COMPARED ANALYSIS OF THE REFLECTION AND DIFFRACTION EFFECTS OF GPS SIGNALS ON THE PSEUDORANGE DETERMINATION IN RECEIVERS.

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1. Abstract

This paper describes the effects of GPS signals reflection on finite surfaces and diffraction on straight borders. These effects have been evaluated theoretically and verified experimentally. The reflection has been calculated using the Fresnel-Kirchoff integral and the diffraction with the Keller GTD theory. The conclusion emphasize the greater importance of effect of "reflection" compared to those of "diffraction", much more localized and of lower amplitude.

2. Introduction

Multipath effects are one of the technical aspects with greater influence on the pseudorange accuracy at GBAS/LAAS reference stations.

These effects may be decreased with appropriate designs of antennae with radiation patterns that attenuate LHP (Left Hand Polarized) signals. Additionally, narrow band correlators provide improvements in the pseudorange determination.

However, both of the above mentioned techniques have inconveniences. Regarding the former, LHP signal reception is not uniform, presenting privileged orientations that can not be attenuated. In the case of the latter, the necessity of having relatively high signal/noise ratios is handicapped by reflections, diffractions and concealment of satellites to the line of sight of the receiver scenarios.

For these reasons, like in other Navigation Systems, we need to pre-analyze the physical surroundings of a GPS receiver, located in a ground reference station, to evaluate the impact of multipaths in the determination of pseudoranges.

If our analysis is focused on Air Navigation and, in particular, on the instrumental precision approach, it seems obvious that reference stations should be located close to the runway so as to guarantee maximum correlation between the incoming signals to the aircraft receiver and those that reach the station receivers. Concurrently, all the satellites must be in the line of sight of the station, even in cases of low mask angles.

The need to have "reliable" tools for the assessment of multipath effects for reference stations, knowing the physical characteristics of the surroundings areas, has encouraged the Department of Infrastructure, Airspace systems and Airports of the Universidad Politécnica de Madrid to work in the development of a whole set of field experiments and mathematical models that are supporting our advancement in the construction of a simulation tool capable of evaluating multipath effects for any given scenario.

In particular, this report presents the results reached so far, in relation to reflection on finite walls and diffraction on straight borders, clearly establishing their differences.

3. Reflection and Diffraction effects on the correlation function: Theoretical model

The correlation function between the incoming signal corrupted by multipath effects, and the replica signal is distinct from that of its ideal shape due to the time delay and phase relationship between the direct and reflected/diffracted signals. Figures 1 and 2 show the theoretical effects of reflection and diffraction, respectively, on the correlation function for the experimental trials conditions described in paragraph 4 below.

The DLL considered for the receiver model uses classical 1µs time difference between early and late replica codes.

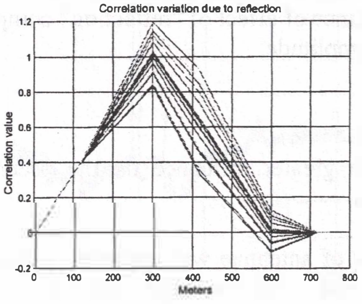

Figure 1.

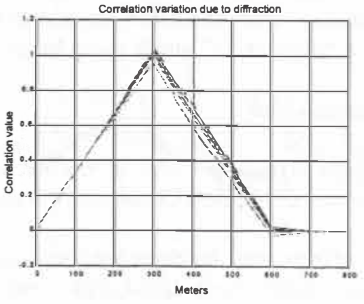

Figure 2

Radiation patterns of the antenna used in the trials, has been experimentally evaluated giving a non-simetrical pattern and differences between RHP and LHP incoming signals. Figures 3 and 4 show the experimental results. Figure 3 shows the amplitude variation for different azimuth and elevation angles for RHP and LHP. Similarly, figure 4 shows the carrier phase variation.

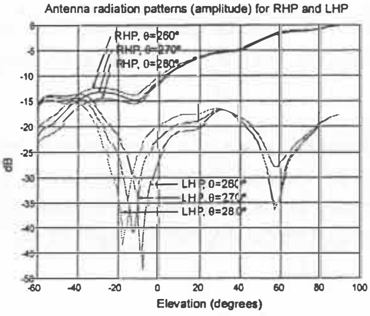

Figure 3

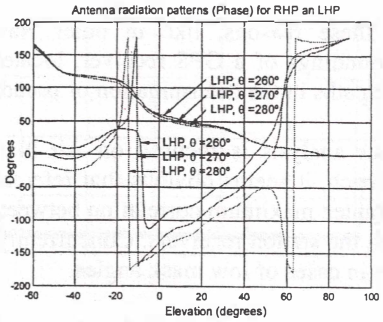

Figure 4

Considering the above results, the simulated received signal has been corrupted each time, adding the effects of direct, reflected and diffracted signal components.

The reflected signal is established from the Fresnel-Kirchoff integral equation given by:

$$\rho_s = \frac{jr_0}{\lambda} \int_{\substack{All\\ surface\\ elements}} \frac{1}{R_r R_t} \varepsilon^{-jk(R_r+R_t-r_0)} G_t G_r \rho_r \rho \frac{\cos\theta_r + \cos\theta_t}{2} ds$$

where:

- ρ_s: Reflected/Direct signal ratio.
- r_0: Transmitter – Receiver distance.
- R_r: Specular reflection point – receiver distance.
- R_t: Transmitter – specular reflection point distance.
- G_t: Transmitter antenna radiation pattern gain for a given elevation and azimuth angle.
- G_r: Receiver antenna radiation pattern for a given elevation and azimuth angle.
- ρ: Reflection coefficient.
- ρ_r: Attenuation coefficient due to roughness.

This integral has been calculated as a sum of small surfaces in which radiofrequency phase differences can be neglected ($\Delta\phi_{max} < 0.05\ \lambda$).

The diffracted signal from sharped borders has been calculated from the **G**eometrical **T**heory of **D**iffraction, given by

$$E_{diffracted} = \frac{e^{-iKr} + e^{i\frac{\pi}{4}}}{\sqrt{\pi}} \left[F\left\{\sqrt{2Kr}\sin\frac{\phi-\phi_0}{2}\right\} - F\left\{\sqrt{2Kr}\sin\frac{\phi+\phi_0}{2}\right\} \right]$$

where: $F(x) = e^{ix^2} \int_x^{\infty} e^{-iu^2} du$; and ϕ, ϕ_0 as indicated in figure 5

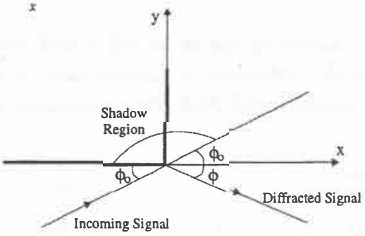

Figure 5

4. Trials description

In order to validate the proposed model, a set of field trials were held. In these, the transmitted signals from satellite 1 of the GPS NAVSTAR constellation were recorded. The recording was done at two different sites, one of them was chosen in order to receive multipaths, the other would be utilised as a reference site without multipaths.

The reference site (figure 6) was the Aeronautical Engineering School of the Universidad Politécnica de Madrid, on whose roof are sited three GPS antennae, aligned and separated twenty centimeters so as to consider them a single point. The exact position of each one was calculated through recordings, using three receivers during 24 hours. 86.400 samples were gathered per receiver (one per second) and thereupon the mean was calculated to obtain an accurate reference position.

The Spanish National Anthropology Museum (figure 7) was chosen as the multipath signals site. The choice was mainly due to:

- The building has a large enough surface to create multipaths.
- The possibility of installing the receiver antenna at a point above surrounding obstacles where direct and multipath signals would arrive.
- Its vecinity to the reference site.

Figure 6

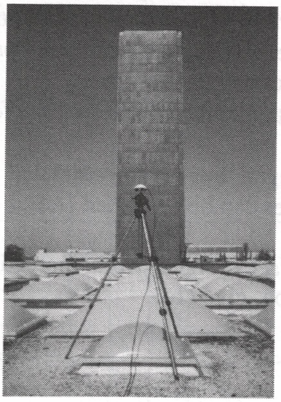

Figure 7

5. Simulation results

Figures 8 and 9 show the results of applying the reflected signal model at the scenario described in paragraph 4. Figure 8 represents the reflected to direct ratio module. Figure 9 represents the pseudorange theoretical error that would result from the correlation between the direct and reflected signals versus the replica signal.

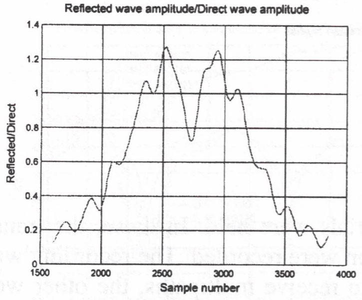

Figure 8

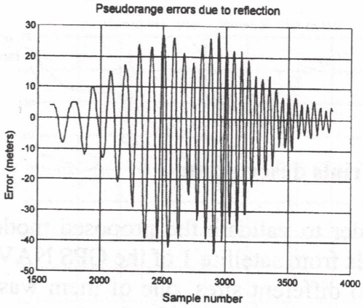

Figure 9

Figures 10 and 11 below show the results of applying the diffracted signal model at the same scenario. Figure 10 represents the diffracted to direct ratio amplitude. Figure 11 represents the pseudorange theoretical error that would result from the correlation between the direct and diffracted signals versus the replica signal.

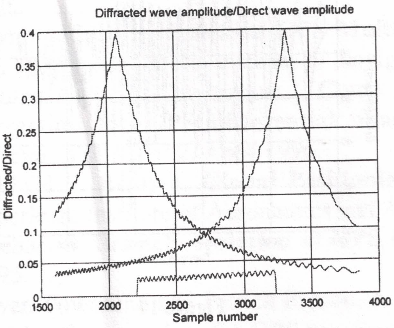

Figure 10

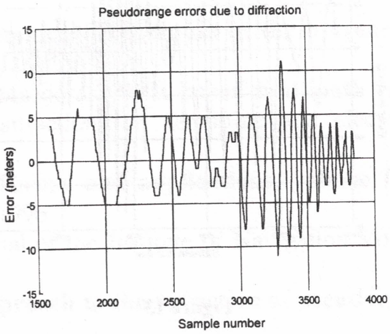

Figure 11

If the correlation is done considering the reflected and diffracted signals jointly, the pseudorange theoretical error is shown, for the mentioned scenario, in figure 12.

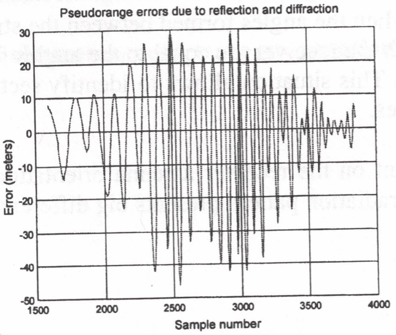

Figure 12

6. Trials results

Figure 13 presents the results of the trial carried out on the 22/7/98. On the graphic, sample number 1600 corresponds to 9h 51'40" GPS time. This figure shows the pseudorange error obtained from the recorded data at the trials scenario. The error was calculated using two different methods. The first, via the difference between the carrier phase minus the carrier code recorded at the trials (black line); the second, via the difference between the recorded code signals at both sites (grey line). As shown in the figure, in both cases, the error signal is approximately the same.

7. Comparison of trials and simulated results

Figure 14 shows both results, experimental (grey line) and theoretical (black line) pseudorange errors. The high correspondance between them can easily be appreciated. The error oscillation corresponds exactly, whilst there is a minor difference in the amplitude values.

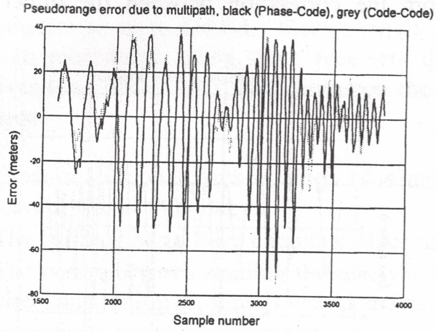

Figure 13

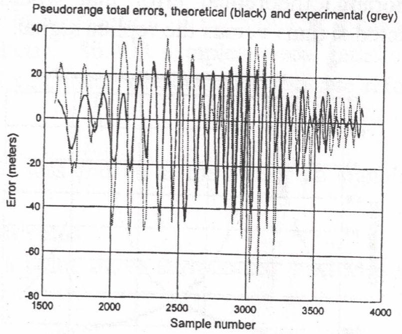

Figure 14

8. Conclusions

The results permit to conclude that the reflection effects are more extensive and intense than that of the corresponding diffraction ones.

The latter are only significant when the angles formed between the straight border and the lines that join the points of the border with the receiver are equal to the angles formed between the border and the line of sight of the satellite. This situation allows to identify sectors of the reception pattern of LHP signal with minimum values.

The results are highly dependant on the receiver antenna orientation with respect to the reflector surface. This is so, because the radiation pattern presents big differences in gain for distinct azimuth and elevation angles.

9. Future Activities

Future activities include further validation in other scenarios of the results presented in this report. Other recording sessions have just been carried out using as a reflector surface a hangar wall at Madrid-Barajas airport. In this case, the new surfaces have different electric parameters.

10. Acknowledgements

The authors express their appreciation to the Spanish National Anthropology Museum for allowing us to use their installations.

11. References

[1] Janet S. Booth. **A statistical interpretation of the presence of multipath at ground reference sites**. Proceedings of the National Technical Meeting Navigation 2000, 22-23 January, 1998.

[2] Ronald R. Hatch, Richard G. Keegan and Thomas A. Stansell. **Leica's code and phase multipath mitigation techniques.** Proceedings of the Institute of Navigation, 14-16 January, 1997.

[3] Greg Johnson and Dennis King. **Low cost multipath mitigation in a single frequency environment for a DGPS station.** Proceedings of the Institute of Navigation, 22-24 January, 1996.

[4] Raymond Barber. **Practical GPS Multipath Measurement Techniques in the presence of SA.** Proceedings of the Institute of Navigation, 22-24 January, 1996.

[5] Penina Axelrad, Christopher J. Comp and Peter F.Macdoran. **SNR based multipath error correction for GPS differential phase.** IEEE Transactions on aerospace and electronic systems, Vol 32, nº 2, April 1996.

[6] Michael S. Braasch. **Global Positioning System: Theory and applications**, volume I. Ed Americam Institute of Aeronautics and Astronautics. 1996.

[7] Michael S. Braasch. **Isolation of GPS Errors**. Journal of the Institute of Navigation Vol 41. 1995.

[8] Bryan Townsend and Patrick Fenton. **A practical approach to the reduction of pseudorange multipath errors in a L1 GPS receiver.**

[9] Richard D.J. Van Nee. **Multipath Effects on GPS code Phase Measurements.** Journal of the Institute of Navigation. Vol 39. 1992.

[10] Georgiadou, Y. And Kleusberg, A. **On carrier signal multipath effects in relative GPS positioning.** Manuscripta Geodaetica 1988.

[11] D.S. Lones. **Methods in electromagnetic wave propagation.** Second edition, Clarendon Press Oxford 1994.

[12] Jones, D.S. **"Methods in electromagnetic wave propagation"**. Oxford science publications. 1994.