An Approach to GPS Satellite Failure Detection

A. Jakab, *NovAtel Inc.*

BIOGRAPHY

Andy Jakab received his B.Sc. in 1997 from Geomatics Engineering at the University of Calgary and is currently pursuing a masters degree part time. After receiving his undergraduate degree, he joined NovAtel in the test group working on MiLLenium® and WAAS receiver testing. Shortly after, he moved to the Custom Products group where he developed end user software for NovAtel's survey package SoftSurv™. Andy is currently GPS Systems Engineer for the Aviation group working on receiver certification and development activities.

ABSTRACT

Anomalous GPS satellite signals can have a very unfavorable impact on GPS receiver integrity. In a Wide Area Augmentation System (WAAS) or Local Area Augmentation System (LAAS) the corrections must accurately reflect the current satellite signal integrity. For airborne users who rely solely on this information for navigation purposes it is especially critical they not be led into a potentially hazardous and life threatening situation. They must be quickly warned of any problems that would lead them astray and then take appropriate action.

Since these satellite anomalies are assumed to be based in circuit reality, we can expect only a few possible types of waveforms. However, when combined together, these anomalous signals can have a very deleterious (some may say "evil") effect on safety critical navigation systems.

Current techniques to detect and guard against these "Evil Waveforms" are discussed which include the use of broadcast satellite information, multiple correlators, Receiver Autonomous Integrity Monitoring (RAIM), and adjustable correlator widths. Most methods have limitations that relate to current receiver technologies and stringent time to alarm (TTA) constraints. An important aspect to realize is that a single receiver with a single observation cannot distinguish between a multipath condition and an anomalous satellite signal. Multipath observed at a stationary receiver is repeatable day to day, but anomalous satellite signals are not, therefore these two errors are separable if some time history is analyzed.

NovAtel has researched methods for mitigating the effects of anomalous GPS signals for WAAS and LASS receiver applications. In addition, an approach to the detection of GPS signal anomalies is presented using a NovAtel MiLLenium™ receiver configured to track one satellite signal with a very large number of correlators. Experimental results will be presented from data collected in a variety of signal conditions. Conclusions will also be drawn from these results.

INTRODUCTION

Anomalous satellite signals are the result of data transmission failures at or on the GPS satellite itself. In order to maintain the stringent integrity requirements of WAAS and LAAS, some kind of monitoring scheme needs to be in place at the reference receiver that will warn its users of potentially hazardous misleading information (HMI) within the TTA (for avionics applications this is 6 seconds).

In an effort to provide an overly critical monitoring function, data was collected using a standard NovAtel MiLLenium™ receiver that was modified to track one satellite with a very large number of correlators. This produced an excellent map of the correlation function from approximately –1.0 to +1.40 C/A code chips from the punctual code. The receiver still tracks the one satellite using NovAtel's NarrowCorrelator™ technology while the other correlators are spaced along the remainder of the correlation function at equally spaced intervals. Raw in-phase and quadrature components of the correlated signal are averaged over a 1-second interval before being output from the receiver. These values are the actual values that are used by the discriminator in the tracking loops. No pre-processing has been done to them prior to being dumped out of the receiver. There is also a measurement of the 10 millisecond noise floor value being output, for signal quality monitoring.

The correlation function is generated by time-shifting the internal receiver generated code sequence and comparing it to the received code sequence from the satellite. Under ideal circumstances, this correlation function will have the shape of a prefect triangle. As the codes become more correlated, the calculated power of the signal will increase to a point where the codes are perfectly correlated and the maximum value is obtained. Similarly, as the codes become more de-correlated the power will decrease. A real measure of this correlation peak is shown in Figure 1, as output from the modified NovAtel receiver.

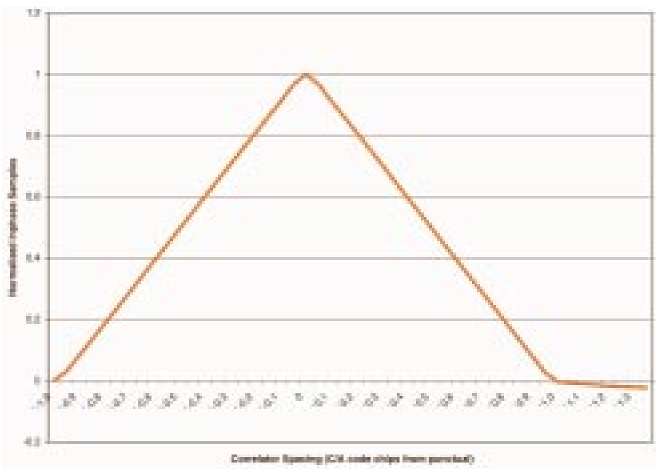

Figure 1: Example of normal correlation peak

The 3D-plots used throughout this paper are contour plots of correlator spacings vs. in-phase correlator samples vs. time. In some plots the in-phase samples have been normalized by the punctual code sample, for all correlator values in that time sample. This was done to preserve the general effect of the time varying results. The correlator output rate was at the same interval as the update rate of the delay lock loop (DLL). Samples in time are in units of seconds which is also the units of updated DLL periods.

ANOMALY EXPLANATIONS

In a recent meeting of RTCA SC159 WG4 dealing with the issue of anomalous satellite signals, a potential solution was introduced.

One of the first things that needed to be settled was the concept of the most evil waveform (MoEvWF). In order to determine a method of protection against the MoEvWF, the true nature of the beast must be known. However, the MoEvWF was defined in such a way that it resulted in a failure to detect the anomalous signal for all possibilities and combinations of correlator spacings. This definition was detrimental to finding a solution to guard against it, because there was none!

In order to determine a practical solution, there are limiting factors that can be attributed to the MoEvWF in order to have it based on practical satellite failures rather that on boundless failure modes. These limiting factors include defining a waveform that accurately portrays the true nature of the anomalous signal. Per Enge, of Stanford University and chairman of RTCA SC159 WG4, was one of the key players in determining what form the anomalous signals could have. There was a confidential report from the US military outlining the recent spurious signal failures of GPS SV19. That report was instrumental in Enge's determination of the function used to define evil waveforms.

From this confidential report, Enge suggested that there were some possible failures modes that could occur at the satellite. These failures included both analogue and digital signal problems. Both failure types in combination or on their own, can lead to distortion of the correlation function used to track the satellite signal.

Distortions that can arise in the satellite signal include flat, distorted, and multiple peaks. Examples of the flat and multiple peak are found later in the document. An example of a distorted peak is found in figure 2. Any of these signals can have a negative impact on the broadcast differential corrections, and consequently the airborne receiver, resulting in a potentially hazardous and life threatening situation for aviation users.

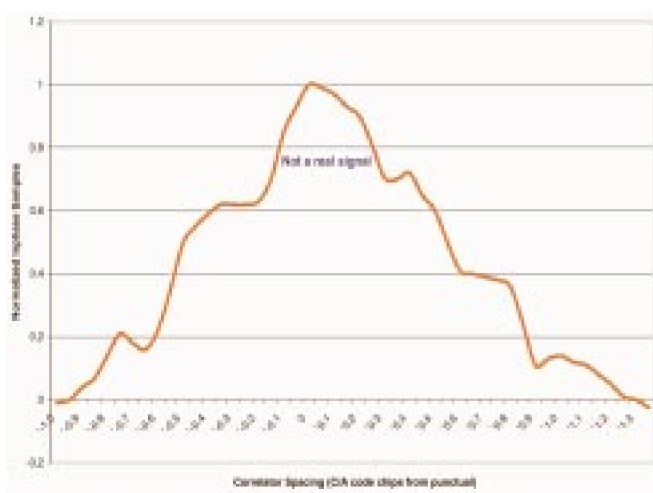

Figure 2: Example of distorted peak (not a real signal)

In developing the evil waveform hypothesis, there are two key assumptions:

1. The satellite failure modes are based in circuit reality and can be generated at the satellite by the Navigation Data Unit (NDU). This type of failure

will introduce either a lead or lag in the falling edge of the broadcast code chips or a reflective source at the satellite which could change the phase, polarity, and/or frequency of the transmitted signal [2].

2. When the satellite fails, it will fail permanently. There are no intermittent failure modes.

The lead / lag effect is shown in figure 3. This effect will delay the falling edge of the chip or cause the rising edge of the chip to occur too soon. However, the combination of both of these effects together is not possible. The NDU will only have one of these failure modes present at one time, never both.

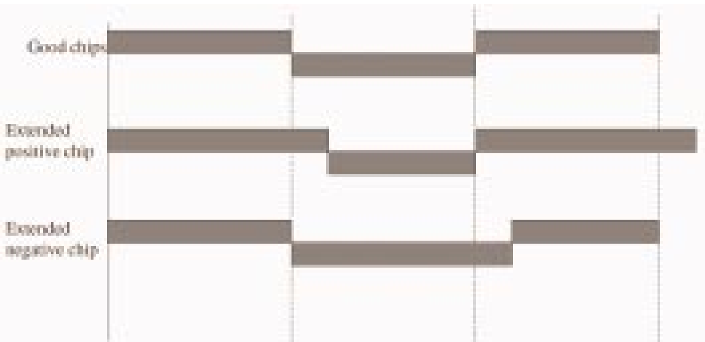

Figure 3: Code Lead / Lag from Digital Evil

The analogue part of the anomalous signal will result in a ringing of the chip transitions. So, instead of having a crisp step transition of the chips they look like those described in figure 4. This effect can have a varying frequency and amplitude.

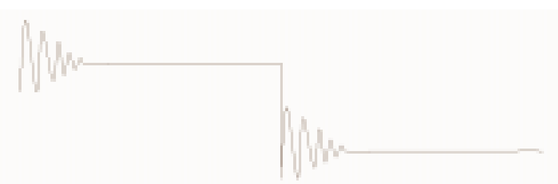

Figure 4: Chip Transition Effects from Analogue Evil

Given these possible failure modes, the model for the analogue portion of the anomalous satellite signal model was chosen by Enge to be a 2nd order step response. This function is described in the equation below:

$$e(t) = 1 - e^{(-\sigma t)}\left[\cos(\omega_d t) + \frac{\sigma}{\omega_d}\sin(\omega_d t)\right]$$

Where ω_d = period of anomalous signal
σ = damping of anomalous signal

This function provides for a varying amount of damping of the ringing effect, as well as a multitude of periods.

The signal is also subject to a lead or lag of the falling edge, defined as Δ.

In a effort to further reduce the threat space of the anomalies, limits were placed on these parameters such that:

$$3 \le F_d \le 14 MHz$$

Where F_d = frequency of anomalous signal.

The reason for limiting the frequency values of evil waveforms is that the receiver will significantly band limit those frequencies which enter the receiver. This means that higher frequency components will not be visible. The extent of the band limiting is dependent on the front-end RF bandwidth of the receiver and the type of filters implemented. As well, the lower order frequency components will have little to no effect on the correlation curve since their error would be less than other noise sources (such as ionospheric delay).

Limiting factors on the chip delay were assumed such that:

$$0 \le \Delta_{falling} \le 300 ns$$

$$0 \le \Delta_{leading} \le 300 ns$$

Since the digital evil waveform can effect both the leading and falling edges of the chip transitions, both are limited to less than 300 nanoseconds.

Another important aspect of the anomalous signals to consider is their advance due to the group delay of the front-end RF filters in the GPS receiver. In differential positioning, both the user and reference receivers must have a similar group delay in order to generate the same effects. For example, if the monitor has a very large group delay, the anomalous signal will be shifted away from the correlation peak. Perhaps this shift will be enough so as to allow the phenomenon to go through undetected. But, if the receiver acquiring these differential corrections has a much shorter group delay, the anomalous signal could end up right at the peak of the correlation curve. This could introduce a significant error in the corrected position if the peak is sufficiently distorted. As a result, a restriction needs to be placed on the variation in group delay at the ground and airborne receivers so that this effect is minimized. RTCA SC159 WG4 has proposed a limit on the differential group delay for airborne receivers of less than 150ns (including antenna delays).

MONITORING TECHNIQUES

In order to protect against these anomalous satellite signals, there are a number of practical solutions. The first line of defence against an anomalous signal is the data message itself. When the signal has become corrupted, the data bits of the message may also have been effected. This will lead to invalid decoding of ephemeris or navigation data. In most cases the satellite will be removed from the position solution and no differential corrections will be broadcast.

The data message from the satellite can also be decoded to determine the current satellite integrity. However, the time required to perform this decoding would violate the stringent TTA requirements. For this reason, additional monitoring techniques are required.

Should the broadcast data message be unchanged as a result of the satellite failure, we require a different method to verify the integrity of the signal. In order to guard against the anomalous satellite signals that can introduce HMI, we need to monitor the correlation function. Since both the digital and analogue failures combine to give non-ideal correlation peaks, monitoring this peak is one method of detecting evil waveforms.

Monitoring the correlation peak detected at the receiver can be accomplished by a number of possible schemes. The placement of the correlators on the peak is a function of the number of available correlators in the receiver. The precise placement of the correlators provide monitoring of specific areas of the correlation function while allowing anomalous signals to penetrate others. The most optimum solution is to place all available correlators in a manner such that the largest region around the correlation peak is protected from anomalous signals. The more correlators we have the larger the are that we can monitor and the more information we can gather about the peak.

Another simpler method for detection of anomalous signals is to monitor the code-carrier divergence of the satellite signal. If there are any sudden jumps in the code carrier divergence rate, significantly above the expected change, the satellite could be removed from the broadcast differential message, or removed from the user position solution. Significant changes to the code-carrier divergence rate could be the result of the presence of multiple correlation peaks. If the receiver suddenly jumps to track a different peak, there is most likely a problem with the satellite signal.

Another variation of the monitoring technique is to perform a scan of the correlation function. This scan would examine all portions of the peak in an effort to determine if there are any anomalous signal present. This scan could be completed on acquisition and re-acquisition of the satellite before it is to be used in the broadcast messages or user position solution. Another variation would be to continuously scan the peak throughout all stages of tracking.

One of the advantages of having multiple correlators is to provide measures of the slope of the correlation function around the peak between the monitored points. Slope values could be computed between all unique spacing pairs to monitor for flat peaks and peak asymmetry. If the slope tests fail, we can also exclude the satellite from the broadcast messages.

Another technique that could be used for the monitoring is called code dither. This technique involves the shifting of the available correlators around the peak so that a larger area is monitored while still tracking the satellite. However, with larger numbers of correlators becoming available on newer hardware, this technique is less appealing because of its difficulty to implement.

During times of increased availability, the technique of RAIM can be implemented. It is important to note that to implement this technique we require more than the minimum number of visible satellites required for a position solution. RAIM should only be used when there is an excess of visible satellites such that by using the technique to determine faults there are no penalties to availability. Many different RAIM techniques are available that will detect the presence of an error and isolate a specific satellite as failed[1].

Finally, the entire correlation peak could be monitored to detect what it's true shape. This method is useful in researching algorithms to detect an anomalous signal. In terms of slope testing, it will also provide a practical measure of the test criterion to use. For a multiple channel GPS receiver it may be impractical to monitor the correlation peak to the extent that was done here. However this method provides additional information about the nature of the correlation peak and how the receiver tracking reacts to the presence of an evil waveform. A more sparsely monitored correlation peak would not provide as good a measure of this information.

ANOMALY GENERATION

It is important to remember that the receiver can not distinguish the source of the anomalous signal, only that there is something wrong with the satellite signal. As a result, multipath signals are a valid source of anomalous signal generators that can be used on live or simulated data. In creating these anomalous signals using multipath, we endeavoured to create approximations of all possible satellite failure modes at the receiver level. More detailed explanations of each multipath setup will be explained for each individual trial.

In order to simulate these possible satellite failure modes generating flat, distorted, and multiple peaks, a 24 channel Global Simulation Systems STR4760 GPS Simulator and a 12 channel Stanford Telecom 7220 NAVSTAR GPS Constellation Generator were used. Two different simulator were used to verify the finding of one against the other and to include some methods of testing that were unavailable on the other simulator.

Through the use of strategically placed multipath sources both the flat peak and multiple peak anomalies were produced. However, in order to simulate a distorted peak it would be best to use phase variations in the signal itself. Although theoretically possible and verifiable using Fourier transforms it is a difficult signal to consistently reproduce under lab conditions. The simulators will introduce some phase variations due to the signal generation, but these are uncontrollable by the authors.

The intent of the following analysis is to show that multipath signals can be used to generate approximations of the failure modes of the satellite. It is important to keep in mind that we are attempting to simulate the satellite failure only as detected at the receiver level. Finally, it is anticipated that this research will be useful in developing procedures to test a satellite failure detection capability in a reference receiver.

ANOMALY GENERATION TEST RESULTS

The flat peak phenomenon was easily produced using two signals of equal power at a pseudorange separation of 100 meters using PRN 13. This effect was similarly generated on the same receiver using both simulators. The combination of these direct and multipath signals resulted in the flat peak seen in figure 5.

This is indeed a very flat top with a separation (from edge to edge, within approximately ±1% of punctual) of 0.36 C/A code chips or 105 meters. The graph also shows that there is no time variation in the peak, so it is possible to generate a consistently flat peak for any length of time with a signal simulator.

The problem that arises with a flat correlation peak is that there are a multitude of possible code alignments. All of these alignments would be equally acceptable from the receiver's perspective when using early, late, or punctual correlators, within the flat region of the correlation function. All code alignments in the flat region will produce the same magnitude of in-phase power, resulting in a range of tracking positions. When the receiver is tracking this signal, it will also result in a much noisier measurement of the code.

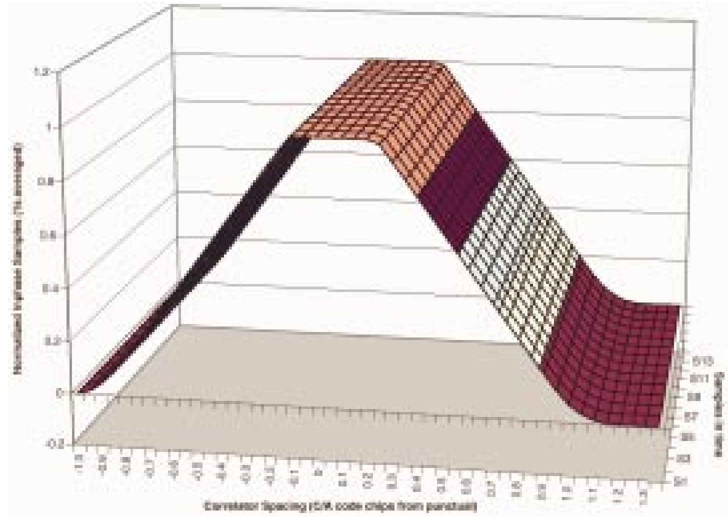

Figure 5: Example of flat correlation peak

As can be seen by the graph in figure 5, the punctual code sample (spacing of 0) was placed somewhere in the center of the flat region. Other tests of the same setup have shown the receiver to track the leading edge of the flat region. It is difficult to determine which part of the flat region corresponds to the true peak of the underlying function since the leading and trailing edges are so consistent in their slope. There is a slight change in slope around the –0.7 C/A code chip spacing which corresponds to the start of the multipath signal. In any case, the reason for the difference in tracking positions is most likely due to some slight variations in the noise on the signal. When dealing with such a flat peak even the slightest amount of noise will have an adverse effect causing the discriminator to shift the tracking position until a local maximum is reached.

Given that the same receiver will track differently under the same conditions there is no guarantee that the airborne and reference receivers (potentially of different manufacturers) will track the same position of the correlation curve. The signal variations seen in the airborne may have different noise characteristics, been attenuated, smoothed, or band limited by the RF filters and not resemble what is being seen on the ground. The onus should be on the reference receiver to detect these failures and remove the effected satellite from the broadcast messages (thus not allowing the airborne receiver to use the satellite in its differential position computations). The reference receiver would do this by having the largest practically possible front end RF bandwidth to allow for a maximum of the spread spectrum signal to enter the receiver, while still meeting the RF interference limitations. This would allow for more thorough testing of the signal. The reference receiver should also be using RF filters that introduce similar group delay as the airborne receiver filters. This ensures similar distortion of the signal in both receivers.

The avionics receiver should not be put in a position to determine the integrity of the signal on its own when there is, potentially, a more robust system on the ground.

Such a large variation in tracking areas due to this flat peak phenomenon is an unacceptable error source and would definitely be classified as HMI if it was part of the broadcast messages. Such a correlation peak should be detected using multiple correlators and checking that the slope between them all is non-zero (within some pre-determined tolerance).

One of the important questions that remains unanswered is the speed at which anomalous signals can present themselves. In an effort to show multiple occurrences of the flat peak phenomenon at differing speeds, we first show an almost instantaneous jump in the correlation peak from normal to flat. This effect is seen over two seconds in figure 6 using PRN 13.

This effect was generated by introducing a single multipath source at -1dB with an offset of +200 meters. As the multipath signal is introduced, the one second accumulations of correlation values are almost completely seen in the first sample. The second sample of the signal shown the complete effect of the combined signal sources.

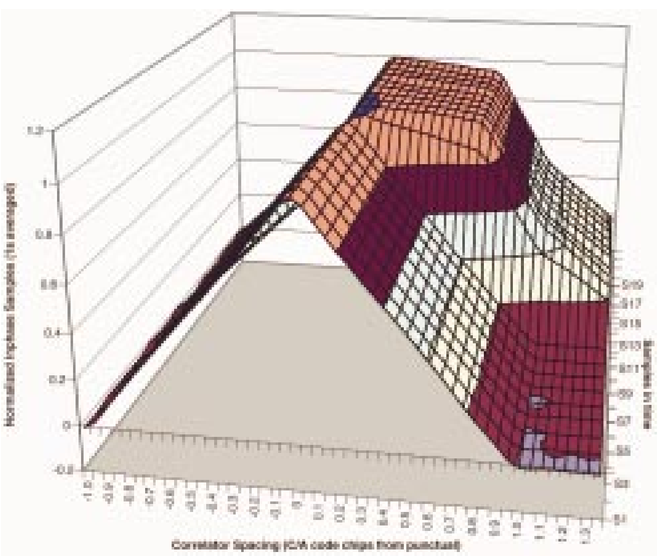

Figure 6: Instantaneous Flat Correlation Peak

With adequate slope testing this effect would definitely be noticeable within the TTA. Within two seconds after the introduction of the anomalous signal the effect is completely visible in the correlation peak and continues at a consistent level.

Provided the receiver does not time average the correlator values, prior to the processing for anomalous signal detection, the TTA requirement should not be violated in the receiver. If there is significant time averaging implemented, then there is the risk of smoothing out the phenomenon and not meeting the TTA requirement.

A more gradual introduction of a flat peak produced some very interesting results. The test receiver was tracking a multipath free signal on the satellite simulator when a second signal of equal power was introduced at the exact same pseudorange. Both signals were using PRN 18. This second signal was then given a pseudorange movement rate of +1.0 m/s. The time varying effects of this phenomenon are seen in figure 7.

We can see that the shape of the correlation peak starts out as quite normal. As the multipath signal moves farther away from the original tracked signal the shape of the peak becomes quite flat. As time continues, the flat region in the middle of the graph actually becomes quite large. At the end of the test, approximately 400 seconds after introduction of the multipath signal, the flat region (approximately ±1% of the punctual) stretches 0.6 C/A code chips or 175 meters! To make the waveform even more of a quandary, the flat region is surrounded by the two original signal peaks. The separation from peak to peak is 1.3 C/A code chips or 381 meters! Clearly, even if searching for multiple peaks at a maximum of 1 C/A code chip from the punctual code, a superfluous peak may not be determined. A pseudorange error of 175 meters can have a position domain error of at least 50 meters (depending on the satellite geometry), and potentially much more. Such an error would definitely be considered HMI and could lead to serious navigational errors.

However, when checking for the occurrences of multiple peaks it would be best not to limit the searching criterion to a local maximum. Slope testing should also be performed between all available correlator outputs to check for flat zones outside of the immediate tracking space to improve the integrity monitoring of the signal. If this is the case, the flat region on the side of the peak should be detected since the distance from either peak to the beginning of the flat region is ~0.35 C/A code chips. In other words, anomaly detection should not be limited to a one parameter test, testing only for a local maximum, but should also include the detection of flat peaks. Either incident, no matter where detected, should raise a flag and remove the signal from the broadcast corrections.

It is very interesting to see that the receiver does not shift its tracking position from the original peak of the multipath free signal. From the receivers point of view, it has always been tracking an appropriate signal. From the original signal at sample time 1, we can see that the receiver is tracking the true peak of the signal. The discriminator in the receiver uses the early power minus late power, at a spacing of 0.1 C/A code chips, to judge it's tracking adequacy. As the pseudoranges begin to separate and the peak begins to flatten, the E-L value is still adequate.

As can be seen in figure 8, the time series of the multiple peaks shows alternating positive and negative slopes (as well as nearly flat samples) between the two peaks. This is due to slight phase variations in the signal being generated by the simulator and the general movement of the multipath signal source. After approximately 125 seconds, the varying slopes begin to manifest themselves. There is an apparent left and right motion of the peaks as a result of the shifting discriminator. This means that the precise position of the punctual correlator code value is moving back and forth. As the discriminator attempts to compensate it is immediately turned around to go towards the other peak by the changes in the slope of the correlation curve at the next epoch. As a result, the discriminator is forced to track in the middle of the flat and slope varying region, right between the two much larger peaks.

Since the tracking of the signal only involves the E-L and punctual correlators, there is no way for the receiver to determine that there is a problem. With only three code samples, the receiver is quite oblivious to its surrounding conditions, and tracks the flat region of the signal. The receiver believes that it is on a side slope of the correlation curve and attempts to compensate and move towards the peak, only to be thwarted in its efforts by the next sample. As can be seen from the single time sample in figure 9, the double peaks are clearly visible with the receiver tracking right in the middle of the flat region (correlator spacing of 0). This is truly an evil waveform!

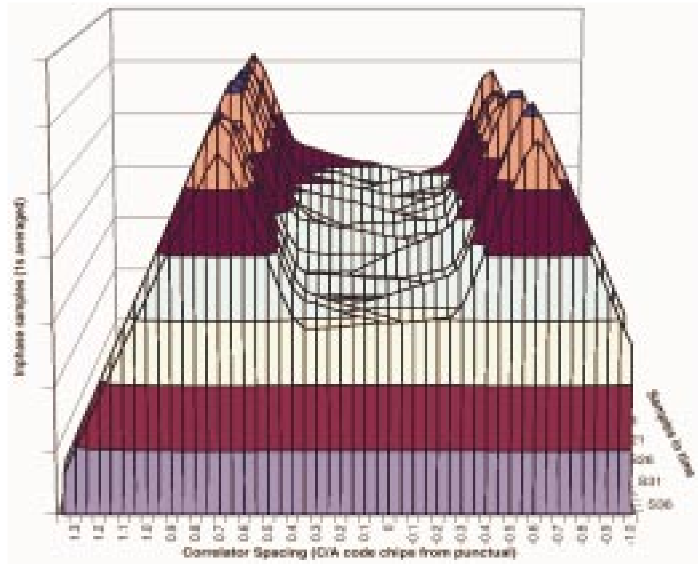

Figure 8: Close-up of multiple peaks in time series

In order to detect such an anomalous signal, the receiver would require multiple correlators and a slope test capability. Again, performing an instantaneous test, on each available correlator output message would be the best method of detection. If time averaging of the correlator values were to be done before testing, the TTA requirements would probably be exceeded.

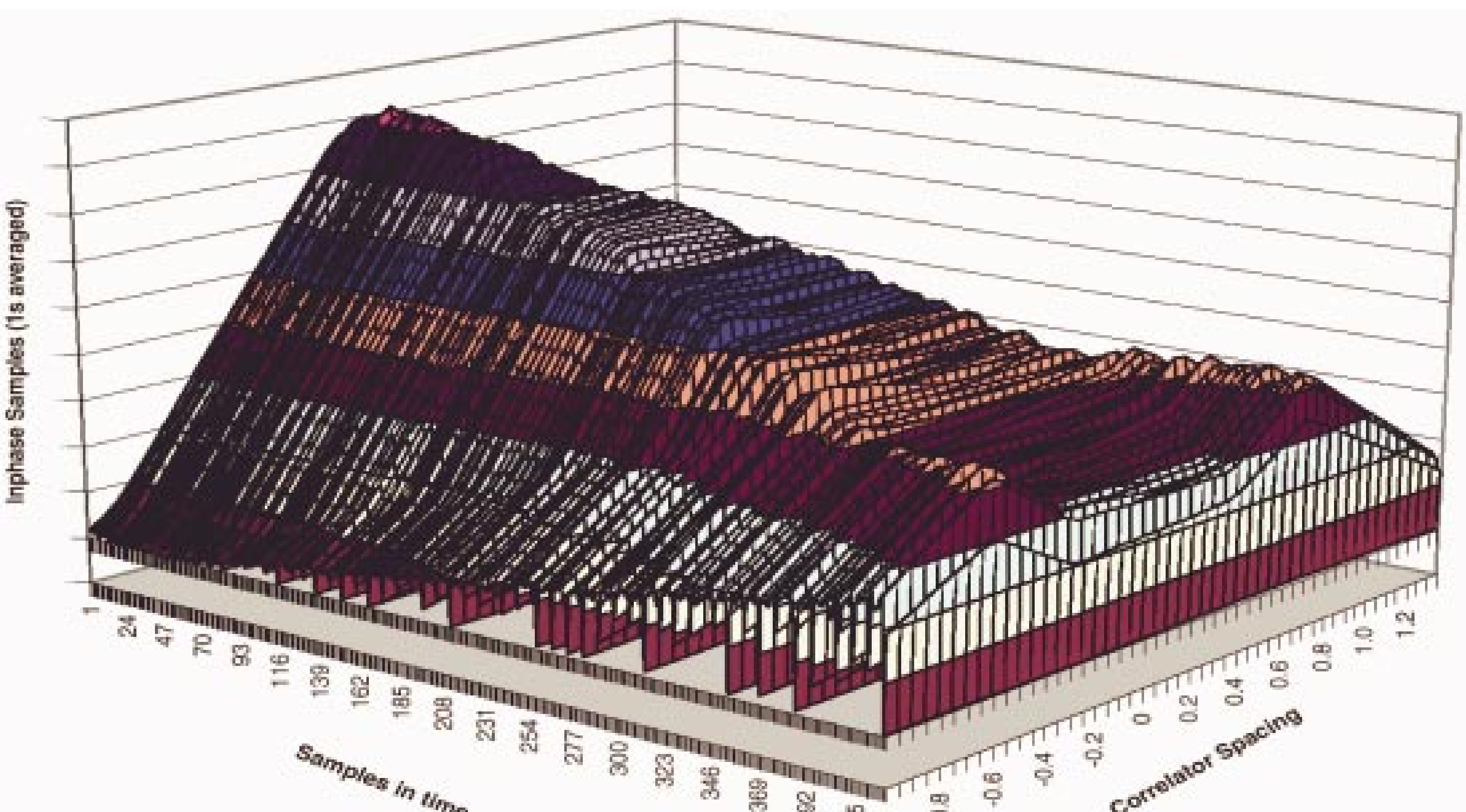

Figure 7: Slow moving multipath source

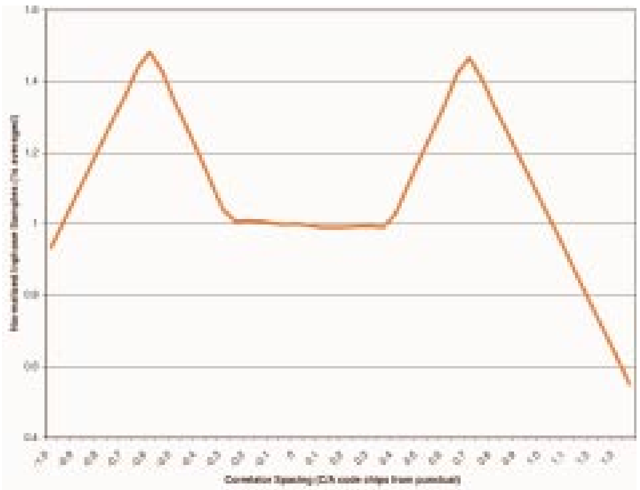

Figure 9: Multiple peak as a result of slow moving multipath

Therefore, regardless of the speed of the anomalous signal generation, instantaneous or slow moving, it would be best to perform non-time averaged slope testing of the correlator outputs in order to set the error flag within the TTA limitations.

It should also be noted that the first line of defence (the message decoding) has detected an error. There are continuous parity failures throughout the data collection when checking the navigation data message. As a result, no valid pseudoranges are output beyond sample 25 in figure 7. The receiver is still attempting to track the satellite and obtain a valid code lock but parity errors are preventing this from occurring. At that point, the signal is not distorted and there is no sign of a multiple or flat peak. However, the time required to decode the message and determine the error is much longer than the allowed TTA. For this reason, additional monitoring of the correlation function is required.

Since this test is only simulating an anomalous signal and can in no way reproduce what may happen at the satellite itself, there is no guarantee that these same data decoding parity errors would manifest themselves on a live signal and result in no pseudorange output. The parity errors will not necessarily be present on a failed satellite.

In other tests runs, the receiver also continued to track in the flat region between the peaks until the power became so low that the receiver lost lock and re-acquired one of the peaks some time later. The peak that is re-acquired would be determined by the search algorithm of the particular receiver (whether it searched for a positive or a negative shift from the current location when loss of lock occurred).

As seen in the previous cases, the multiple peak phenomenon can result in some serious tracking problems if they arise from the splitting of one peak. The next test

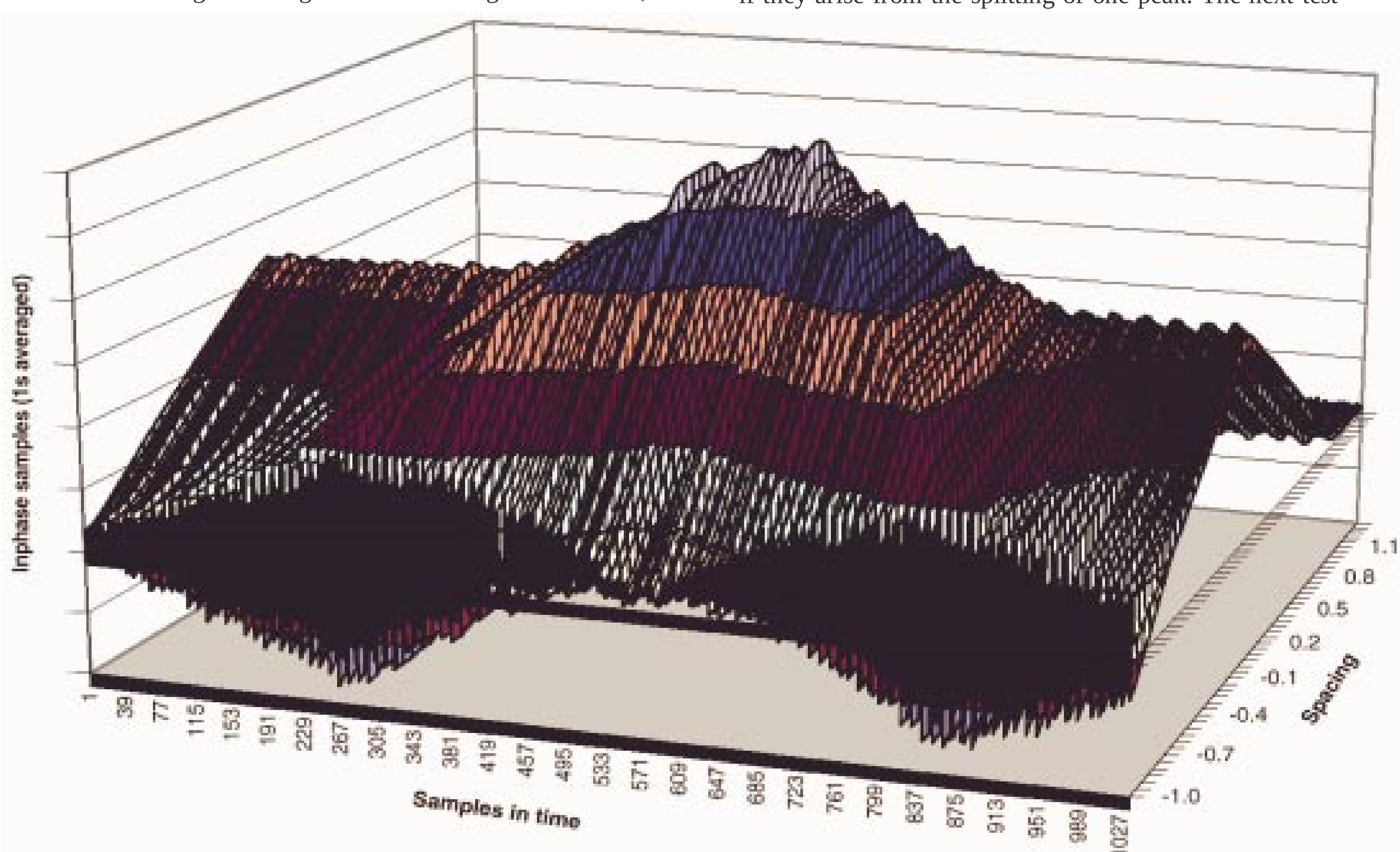

Figure 10: Correlation peak from colliding signals on leading edge

shows the result of multiple peaks as they collide together from a spacing of more than 2 C/A chip away. The result are shown in figure 10.

These results were generated with two simulated signal sources of PRN 7. The receiver was first tracking a signal with a fixed pseudorange. After valid code lock on the signal, a second signal was introduced with a pseudorange of 600 meters less than the original signal. The multipath signal was also given a range rate of +0.1 m/s. Figure 10 shows this data sub-sampled such that the time axis is in units of 10 seconds per tick mark.

We can see that as the multipath source enters the field of view from the leading edge, the observed signal begins to flatten out. As the two signals begin to reach the same pseudorange, the power level of the peak begins to rise. This is expected as there are now two overlapping signals as opposed to one. At this point, the graph looks very reminiscent to the flat peak graphs generated earlier. It's curious to note that we do not see the double peak phenomenon when the multipath signal is forced through the leading edge of the tracked signal. The signal only begins to flatten out.

We also see the same variations in the slope of the flat region. Although not as pronounced as in figure 8, the variations are still present. The slope also has a consistent downward trend towards the rising edge of the tracked signal. As well, the trailing edge of the signal remains unaffected throughout the test.

After the two signals merge, the receiver begins to track the signal with the range rate, which is different from the original signal source. This is evident because as the signals diverge, the interference is still on the leading edge of the signal. This tells us that the multipath source had a smaller pseudorange value than the tracked signal. The graph seems symmetric about the time axis at the point when both signals had the same pseudorange.

As expected, the amount of correlation between the signals is a direct result of the PRN numbers chosen for the simulation. However, the amount of this correlation was not known. We can see a significant change between the same test conditions shown in figures 10 (using PRN 7) and figure 7 (using PRN 18), when the multipath signal is diverging from the tracked signal. Figure 7 shows a high second peak while figure 10 shows a more moderate second peak.

In other tests runs using PRN 7, the same symmetric phenomenon is seen even if the signal is brought in from the trailing edge of the original tracked signal.

We can also see some slight variations from sample to sample in figures 7 and 10. During their 1-second accumulation time, there are some samples that have larger numbers of in-phase samples in them than the next sample in time. This can be attributed to phase variations between the multipath and direct signals. This effect is also dependent of PRN code as seen by the variations between the two mentioned plots.

CONCLUSIONS

Through the use of a satellite signal simulator, anomalous waveforms comprised of flat and multiple peaks can be produced. It is a more arduous task to control the phase variations of the signals in order to produce distorted peaks. When generating these signals, it is important to use a PRN code that produces the most desirable signal when combined into a multipath environment, thus maximizing the cross-correlation effects seen at the receiver. From this analysis, PRN 18 produces an excellent double peak phenomenon as a result of the cross-correlation of the two signals. Using the same test conditions as for PRN18, PRN 7 produced quite different results. Depending on the desired outcome at the receiver, a different PRN code will have to be used.

With the use of multiple evenly spaced correlators around the correlation peak, these anomalous signals can be detected using slope tests between correlator output values. However, the threshold value for detecting these slope errors has yet to be determined. This threshold would have to be determined in such a way to minimize the probability of misdetection.

The optimal placement of the available correlators to maximize the informational content of the correlation function must also be determined in manner that allows for the receiver to maintain its "all-in-view" tracking capability.

ACKNOWLEDGEMENTS

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