ABSTRACT

Global Positioning System (GPS) is a navigation and precise-positioning tool. In the scientific community, GPS plays an important role in the Earth sciences. There are many type of GPS applications and usage. In this project, GPS being used to analyze the scintillation of GPS signals at the Wireless and Radio Science Centre (WARAS) Research Centre UTHM. The GPS signal propagate through the ionosphere, it will be scintillated. Ionosphere scintillation is a rapid fluctuation of GPS signal's phase and amplitude. This is due to the content and the formation of the ionosphere over the equatorial region. By using GPS receiver in WARAS, the scintillation effect of the GPS signal will be determined. Then, the scintillation effect will be analyzed under the three conditions like the data before the GPS antenna have been removed, the data after the GPS antenna have been removed and the data on rainy days. By doing so, the relationship between the variation of the ionosphere over the region with the scintillation to the GPS signal will be known. Overall, the scintillations parameter of the GPS signals was identified using the amplitude and phase scintillation. Each of the parameter will verify using the effect of scintillation at C/No, S_{4cor}, ambient noise, thermal noise and elevation angle.

ABSTRAK

Sistem Kedudukan Global (GPS) adalah alat yang tepat dalam menentukan kedudukan pelayaran. Dalam komuniti saintifik, GPS memainkan peranan yang penting dalam sains bumi. Terdapat banyak aplikasi dalam penggunaan GPS. Dalam projek ini, GPS digunakan untuk menganalisis scintillation pada isyarat GPS di Pusat Wayarles dan Radio Sains (WARAS) Pusat Penyelidikan UTHM. Isyarat GPS merambat melalui ionosfera lalu berlaku scintillation. Scintillation ionosfera turun naik dalam fasa radio dan pada isyarat amplitud dengan pantas. Ini adalah disebabkan oleh kandungan dan pembentukan ionosfera di kawasan khatulistiwa. Dengan menggunakan penerima GPS dalam WARAS, kesan scintillation pada isyarat GPS akan ditentukan dan dianalisis. Kemudian, kesan scintillation akan dianalisis pada tiga keadaan iaitu data sebelum antenna GPS dipindahkan, data selepas antenna GPS dipindahkan dan data pada hari hujan. Dengan ini, hubungan antara perubahan ionosfera di rantau ini dengan scintillation pada isyarat GPS akan diketahui. Secara keseluruhanya, parameter pada scintillation isyarat GPS telah dikenal pasti menggunakan amplitud dan fasa. Setiap parameter memberi kesan scintillation pada C/No, S_{4cor}, bunyi sekeliling, bunyi terma dan sudut ketinggian.

CHAPTER 1

INTRODUCTION

This project is being carried out to determine the scintillation effect of the Global Positioning System (GPS) signal over the Wireless and Radio Science Centre (WARAS) Research Centre University Tun Hussein Onn Malaysia (UTHM). In WARAS laboratory, the GPS receiver model is GSV 4004B GPS Ionospheres Scintillation and TEC Monitor (GISTM). The primary purpose of the GSV 4004B GISTM is to collect ionospheric scintillation and TEC data for all visible GPS satellites. This receiver could give all the related parameters that can define the scintillation of GPS signal.

Ionosphere scintillation is a rapid fluctuation of any radio-frequency's signal phase and amplitude, generated as a signal passes through the ionosphere. Scintillation occurs when a radio frequency signal in the form of a plane wave traverses a region of small-scale irregularities in electron density. Scintillation is caused by small-scale fluctuations in the refractive index of the ionosphere medium which in turn are the result of in homogeneities [3].

Then, the effect of the ionosphere over the equatorial to the scintillations of the GPS signal will be analyzed using the data from GISTM. Inhomogeneities in the ionospheric medium are produced by a wide range of phenomena and those responsible for scintillation occur predominantly in the F-layer of the ionospheric at altitudes between 200 and 1000 km. Ionospheric scintillation is primarily an equatorial and high-latitude ionospheric phenomenon, although it can occur at lower intensity at all latitudes.

Total electron content (or TEC) is an important descriptive quantity for the ionosphere of the Earth. TEC is the total number of electrons present along a path between two points, with units of electrons per square meter, where 10^{16} electrons/m^2 = 1 TEC unit (TECU). TEC is significant in determining the scintillation and group delay of a radio wave through a medium. Ionospheric TEC is characterized by observing carrier phase delays of received radio signals transmitted from satellites located above the ionosphere, often using GPS satellites. TEC is strongly affected by solar activity. TEC and scintillation parameters were extracted from dual-frequency GPS monitoring data.

In this project, the analysis of the scintillation of the GPS signal can be learnt and implemented. The main procedure is to find the ionospheric scintillation, study the terminology and basic structure of the scintillation to GPS system. This project is experimentally-oriented engineering methods for implementing the scintillation of the GPS signal over the WARAS Research Centre. The verification the simulation of this project was done using MICROSOFT EXCEL and MATLAB with the assistance from the measured data.

1.1 Problem Statement

A GPS that is installed at WARAS Research Centre located over the equatorial region at latitude 1.86°N and longitude 103.8°E. Base on this, the scintillation of the GPS signal is greatest because the TEC over the equatorial region is greatest.

So, this area is highly prone scintillation to GPS signal. GPS data will be determined and analyzed to study the effect of scintillation to GPS signals.

1.2 Strategies to overcome problems

According to the problems mentioned earlier, the scintillation of the GPS signal over the WARAS Research Centre should be studied based on these aspects:

(i). Ionosphere

(ii). TEC (GISTM) Monitor Receiver

(iii). Scintillation of GPS signal at WARAS Research Centre

1.3 Project Objectives

The main objectives of this project are:

1) To determine the scintillation effects to GPS signal over the WARAS Research Centre.
2) To analyze the scintillations effect to the GPS signals.

1.4 Project Limitations

In order to understand about this title, the scope of the project is listed:

1) The project research will be focused only to the scintillation effect of GPS signals over the WARAS Research Centre.

1.5 Expected Results

At the end of this project, it's expected to:

1) Model the scintillations variations at different conditions.
2) Identify factors or conditions that can minimize the scintillations effect to GPS signal over WARAS.

In the following chapter, the literature review of the theoretical studies that was carried out to conduct this research has been given.

CHAPTER 2

LITERATURE REVIEW

At this part, the focus will be to determine the most appropriate method or concept of researches that suits this project. Hence, further discussion on the theories of the chosen concept or software will be explained.

2.1 Study on the available researches done on GPS signal system.

Many researches have done using the GPS signal application. But almost all the researcher has difference applications and system used depending on their objective. As an example, the TEC and Scintillation Study of Equatorial Ionosphere: A Month Campaign over Sipitang and Parit Raja Stations, Malaysia was done just to determine activity on TEC and ionosphere scintillation in Malaysia using GPS measurements [15].

An other research using the GPS signal it base on the Characteristics of Deep GPS Signal Fading Due to Ionospheric Scintillation for Aviation Receiver, research on the solar maximum data set analyzed in this scintillation, which could significant reduce number of simultaneous tracked satellites [13].

Those researches explain about the Observations of Signal-to-Noise Ratios (SNR) at Geodetic GPS Site CASA: Implications for Phase Multipath research on the complexity of SNR behavior and multipath environments make it challenging to implement such as technique [20]. Statistics of number of tracked satellites under 45 minutes of strong scintillation are given in this paper and importance of shorter reacquisition time of a receiver is also emphasized.

The scintillation of the GPS signal affects trans-ionospheric radio signals up to a few GHz in frequency and as such has detrimental impacts on satellite-based communication and navigation systems and also on scientific instruments requiring observations of transionospheric radio signals. The research about the Analysis of Problem That could Arise with GPS Ionospheric Scintillation Measurements [12].

Besides that, the other research about the Ionospheric Scintillation effects on Single and Dual Frequency GPS Positioning explained about the low latitude ionosphere poses a challenge to both GPS users and Satellite-Based Augmentation System (SBAS) providers [11]. This research explained the scintillation occurs when the GPS or SBAS satellite signal travels through small-scale irregularities in electron density in the ionosphere, typically in the evening and nighttime in equatorial regions. Frequent scintillation and high rates of change in TEC can cause loss of lock to dual frequency and even single frequency receivers.

The Ionospheric Scintillation Monitoring Using Commercial Single Frequency C/A Code Receivers was done just to determine the problems for many radio applications and navigation systems [21]. Furthermore, Scintillations effects on satellite to Earth links for telecommunication and navigation purposes research on a new modeling technique, able to describe the scintillation derived modifications of transionospheric propagating fields [22].

2.2 GPS Silicon Valley's GPS Ionospheric Scintillation

Figure 2.1: GPS Silicon Valley's

The GPS Silicon Valley's model GSV4004B with its optional antenna consists of three major components: an L_1/L_2 GPS Antenna, a GPS receiver and power supply with various interconnecting cables. The EuroPak-3M enclosure houses the GPS receiver and a low phase noise oven-controlled crystal oscillator that is required for monitoring phase scintillation. The GPS receiver, the Euro-3M, with modified software (firmware), can track up to 11 GPS signals at the L_1 frequency (1575.42 MHz) and the L_2 frequency (1227.6 MHZ) [10].

It measures phase and amplitude (at 50Hz rate) and code/carrier divergence (at 1 Hz rate) for each satellite being tracked on L_1 and computes TEC from combined L_1 and L_2 pseudorange and carrier phase measurements. The primary purpose of the GSV4004B GISTM is to collect ionospheric scintillation and TEC data for all visible GPS satellites.

2.3 GPS Signals

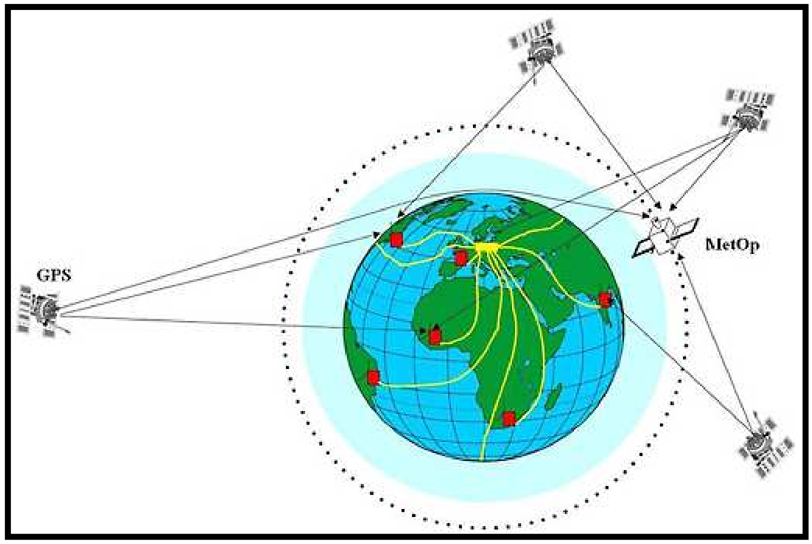

Figure 2.2: The GPS Signals [24]

The GPS concept was conveyed in the early 1960s by the Aerospace Corporation as an improved navigation method for military systems (ballistic missiles and fighter aircraft). If there are four precisely positioned satellites transmit radio waves, then four different propagation times can be measured by a GPS receiver. That four unknown data need to solved by the receiver is the position (3 data which is in 3D position latitude, longitude and height) of the user and also the time offset of the user's clock [5]. Therefore to determine the accurate position of the receiver, there must be to consider the errors occur when the GPS ray is propagates. The error must be consider so that can reduce the error occur. There is important to obtain as accurate as possible of the positioning especially for the navigation for rescue and searching service [8].

A system that use at least 28 Medium Earth orbiting satellites that transmit precise microwave signal, that enable GPS receiver to determine the location, speed, direction and the time. After receiving the signal, GPS receiver will compare the time signal was transmitted by satellite with the time it was received, with the timing difference the receiver how far of it from the satellite.

GPS system can determine the position of an object on the Earth at anywhere and anytime. GPS satellite transmits a spread spectrum signal on L_1 and L_2 at 1575.42 MHz and 1227.6 MHz respectively.

The GPS signal has the some part get the signal error. It will make the position determine by receiver is not the actual position in the Earth. The GPS signal error can be classified into some type, there are ionosphere and troposphere delay, signal multi-path, receiver clock error, orbital error and the number of satellite visible.

2.3.1 GPS Segments

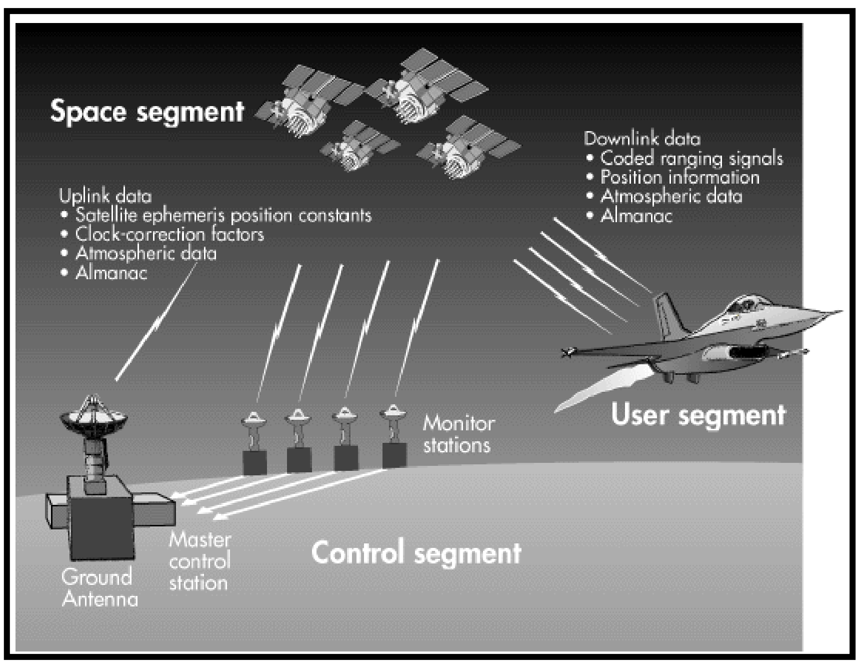

Figure 2.3: The GPS Segments [25]

Overall GPS system can be divided into three types of GPS Segments. There are the Space Segment, User Segment and Control Segment.

(a) Space segment

Space segment consists of the 24-satellite constellation; each GPS satellite transmits a signal, which has a number of components that is two sine waves (also known as carrier frequencies), two digital codes and navigation message. The codes and the navigation message are added to the carries as binary biphase modulations. The carrier and the codes are used mainly to determine the distance from the user to the receiver of the GPS satellites. The navigation message contains, along with other information, the coordinates (the location) of the satellites as a function of time. The transmitted signals are controlled by highly accurate atomic atoms onboard the satellites [25].

(b) Control segment

The control segments of the GPS system consists of a worldwide network of tracking stations. The primary task of the operational segment is tracking the GPS satellites in order to determine and predict satellites locations, system integrity, and behavior of the satellite atomic clocks, atmospheric data, the satellite almanac, and other considerations. This information is then packed and uploaded into the GPS satellites through S-band link [25].

(c) User segment

The user segment includes all military and civilian users. With a GPS receive connected to a GPS antenna, a user can receive the GPS signals, which can be used to determine his or her position anywhere in the world. GPS is currently available to all users worldwide at no direct charge [25].

2.3.2 Coarse/Acquisition code

The C/A code is a 1,023 bit deterministic sequence called pseudorandom noise (also pseudorandom binary sequence) (PN or PRN code) which, when transmitted at 1.023 megabits per second (Mbit/s), repeats every millisecond. These sequences only match up, or strongly correlate, when they are exactly aligned. Each satellite transmits a unique PRN code, which does not correlate well with any other satellite's PRN code. In other words, the PRN codes are highly orthogonal to one another. This is a form of code division multiple access (CDMA), which allows the receiver to recognize multiple satellites on the same frequency.

An important consideration in the design of a spread-spectrum signal for Code Division Multiple Access (CDMA) applications such as in GPS is to select PRN codes to minimize what is known as CDMA noise. The code selection process can be very tedious, depending on the number of codes needed and the number of codes available in a given code set.

2.3.3 Code-Carrier: Code-Phase vs Carrier-Phase

The words 'Code-Phase' and 'Carrier-Phase' may sound like electronic mumbo-jumbo but, in fact, they just refer to the particular signal that we use for timing measurements. Using the GPS carrier frequency can significantly improve the accuracy of GPS. The concept is simple but to understand it let's review a few basic principles of GPS. Code phase processing- GPS measurements based on the pseudo random code (C/A or P) as opposed to the carrier of that code.

(1-5 meter accuracy) Carrier phase processing- GPS measurements based on the L_1 or L_2 carrier signal (sub-meter accuracy). Carrier- A signal that can be varied from a known reference by modulation.

Code phase is one processing technique that gathers data via a C/A (coarse acquisition) code receiver, which uses the information contained in the satellite signals (the pseudo-random code) to calculate positions. After differential correction, this processing technique results in 1-5 meter accuracy. (If more than 180 position records are recorded, the average will be within 1 meter.) Carrier phase is another processing technique that gathers data via a carrier phase receiver, which uses the radio signal (carrier signal) to calculate positions. The carrier signal, which has a much higher frequency than the pseudo-random code, is more accurate than using the pseudo-random code alone. The pseudo-random code narrows the reference then the carrier code narrows the reference even more. After differential correction, this processing technique results in sub-meter accuracy.

2.4 The GPS navigation message

The GPS navigation massage is a data stream added to both the L_1 and the L_2 carries as binary biphase modulation at a low rate of 50 kbps. It consists of 25 frames of 1500 bits each or 37500 bits in total. This means that the transmission of the complete navigation massage takes 750 seconds, or 12.5 minutes. The navigation massage sontains, along with other information, the coordinates of the GPS satellites as a function of time, the satellites health status, the satellite clock correction, the satellites almanac, and atmospheric data. Each satellite transmits its own navigation message with information on the other satellites, such as the approximate location and health status.

2.5 Ionosphere

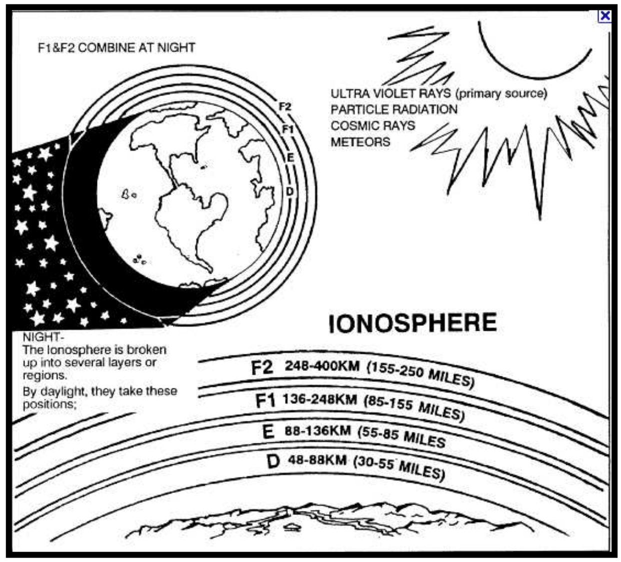

Figure 2.4: Structure of the Ionosphere [26]

The ionosphere is an electrically charged (ionized) region of the atmosphere that extends from about 60 kilometers (37 miles) to 1,000 kilometers (620 miles) above the Earth's surface. The ionization results from energy from the sun and causes radio signals to return to Earth. Although the ionosphere exists up to 1,000 kilometers, the important area for HF communication is below 500 kilometers. This area is divided into four regions: D, E, F_l, and F_2 [11].

- The majority of HF sky-wave communications depend on the F_1 and F_2 regions, with the F_2 region being used the most for long-range daytime communications.

- The E region is the next lower region. It is present 24 hours a day, although at night it is much weaker. The E region is the first region with enough charge to bend radio signals. At times, parts of the E region become highly charged and can either help or block out HF communication. These highly charged areas are called sporadic E. They occur most often during the summer.

- The D region is closest to earth and only exists during the day. It cannot bend a radio signal back to earth, but it does play an important role in HF communication. The D region absorbs energy from the radio signal passing through it, thereby reducing the strength of the signals

The ionosphere is created by Sun immediately, so it will vary also with the time of a day, season and also the position on the surface of the Earth.

2.5.1 Variation of Ionosphere

The variation of the ionosphere is mainly on the phenomenon of zenith angle of the sun. So it makes the variation of ionosphere by the diurnal (thought the day), seasonal (thought the year), location (geographic & geomagnetic), solar activity (solar cycle and disturbance) and also the height (different layer) [2]. For the seasonal, the ionosphere varies throughout the year, partly because of the solar zenith angle has a seasonal as well as diurnal variation. For location, the variation of ionosphere is with the position at Earth, making the variation with the solar zenith angle.

The ionosphere varies with the changes in solar activity of the Sun. It is found that the monthly median of the critical frequency of the ionosphere for a particular month are linearly related to the monthly average value of the sunspot number smoothed or averaged over 12 months.

As the signal propagation continues after passing through the region of irregularities, phase and amplitude scintillation develops through interference of multiple scattered signals.

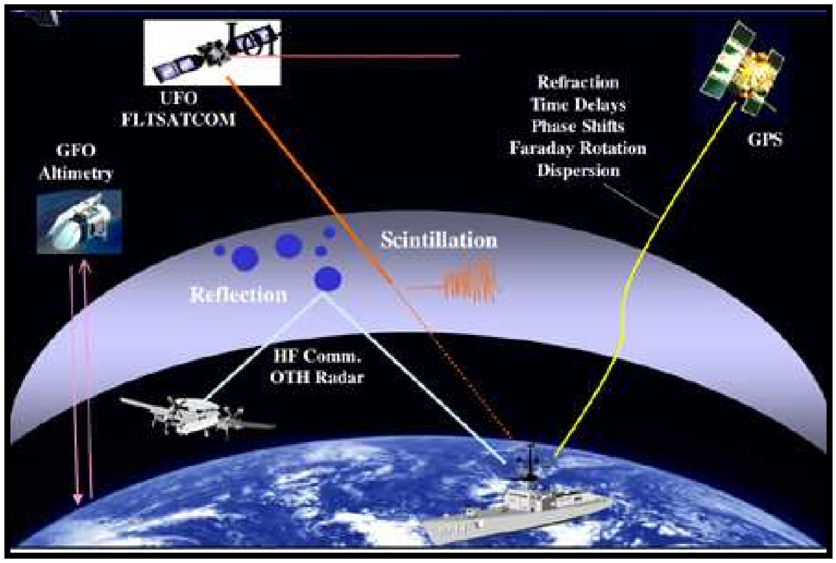

Figure 2.5: The Ionosphere effect at the scintillation [27]

The ionosphere is made up of layers of electrons and ions that are suspended in the atmosphere at altitudes of 40 to 400 kilometers above the surface of the Earth. Short wave radio signals are reflected from the bottom side of these layers and return to Earth. However, high frequency radio signals punch through the ionospheric layers and can be received by satellites in orbit around the Earth. And likewise, radio signals from the satellites can be received at ground stations. In some ionospheric regions, however, these layers are filled with small-scale irregular density structures. The density structures cause radio signals propagating through them from a satellite to experience random fading in amplitude and changes in phase, called scintillations. The net result is that information can be lost or become extremely difficult to decipher.

There are 3 major sectors of scintillation activity. These are the equatorial region and the north and south Polar Regions. Irregularities in the polar region are caused by precipitating high velocity aurora particles. The aurora particles violently collide with atmospheric particles, knocking electrons free, and creating enhanced densities. The fluxes of high-velocity precipitating particles are very structured in space and create irregular structures in the ionosphere.

These same particles are responsible for the aurora lights. In addition, the flow of ionospheric plasma from the dayside to the night side and vice-versa at high-latitudes results in the formation of large-scale plasma blobs and density troughs. The steep edges of these structures are unstable and soon generated intense regions of small-scale density irregularities that produce severe scintillation effects. These types of irregularities vary in severity and geographic location during space weather disturbances.

In the equatorial regions, irregularities result from bubbles that form at the bottom of the F region ionization layer upward through the topside ionosphere, emerging just after sunset, distorting into plumes. The steep edges of the plumes are unstable and smaller-scale irregular density structures develop along these edges. The small-scale irregularities cause intense scintillation effects. Individual patches of irregularities have lifetimes of 2-3 hours. However, irregularities have been seen to continually disrupt this region for periods of up to 8 hours. These types of irregularities are not related to space weather disturbances but do increase with the solar activity cycle [10].

2.6 Impact of Ionospheric Scintillation

Ionospheric scintillation affects trans-ionospheric radio signals up to a few GHz in frequency and as such can have detrimental impacts on satellite-based communication and navigation systems (such as GPS-based systems) and also on scientific instruments requiring observations of trans-ionospheric radio signals (example radio-astronomy).

Amplitude scintillation directly affects the signal to noise ratio (C/No) of signals in a GPS receiver, as well as the noise levels in code and phase measurements. Amplitude scintillation can be sufficiently severe that the received GPS signal intensity from a given satellite drops below the receivers tracking threshold, causing loss of lock on that satellite, and hence the need to re-acquire the GPS signal(s). This results in reduced accuracy navigation solutions, data loss and cycle slips.

The nominal C/No for the L_1 signal is about 45dB-Hz, and tracking may be lost when the signal drops below ~25dB-Hz, dependent on the receiver-specific tracking loop [3].

Since the signal power on the GPS L_2 frequency is significantly less than that of L_1 (~6dB lower), and civil dual frequency receivers use non-optimal codeless or semicodeless techniques for tracking L_2 which results in lower C/No values, ionospheric scintillation is much more likely to impact the GPS L_2 signal.

Phase scintillation, if sufficiently severe, may stress phase-lock loops in GPS receivers resulting in a loss of phase lock. Phase scintillation also has a significant impact on phase-sensitive systems such as space-based radars and some ground-based radio-astronomy facilities.

Early researchers demonstrated that the most likely regions for observing scintillation wear near the magnetic equator, including the Appleton anomalies, and within the auroral oval and polar cap that the scintillation amplitudes demonstrated a solar cycle dependence with maximum amplitudes at the solar cycle maximum when solar UV fluxes and ionospheric density were also a maximum and the equatorial scintillations demonstrated a seasonal dependence, depending on the longitude [18].

For heavily rain weather, clear-sky amplitude scintillation manifests itself as rapid random fluctuations around the mean signal level. If rain is present on the propagation path, the receiver will see fast amplitude fluctuations superimposed on the slow variations caused by rain attenuation. This type of amplitude scintillation is often referred to as wet scintillation. In heavy rainfall climates, the attenuation caused by rain is often too severe to be accounted for by a fixed margin in the link budget.

Scintillation varies diurnally, and it is principally a nighttime phenomenon. It exhibits a climatology that is unique to four geographical regions:

(i) Equatorial
(ii) Midlatitude
(iii) Auroral
(iv) Polar cap.

The most virulent zone corresponds to the post-sunset equatorial region, and the least active zone is at middle latitudes. Scintillation at equatorial latitudes peaks shortly following sunset and many persist throughout the evening but with decreasing virulence after local midnight. At high latitudes, scintillation is also more intense during the night in concert with the natural growth in oval intensity, but midlatitude scintillation may arise during storms as the scintillation boundary descends equatorward.

Moreover, the normal diurnal variation of scintillation may become distorted by the superposition of storm-time influences. Daytime scintillation events may also arise at midlatitudes as a result of sporadic E, and these events are sometimes termed ringing irregularities.

In the equatorial regions, irregularities result from bubbles that form at the bottom of the F region ionization layer and percolate upward through the topside ionosphere, emerging just after sunset, distorting into plumes. The steep edges of the plumes are unstable and smaller-scale irregular density structures develop along these edges. The small-scale irregularities cause intense scintillation effects. Individual patches of irregularities have lifetimes of 2-3 hours. However, irregularities have been seen to continually disrupt this region for periods of up to 8 hours. These types of irregularities are not related to space weather disturbances but do increase with the solar activity cycle.

All the cases study shows that have many factors influence the amplitude scintillation activity. The nature of the ionosphere structures, which give rise to the radio wave amplitude scintillations. Other aspects important are dependencies on solar and magnetic activity. The regionally-averaged scintillation activity increases over the equatorial region as the sunspot number increases. This is particularly true for the equatorial anomaly region, the area approximately 20° from the magnetic equator, where the most intense GHz scintillation is noted. The same effect is for the high-latitude regions (or polar regions). Even when the magnetic conditions are held constant, scintillation activity is observed to be higher during years of enhanced solar flux. Although sunspot number and magnetic activity are not perfectly correlated, it is still being found out that the number and intensity of magnetic storms increases with an increase in solar activity [11].

Scintillation measurements at frequencies from 2GHZ to above 30GHz show broad agreement in general characteristics for scintillation at high elevation angle (20° to 30°). In temperate climates the scintillation is in the order of 1 dB peak-to-peak in clear sky in the summer, 0.2 to 0.3 dB in winter, and 2 to 6 dB in cloud conditions. Scintillation fluctuations vary over a large range, however, with fluctuations from 0.5 Hz to over 10 Hz.

A much slower fluctuation component, with a period of one to three minutes, is often observed along with the more rapid scintillation discussed above. At low elevation angles (below about 10°), scintillation increase drastically with less uniformity in structure and predictability. Deep fluctuations of 20 dB or more are observed, with durations of a few seconds in extent.

The locations of the maximum equatorial scintillation amplitudes are not at the magnetic equator but instead are about 15 degrees on either side of the magnetic equator where the Appleton anomalies or equatorial anomaly crests are located. These crests are formed during the daytime when solar heating of the thermosphere drives an eastward dynamo electric field. The electric field drives an upward flux of ionization at the equator, which subsequently falls down magnetic field lines at more polar locations, increasing the ionization density in two bands called the equatorial or Appleton anomalies. The enhanced ionospheric densities remain through darkness depending on the altitude and recombination rate.

Consequently, a higher intensity of scintillation is observed in hot seasons, during wet days and in the hottest hours of the day. In a similar way, scintillation is higher in humid areas (tropical and equatorial areas) than in dry regions. However, local characteristics such as localized convection phenomena with cumulus clouds and orographic effects can also produce strong scintillation.

Scintillation effects are significant in equatorial regions (±30° geomagnetic latitude) with largest effects in the region of ±10°. Equatorial scintillation is usually present during 1900-2400 hours local time. Amplitude fading can be larger than 20 dB in this region during high solar activities. Scintillation effects are also observed in the auroral zone and polar cap region (65° - 90° geomagnetic latitude), particularly during magnetic storms. This phenomenon is different from the equatorial scintillation effects and the two are not correlated. The high latitude scintillations are not restricted to any particular local time period and can last for many hours, even days. The auroral zone scintillation effects are less severe than the equatorial scintillation effects and can have maximum amplitudes fading of 10 dB [18].

Scintillation also has a seasonal dependence. Scintillation is less common at the American, African and Indian latitudes during the months of April to August, while scintillation has maximum frequency in the Pacific region. These effects are reversed during the rest of the year have determined a strong correlation between ionospheric scintillation and sunspot number. Scintillation effects are therefore expected to be larger and more frequent during solar maximum [18].

2.6.1 Measuring Ionospheric Scintillation

There are numerous method to measure the ionospheric scintillation. Perhaps the most common of these is the amplitude scintillation index S_4, and the phase scintillation index P_{rms}. Ionospheric scintillation models produce statistical measures of the specified scintillation index [11].

(i) Amplitude scintillation - S_4

Amplitude scintillation is quantified by the S_4 parameter which is defined as the square-root of the normalized variance of signal intensity over a given interval of time.

$$S_4 = \sqrt{(\langle I^2 \rangle - \langle I^2 \rangle)/\langle I^2 \rangle} \qquad (2.1)$$

where I is the signal intensity.

S_4 is a dimensionless number with a theoretical upper limit of 1.0, commonly estimated over an interval of 60 seconds. There are two defined regimes of amplitude scintillation – weak and strong, which roughly correspond to the type of scattering associated with each. Strong scintillation is generally considered to occur when S_4 is greater than ~0.6 and is associated with strong scattering of the signal in the ionosphere. Below this is weak scintillation. An S_4 level below 0.3 is unlikely to have a significant impact on GPS [21].

The S_4 values are normally computed over 60 second intervals. In the ISM, values are stored on a file and displayed for each satellite along with the storage and display of the phase data as described earlier. As noted below, the standard deviation of the code/carrier divergence is also computed over the same 60 second interval and stored as an indicator of multipath activity. The recording of raw detrended intensity data, at a 50 Hz rate, can be selected by the operator. The raw intensity data has a single-sided noise bandwidth of 25 Hz.

(ii) Calculation of C/No

A signal to noise ratio is equal to composite signal amplitude, Ac. Using the GPS data the composite signal amplitude is same as the amplitude scintillation value, S_4 [12].

$$C / N_o = Ac^2 = S4^2 = 10\log_{10}(S4)^2 + 43dB \qquad (2.2)$$

where 43 dB is the processing gain.

Processing gain is realized at the output of bandpass filter of the sliding carrier based correlator when code alignment is achieved. When the receiver replica C/A code is not aligned with the transmitted C/A code the received GPS signal power at the output of the bandpass filter is spread over approximately 2 MHz of bandwidth (center lobe of C/A BPSK spectrum is approx 2 MHz). When the receiver C/A code is aligned with transmitted code the signal power at the bandpass output is now squished into approximately 100 Hz of bandwidth (center lobe of 50Hz random data spectrum). A rule of thumb is to use the ratio of these two bandwidths as the processing gain. Processing gain is remarkable. It is as if the signal is amplified without also amplifying the noise at the same time.

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