Ll Carrier Phase Multipath Error Reduction Using MEDLL Technology

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BIOGRAPHY

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Richard D.J. van Nee was born in Schoonoord, the Netherlands. He received an MSc. in Electrical Engineering Cum Laude from Twente University in Enschede, The Netherlands in 1990. In May 1995, he received his Ph.D. Cum Laude from the Technical University at Delft, The Netherlands. His Ph.D. thesis is on multipath problems in navigation and communication receivers.

ABSTRACT

In single frequency (Ll) GPS receivers, multipath is the dominant error source in differential carrier phase and pseudorange measurements. Consequently, it is the dominant error effecting DGPS positioning accuracy.

The Multipath Estimating Delay Lock Loop (MEDLL) is a method for mitigating the effects due to multipath within the receiver tracking loops. The MEDLL does this by separating the incoming signal into its line-of-sight and multipath components. Using the line-of-sight component, the unbiased measurements of code and carrier phase can be made.

In previous papers, the authors have demonstrated MEDLL performance in mitigating the effects of multipath on C/A code pseudorange measurements, Also, they have shown that it is possible to use the MEDLL derived parameters to calculate a multipath error correction for the carrier phase measurements. This carrier phase multipath correction has now been implemented in NovAtel's MEDLL receiver.

Using a GPS signal simulator, the carrier phase performance of the MEDLL receiver for a single multipath and a multiple multipath case was compared to a standard phase lock loop. The results showed the MEDLL receiver was able to substantially reduce the carrier phase multipath errors as compared to a standard NovAtel receiver.

INTRODUCTION

GPS pseudorange and carrier phase measurements suffer from a variety of systematic biases. The satellite orbit, satellite timing, ionospheric, and tropospheric errors are usually handled through DGPS techniques. The measurement bias caused by signal multipath acts differently. Unlike the other error sources, multipath is normally not correlated between antenna locations. Hence, because the base and remote receivers experience different multipath conditions the DGPS techniques are often ineffective and, as a result, multipath is the dominant error source.

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MULTH'ATH 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.

Since GPS is a ranging system, it is desirable to perform measurements on the direct path signal only. The presence of multipath signals corrupts this process because a standard receiver can not distinguish between the signals and tries to correlate with all signals that are present.

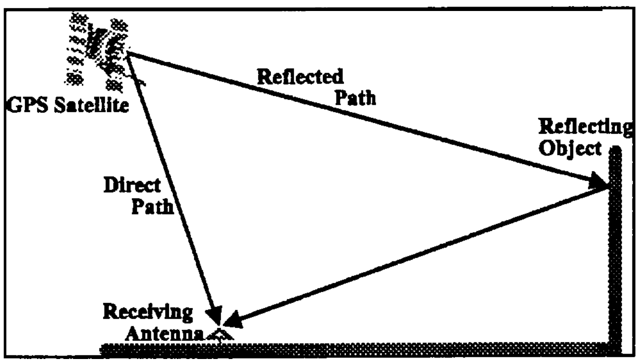


Figure 1: The Direct Path and One Reflected Path (Multipath) Signals

Some important characteristics of multipath are as follows [Townsend and Fenton, 1994]:

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 pseudo-random (PRN) codes are designed so that correlation power will be negligible.

THis paper deals with the normal case that the direct path signal is present and is stronger than the multipath signals.

THE EFFECT OF MULTIPATH ON A STANDARD GPS RECEIVER

A standard GPS receiver uses a dot-product or early minus late delay-lock-loop (DLL). This is illustrated in Figure 2. Since a normal DLL is designed to feedback to the hardware in such a way to keep the power at the early and late corrclators equal, a correlation function distorted by multipath, biases this process.

The phase tracking is affected in a similar fashion. The phase-lock-loop (PLL) is driven from the punctual correlator. The phase of the composite signal is rarely the same as the direct path signal and therefore a tracking error is introduced.

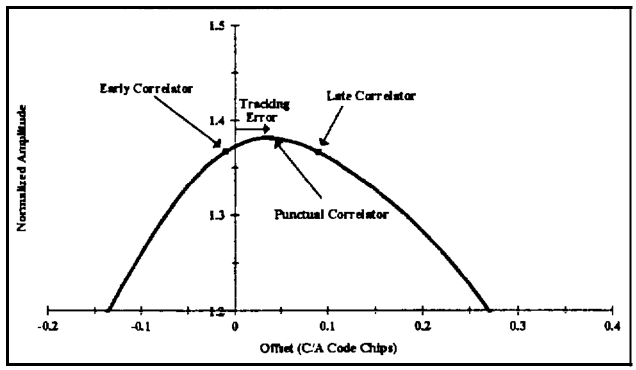


Figure 2: Early-Late DLL Tracking Error Due to Multipath

THE GPS SIGNAL CORRELATION FUNCTION

The received signal at the input of a direct-sequence spread-spectrum receiver can be written as:

$$r(t) = \sum_{m=0}^{M-1} a_m p(t - \tau_m)\cos(\omega t + \theta_m) + n(t) \quad (1)$$

where,

M = number of signals.
t = time.

$p(t)$	=	the spread-spectrum code
n(t)	=	white Gaussian noise.
a_m	=	component signal amplitude.
τ_m	=	component signal delay.
θ_m	=	component signal phase.

As can be see from this mathematical representation of the GPS signal, the resulting signal correlation function r(t) is really just the linear sum of all signals present. Each signal is defined by a unique amplitude ***(a,),*** phase (θ_m), and delay (τ_m) parameters.

Given the make up of the GPS signal correlation function, it should be possible to measure the correlation function and decompose it into its direct path and multipath components. One method for doing this is using MEDLL technology and this is described in the following section.

THE MULTIPATH ESTIMATING DELAY LOCK LOOP (MEDLL)

For a positioning system like GPS, the parameters of interest are the direct path signal delay and phase. In order to estimate these parameters, the direct path correlation function needs to be determined. The MEDLL approach used here involves the decomposition of the correlation function into its direct and multipath components.

The MEDLL estimates the amplitude, delay, and phase of each multipath component using maximum likelihood criteria. Other criteria such as least squares could be used, but it was found that using maximum likelihood criterion was the most suitable. Each estimated multipath correlation function component is in turn subtracted from the measured correlation function. Once this process is complete an estimate of the direct path correlation function is left. The phase and delay of the direct path is measured and these values are used to correct the carrier phase and pseudorange measurements respectively.

RECEIVER ARCHITECTURE AND DESIGN

The MEDLL algorithms require that the complete correlation function be measured in order to detect distortions caused by multipath. This is achieved by multiple correlator sampling of the correlation function as shown Figure 3.

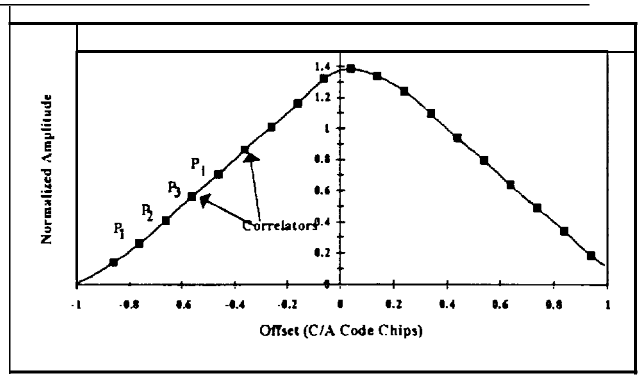


Figure 3: Multiple Correlator Sampling of the Correlation Function

A traditional GPS receiver dedicates only two, possibly three, correlators to each satellite tracking channel. The MEDLL algorithms require many more. Theoretically, the MEDLL only requires three correlators per direct path and multipath signal. In reality more correlators are required in order to obtain the initial estimates of each signal.

The extra correlators require that more hardware be used. This was achieved at NovAtel by grouping some of the standard GPSCards into a multi-card system. The cards are linked to the same RF deck and external OCXO to minimizes cross channel biases. The OCXO also gives better clock stability then the TCXO used on the standard GPSCard. The interface to the MEDLL receiver is similar to OEM receiver presently sold by NovAtel. Figure 4 shows a picture of the MEDLL receiver. Its dimensions are 5.5" X 4.5" X 8.5".

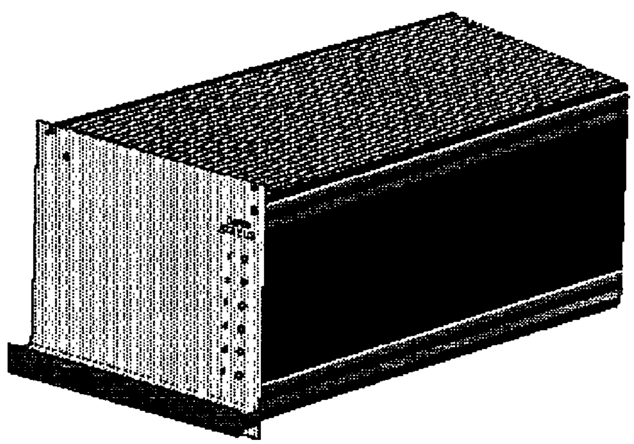


Figure 4: NovAtel MEDLL Receiver

THEORETICAL CARRIER PHASE TRICKING PERFORMANCE

Figure 5 shows a plot of the theoretical phase tracking of MEDLL and a standard PLL is the presence of a 0.5 amplitude multipath signal.

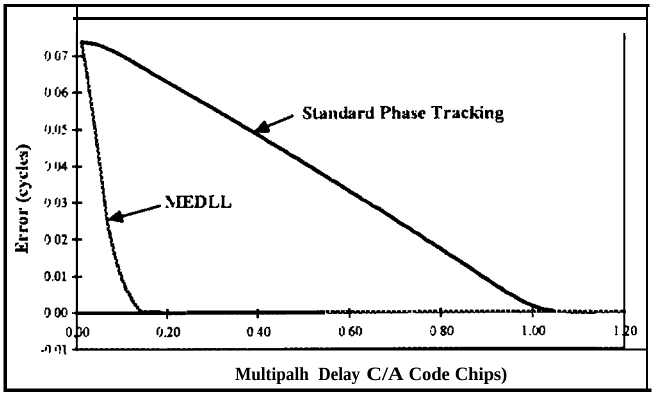


Figure 5: Theoretical MEDLL and Standard Receiver Phase Tracking Performance in the Presence of One Multipath Signal

The multipath signal was varied in delay from 0 to 1.2 chips and the maximum phase error was plotted.

The plot was generated using a simulated correlation function. A precorrelation band width (BW) of 8 MHz was assumed so as to emulate the filtering going on inside the MEDLL receiver.

The plot shows that the MEDLL is significantly better than standard receivers. It virtually eliminates any multipath biases for delays greater than 0.15 chips.

GPS SIMULATOR TEST BED

To evaluate the performance of the MEDLL carrier phase measurements under controlled multipath conditions, a GPS simulator test bed was set as shown in Figure 6. The test bed consists of a Stanford Telecom 7220 GPS signal simulator connected to two NovAtel receivers, the MEDLL and the GPSCard model 3151R using punctual correlator phase tracking. This set up allows us to make a direct comparison in performance between the MEDLL receiver and the GPSCard.

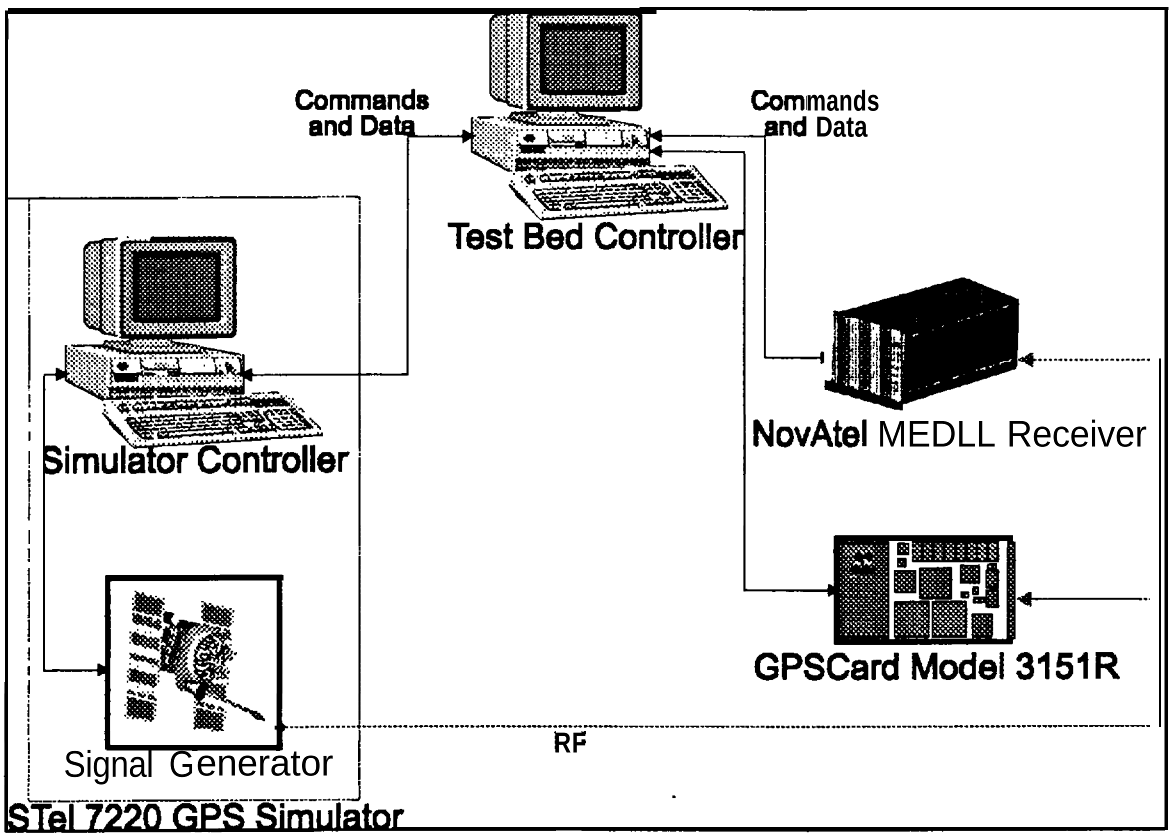
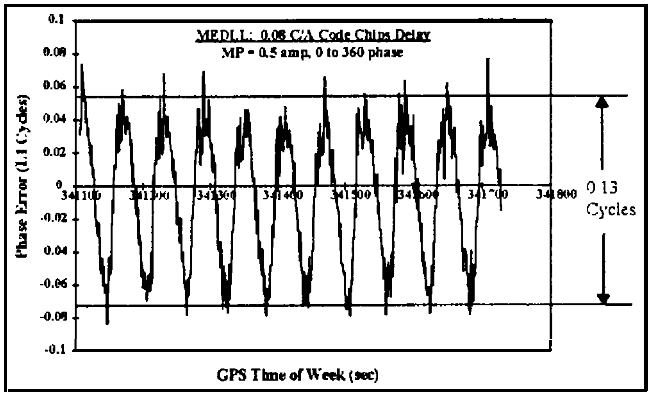


Figure 6: GPS Signal Simulator Test Bed

For each multipath simulation scenario, one channel of the simulator was set up to produce a multipath free signal using PRN 1. The multipath corrupted signal was created by setting 2 or more of the remaining simulator channels to generate a signal using PRN 2. One channel is set to simulate the direct path signal while the other channels generate the multipath signals.

The carrier range error is measured by differencing the PRN 1 measurement with the PRN 2 measurement. The carrier phase ambiguity is subtracted out and the remaining residual is largely due to the multipath error. Figure 7 shows a plot of the residuals.



Residuals

RESULTS - ONE MULTIPATH CASE

For this test, a 0.5 amplitude multipath signal is generated at various delays relative to the direct path. The selected measurement points were 0.02, 0.04, 0.06, 0.08, 0.10, 0.14, 0.20, 0.10, 0.60, 0.80, 1.00, and 1.20 chips delay.

A new simulator scenario was initiated for each measurement point and the GPS receivers were reset at the same time. The simulator channels were configured in the following way:

Channel 1: PRN 1
Channel 2: PRN 2 (direct path signal)
Channel 3: PR.N 2 (multipath signal)
Channels 4 to 10: Idle

The relative doppler between channels 2 and 3 was l/60 Hz. That is, at the beginning of the scenario, the multipath delay set to the same as the measurement point delay, then it is increased by one carrier cycle every minute. This allows the multipath signal to rotate through a full 360 degrees of phase relative to the direct path signal. The effects of this can be seen in Figure 7. The period between peak residual points is approximately one minute.

The plot in Figure 8 shows measured phase tracking error versus the theoretical phase tracking error from Figure 5.

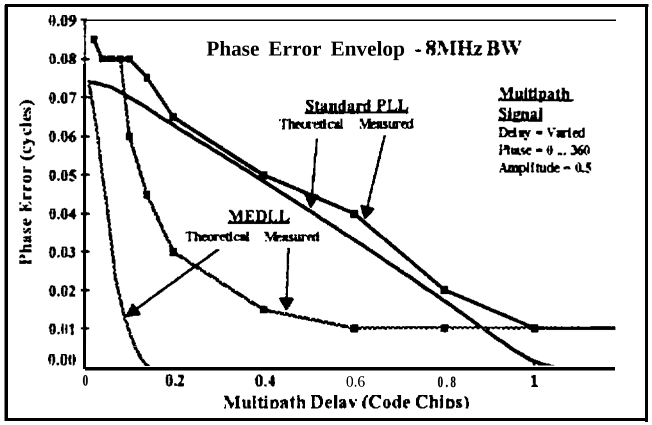


Figure 8: Measured Phase Tracking Error vs. Theoretical Phase Tracking Error

The results show the following:

1. Both plots of the MEDLL and GPSCard measured phase errors converge to a value of around 0.013 cycles. The phase noise of the receiver is about this level. This is also shown in Figure 7 by the higher noise present on top of the large sinusoidal type trend in the residuals.

2. The standard PLL follows closer to the theoretical values then the MEDLL does. The reasons for this are probably errors in the reference correlation function used inside the MEDLL receiver and residual second order effects in applying the carrier phase correction. The MEDLL carrier phase correction is very sensitive to errors in the quadrature of the reference correlation function This could be improved by measuring the reference function at more points. The residual second effects are caused by the PLL in the MEDLL receiver operating in real time and the correction to the carrier phase being calculated slightly post real-time. This can likely be tuned to improve results.

3. The MEDLL shows a marked improvement over the standard PLL.

RESULTS - TWO MULTIPATH CASE

For this test. a 0.5 amplitude multipath signal is generated at various delays relative to the direct path. The selected measurement points were 0.02, 0.10. 0.20, 0.80. and 1.20 chips delay. At the same time a 0.3 amplitude multipath signal is held static at 0.5 chips delay.

As before, a new simulator scenario was initiated for each measurement point and the GPS receivers were reset at the same time. The simulator channels were configured in the following way:

Channel 1: PRN 1
Channel 2: PRN 2 (direct path signal)
Channel 3: PRN 2 (0.5 amp. multipath signal)
Channel 4: PRN 2 (0.3 amp. multipath signal)
Channels 5 to 10: Idle

The relative doppler between channels 2 and 3 was l/60 Hz while channel 4 was held at 0 degrees phase relative to channel 2.

The plot in Figure 9 shows the measured phase tracking error for the two multipath case along with the phase tracking error from the single multipath case.

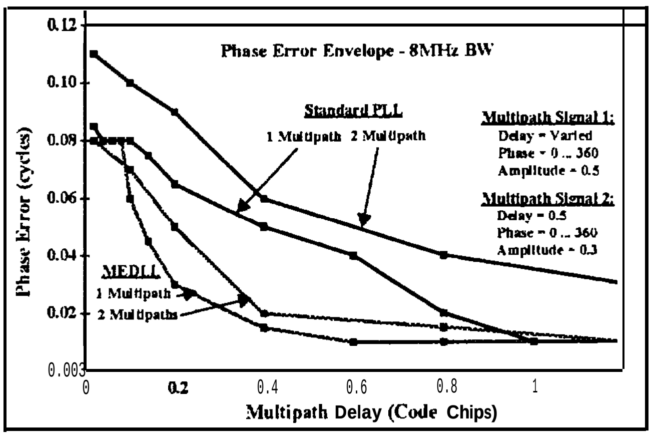


Figure 9: One Multipath Case vs. Two Multipath Case

The results show that the both the MEDLL and the standard PLL suffer a degradation in accuracy due to the addition of one more multipath signal. Relatively speaking, the MEDLL suffers much less then the standard PLL. This indicates that the MEDLL is successfully detecting and removing the additional multipath signal.

CONCLUSIONS

The results show a marked improvement in the MEDLL carrier phase tracking performance over the standard PLL. This shows that MEDLL is able to detect and remove the multipath signal(s). The tracking performance does degrade with the addition of more multipath signals, but the MEDLL suffers much less than the standard PLL.

Still the MEDLL did not perform as well as the simulations indicated it would. This suggests that these results can be improved upon. Some possible areas of improvement are a more accurate reference correlation function and more accurate modeling of second order effects when applying the carrier phase correction.

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