A Practical Approach to the Reduction of Pseudorange Multipath Errors in a Ll GPS Receiver

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BIBLIOGRAPHY

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ABSTRACT

The reduction of multipath biases on GPS measurements has traditionally been achieved through innovative antenna design, such as choke ring ground planes, and careful antenna site selection. These methods, although effective, are not always practical, especially in a kinematic environment. The implementation of Narrow Correlator spacing design in GPS receiver code tracking loops has greatly reduced the multipath bias and the measurement noise on C/A code pseudorange measurements. Even with these advancements the bias due to multipath is still dominant in GPS position calculations. This paper introduces a new tracking loop which takes full advantage of the Narrow Correlator™ spacing design, but in addition, is much more resistant to multipath effects on the correlation function and thereby reduces the multipath bias on the pseudorange measurements. The theory behind this new tracking loop design is presented along with its implementation into existing receiver hardware. Test results from a prototype receiver are presented. They show a 25 to 50 percent reduction of multipath error effects in the DGPS position solution as compared to a standard narrow correlator receiver.

INTRODUCTION

GPS pseudorange and carrier phase measurements suffer from a variety of systematic biases. The sources of these are:

(i) Satellite Orbit Prediction
(ii) Satellite Clock Drift
(iii) Ionospheric Delay
(iv) Tropospheric Delay
(v) Receiver Clock Offset
(vi) Signal Multipath

The satellite orbit, satellite timing, ionospheric, and tropospheric errors can be removed by differencing techniques or significantly reduced by modeling. The receiver clock offset can also be removed by differencing but is often solved for as an unknown in the position solution.

The measurement bias caused by signal multipath acts differently. Unlike the other error sources, multipath is normally uncorrelated between antenna locations. Hence, the base and remote receivers experience different multipath interference and as a result differencing between them will not cancel the errors. Also, modeling multipath for each antenna location is difficult and impractical.

In the presence of multipath, most GPS positioning methods suffer a degradation in accuracy and an increase in processing time. Pseudorange multipath at a real-time differential GPS monitor station will result in errors creeping into the differential corrections causing large position biases for DGPS users.

The most common methods of reducing multipath are by improved antenna design (e.g. choke ring ground planes) and careful site selection. Unfortunately, it is often not possible to change either of these parameters. For example an antenna mounted on an airplane fuselage will not be easily moved or replaced. Therefore the method of reducing multipath that would be most transparent to the user is to remove it at the signal level within the GPS receiver itself.

MULTIPATH CHARACTERISTICS

The term multipath is derived from the fact that a signal transmitted from a GPS satellite can follow a 'multiple' number of propagation 'paths' to the receiving antenna. This is possible because the signal can be reflected back to the antenna off surrounding objects, including the earth's surface. Figure 1 illustrates this phenomena for one reflected signal.

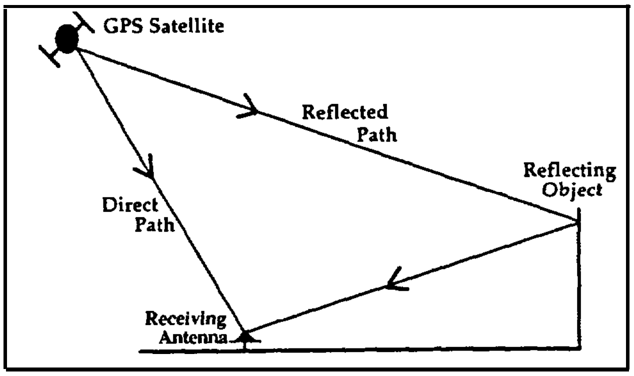

Figure 1: Direct Path **and Multipath** (Reflected **Path) Signals**

Some important characteristics of multipath are as follows:

i) The multipath signal will always arrive after the direct path signal because it must travel a longer propagation path.
ii) The multipath signal will normally be weaker than the direct path signal since some signal power will be lost from the reflection. It can be stronger if the direct path signal is hindered in some way.
iii) If the delay of the multipath is less than two PRN code chip lengths, the internally generated receiver signal will partially correlate with it. If the delay is greater than 2 chips the correlation power will be negligible [Proakis, 19831.

For this paper it is assumed the direct path signal is present and is stronger than the multipath signals.

THE EFFECT OF MULTIPATH ON EARLY-LATE DLL

Since GPS is a ranging system it is desirable to perform measurements on the direct path signal. The presence of multipath signals corrupts this process because the receiver tries to correlate with both signals. Figure 2 shows the plots of the correlation functions for a direct path signal, multipath signal, and the resulting composite signal.

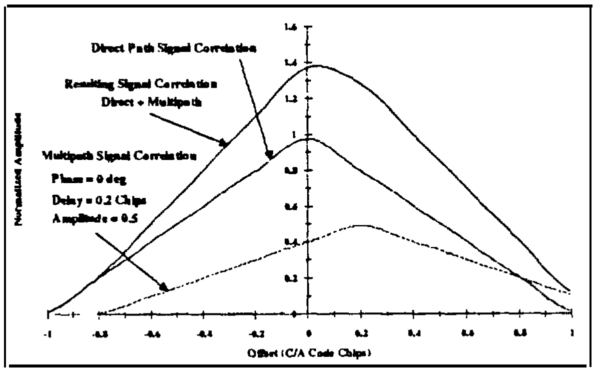

Figure 2: Direct Path, Multipath (In Phase) and Resulting Correlation Functions

In this case the multipath signal has a delay of 0.2 chips, an amplitude of 0.5 relative to the direct path signal and is in phase with the direct path signal. These curves were calculated assumming a pre-correlation bandwidth (BW) of 8 MHz and a brickwall filter. An 8 MHz bandwidth is similar to that used in the GPSCard™ [Fenton et al, 1991]. Figure 3 shows the resulting correlation function when the same multipath signal is 180 degrees out-of-phase with the direct path and therefore has a negative correlation.

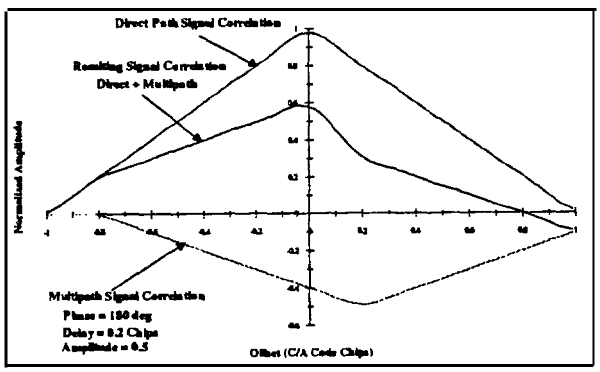

Figure 3: Direct Path, Multipath (out of phase) and Resulting Correlation Functions

It is important to note that in both the cases shown in Figures 2 and 3 the resulting correlation function is skewed and non-symmetric.

The effect multipath has on a normal dop-product or early minus late delay-lock-loop (DLL) is illustrated in Figure 4. Since a normal DLL is designed to feedback to the hardware in such a way to keep the power of the early and late correllators equal, a distorted correlation function will **bias** this process.

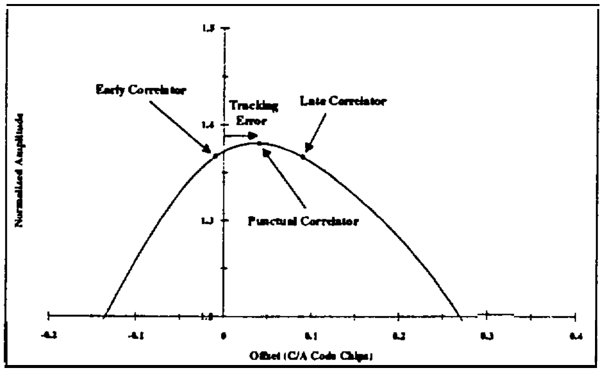

Figure 4: Tracking Error Due to Multipath

Since the multipath signal causes distortion in the correlation function it should be possible to measure distortion in the correlation function and derive a correction for multipath.

THE EARLY LATE SLOPE TECHNIQUE

In deriving the early-late slope (ELS) technique it is convenient to consider the ideal situation where the pre-correlation BW is infinite and the resulting correlation function is triangular. Figures 5 and 6 show the resulting correlation functions for the same situations as in Figures 2 and 3 respectively. The resulting correlation functions in Figures 5 and 6 share two important common characteristics. Firstly, the desired tracking point is at maximum power in both cases. Secondly the slope of the function either on side of the peak is not equal.

Figure 7 is a close-up of a similar correlation function peak with two correlators placed on the early and late side. In Figure 7, y_1 and y_2 are the amplitude of early and late correlators respectively. The slope of the correlation function on the early side of the peak is a_1, and a_2 is the slope on the late side of the peak. The spacing between the early and late correlators is d.

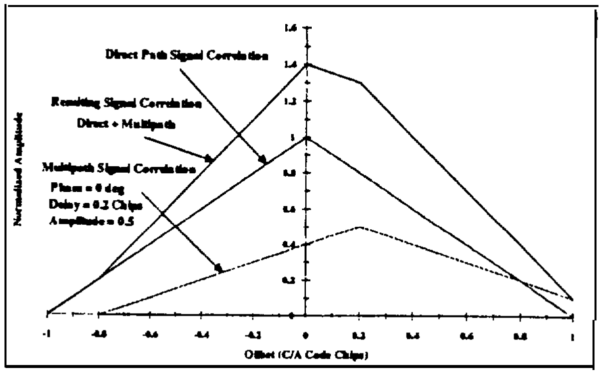

Figure 5: Direct Path, Multipath (in phase) and Resulting Correlation Functions -- Ideal Case

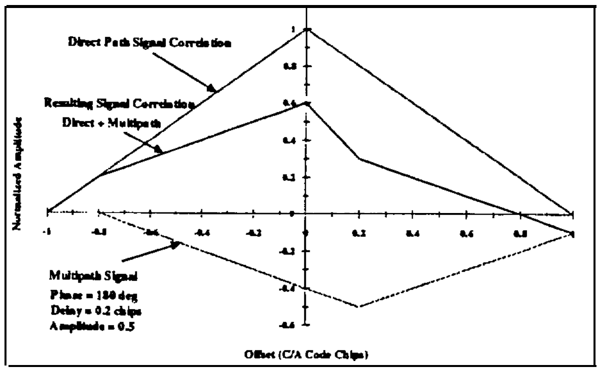

Figure 6: Direct Path, Multipath (out of phase) and Resulting Correlation Functions -- Ideal Case

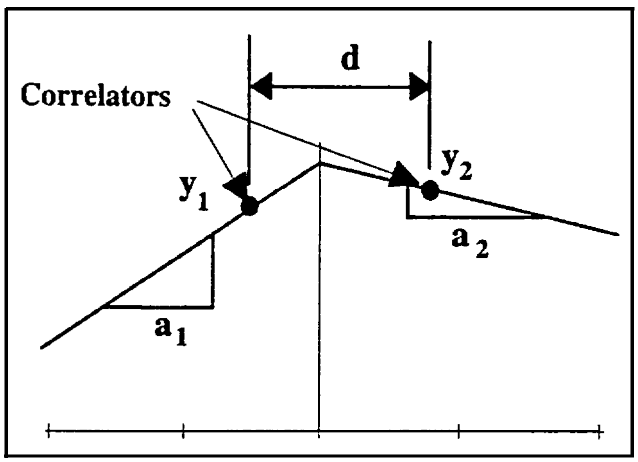

Figure 7: Early Late Slope Technique -- Ideal Case

Using the slope information the following DLL discriminator can be derived to accurately estimate how much the cot-relators need to be moved so that they are centred on the peak:

$$T = \frac{[(y_1 - y_2 + d/2 (a_1 + a_2]}{(a_1 - a_2)}$$

where T = the tracking error.

T will equal zero when the two correlators are positioned equidistant on each side of the peak. When T is non-zero it can be used to feed back to the hardware to keep the early and late cotrelators centred on the peak.

In the ideal case this DLL discriminator will estimate exactly the amount the cot-relators have to be moved. Applying this discriminator to the bandlimited case is straightforward. Figure 8 shows how this can be accomplished. Two additional cot-relators are added at a wider spacing so that the early and late slopes can be calculated. The inside two correlators are spaced wide enough apart so that they are not affected by the flatness at the peak of the correlation function.

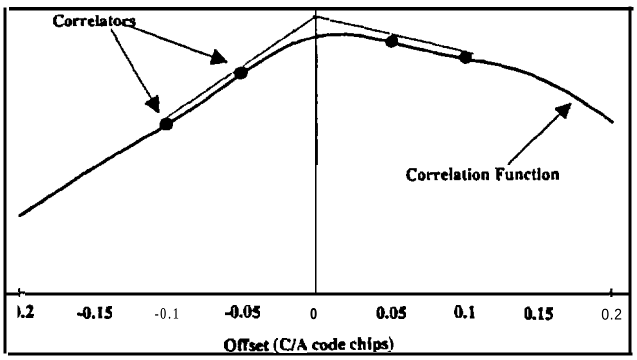

Figure 8: Early Late Slope Technique -- Band Limited Case

The next question is -- does the ELS DLL give any improvement in accuracy over the standard narrow cot-relator DLL. To test this, the 8 MHz bandlimited correlation function from Figures 2 and 3 was used to estimate the multipath error envelopes for a narrow correlator spacing DLL similar to one used in NovAtel's GPSCard™ and an ELS DLL. The error envelopes were calculated by taking the DLL equations and solving for the tracking error as 0.5 amplitude multipath signal is varied in delay from 0 to 1.5 chips. The error is calculated at the maximum points when the multipath signal is at 0" in phase or 180° out of phase with respect to me direct path signal.

Figure 9 shows a plot of the multipath error envelopes. It indicates that in this case the ELS DLL will decrease the bias due to multipath by 30 to 70 percent for multipath signal delays greater than 0.1 chips.

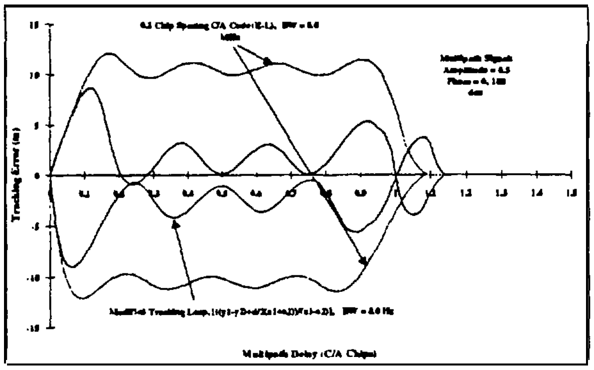

Figure 9: Multipath Error Envelopes For Narrow Correlator and Early Late Slope Technique

TEST RESULTS

In order to test the ELS technique further, a 6 channel prototype receiver was configured to operate using the ELS DLL. Since we are most interested to know if there is an improvement in performance over the namow correlator receiver, a test system was set up as shown in Figure 10. The monitor and remote antennas, named A and B respectively, were located on the roof of the NovAtel building in Calgary. Antenna A has a choke ring antenna ground plane and is expected to be experiencing a low multipath enviroment. Antenna B did not have a ground plane and was raised up on a tri-pod. It was expected to be experiencing much more multipath than antenna A.

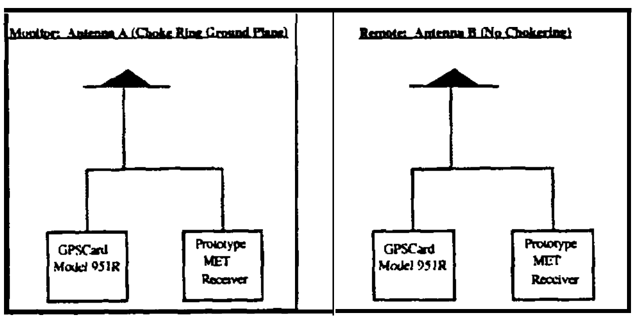

Figure 10: Equipment Setup

The signal from each antenna was split so that it could be connected to one Model 951R GPSCard™ (Narrow

Correlator™ receiver) and one MET™ prototype receiver. MET™ is the product name for the ELS receiver. It stands for Multipath Elimination Technology. With this setup both receivers are receiving the same signals.

On June 20, 1994 a 1200-second long set of measurement data was collected using the above equipment setup. The data was collected at 1 Hz and double difference residuals (DDRs) where calculated using the pair of 951R receivers. DDRs were also computed for the pair of MET receivers. Since the baseline between antenna A and B was known and was removed from the DDRs, the resulting DDRs only contained measurement noise and the combined multipath bias for the four pseudoranges used to calculate them. Figures 11 and 12 show DDR plots from the 951R and MET receivers respectively. Comparing the two figures one can see the MET receiver shows a significantly smaller multipath signature.

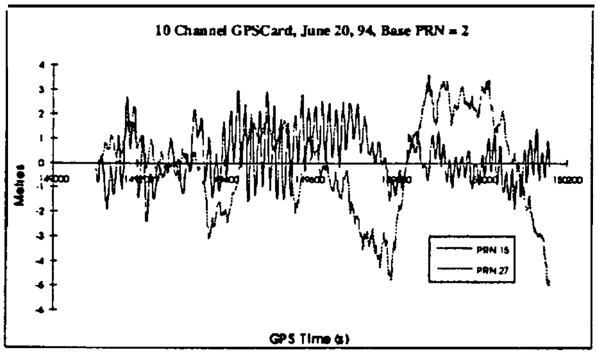

Figure 11: Double Difference Residuals -- Model 951R GPSCards

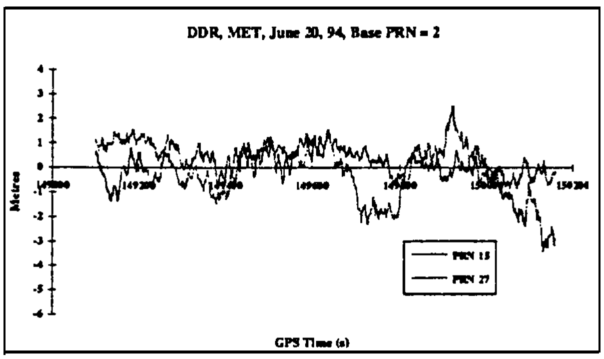

Figure 12: Double Difference Residuals -- MET GPSCards

Figure I3 shows a comparison **of** the RMS statistics for each receiver and satellite pair. These values were calculated by computing the RMS of each set of DDRs. The RMS was divided by 2 so that it reflects the value that could be expected of one pseudorange measurement. The comparison in Figure 13 shows an across the board reduction of 25 to 50 % in bias over the narrow cot-relator receiver.

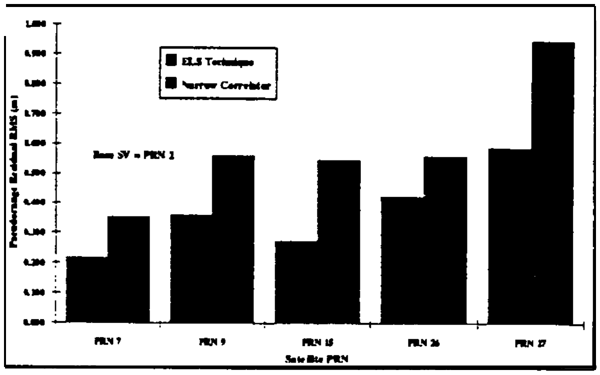

Figure 13: Comparison of RMS Residuals

The next test was carried out on June 21, 1994. In this test a differential link was connected between the monitor and remote receivers so that a realtime DGPS position was calculated at the remote receiver. The DGPS position for each pair of receivers was collected from the remote receivers every 10 seconds for 14 hours. Using the known coordinates for antenna B, residual for latitude, longitude and height were calculated. Table 1 gives a summary of RMS residual statistics for each remote receiver.

Table 1: Comparison of DGPS Position Results

	MET1		
	Latitude	**Longitude**	**Vertical**
mean (m)	**0.081**	**-0.028**	**0.341**
stdev (m)	**0.905**	**0.479**	**1.229**
rms(m)	**0.909**	**0.480**	**1.275**
N. Samp.	**4980**	**4980**	**4980**
	951R		
	Latitude	**Longitude**	**Vertical**
mean (m)	**0.350**	**0.051**	**0.211**
stdev (m)	**1.293**	**0.572**	**1.710**
rms(m)	**1.339**	**0574**	**1.723**
N. Samp.	**4980**	**4980**	**4980**

The MET receiver shows consistently better results. Table 2 takes it one step further by calculating the RMS for the horizontal and 3-D position. Again, the MET receiver shows better results.

Table 2: Comparison of Horizontal and 3-D Position Results

	Horizontal	3-D
95 lR (m)	1.457	2.257
MET (m)	1.028	1.638
Improvement	29%	27%

CONCLUSIONS

The results show the ELS technique reduces multipath errors by 25 to 50% under normal conditions. This is about the level of improvement one could expect using a choke ring antenna ground plane. Hence, the ELS DLL gives choke ring level multipath reduction on the pseudorange measurements without using choke rings.

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