NovAtel Communications Ltd. - What's New ?

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BIBLIOGRAPHY

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ABSTRACT

This paper contains a rare inside look at some of the new GPS developments on the drawing board at NovAtel communications Ltd. It describes two multipath elimination techniques, MEDLL™ and MET™, being integrated into the new 12 channel C/A code LI receiver. Other technologies disclosed are procedures for providing velocity and acceleration measurements accurate to less than 1 mm/s and 1 mm/s^2 respectively.

INTRODUCTION

This paper contains a rare inside look at some of the new GPS developments on the drawing board at NovAtel communications Ltd. These technologies are expected to be implemented into the NovAtel product line in the near future.

MULTIPATH

In a typical antenna installation there are often many objects in the area that reflect the signal transmitted from the GPS satellites. The GPS receiver antenna will receive some of these reflected signals along with the direct line **of** sight signal. The reflected signals are called 'multipath' signals because they may follow a 'multiple' number paths to the antenna. The presence of multipath signals will often cause a bias within the **receiver measuring** process. At **NovAtel,** a concerted effort has been put forward to develop ways of reducing multipath biases that are most transparent to the user. The two methods presented here involve reducing multipath effects in the receiver tracking loops.

Multipath Estimating DLL (MEDLL™)

Using an array of correlators, the Multipath Estimating Delay Lock Loop (MEDLL™) measures the shape of the received correlation function. Using maximum likelihood estimation technique, MEDLL™ attempts to deconvolve the incoming signal into its direct and multipath signal components by estimating the amplitude, delay and phase angle of each signal.

The number of correlators required per channel is a function of how accurately and how many multipath signals are to be estimated. Ideally an infinite number of correlators spaced across the correlation function curve would be required. Spacing of the correlators is a function of the band width of the receiver. Each correlator must be spaced just far enough apart to be making statistically independent measurements. The wider the bandwidth the closer the correlators can be placed together.

The correlation function curve is described mathematically by the following formula:

$$r(t) = \sum_{i=0}^{M} a_i p(t+\tau_i)\cos(\theta_i) + n(t) \qquad (1)$$

Where:

- r(t) is the received distorted signal.
- *M* is the number of signals received from the satellite consisting of the direct path as well as all multipath components.

- a_i is the amplitude of each signal, p(t) is the expected filtered C/A code correlation function.
- τ_i is the relative delay of each multipath signal.
- θ_i is the phase angle of each signal with respect to the channel reference angle.
- $n(t)$ is white gaussian noise.

The technique requires that each tracking channel has a number of correlators distributed across the received correlation function. Each correlator is positioned at unique values of t and will measure a **single** value of r(t). All of the measured values of r(t) are used to solve for all the signal components $(a,\tau,\theta)_i$ i = $0..M$, by solving a set of simultaneous equations of (1). The signal component with the earliest value of t would represent the direct line of sight signal, (assuming that the direct **line** of sight to the satellite is not obstructed). The values **of t** and θ_x can be used as feed back values to the hardware tracking loops or to derive a correction for the measurements.

This patented technique provides up to 90% reduction of errors due to multipath distortion. This can be seen as the very small error envelope on the left side of Figure 1. The MEDLL™ technique can effectively remove all multipath signals that have a delay of more than the minimum correlator spacing. The leftover multipath effect on the C/A code measured range is in the same order of magnitude as a "P" code GPS receiver.

Multipath Elimination Technology **(MET™)**

A second method for mitigating the affects of multipath is called the Multipath Estimation Technique **(MET™).** The principal **MET™** uses is to model the shape of the peak of the correlation function. It assumes that:

1) The dominant power source **in** the r(t) is **from** the direct line of sight signal.
2) The t values for minor multipath signals are more than then twice the minimum correlator spacing distances.

The technique involves the use of 4 correlators spread out symmetrically and as close as possible together at the peak of the correlation function. The intersection point of the slopes from both sides of the function as estimated by the correlators, is used as the τ point of the line of sight signal.

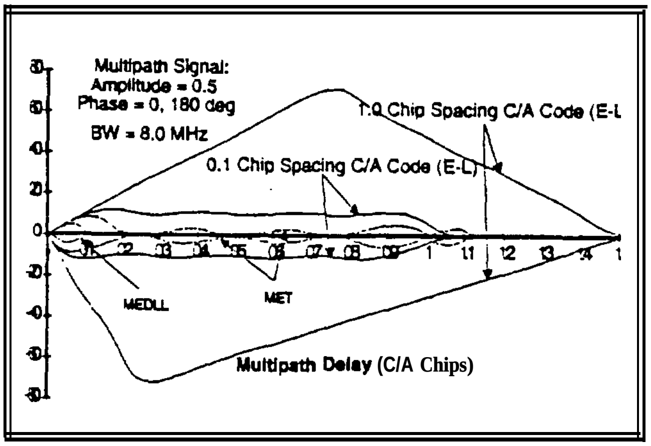

Figure 1: Multipath Error Envelopes

In practice the patented MET™ technique provides up to 50% reduction of multipath noise Townsend and Fenton, 1994]. This can be seen in Figure 1 as the middle envelope. It provides better performance than the narrow correlator receiver.

VELOCITY AND ACCELERATION

There is a need to measure velocity and acceleration of a moving vehicle without the use of expensive accelerometers or inertial platforms. These measurements are useful to remove the affects of aircraft motion on gravity or synthetic radar measurement equipment. They are also useful to provide very accurate velocity information for harbor approaches for super-tankers.

General approach

Statistically independent carrier phase measurements can be taken at a rate of up to 50 Hz on a NovAtel GPSCard™ receiver. The carrier phase measurements have **a** conservatively estimated RMS noise level of 4 mm. These line of site range measurements can be converted to velocity and acceleration measurements by taking time derivatives. This was accomplished by fitting parabolas over time intervals. From analysis of the covariance matrix of **a** least squares fit, the expected standard deviation of the output values can be determined as a function of the measurement period and the noise level.

Pre-Analysis

The expected measurement results as a function of integration time can be seen in Figure *2.*

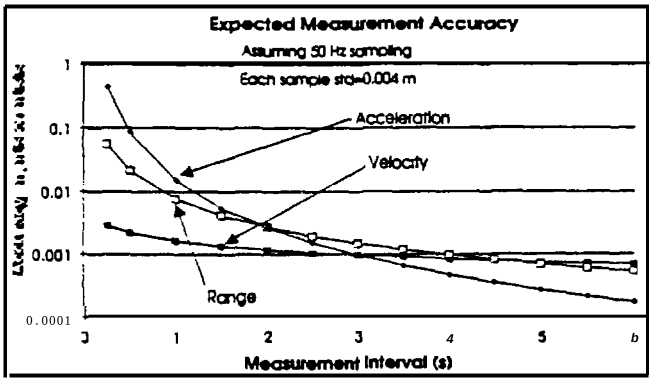

Figure 2: Expected Accuracy of Filtered Measurements

From Figure *2* it can be seen that the expected measurement accuracy of velocity and acceleration measurements is less then 1 mm/s and 1 mm/s^2 with greater than a 3 second measurement interval. In practice, the data is processed with as long a measurement interval time as possible. Goodness of fit tests are used to determine the maximum length. A dynamically adjustable window is used. During periods of calm vehicle motion, long measurement intervals could be used, conversely during periods of turbulence, short intervals could be averaged or the data from these periods could be omitted. **A** real time monitor in the vehicle is used to give the crew a statistic of how good the data is.

The translation from line of sight measurement accuracy to position computational accuracy is the GDOP. Therefore if the current geometry provides a GDOP of 4.0 the expected vertical acceleration error is 4 times the line of sight measurement accuracy.

Test Results

Figure 3 shows the typical residuals from **a 5** second curve fit over 250 samples collected at 50 Hz from a stationary receiver. The residuals are well within the estimated 4 mm noise level. From Figures **4a, 4b,** and **4c** we can see that from zero base line test results accuracy of the range, velocity and acceleration measurement from this solution are between 1 mm and l/10 of a mm.

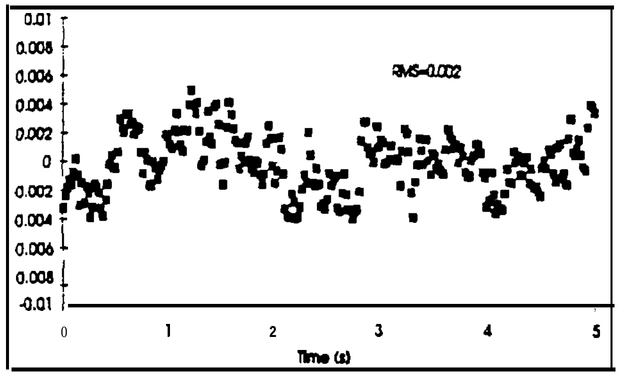

Figure 3: Residuals From 5 Second Fit Over 50 Hz Data

The theory was tested by comparing the curve fit measurements from two tracking channels taking measurements from the same satellite, same stationary antenna using the same oscillator.

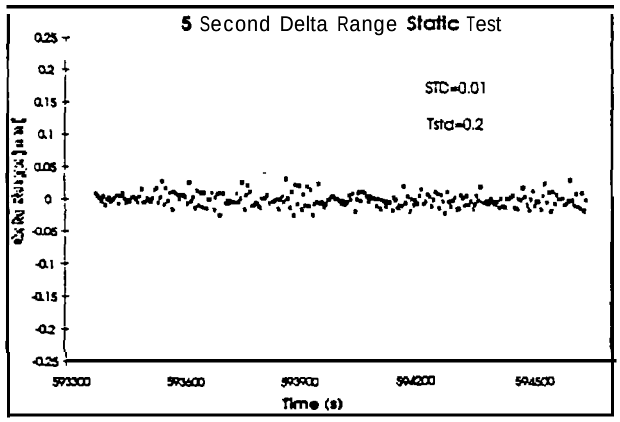

Figure 4a: Zero Base Line Delta Range Results

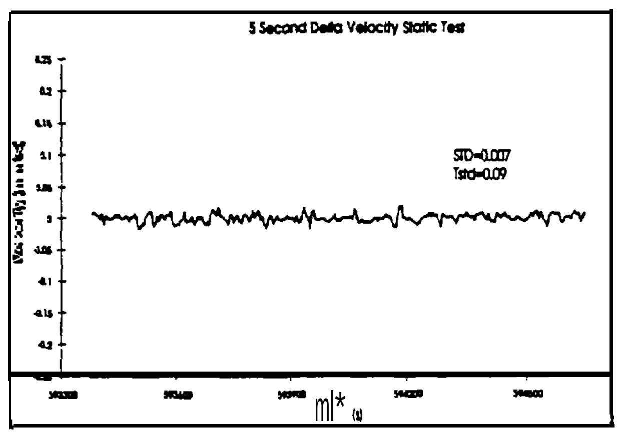

Figure 4b: Zero Base Line Delta Velocity Results

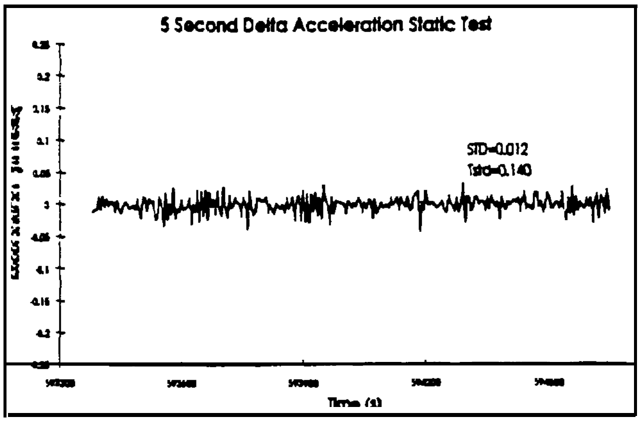

Figure 4c: Zero Base Line Delta Acceleration Results

Figures 4a, 4b and 4c shows the agreement between the measurements from the two channels over **a** period of *20* minutes. The accuracy of each parameter (Tstd) is computed from the variance estimate of each parameter from the least squares covariance matrix scaled by the variance of the residuals from each fit.

Note that the resulting noise level of the zero base line results are well under the theoretically expected values. The zero base line measurements are better than an order of magnitude cleaner than expected. This is probably due to our conservative estimate of 4 mm noise per measurement and the high noise correlation between the channels as a result of using same antenna and oscillator. It proves that there are no gross errors in the implementation and that the theory is reasonable.

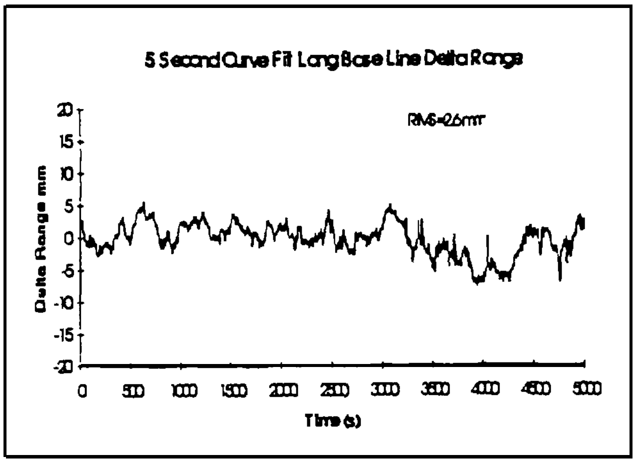

Figure 5a: *7* **Km Base Line Delta Range Results**

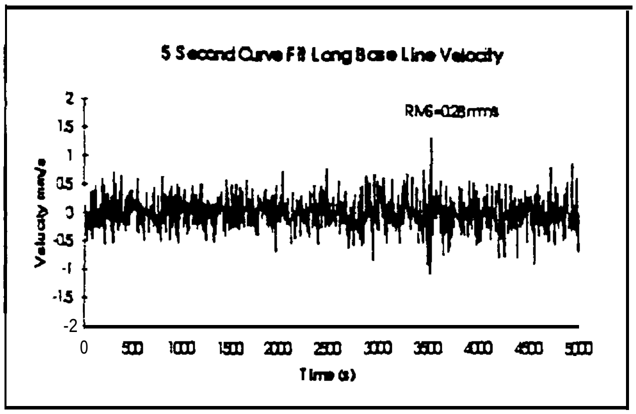

Figure **5b:** 7 **Km base line delta Velocity results**

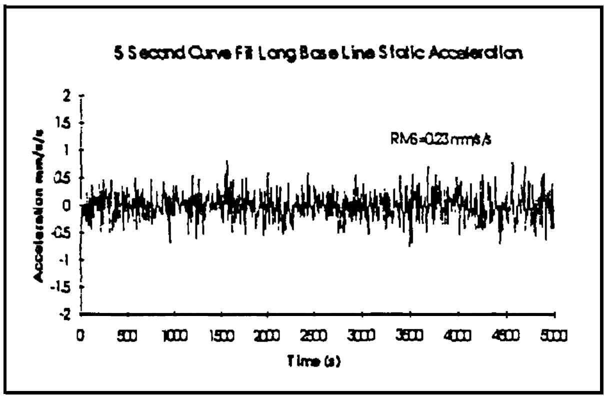

Figure 5c: 7 Km Base Line Delta Acceleration Results

Figures 5a, Sb, and 5c along with column 4 in Table 1 show the results from a 7 Km baseline static test. The results for velocity and acceleration are consistent with the theoretical estimates. The delta-range accuracy however has **a** much higher value then expected. Note the low frequency trends in the residuals. This 3 to 5 minute period is characteristic of multipath distortion. Also, the multipath does not adversely affect the velocity or acceleration measurements, (Figures 5b and Figure **5c).**

Table 1: Summary of Zero Baseline and 7 km Baseline Results

Parameter	Theoretical from Fig 3	Measured (RMS) Zero Base Line	Measured (RMS) 7 km Base tine
Range (mm)	0.8	0.01	**2.6**
Velocity **(mm/s)**	0.7	0.007	0.28
Accel. (mm/s^2)	0.2	0.012	0.23

CONCLUSIONS

The MEDLL™ technology will provide a method of removing the affects of multipath that approach the accuracy of P code receivers. The MEDLL™ technology requires an increased number of continuous correlators per channel. The MET™ technology provides improved accuracy over the Narrow Correlator™ tracking loop and can be implemented on existing GPSCard™ equipment. Curve fitting over high frequency carrier phase measurements can provide velocity, and acceleration measurements with accuracy under 1 mm/s and 1 mm/s^2 respectively.

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