View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by UTHM Institutional Repository

Proceeding of the 2013 IEEE International Conference on Space Science and Communication (IconSpace), 1-3 July 2013, Melaka, Malaysia

Significant of Earth's Magnetic Field and Ionospheric Horizontal Gradient to GPS Signals

K Nagarajoo[1]
Chong Sze Fah
[1]*Department of Communications Engineering, Faculty of Electrical and Electronic Engineering,*
Universiti Tun Hussein Onn Malaysia, P.O Box 101, 86400 Batu Pahat, Johor, Malaysia
[1]*karthi@uthm.edu.my*

***Abstract*-Ray tracing technique can be used to determine the effect of Earth's magnetic field to (Global Positioning Systems (GPS) signals with and without the presence of ionospheric horizontal gradient. In this project, Jones 3D Ray Tracing program was employed to study the effect of the ionosphere on GPS rays (L_1 and L_2). The group path or delay is obtained from the difference between the distances of the ray path to the Earth station from the GPS satellite determined from the ray-tracing and the distance for propagation over the line of sight (LOS). Then, the residual range error (RRE), which is the difference between the standard dual frequencies models corrected range and LOS, will be calculated. The gradient ionospheric profile was then used to compare the effect of the ionosphere with and without gradient on GPS ray tracing. Results show that there is difference in between the RRE calculation with and without the presence of the ionospheric gradient. The Earth's magnetic field effect to GPS signal is normally neglected since it has very minimal effect. However, in this research, results obtained show that the Earth's magnetic field has to be taken into account in order to determine more accurate GPS ray tracing.**

Keywords: Ionospheric horizontal gradient, electron density, Jones 3D Ray Tracing, Earth's magnetic field

I. INTRODUCTION

Ionosphere is the main source of error in GPS positioning, especially over the lower geographical region such as Malaysia. The inhomogeneous formation of the ionosphere and the presence of magnetic field do affect the final GPS positioning [1, 2]. In order to determine the characteristics of the GPS signals (such as group path length and phase path length) due to the presence of the ionosphere and magnetic field, a Versatile Three-Dimension Ray Tracing Computer Program for Radio Waves in The Ionosphere, known as the Jones 3-D Ray Tracing program [3] will be used.

Jones 3-D ray tracing program consists of various subroutines that make up the main deck and those which are frequently exchanged with alternative versions of subroutines to perform specific tasks in calculating the GPS ray paths.

Before execute the main program (*Raytr*) all the subroutines are added in the workspace. The whole program is ready to execute after all the subroutines are compiled and built. However, the inputs; such as the transmitter location (longitude, latitude and height above ground range), the GPS carrier frequency, the direction of the transmission (both elevation and azimuth), the receiver height and other relevant input values have to be given first through the input file (*ray.dat)* [4].

In order to determine ionospheric corrections for GPS positioning, the ionosphere needs to be modelled mathematically before being executed using Jones 3D Ray Tracing program. Since our main concern is the presence of ionospheric horizontal gradient, the model developed will be focussed more on this parameter.

The ionospheric horizontal gradient is the variation of electron density with latitude and longitude which can cause the azimuthal deviation of the GPS ray path [5]. Over the equatorial region, the inhomogeneous formation of the ionosphere introduces greater ionospheric horizontal gradient which could give greater positioning error for a user station in a GPS system. Ionospheric horizontal gradient can either increase or decrease the propagation time of the GPS signal depending on the path or trajectory of the signal with respect to the gradient direction [6].

For the magnetic field effect, Zhang et al. [7] found out that when electro-magnetic wave propagates in the magnetic and electric field, its ray path is affected by the two fields. When geomagnetic field is disturbed by solar activities, the ionosphere is disturbed and radio ray path will be disturbed as well. The effect of Earth's magnetic field leads to significant non-planar ray path.

Figure 1 shows the plot of the ray paths in inhomogeneous ionosphere with and without magnetic field. It can be seen that the ray paths and ground ranges for with and without magnetic field are quite different. However, in the research, the

978-1-4673-5233-8/13/$31.00 ©2013 IEEE

authors are only considering constant geomagnetic field with moderate strength affects' to GPS ray path using Jones 3D Ray tracing program.

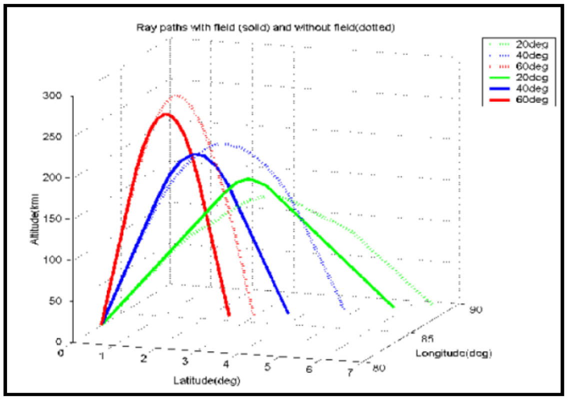

Figure 1: 3D ray paths with and without magnetic field at UT=09, 18 Mar 03, operating frequency =10MHz, azim0 = 45º. (Solid lines: with field, dotted lines: without field) [7]

In this project also, the Residual Range Error or RRE will be obtained. The RRE is the difference between the line-of-sight (LOS), P_{LOS} (determined from the ray-tracing) and the standard dual frequency model's corrected range.

II METHODOLOGY

Since GPS is a system with two fairly widely spaced carrier frequencies (f_1 =1575.42 MHz and f_2 =1227.6 MHz), the ionospheric scaling factor $f_2^2/(f_1^2-f_2^2)$, will be 1.546. By using this scaling factor which was determined from the frequency dependence of the group refractive index, the ionospheric delay (or advance) could be eliminated by employing the dual frequency model [8]. The dual frequency model is a mathematical model that eliminates the ionospheric error from code delay (or carrier phase advance) by using the range measurements from both L_1 and L_2 in order to obtain a range without the ionospheric delay.

$$P_{LOS} = \frac{P_1 - \frac{f_2^2}{f_1^2} P_1}{1 - \frac{f_2^2}{f_1^2}} \qquad (1)$$

where P_{LOS} is the range measurement after the ionospheric delay and P_1 and P_2 are the group delay (or phase advance) corresponding to GPS frequencies, f_1 and f_2 respectively.

The RRE will be obtained using Equation (2) below;

$$RRE = LOS - P_{LOS} \qquad (2)$$

where the LOS is the straight unobstructed distance between the GPS satellite and the user or Earth station, presuming the location of the user is known.

III. RESULTS AND DISCUSSION

This section describes the results obtained from the simulation by using the Jones 3D Ray Tracing program and MATLAB. The result shows the characteristic of the GPS rays (L_1 and L_2) from Earth station to the GPS satellite.

The simulation was executed at different parameters in terms of elevation angle (take off angle), azimuth angle and frequency. The results have been analyzed and compared with few different scenarios in order to see the effect of ionospheric horizontal gradient and magnetic field to the GPS signals. There are without ionspheric gradient (with and without magnetic field) and with ionspheric gradient (with and without magnetic field).

A. The Variation in Group Path for Without Ionospheric Gradient (with and without magnetic field)

For this phenomenon, the Jones 3D ray tracing program was executed at different elevation angles; from 10 to 60˚, at every 10˚ of interval to determine the group path of GPS rays at both L_2 and L_1. The Earth station was fixed at 1˚ of latitude and 110˚ of longitude with 20˚ of azimuth angle in the ray tracing program. The GPS satellite was orbiting at height of 20200km from the Earth.

TABLE 1
THE L_2 GROUP PATH WITHOUT IONOSPHERIC GRADIENT FOR WITH AND WITHOUT MAGETIC FIELD

Elevation (°)	Without Gradient	
	Group Path (km) With Field	Group Path (km) No Field
10	24674.35301	24674.40967
20	23669.98550	23670.00775
30	22767.81683	22767.82740
40	21985.49396	21985.50007
50	21335.07857	21335.08266
60	20824.18032	20824.18339

TABLE 2

THE L_1 GROUP PATH WITHOUT IONOSPHERIC GRADIENT FOR WITH AND WITHOUT MAGNETIC FIELD

Elevation (°)	Without Gradient	
	Group Path (km) With Field	Group Path (km) No Field
10	24674.29412	24674.32854
20	23669.95650	23669.97002
30	22767.80182	22767.80824
40	21985.48514	21985.48885
50	21335.07270	21335.07519
60	20824.17598	20824.17784

Table 1 and 2 show that without ionospheric gradient, the group path of the GPS ray for without magnetic field is greater than with field. This means that the field has less effect on the group path without ionospheric gradient. The group path of L_2 is always greater when compared to the group path of L_1 for both with and without field cases. This is because L_2 takes longer path to propagate through the ionosphere compared to L_1 due to the effect of refraction. The group path of the ray for both with field and no field are decreasing as the elevation angle increases. This is because the height of the object is constant and by changing the elevation angle, the range also will change in trigonometric equation. By increasing the elevation angle the range will decreasing and this satisfy the result obtained.

In figure 2, the whole result for this scenario has been summarized. It can be seen that as the elevation angle increases, the difference in the L_1 and L_2 decreases. The same nomenclature applies for the case with and without magnetic field.

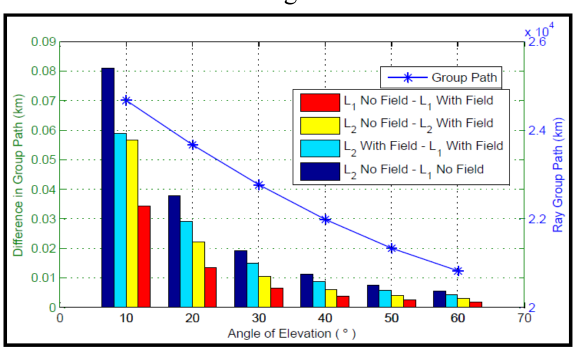

Figure 2: The relation of group path and the differences in group path of ray L_1 and L_2 for without gradient in with field and no field at different elevation angle.

B. The Variation in Group Path for With Ionospheric Gradient (with and without magnetic field)

As for the second scenario, with the presence of ionospheric horizontal gradient, some interesting results have been obtained.

TABLE 3

THE L_1 GROUP PATH WITH IONOSPHERIC GRADIENT FOR WITH AND WITHOUT MAGNETIC FIELD

Elevation (°)	With Gradient	
	Group Path (km) With Field	Group Path (km) No Field
10	24677.79548	24677.79369
20	23672.88373	23672.88219
30	22769.72630	22769.72524
40	21986.73194	21986.73124
50	21335.90062	21335.90014
60	20824.73680	20824.73649

TABLE 4

THE L_2 GROUP PATH WITH IONOSPHERIC GRADIENT FOR WITH AND WITHOUT MAGNETIC FIELD

Elevation (°)	With Gradient	
	Group Path (km) With Field	Group Path (km) No Field
10	24680.12717	24680.12337
20	23674.81329	23674.81001
30	22770.98997	22770.98773
40	21987.54928	21987.54779
50	21336.44317	21336.44217
60	20825.10462	20825.10396

From Table 3 and 4 above, the group path of the GPS signals with field is greater compared to without field. It shows that in the realistic formation of the ionosphere (with the presence of ionospheric horizontal gradient), the magnetic field cause greater group path. Thus, the field effect has to be taken into consideration in order to determine accurate GPS ray tracing.

C. The Significant of the Ionospheric Horizontal Gradient than Magnetic field Effect

From Figure 3, it can be seen that the difference between the group path with and without ionospheric gradient with the presence of magnetic field (the red and blue curve) is much larger than that between the group path in with ionospheric gradient with and without magnetic field (the purple and green plot). This implies that the effect of ionospheric gradient is much more important than the effect of magnetic field on GPS rays propagation.

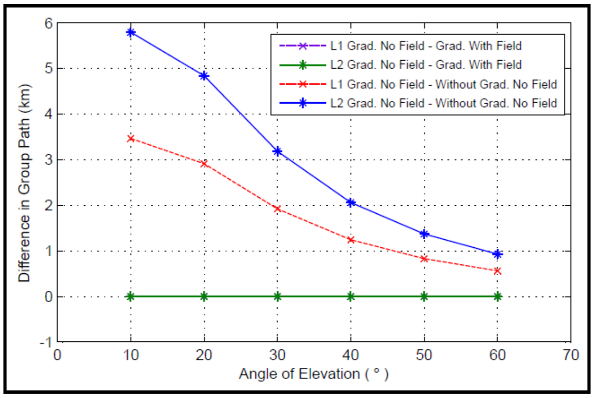

Figure 3: The significance of the group path difference due to ionospheric horizontal gradient effect than magnetic field effect

D. *Residual Range Error (RRE)*

Additionally, the RRE has also been obtained from the simulation result. Figure 4 and 5 show that RRE group path for with and without ionospheric gradient have different variations.

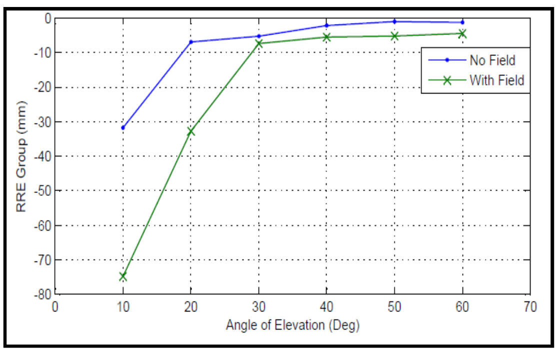

Figure 4: RRE for the group path without ionospheric horizontal gradient

The RRE group path is the extra ionospheric delay in meter due to the first order refractive index, which still exist after the application of the dual frequency ionospheric correction method. The RRE group path is underestimated. The RRE group path is approached to zero mm as the elevation angle is increased. The absolute value of RRE group with field for both with and without gradient is about three times larger than RRE of group with no field because the absolute value of group path with field is larger than that of no field in higher order of refractive index. It is also shown that the field has greater effect on GPS signal's group path.

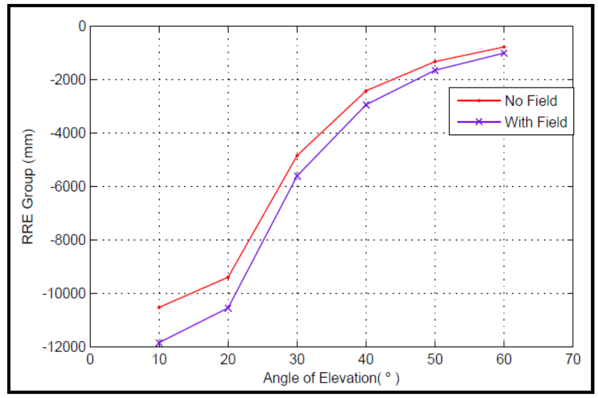

Figure 5: RRE for the group path with ionospheric horizontal gradient

Their differences are also because of the dual frequency correction model, which assumes that both GPS frequencies experience the same composition of ionosphere, only eliminates the first order term of the refractive index. The higher order term is normally will be neglected since its too small in value and much less than the first order term. However, the results of ray-tracing showed that it clearly does contribute some effects to final GPS positioning.

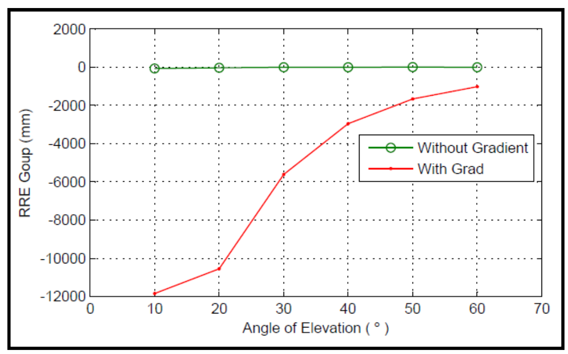

Figure 6: RRE for the group path with and without ionospheric gradient with the presence of magnetic field

Figure 6 shows the group path with gradient is much larger than the without gradient in the presence of magnetic field. As expected, the effect of magnetic field to the RRE group path with ionospheric gradient is greater than without gradient. This means that the magnetic field will greatly increase the group path with the presence of ionospheric horizontal gradient than without gradient.

IV. CONCLUSIONS

From the results obtained, it is known that both Earth's magnetic field and ionospheric horizontal gradient have some significant effect to the GPS group path. Though its effect is very minimal, however it cannot be neglected if millimeter level of accuracy is required in precise GPS positioning, especially over the equatorial region.

REFERENCES

[1] Parkinson, B. W. and Spilker J.J. Jr., 'Global Positioning System: Theory and Application's Volume 1. 1996.

[2] Klobuchar, J.A. 'Ionospheric Effects on GPS'.In: Parkinson, B. W. and Spilker, J.J. Jr. (Ed.). Global Positioning System: Theory and Applications Volume 1 [Book], Chapter 12, pp485-515, 1996.

[3] Haselgrove J., 'Ray theory and a new method for ray tracing', presented in a conference on the Physics of the Ionosphere, Phys. Soc. of London, London, pp. 355–364, 1954.

[4] Jones R. M., and Stephenson J., 'A versatile three-dimensional ray tracing computer program for radio waves in the ionosphere', OT report 75-76, U.S. Department of Commerce, October 1975.

[5] Nagarajoo K., 'DGPS Positional Improvement by Mitigating the Ionospheric Horizontal Gradient using GPSurvey', Proceeding of the 2011 IEEE International Conference on Space Science and Communication (IconSpace) Penang, Malaysia, 12-13 July 2011.

[6] Nagarajoo K. and Mohd Z.A.F., 'DGPS Positional Improvement by Mitigating the Ionospheric Horizontal Gradient and Elevation Angle Effects', Proceedings of 2010 IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE), 2010.

[7] Zhang, Rui Xue and Lock Yue Chiew, Kien Boon Teo., 'The Ionospheric Effect on HF Wave Propagation in Equatorial Region', 2003.

[8] Zulkifli, Siti Sarah Nik, Abdullah, Mardina and and Mahamod Ismail., 'Application of 3-D Ray-Tracing for Accurate GPS Range Finding', Member IEEE, SCOReD, 2007.

[9] Ciraolo L., Azpilicueta F., Brunini C., and Meza A., 'Calibration errors on experimental slant total electron content (TEC) determined with GPS', Journal of Geodesy, vol. 81, pp. 111-120, 2006.