS satellites are controlled by on-board atomic caesium clocks and have two carrier waves, L<sub>1</sub> and L<sub>2</sub>, and offer two levels of service; the channel of standard accuracy (CSA) and the channel of high accuracy (CHA). The CSA is available for general public use, but the CHA is available only to authorized users. Unlike GPS, all 24 GLONASS satellites transmit at a different frequency but are modulated with the same binary code pattern (Schofield, 1998).

### CONTROL SEGMENT

The control segment has the role of supervising the satellite timing system, the orbits and the mechanical condition of the individual satellites. Neither the timing system nor the orbits are sufficiently stable to be left unchecked for any great period of time. The GPS satellites are tracked by five monitor stations at Kwajalein, Hawaii, Ascension and Diego Garcia, with the master control in Colorado Springs. The positional data from all the tracking stations are sent to the master control for processing. These data, combined with the satellite's positions on previous orbits, make it possible to predict the satellite's position for several hours ahead.

This information is uploaded to the satellite for subsequent transmission to the user, every eight hours. The master control is also connected to the time standard of the United States Naval Observatory in Washington, DC. In this way satellite time can be synchronized and data relating it to Universal Time transmitted. Other data regularly updated in satellites system are the parameters defining the ionosphere to facilitate the computation of refraction corrections to the distances measured.

### USER SEGMENT

The user segment consists essentially of a portable receiver/processor with power supply and an omnidirectional antenna. Two fundamental methods can be used to establish the distance between the satellite and receiver: pseudo-range and carrier phase measurement.

In the pseudo-range, satellite positioning is a unidirectional method of distance measurement, which depends upon accurate time measurement and precise synchronization of clocks in both satellite and receiver; but because the latter is almost impossible to achieve the technique is known as pseudo-range. The satellite continuously transmits its code, and because in the case of GPS C/A-code this repeats every millisecond, the receiver can lock onto it and establish the pattern. The receiver is pre-programmed with the (Precise) P-code pattern for distance measurement. Fig. 1 illustrates this aspect of measurement, as in Bannister et al (1988).

The basic equation for distance from the receiver to the satellite is:

$$R = c ( t - e ) \tag{1}$$

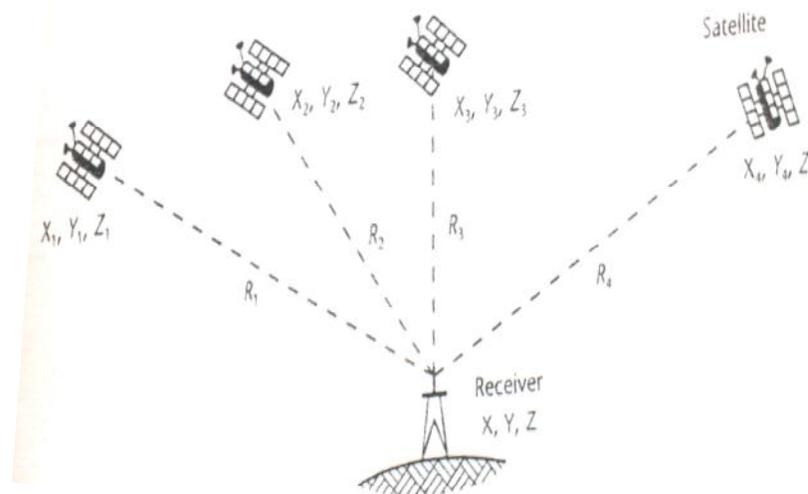
where R = actual range between receiver and satellite, c = speed of light, t = transit time and e = timing errors. In fig. 1, the satellites can be considered to be control stations of known coordinates  $X_i, Y_i, Z_i$ , and if the receiver coordinates are x, y, z, then

$$\sqrt{[(X_i - x)^2 + (Y_i - y)^2 + (Z_i - z)^2]} = c(\delta t_i - e) \tag{2}$$

Having obtained the distance simultaneously from four or more satellites, which should be reasonably spread and in at least two orbital paths, the computation of receiver location involves the process of trilateration (Bannister et al, 1998). The four observations yield four simultaneous equations and hence allow the unknown parameters x, y, z and e to be evaluated (assuming e is the same for all observations, i.e no SA-dither).

In the carrier phase measurement method, the signal is transmitted one way, satellite to receiver, and thus the true phase shift is related to the accurate synchronization of the two clocks on-board satellite and receiver.

It is to be appreciated however, that the type of receiver used will depend largely upon the requirements of the user. For instance, if GPS is to be used for absolute as well as relative positioning, then it is necessary to use pseudo-range. If high-accuracy relative positioning is the requirement, then the carrier phase would be the observable involved. From this consideration it can be seen that for real-time pseudo-range positioning, the user would need access to the navigation message-the Broadcast Ephemeris. If carrier waves are to be used, the data are post-processed and an external precise ephemeris may be used. Thus where the navigation message is essential, a code-correlating receiver would be used. If carrier phase and post-processing are the requirement, a codeless receiver may be preferred.

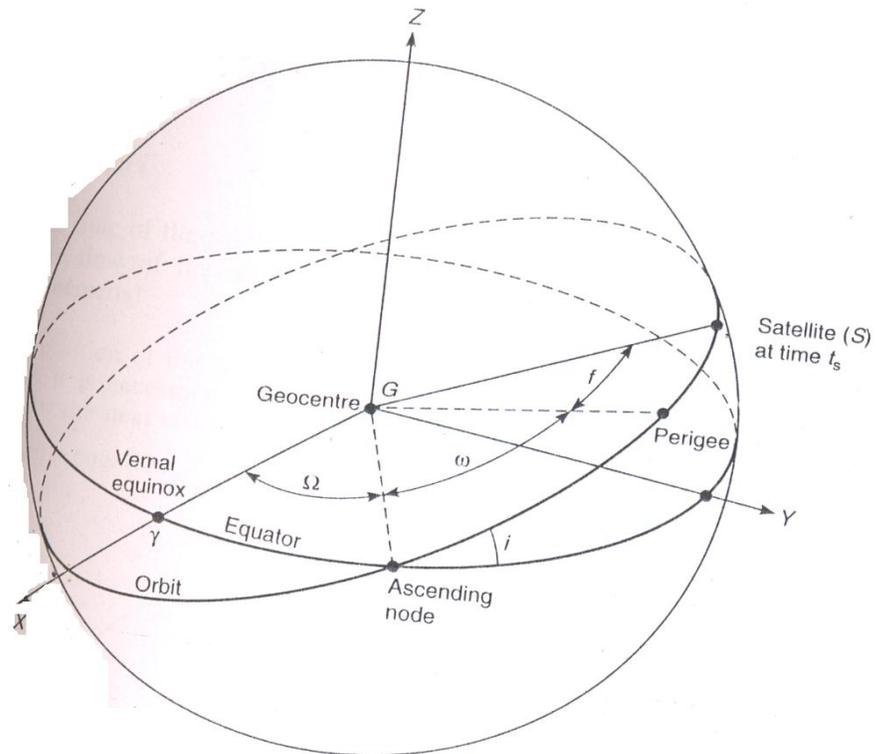


**Fig. 1 User Segment (Pseudo-range).**

### SATELLITE ORBIT

A critical examination of the satellite orbits parameters reveals that most of them are time related. Reference to Kepler's Laws concerning the movement of planets around the sun, which have been applied to the movement of satellites around the earth, it was established that: satellites move around the earth in elliptical orbits, with the centre of mass of the earth situated at one of the focal points: the radius vector from the earth's centre to the satellite sweeps out equal areas at equal time intervals; and that the square of the orbital period ( $T$ ) is proportional to the cube of the semi-major axis  $a$  (i.e  $T^2 = a^3 \times \text{constant}$ ).

These laws, therefore, define the geometry of the orbit, the velocity variation of the satellite along its orbital path and the time taken to complete an orbit. Other parameters of the satellite related to time are: the right ascension (RA); the inclination of the orbital plane to the equatorial plane ( $i$ ); argument of perigee ( $\omega$ ) measured in the plane of the orbit from the ascending node; the true anomaly, measured at the time when the satellite passes through the perigee; the time for passing through the apogee; etc. Fig. 2 Illustrates the satellite orbit in space.



**Fig. 2 Satellite orbit in space.**

Furthermore, the space coordinates of the satellite is computed at a given time,  $t$ . These are;

$$\begin{aligned} X_o &= r \cos f \\ Y_o &= r \sin f \\ Z_o &= 0 \text{ (in a pure Keplerian orbit)} \end{aligned} \tag{3}$$

where  $r$  = the distance from the earth's centre to the satellite  
 $f$  = angle of location of the satellite relative to the perigee.

The space coordinates can further be computed using the information contained in the broadcast ephemeris. The procedure involves: Computing  $T$ , which is the orbital period of the satellite, i.e the time it takes to complete its orbit. Using Kepler's third law:

$$T = 2\pi a (a/\mu)^{1/2} \tag{4}$$

where  $\mu$  = the earth's gravitational constant, being equal to  $398601 \text{ km}^3/\text{s}^2$   
 Another method is to compute the "Mean anomaly"  $M$ , which is the angle swept out by the satellite in the time interval  $(t_s - t_p)$ ; from

$$M = 2\pi(t_s - t_p)/T \tag{5}$$

where  $t_s$  = the time of the satellite signal transmission (observed),  
 $t_p$  = the time of the satellite passage through perigee (obtained from the broadcast ephemeris)

M defines the position of the satellite in orbit but only for ellipses with  $e = 0$ , i.e. circles. To correct for this it is necessary to obtain the “eccentric anomaly”  $E$  and the “true anomaly” for the near-circular GPS orbits. Thus the position of the satellite can be defined in the mathematically pure Keplerian orbit at the time ( $t_s$ ) of observation.

The actual orbit of the satellite departs from the Keplerian orbit due to the effects of the following forces, most of which have intrinsic or extrinsic time elements in their determinations. They are: the non-uniformity of the Earth’s gravity field; the attraction of the moon and sun; atmospheric drag; direct and reflected solar radiation pressure; earth tides; and ocean tides. These forces produce orbital perturbations, the total effect of which must be mathematically modeled to produce a precise position for the satellite at the time of observation.

### BASIC PRINCIPLE OF POSITION FIXING

As previously stated, the principle involves the measurement of distance (or range) - to at least three satellites whose  $X_s$ ,  $Y_s$ , and  $Z_s$  position is known in order to define the user’s  $X_p$ ,  $Y_p$ , and  $Z_p$  position. In its simplest form, the satellite transmits a signal on which the time of its departure ( $t_D$ ) from the satellite is modulated. The receiver in turn notes the time of arrival ( $t_A$ ) of this time mark. The time which it took the signal to go from satellite to receiver is then  $(t_A - t_D) = t$  (delay time). The measured range  $L_R$  is obtained from

$$L_R = (t_A - t_D)C = t \cdot c \quad (6)$$

where  $c$  = the velocity of light

Whilst the above describes the basic principle of range measurement, to achieve it, one would require the receiver to have a clock as accurate as that of the satellite and perfectly synchronized with it. As this would render the receiver impossibly expensive, a correlation procedure, using the pseudo-random binary codes (P or S), actually “S”, is adopted.

The signal from the satellite arrives at the receiver and triggers the receiver to commence generating the S-code. The receiver-generated code is cross-correlated with the satellite code. The ground receiver is then able to determine the time delay ( $t$ ) since it generated the same portion of the code received from the satellite. However, whilst this eliminates the problem of an expensive receiver clock, it does not eliminate the problem of exact synchronization of the two clocks. Thus the difference between the two clocks (clocks bias), results in an incorrect assessment of  $t$ . The distances computed are therefore called pseudo-ranges.

The usefulness of time in satellite navigation and guidance has resulted to concerted efforts being made to improve the performance of atomic clocks onboard satellites and receiver, in order to improve the determination of range. One such innovative initiative, is the onboard Galileo Atomic Clocks manufactured by the European Space Agency (ESA).

### THE ONBOARD GALILEO ATOMIC CLOCKS

Galileo is a joint initiative of the European Commission and the European Space Agency for building a state-of-the-art global navigation satellite system (GNSS). The Galileo experimental satellite (Giove A) was launched on 28<sup>th</sup> December, 2005. The Galileo will provide a highly accurate guaranteed global positioning service under civilian control and will be interoperable with GPS and GLONASS (Droz, 2005). The Final Galileo system will consist of thirty satellites. 27 operational and three active

spares, stationed on three circular Medium Earth Orbits at an altitude of 23,222km, with an inclination of  $56^\circ$  to the equator. After more than ten years of development an overall budget of 30 million Euro, two onboard atomic clock technologies have emerged.

### **GSTB - V2 ATOMIC CLOCK**

Atomic clocks are critical for satellite navigation. The Rubidium Atomic Frequency Standard (RAFS) and Passive Hydrogen Maser (PHM) are the projected onboard clock technologies for Galileo. Every satellite will embark two RAFSs and two PHMs; dual technology is necessary to ensure reliability (technology diversity) and satellite lifetime of twelve years. The development of RAFS and PHM are based on studies done by the Observatory of Neuchatel late 1980s and by Temex Neuchatel Time (TNT) since 1995. The studies are supported by ESA. The activities related to Galileo System Test Bed (GSTB-V2) experimental satellite and implementation of the In Orbit Validation Phase are in progress. Two experimental satellites with a lifetime of three years have been launched in late 2005 aiming at: securing Galileo frequency filings; testing some critical technologies, such as the atomic clocks: experimenting with Galileo signals; and characterizing Medium Earth Orbits environment. Nine flight model clocks are being produced for the GSTB-V2 experiment; six RAFSs and three PHMs. Prior to launch, both types of clocks are subject to electronic tests and shock and vibration tests.

### **RUBIDIUM ATOMIC (RAFS) DEVELOPMENT**

The development of RAFS technology began at TNT in 1997. In early 2000, one RAFS I Engineering Model was completed. Updated RAFSI development began in June 2000 and was completed in early 2002. These activities included; improvement of clock stability with insertion of thermally regulated base-plate to better than  $4 \times 10^{-14}$  at 10,000 seconds; review of electronics package layout and components, manufacture of live Engineering Qualification models for lifetime qualification; manufacture of one Qualification Model.

In addition to the vibration and qualification tests, two radiation tests were carried out at CNES in Toulouse, France. The first, which simulated Galileo orbit (four cycles of 3rad per day during one week), showed no frequency radiation sensitivity. The other test, which simulated the total dose over the duration of the mission (30 K rad, continuous radiation at 400rad/h during three days) showed no electronic failure or performance degradation, although the drift of the crystal oscillator needed compensation; subsequent models have been modified accordingly.

RAFS2, initiated at the end of 2001 and completed at the beginning of 2003 with the delivery of an Engineering Model, is the baseline unit for development of the flight models for GSTB-V2. Two main objectives were achieved: further optimization of the physics package to reduce flicker floor to better than  $3 \times 10^{-14}$  (drift removed:  $2 \times 10^{-14}$ /day); inclusion of a DC/DC converter and the satellite TT&C interface compatible with new ESA requirements.

### **PASSIVE HYDROGEN MASER (PHM) DEVELOPMENT**

The space hydrogen maser will be Galileo's master clock. The first maser development for navigation applications which started in 1998, was initiated by the development of an active maser at Observatory of Neuchatel. However, the Galileo definition phase showed that the active maser was too heavy and too voluminous,

whilst its excellent frequency stability was not required. Therefore, in 2000, development was re-orientated towards building a PHM. The development of the PHM Engineering Model was completed in early 2003. Since June 2003 the instrument has been continuously tested to assess long-term performance and early identification of reliability and lifetime problems. Manufacturing for future flight production began in January 2003. The instrument was redesigned by Temex Neuchatel Time to increase compactness and ease assembly, integration and on-satellite testing by the inclusion of an external vacuum envelope. Main efforts focus on repeatable and reliable manufacturing. Two technological models, one structural and one Engineering Qualification Model were built. In addition, five qualification Models are being manufactured for life demonstration. One Proto-Flight Model is completing proto-qualification testing and is now integrated in the GSTB-V2 satellite. A second flight Model is about to be delivered.

### **ERROR SOURCES IN SATELLITE MEASUREMENT**

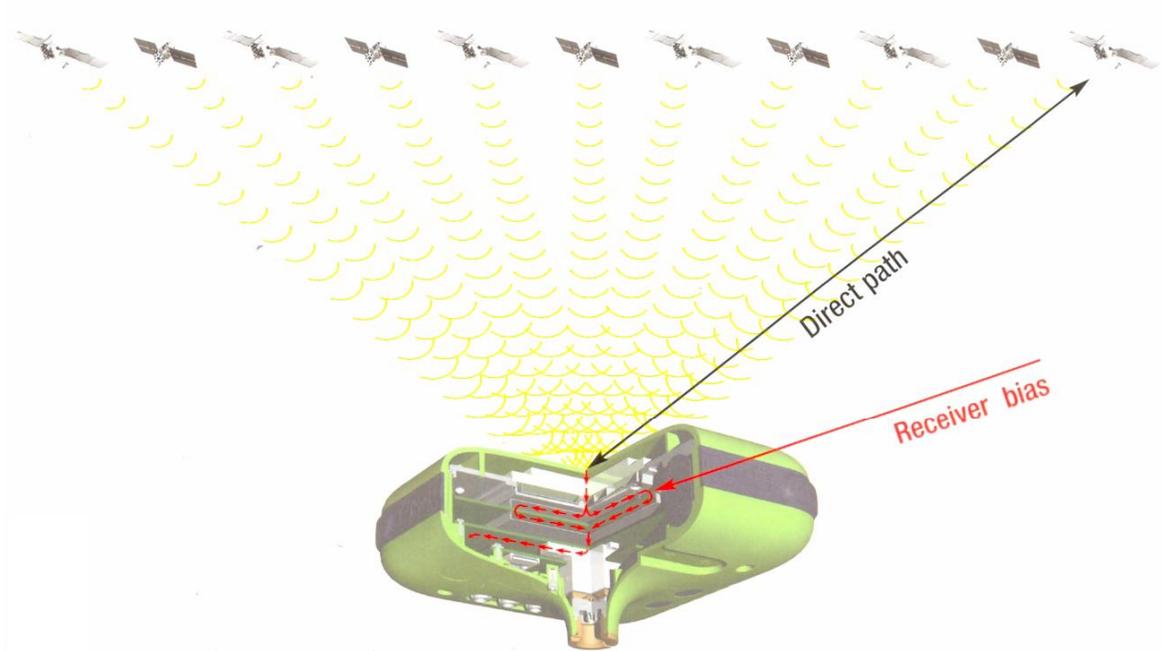
Different methods have been adopted to improve the accuracy of range in satellite position fixing. These include the use of GPS in three modes (single differencing; double differencing; triple differencing); kinematic GPS (pseudo-kinematic, and kinematic techniques). In the later case, to avoid cycle slips which occur when there is an obstruction between satellite and receiver, many more than four satellites are usually observed. However, despite these approaches, the final position of the survey station can be influenced by: the error in the range measurement; the satellite receiver geometry; the accuracy of the satellite ephemerides; the effect of atmospheric refraction; the processing software; error in integer number of wavelengths; phase difference, etc. The major error sources to be briefly discussed here, are as follows: receiver clock error; receiver noise; satellite clock error; satellite ephemeris error; atmospheric refraction error; multi-path error; and geometric dilution of precision (GDOP).

### **RECEIVER CLOCK ERROR, AND RECEIVER NOISE**

Time measurement is very significant, for an error of 0.01s approximates to a range of 3000km. However, the error can be minimized or eliminated by observation to at least four satellites in which the time bias between the satellite and receiver clocks may have been eliminated. The receiver noise has a random effect of about 3meters in range and is not removed in differential measurement. However, due to the great improvements in receiver design, the problem is significantly reduced. This is demonstrated by JAVAD GNSS Technology (2008) of United States of America as illustrated in Fig. 3 below.

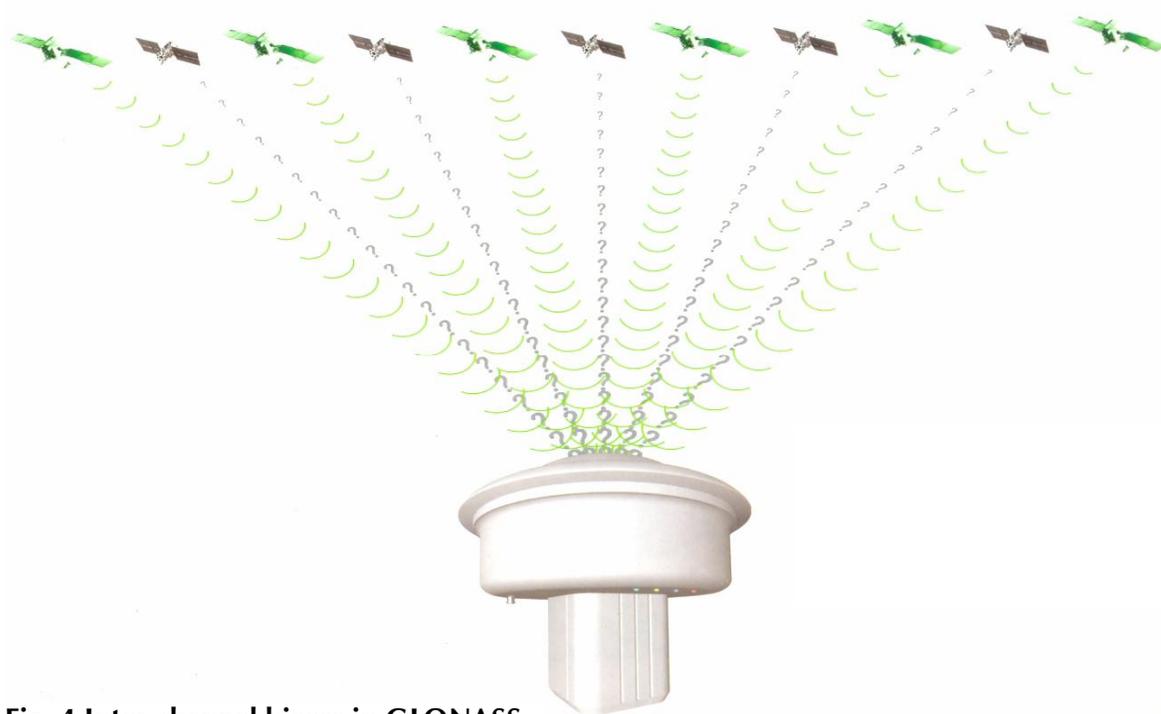
### **SATELLITE CLOCK ERROR**

Excessive temperature variations in space may result in the variation of the satellite clock from the GPS receiver time. However, Javad (2008), comparing GPS and GLONASS, explained that the latter experiences inter-channel biases while the former does not. Careful monitoring allows the amount of drift to be assessed and included in the broadcast message. Synchronization between all satellite clocks is kept to within 20 nano-seconds, equivalent to 6metres in range. Differential GPS methods of measurements drastically reduce or eliminate this error.



**Fig. 3: Receiver biases (Javad GNSS, 2008)**

Satellite orbit error results in the satellite not being where it was thought to be at the time of observation. In the past, orbit error of GPS satellite used to be in the region of  $\pm 20\text{m}$ , which would therefore produce an error of  $\pm 20\text{mm}$  (1 ppm) in a 20-km base line with  $L_2 = 20,000\text{km}$ . With improvement in satellite design and operations, orbit errors are in the region of  $\pm 5\text{m}$  or better. However, precise orbits can be computed, whilst in relative positioning the effect is not too significant. Fig 4 illustrates inter-channel biases in satellites (with GLONASS).



**Fig. 4 Inter-channel biases in GLONASS**

Another problem in satellite constellation associated with time, is the issue of unhealthy satellites. An unhealthy satellite is one that has been removed from service, either due to a scheduled outage (satellite and clock maintenance) or from an unscheduled anomaly (for example, degraded clock operation or problems with the spacecraft bus).

The reduced number of filled orbital primary slots stems from unscheduled outages. Scheduled outages have no significant impact on number of satellites usable since the operators typically remove a satellite from service for only a few hours, and such maintenance is performed on the order of once a month per satellite (Lavrakas, 2006). Unscheduled outages, however, can last days and may require significant effort on the part of the satellite operators to resolve. This poses a great problem for users; especially in surveying and aviation where high accuracy of observation results is frequently needed.

According to Vacanti (2006), we recently discovered that in a 5-day period, three GPS satellites were taken off line indefinitely with no explanation as to possible return to service. This is significant in that the constellation that remains is non-optimal" in terms of providing more than four satellites at all locations and so on. This is a very significant loss of availability, he pointed out, as it concerns our aviation operations.

An elaborated information on this, shows that between August and September, 2006, three GPS satellites (namely: PRN 15, PRN 3, and PRN 29) were taken off line for clock swaps. PRN 3 had a previous clock swap in June. Clock swaps typically take a week to 10 days; if there are no problems. This situation happens more frequently as the satellites age further, if they are not replaced.

The PRN 3 returned to service after an absence of 15 days; PRN 29 returned after a 19-day outages. PNR 15 has been off the sky for three times longer than normal for a clock change because its first change from cesium 4 to Rubidium 2, initiated on August 21, did not work. A second clock change, from Rubidium 2 to Rubidium 1, was initiated on September 5, and up till now, this satellite is still off the orbit, suggesting that it may have been lost or discarded. This also highly reflects the critical contribution of time in satellite health for accurate operation for applications.

## **ATMOSPHERIC REFRACTION**

Atmospheric fraction as it affects satellite signals can principally be considered in two parts, namely the ionosphere and the troposphere. The ionosphere is the region of the atmosphere from 50 to 1000m in altitude in which ultraviolet radiation has ionized a fraction of the gas molecules, thereby releasing free electrons. Satellite signals are slowed down and refracted from their true path when passing through the ionosphere. The effect on range measurement can vary from 150 to 50m. As the ionosphere effect is frequency dependent, carrier wave measurement using the different frequencies  $L_1$  and  $L_2$  can be used to assess the effect. However, it is considered in some circles that this process will not yield the accuracies required due to the noise resulting from the frequency-doubling method.

If the ionosphere was of constant thickness and electron density, the differential GPS would, for example, completely eliminate its effect, but this, unfortunately, is not so and residual effects remain. Due to positional and temporal variation in the election density, ionospheric effects cannot be entirely eliminated and may require complex modeling in the software.

In another aspect, the troposphere is even more variable than the ionosphere and is not frequency dependent. If conditions are identical at the monitor station and the roving receiver, then absolute correction is achieved by differential GPS. If not, however, meteorological measurements can be taken and appropriate corrections computed. Schofield (1998), has claimed that tropospheric modeling can reduce the resultant errors by 95%.

### **MULTI-PATH ERROR**

This phenomenon of error is caused by the satellite signals being reflected off local surface, resulting in a time delay and consequently a greater range. At the frequencies used in GPS, for example, they can be of considerable amplitude. Due to the fact that the antenna must be designed to track several satellites and cannot therefore be more directional, antenna design cannot preclude this effect. The only solution at this stage of GPS satellite is the careful siting of the survey station, clear of any reflecting surfaces. In built-up areas, multipath may present insurmountable problems unless the position of the satellites with reference to the ground stations is very carefully planned.

### **GEOMETRIC DILUTION OF PRECISION**

The satellite observation initiative through the resection technique is one of the fundamental methods that lead to high accuracy of measurements of position. As with a distance resection to survey stations on the ground, the geometric relationship of the stations to the resected point will have an effect on the accuracy of the point positioning. Exactly the same situation exists in GPS and other satellite types (Glonass or Galileo), where the position of the satellites will affect the three-dimensional angles of intersection. When the satellites are close together or in a straight line, a low accuracy fix is obtained. When they are wide apart, almost forming a square, a high accuracy is obtained. The satellite configuration geometry with respect to the ground station is referred to as "geometric dilution of precision" (GDOP) and the GDOP number is small for good configuration and large for poor configuration. Other dilution of precision parameters are; VDOP = Vertical vector (one dimension); HDOP = Horizontal vector (two dimensions); PDOP = Position vector (three dimensions); TDOP = Time vector; GDOP = Geometric position and time vector (four dimensions).

### **CONCLUSION AND RECOMMENDATIONS**

The applications of space-borne satellites are increasing in diversity of endeavours; the most notable being its provision of guaranteed access to users of precise, real time and location services. In satellite operation, the receiver position is calculated from the position of satellites and the distances to them. Distance is calculated from time a radio signal travels between satellite and receiver.

An investigation was carried out through a review process mechanism to ascertain the orbit parameter that has great influence on the performance of a satellite in orbit. This was approached through the consideration of the role of time in satellite navigation and positioning, with reference to some principal satellite orbit characteristics and performance, including errors resulting there from. It was found that time is a critical parameter in services rendered through the satellite initiatives. It was also found that since radio signals used in satellites travel at a speed of 300.000km per second, an

inaccuracy in time measurement of one-nanosecond (one billion part of a second) induces a distance error of 30cm in position determination.

Effort made in the design and development of atomic clocks for accurate time keeping in satellite navigation has been highlighted. Without time, and hence, atomic clocks, satellite navigation and positioning infrastructural provision would not be possible. Time is an essential parameter for computing and programming satellite fixes. Comparing the time of the satellite four atomic clocks with similar devices on the ground station provides information on time error (time/clock bias).

The paper has, through the theoretical review, highly identified "time" as the most influential factor in satellite systems operation, amongst others. It is recommended that to improve the performance of satellites, continuous calibration of all the errors highlighted in every receiver be implemented and in real-time with an accuracy of about a sub-millimetre for better users' services. It is also the view of the paper that additional improvement can be achieved through the design of hyper-channel (1000 channels) receivers to track all GPS, GLONASS and Galileo signals.

There is no easy solution, however, to the problem of ensuring that satellites continue to meet today's users' needs, since the field of users and application is becoming more diverse and demanding. One option to the solution may be to launch more satellites, but there are significant cost implications with this approach.

On the other hand, relying on aging constellations to remain operational is also fraught with risk. Many satellites are on their final point of failure due to time error and its other dependent parameters; and the cost of losing satellites is significant for almost all sectors of the global economy. All satellite components are time-programmed and work to achieve real-time efficiency and non realization of this, gives poor services to users, thus implying also that time is the most controlling factor in satellite operations. Future research would attempt to investigate the findings of this work empirically, as a contribution to the development of satellite infrastructure.

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