# Interference Effects on the GPS Signal Acquisition

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## BIOGRAPHIES

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### ABSTRACT

Intentional or unintentional interference and jamming is one of the major concerns in using the Global Positioning System (GPS) in various critical applications. In spite of the GPS frequency bands being protected by International and Federal Communication Commission (FCC) frequency assignments, there is always a chance of disruption of the GPS signal availability in critical times and applications. The GPS system has advantages over narrow-band navigation systems as the signals are spread-spectrum and receiver design techniques can eliminate most of the interference signals. The various sources of unintentional jamming are out-of-band interference caused by nearby transmitters, harmonics of ground transmitters, signals from nearby platforms, pulsed interference and accidental transmission of signals in the wrong frequency band. Any signal or its harmonics near the GPS L1 and L2 frequencies are a potential source of interference. The aim of this paper is to analyze the effect of some interference sources on the GPS spectrum during the acquisition process. The acquisition process determines the signal peak after correlation and then compares it with a detection threshold to determine the success of acquisition. Interference signals cause distortion in the GPS signal resulting in an incorrect, or no correlation peak, during acquisition. The interference signals analyzed in this paper are the continuous wave interference, broadband noise and pulsed interference signals. A GPS simulator (GSS 6560) was used along with a signal generator (E 4431B) and an interference combiner (GSS 4766) to generate the interference signals. The signals were collected using a GPS front end (Signal Tap) data logger. The paper discusses the effect of various interference signals on noise power, signal to noise ratio and effect of coherent/non-coherent integration times on the acquisition process.

### 1 INTRODUCTION

The GPS system is a radio frequency (RF) based satellite navigation system which transmits signals containing information to compute a user position. GPS receivers rely on these external signals which make them vulnerable to RF interference. RF interference can cause degradation in the navigation accuracy or a complete loss of the satellites tracked [Spilker et al., 1996]. It can be intentional or unintentional and the GPS Pseudorandom Noise (PRN) codes have some interference due to cross correlation with other PRN codes. GPS receivers can also be spoofed by a signal similar to GPS with high signal strength. RF interference can originate from friendly, out-of-band, sources for commercial GPS receivers. Non-linear effects in high-powered transmitters can cause low-power harmonics, which become in-band RF interference [Kaplan, 1996].

Theory shows that the effect of interference depends on details of the receiver design, especially the front end bandwidth and the early-late spacing in the discriminator, and that it has a different effect on code tracking accuracy than it does on some other aspects of the GPS receiver performance [Betz, 2000]. Several types of perturbations can affect the signal processed by a GPS receiver and include thermal noise, atmospheric disturbances, multipath and interference. Interference remains the most feared perturbation for civil aviation users because it can affect several tracking channels at a time over a long period [Spilker et al., 1996]. A number of techniques have been designed to increase the robustness of the processing operations carried out by the GPS receiver. The first critical element is the antenna, which can be designed as an adaptive antenna array that either provides additional antenna gain in the direction of each satellite through beam forming, or nulls out interference signals coming from point sources [ibid]. Next, front end filters are designed in RF or intermediate frequency (IF) to reduce out-of-band interference [Tsui et al., 2000]. Adaptive frequency notch filters can also be implemented to attenuate in-band narrow-band interference [Spilker et al., 1996]. Then, the use of an Analog-to-Digital Converter (ADC) mapping on a large number of bits/sample and proper Automatic Gain Control (AGC) can reduce non-linear signal suppression effects. Adaptive ADC can also reduce constant envelope interference effects. Finally, reducing tracking loop bandwidth can decrease its sensitivity to a large class of interferers. Similarly, this can also be achieved using aiding from other sensors such as an Inertial Navigation System (INS) [Macabiau et al., 2001].

The constellation of GPS signal sources that is used for position determination is spread over a large cone of angles relative to the receivers that are used to compute positions. A receiving antenna is therefore required to have a large look angle, i.e. be omnidirectional, in order to see the available signal sources. An interfering signal originating from the Earth can enter the GPS receiver and corrupt the accuracy of the receiver. Locating and nullifying the sources of the interference can mitigate errors [Herold et al., 2002].

A receiver can only acquire satellites with signal–to-noise levels above a certain threshold. In the presence of jamming, the jammer-to-signal ratio increases greatly which influences the probability of acquiring GPS signals. The resulting satellite availability is dependent upon the constellation geometry, the performance of jamming mitigation, and the acquisition times of the receiver [Behre et al., 2002]. The spread spectrum concept is used to minimize the effect of interference signals when the GPS signals are de-spread in a receiver. However, if the power of the interference signal is considerably higher, it will distort the correlation peak or give rise to a correlation peak at the wrong estimate. GPS signals are bi-phase modulated signals and a receiver employs a band pass limiter. The output signal-to-interference ratio is degraded by 6 dB in the presence of strong sinusoidal interference with a significant frequency offset. The frequency offset is defined with respect to the carrier center frequency, i.e. the weaker signal is suppressed relative to strong interference. If the interference is at exactly the same frequency and phase with the GPS signal, it can suppress the desired GPS signal and capture the receiver.

If the interference signal is Gaussian in nature, then it simply adds to the Gaussian thermal noise and increases the noise power. This will affect the acquisition of weak signals as the noise floor is increased and the signal detection threshold will have to be set higher to accommodate the increase of the noise power. A sinusoidal interference can be a continuous wave, a narrowband or a wide band signal like a frequency modulated (FM) signal. Sinusoidal interference can have severe impact on receiver performance. Hardware interference techniques try to reject the interference signal or provide zero gain for this signal. There is still a possibility of an interference signal escaping the interference detectors and passing to the GPS correlator.

GPS acquisition is the first step in the signal processing section of the GPS correlator. The physical application of the autocorrelation function is used to achieve lock-on to the pseudorandom code. The autocorrelation function of the GPS C/A-code is

$$R(\tau) = \frac{1}{1023T}\int_{t=0}^{t=1023} Gi(t)Gi(T+\tau)dt \tag{1}$$

where

- Gi(t) is the C/A-code Gold code sequence as a function of time t for SVi,
- T is the C/A-code chipping period (977.5 ns), and
- $\tau$ is the phase of the time shift in the auto-correlation function.

A special set of pseudorange sequences with relatively low cross correlation properties is used for the C/A-codes; and this set is known as the Gold codes [Spilker et al., 1996]. The auto-correlation function of a C/A-code is a series of correlation triangles with a period of 1,023 C/A code chips (or 1 ms). As a result, the C/A-codes do not have a continuous power spectrum but instead have a 1,000 Hz spaced line spectrum (separated by the inverse of the code period) [Iltis et al., 1999]. The correlation properties of GPS Gold codes are such that the correlation yields a value of 1,023 only when the two codes have the same PRN and match in phase; otherwise the correlation values are close to +63. Thus the correlation process gives a distinct peak at the correct phase which can be distinguished from the other cross correlation peaks which allows the signal to be acquired.

GPS signal acquisition is a search process which requires replication of both the code and carrier of the Satellite Vehicle (SV) to acquire the signal. The acquisition process should replicate the code with the exact code phase and carrier with proper Doppler to acquire the signal. Thus the acquisition search becomes two-dimensional.

There are various different methods for GPS acquisition such as a cell-by-cell search and circular convolution [Tsui et al., 2000]. The circular convolution method was used herein for the interference analysis on the GPS acquisition process since it is performed in software and the circular convolution method is better suited for this case. This method reduces the acquisition search domain by one dimension making the acquisition search process single dimensional, thereby reducing the acquisition time. The acquisition time should be as short as possible and depends on the predetection integration time used in the correlator. The predetection time is a combination of the coherent and non-coherent integration times. Coherent integration is the algebraic sum of the signal and noise over the integration period, while non-coherent integration is the absolute sum of the signal and noise over the integration period. The longer the coherent integration period, the lower the signal level that can be acquired [ibid]. Residual Doppler and navigation data bit transition limit the coherent integration time. The navigation data bit transitions put a limitation of 20 ms on the coherent integration period if the navigation data bit transition instant is known [ibid].

The acquisition process compares the peak obtained after correlation against the detection threshold to determine the acquisition success. The detection threshold should be carefully chosen to avoid false detection, and in the present case, it was computed in the following manner: the correlation noise was assumed to be Gaussian and the detection threshold was computed using the envelopes shown in Figure 1. The noise probability density function (PDF) is determined by finding the mean and standard deviation of all correlation values and taking 97% of the correlation value as the noise power. The false detection probability is then used to determine the detection threshold. A standard value of 10% for false detection probability was used in the analysis. The equation relating noise power and detection threshold is

$$V = Np\sqrt{-2\ln(P)} \qquad (2)$$

where

- V is the detection threshold,
- Np is the noise power, and
- P is the false detection probability.

## 2 DATA COLLECTED FOR ANALYSIS

To analyze the effect of an interference signal on GPS acquisition using a software acquisition method, the digitized RF data from the GPS RF front end has to be collected. The RF front end data logger (Signal Tap) was used to collect the data. Signal Tap is a product from Accord software & Systems, India which allows collection of digitized RF front end data for different sampling frequencies and durations [Shashidhar, 2003]. The Signal Tap RF front end has a bandwidth of 2 MHz before the last IF stage. Interference signals were generated using the Agilent signal generator (E 4431B). The signal generator is capable of generating various types of signals such as a continuous wave, swept wave, amplitude-modulated, frequency-modulated, pulsed signals and broadband noise. A GPS simulator (GSS 6560) was used to generate GPS signals, and signals from the simulator and the signal generator were combined using the interference combiner (GSS 4766). The multi-channel GPS simulator was used in single channel mode to avoid additional interference by other PRN codes. Thus, only the effect of the interference signals on the GPS acquisition process can be determined. For each scenario, a reference signal was collected from the GPS simulator to allow for comparison of a clean GPS signal with the interference signal. The setup for collecting the data set is shown in Figure 2. The sampling frequency was chosen to avoid aliasing effect. Aliasing is the presence of unwanted components in the reconstructed signal and it can occur because signal frequencies can overlap if the sampling frequency is too low compared to the signal bandwidth. Frequencies "fold" around half the sampling frequency, which is why aliasing is often referred to as the frequency fold effect [Proakis et. al 2001]. Details of the interference data sets collected are given in Table 1. Ten data sets were collected for each configuration and results were averaged over all the data sets.

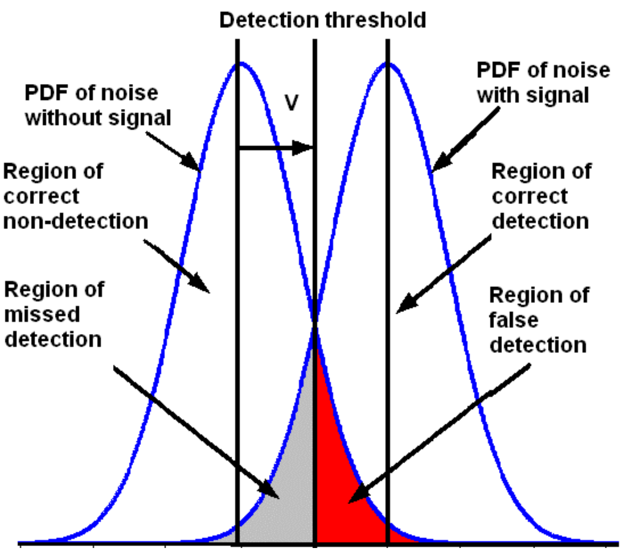


**Figure 1: PDF of noise and signal used in computation of noise power**

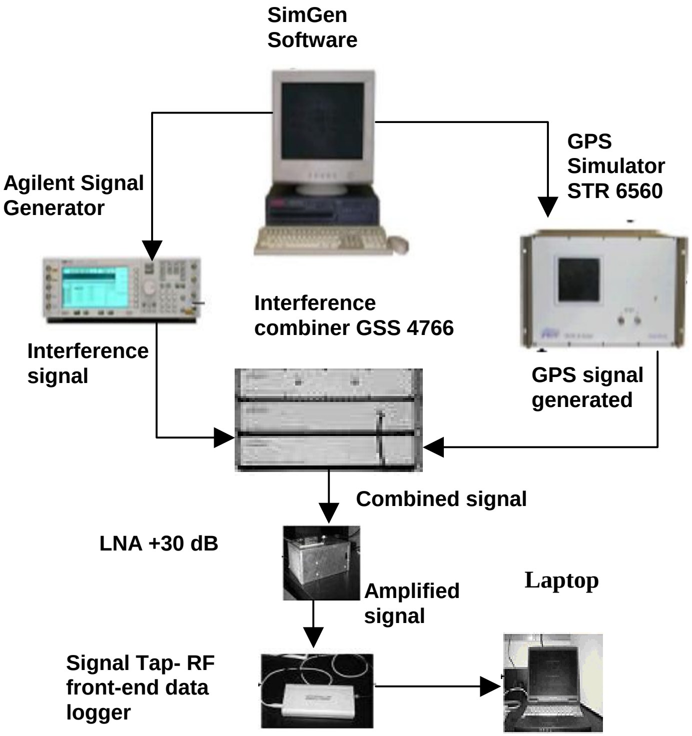


**Figure 2: Set up for collecting GPS data**

**Table 1: Simulator configuration for interference satellite data sets**

| Parameter | Value |
|---|---|
| PRN | 21 |
| GPS signal frequency | L1 frequency |
| Navigation data | ON |
| Signal Power used | -130 dBm |
| Pulse duration | 125, 250, 500 and 1000 microsecond |
| Pulse duty cycle | 10%, 25%, 50% and 90% |
| Pulse Interference power | -130, -100, -70 and –40 dBm |
| Broadband bandwidth | 0.05, 0.1, 0.5, 1, 2, 8, 20 MHz |
| Broadband interference power | -130, -125, -120, -110, -90 and –70 dBm |
| Continuous frequency | L1 $\pm$ 5 KHz |
| Interference power | -135, -130, -125, -120, -115, -110 and –100 dBm |

## 3 PROCESSING METHODOLGY

The circular convolution method was used to determine the effect of the interference signal on GPS acquisition. The code for acquisition scheme was developed in Matlab and C. A combination of MEX (C code complied in Matlab) and Matlab files were used to reduce the processing time. Various acquisition parameters are specified before execution. The set of acquisition parameters specified during analysis is given in Table 2.

**Table 2: Acquisition parameters used during analysis**

| Parameter | Values |
|---|---|
| Intermediate Frequency (IF) | 15.42 MHz (Signal Tap) |
| Sampling Frequency (SF) | 7 MHz |
| Start value of Doppler search | -5KHz |
| End value of Doppler search | +5KHz |
| Coherent integration time | 1, 4,5, 8, 10, 15, 20 ms |
| Non-coherent integration factor | 1, 2, 3, 5 |
| False detection probability | 10% |
| Number of PRNs to be searched | 1 |
| List of PRNs to be searched | 21 |

## 4 RESULTS

The interference analysis results are divided into three parts. The first part analyses the noise power variation in the acquisition process, the second part compares the signal-to-noise ratio (SNR) under various conditions, and the last part gives an indication of the acquisition success percentage under various interference conditions.

### 4.1 Continuous Wave Interference

Continuous wave interference was tested in a narrow in-band range of the GPS L1 frequency (Doppler search range of acquisition process). The interference frequency is within the IF bandwidth of the Signal Tap and is close to the GPS L1 frequency for the RF filters to isolate it. The correlation process spreads the continuous wave signal over the predetection integration bandwidth and decreases the signal power to reduce the effect of the interference signal [Johnston 1999].

#### 4.1.1 Noise Power Analysis

Determination of noise during acquisition is an important task with the computation of the noise power explained in an earlier section. The interference was limited to the Doppler search range of the acquisition method, which is L1 $\pm$ 5 KHz. The interference frequencies were spaced at 1 KHz. For each interference frequency, the signal power was varied from -135 dBm to -100 dBm with the GPS signal strength kept at -130 dBm. The GPS signal strength was chosen, as it is the minimum signal strength of a GPS signal reaching the user in an open sky environment reference. The noise power is computed for different interference frequencies and different interference powers. The noise power at –135 dBm is taken as a reference and the noise power ratio is calculated. The noise power ratio for a coherent integration time of 10 ms and a non-coherent integration factor of 1 is shown in Figure 3.

The results give an indication of the increase in noise power with an increase in the interference power. Thus, for an interference power of –100 dBm at the L1–5 KHz interference frequency, the signal correlation value should be more than a factor of three compared to an interference power of –135 dBm for the same frequency. The noise power ratio grows gradually with an increase in the interference power, and increases by the same ratio for different interference frequencies. The increase in the noise power ratio with interference power decreases the possibility of successful acquisition, as the signal power level is constant while the noise power level is increasing.

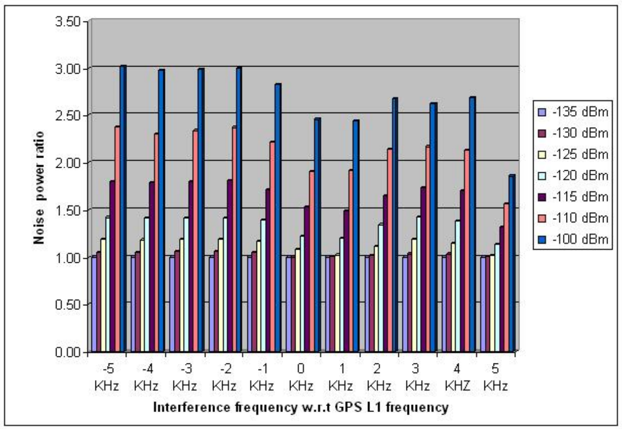


**Figure 3: Noise power for different interference frequencies for a 10 ms coherent integration time and a non-coherent factor of 1**

Increasing the coherent integration time can increase the signal power during the predetection integration process. The longer coherent integration time allows the signal power to accumulate and the noise power to average out. Variation in the noise power with different coherent integration times for an interference frequency of L1+3 KHz is given in Figure 4.

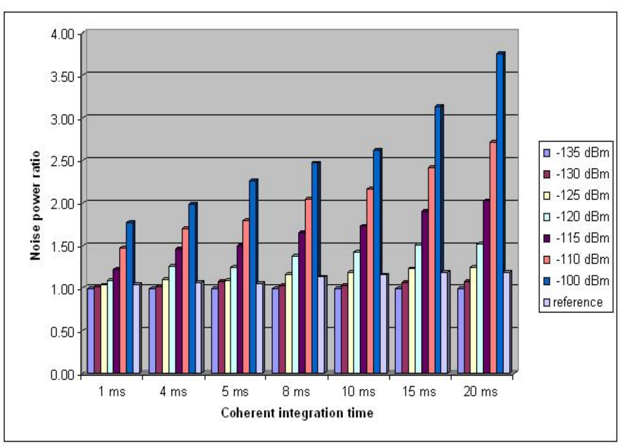


**Figure 4: Noise power ratio for different coherent integration time for interference frequencies of L1+3 KHz**

The coherent integration time was varied from 1 ms to 20 ms which is the maximum coherent integration duration provided the data bit transition instant is known. The noise power obtained for the clean signal at each coherent integration time was taken as a reference. The noise power shows an increase with an increase in the coherent integration time. This is due to more noise being accumulated over a longer coherent integration time. The noise power increases by a factor of almost two for a 1 ms coherent integration period with an increase in the interference power by 30 dB from the reference. For the same increase in interference power, the noise power increases by a factor close to four for a 20 ms coherent integration time. Thus the noise power ratio increases gradually over the coherent integration time. An increase in the noise power level makes acquisition difficult for a lower coherent integration period since the signal level is less for those coherent integration periods. The noise power variation for different interference types tested is similar. The level of increase in the noise power is nearly the same for all interference frequencies within a ± 5 KHz range from the GPS L1 frequency.

Non-coherent integration is used in combination with a coherent integration period to increase the signal level. However, the noise power level also cumulates during the coherent integration period. The noise power variation for different non-coherent integration factors with a coherent integration time of 8 ms at an interference frequency of L1+3 KHz is shown in Figure 5.

The noise power obtained for an interference signal with -135 dBm power with a non-coherent integration factor of 1 is taken as a reference. The results indicate an increase in the noise power with an increase in the non-coherent integration factor. The noise increases significantly more with a higher non-coherent integration factor.

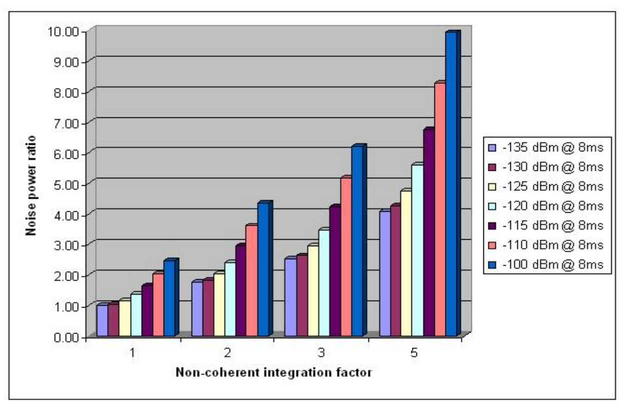


**Figure 5: Noise power ratio for different non-coherent integration factors at an 8 ms coherent integration time for interference frequencies of L1+3 KHz**

With a 35 dB increase in the interference power, and a non-coherent integration factor of 5, the noise power increases by a factor of ten; this is equivalent to a 1000% increase in the noise power level. The results are the same for other continuous wave interference frequencies considered in the analysis. The results show that a continuous wave interference causes an increase in noise power with increasing coherent integration time, non-coherent integration factor and interference power.

### 4.1.2 Signal-to-Noise Analysis

The SNR is an important factor to monitor during the acquisition process. The signal power has to be greater than the noise power for the acquisition process to declare that the signal is acquired. The correlation process gives rise to signal peaks for each code phase and Doppler value. This signal peak has to be compared with the detection threshold to determine acquisition. The detection threshold is a scaled value of the noise power level with the scaling factor dependent on the false detection probability. The previous section analyzed the variation of the noise power level under different conditions, whereas this section analyses the SNR. The correct peak was determined from the reference signal. This information was used to determine the correlation peak at the correct Doppler for all of the interference signals. The signal power level obtained at the correct Doppler was compared with the noise power level for different conditions. Due to interference, there is a possibility of obtaining a correlation peak higher than that at the correct Doppler. The SNRs for different interference frequencies at a coherent integration of 10 ms are shown in Figure 6.

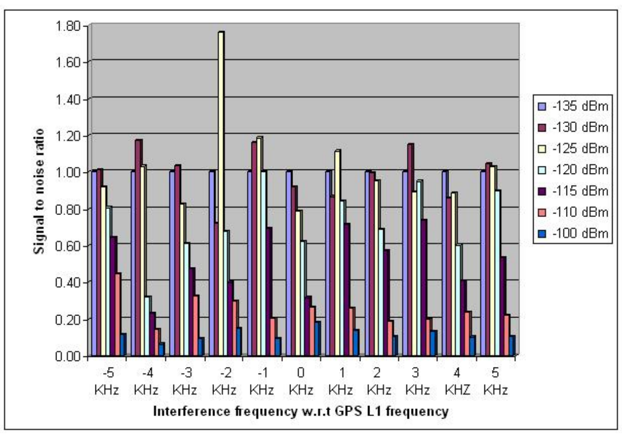


**Figure 6: SNRs for different interference frequencies for a 10 ms coherent integration time and a non-coherent factor of 1**

The results indicate that the SNR is greater than one for an interference power of 15 dB more than the GPS signal power. An interference power higher than 15 dB decreases the signal peak below the noise threshold and the signal is not acquired. The effect of the coherent integration time on the SNR for an L1+3 KHz interference frequency is shown in Figure 7.

The SNR increases with an increase in the coherent integration time, and the ratio is close to one for coherent integration times beyond 5 ms. An interference power of 10 dB more than the GPS signal power is strong enough to reduce the SNR below one. Non-coherent integration can be used to increase the signal power over the coherent integration periods. The effect of the non-coherent integration factor on the SNR is shown in Figure 8.

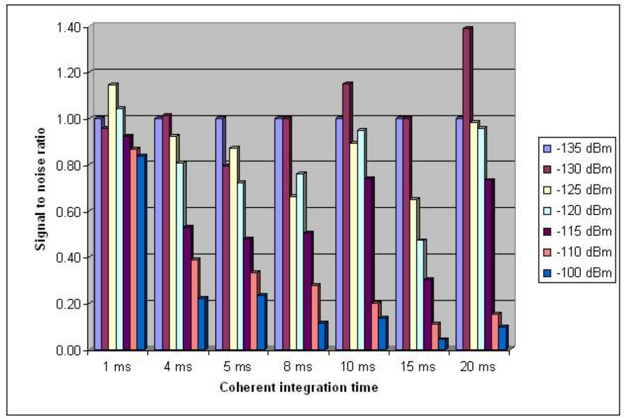


**Figure 7: SNRs for different coherent integration times and interference frequencies of L1+3 KHz**

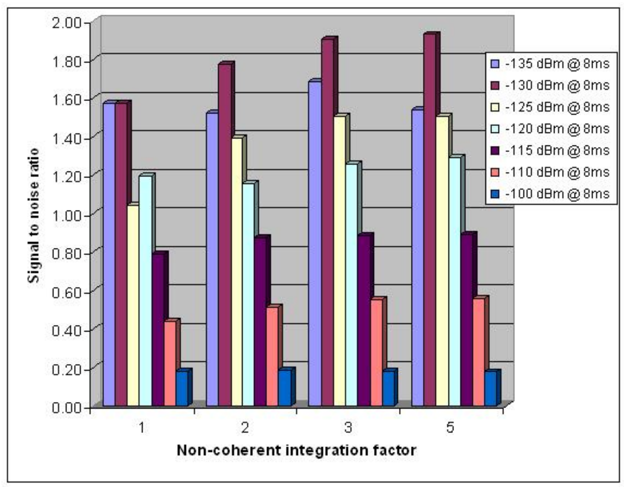


**Figure 8: SNRs for different non-coherent integration factors for an 8 ms coherent integration time and interference frequencies of L1+3 KHz**

The results indicate that with an increase in the non-coherent integration factor, the SNR increases and hence it is able to tolerate more interference power. With an 8 ms coherent integration time, the SNR falls below one for a +10 dB higher interference power than the GPS signal power. The non-coherent integration factor is increased to five which allows for an additional 5 dB tolerance to the interference power.

### 4.1.3 Acquisition Success Percentage

The SNR analysis showed that the signal peak gets buried into noise for a +15 dB interference power over the GPS signal power. Even though the signal peak is higher than the noise floor, the detection threshold is higher than the signal peak and hence the signal is not declared as acquired. In this section, the percentage of times the correct peak is obtained is analyzed irrespective of whether the signal peak is greater than the detection threshold. The success percentage for different interference frequencies with a coherent integration time of 10 ms is shown in Figure 9.

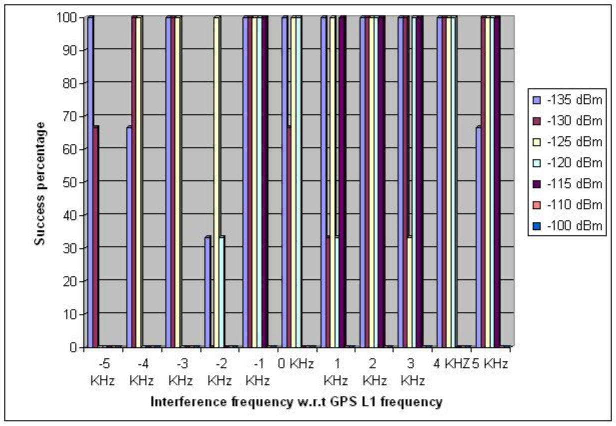


**Figure 9: Percentage of acquisition success for different interference frequencies for a 10 ms coherent integration time and a non-coherent factor of 1**

The results indicate that the correlation peak is obtained correctly for 10 dB more in interference power than the GPS signal power for nearly all interference frequencies. For interference frequencies close to the correct Doppler (+3 KHz), the tolerance is better than for frequencies away from the correct value. The effect of the coherent integration time on the percentage of acquisition success is shown in Figure 10.

The results indicate that with a 20 ms coherent integration time, the peak is correctly obtained for +15 dB more in interference power than signal power while for a lesser integration time, the percentage of success decreases, indicating that the wrong correlation peak is higher than the signal peak most of the time. This might lead to false acquisition if the cross correlation peak exceeds the noise power. The effects of the non-coherent integration time on the percentages of success are shown in Figure 11.

The results show that with an increase in the non-coherent integration factor, the percentage of success increases and the signal gets jammed with only 20 dB more in interference power than the GPS signal power.

The analysis of continuous wave interference indicates that the GPS signal can be successfully jammed with 15-20 dB more in interference power than the GPS signal power. The spectrum gets distorted causing cross correlation peaks to be higher than the signal peak and thus increasing the possibility of false detection [MacGougan, 2003].

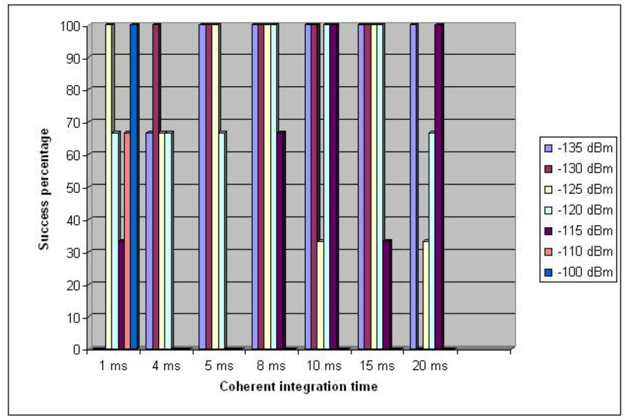


**Figure 10: Percentages of acquisition success for different coherent integration times for interference frequencies of L1+3 KHz**

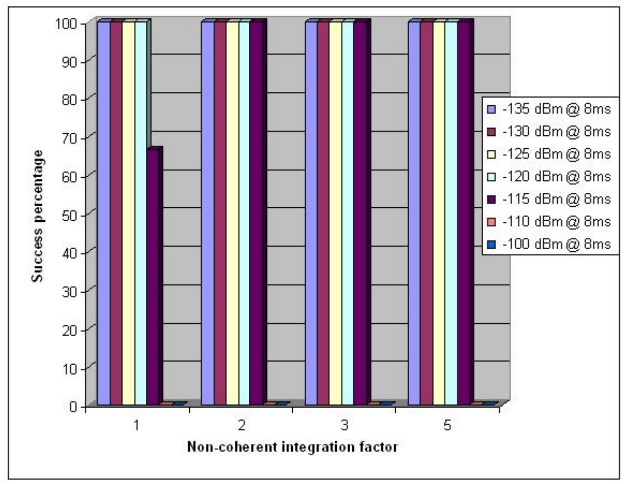


**Figure 11: Percentages of acquisition success for different non-coherent integration factors for an 8 ms coherent integration time and interference frequencies of L1+3 KHz**

### 4.2 Broadband Interference

Broadband interference is a wideband Gaussian interference signal that is usually generated by an intentional noise jammer [Spilker et al., 1996]. Intentional jamming is generally anticipated in military GPS receivers. The broadband interference signal is basically similar to the GPS signal noise and in this case, the broadband interference signal was generated using the noise function of the Agilent signal generator. The broadband signal adds to the GPS correlation noise to increase it in the bandwidth of the broadband signal.

#### 4.2.1 Noise Power Analysis

The noise power was analyzed for different bandwidths, coherent integration times and non-coherent integration times for different interference powers. The noise power ratios at different bandwidths with 10 ms of coherent integration time are illustrated in Figure 12.

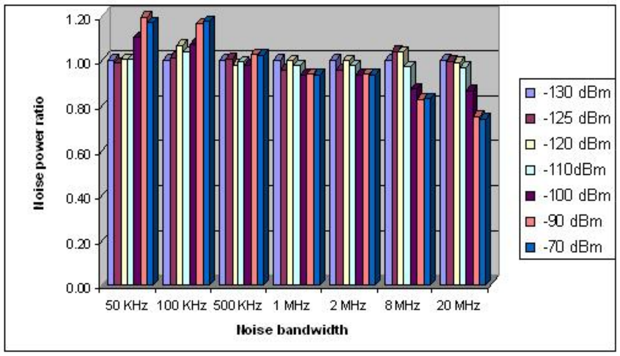


**Figure 12: Noise power ratios for different noise bandwidths at a 10 ms coherent integration time**

The results indicate that the noise power levels increase by a maximum of 17% with an increase in the interference power level by 60 dB. However, from a noise bandwidth above 1 MHz, the noise power shows a decrease by about 26% for 20 MHz, which is probably due to the RF bandwidth being 2 MHz and the cancellation of noise with correlation noise of the GPS signal. The level of increase in the noise power is comparatively less relative to that for continuous wave interference. The interference signal is Gaussian in nature allowing the signal to add or cancel over a period of time. The noise power variation with different coherent integration times for an interference bandwidth of 100 KHz is shown in Figure 13. The noise power obtained for each coherent integration time at an interference power of -130 dBm is taken as a reference.

The noise power increases by a factor of 35% for a 1 ms coherent integration time, while it increases by only 3% for a 20 ms coherent integration time, with a 60 dB increase in interference power. The increase in the coherent integration period causes noise to average out and thus reducing it for higher coherent integration times. For different interference bandwidths, the amount of increase in the noise power reduces with longer coherent integration times.

The amount of increase in the noise power also reduces with an increase in the noise power bandwidth. Variations in the noise power with non-coherent integration factors for an interference bandwidth of 100 KHz are shown in Figure 14. The noise power level obtained for an interference power of -130 dBm and a non-coherent integration factor of 1 is taken as the reference level.

Non-coherent integration accumulates the signal across coherent integration periods, which causes an increase in the noise level. The increase in the non-coherent integration period increases the noise power level by a factor of four for an increase in the interference power by 60 dB, and the non-coherent integration factor by five. This increase in the noise power level decreases the SNR and prevents signal from being detected.

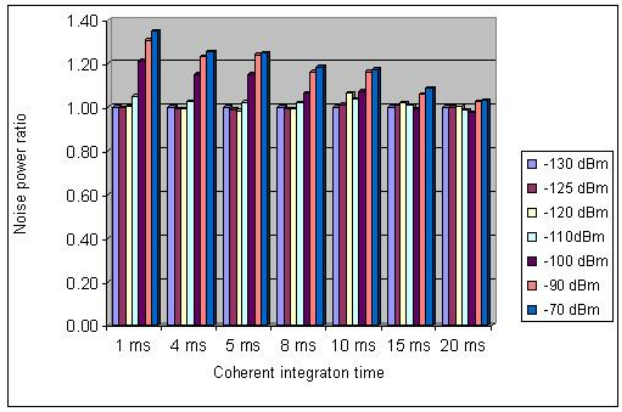


**Figure 13: Noise power ratios for different coherent integration times at a 100 KHz interference bandwidth**

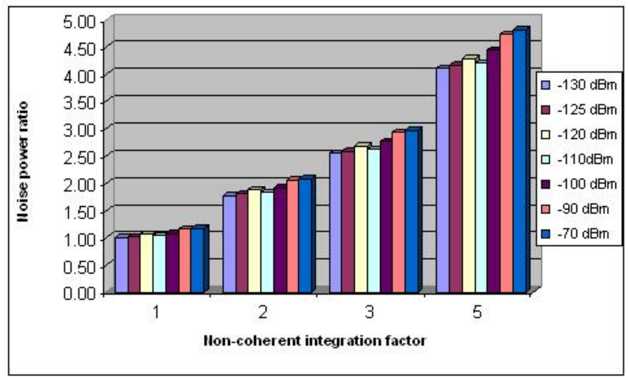


**Figure 14: Noise power ratios for different non-coherent integration times at an interference bandwidth of 100 KHz**

### 4.2.2 Signal-to-Noise Analysis

The reference signal was processed to determine the location of the correct peak for the GPS signal. The correlation peak obtained at the correct Doppler for different interference conditions was compared against the noise power level and the SNR variation under different conditions was analyzed. The SNRs for different interference bandwidths at a coherent integration time of 10 ms is shown in Figure 15.

The SNR is less than one, which indicates that even though the peak is obtained at the correct Doppler, the acquisition process has not declared the signal as acquired as it is below the detection threshold. The SNR decreases with an increase in the interference power level. This is because of the increase in the noise power level with an increase in the interference power level. Increasing the false detection probability can decrease the noise power level but it will increase the possibility of false acquisition. The signal level increases with an increase in the coherent integration time. The SNRs for different coherent integration times for an interference bandwidth of 100 KHz are shown in Figure 16.

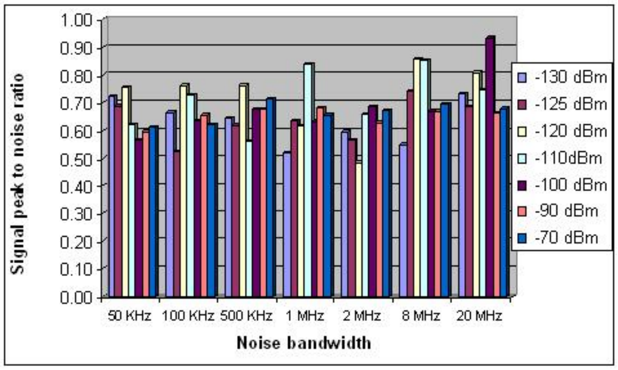


**Figure 15: SNRs for different noise bandwidths at a 10 ms coherent integration time**

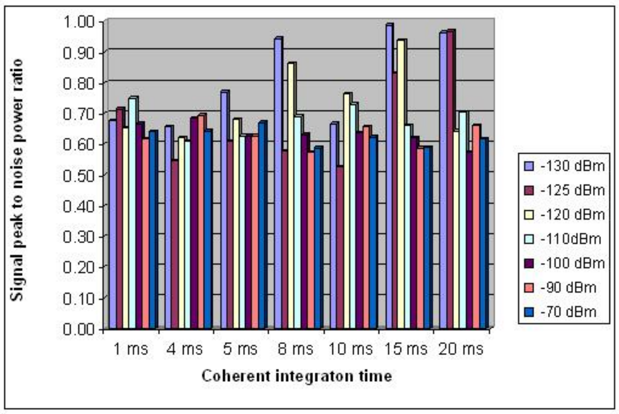


**Figure 16: SNRs for different coherent integration time at 100 KHz interference bandwidth**

Thus with an increase in the coherent integration time, the SNR increases and is close to one for an integration time above 8 ms at an interference power level of -130 dBm. With an increase in the interference power level, the SNR decreases and the signal peak gets buried in noise. Thus with an increase in the interference power by 10-15 dB, the signal peak falls below the noise power level causing jamming and making acquisition difficult. The results for coherent integration times are the same for different interference bandwidths with the SNR decreasing with an increase in the interference bandwidth. Thus, the higher the bandwidth, the less the interference power required to jam the signal. The effect of non-coherent integration factors on the SNR for a 10 ms coherent integration time and an interference bandwidth of 100 KHz is shown in Figure 17.

The results show that an increase in the non-coherent integration factor increases the SNR for low interference powers. However, the SNR is less than one indicating that the signal peak is buried in noise. The results obtained for different interference bandwidths coincide, indicating that the non-coherent integration factor does not boost the signal level to exceed the noise power.

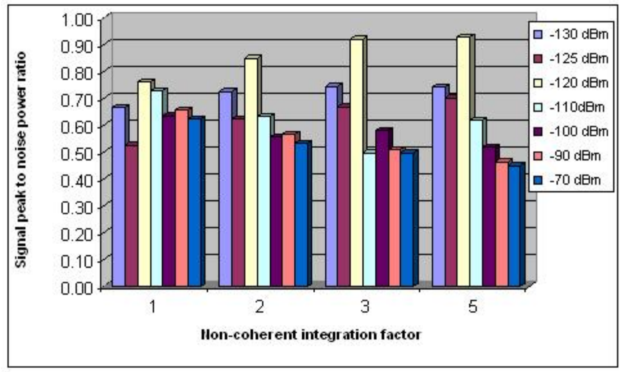


**Figure 17: SNRs for different non-coherent integration times for a 10 ms coherent integration time and an interference bandwidth of 100 KHz**

### 4.2.3 Acquisition Success Percentage

The previous section analyzed the SNR, wherein the signal value obtained at the correct Doppler was considered. However with an interfering signal, there is a possibility of the correlation peak being greater than the peak at the correct Doppler. This section analyses whether the correlation peak obtained is the correct one. The acquisition was considered as a success if the correlation peak obtained was at the correct Doppler irrespective of whether the signal peak was higher than the noise power level. The percentage of success indicates the influence of interference signals to cause a distortion in the GPS spectrum. There is also a possibility of a wrong peak being obtained due to a navigation data bit transition. The percentages of acquisition success for different interference bandwidths are shown in Figure 18.

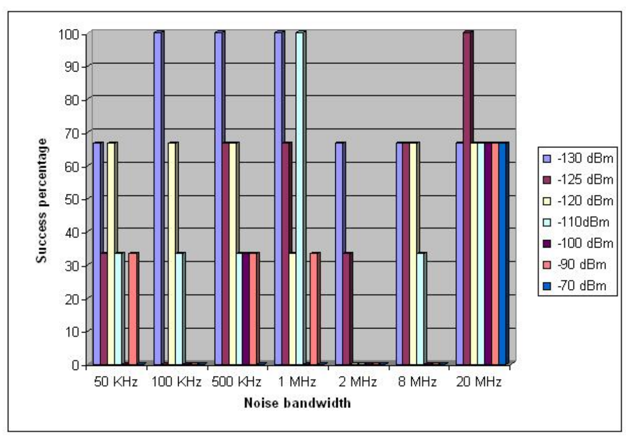


**Figure 18: Percentages of acquisition success for an 8 ms coherent integration time and a non-coherent integration factor of 1**

The results indicate that the percentage of time the correct peak is obtained increases for wider bandwidths. The effect of the coherent integration time on the correlation peak for a 100 KHz noise bandwidth is shown in Figure 19.

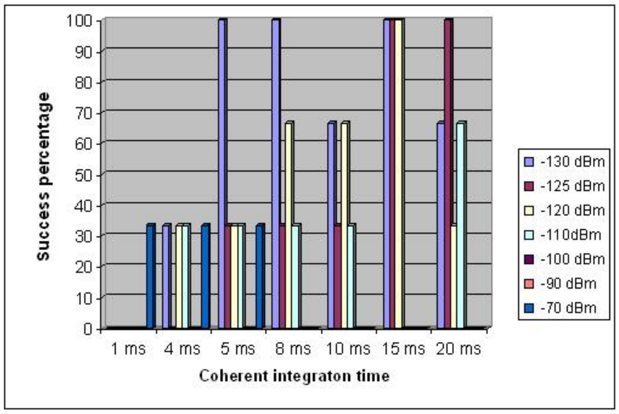


**Figure 19: Percentages of acquisition success for different coherent integration at broadband noise bandwidth of 100 KHz**

Thus with a longer coherent integration, a higher interference power can be tolerated. However with an interference power of +30 dB higher than the GPS signal power, the percentage of success drops to zero and the signal gets jammed. The effects of the non-coherent integration time on the correlation peak are shown in Figure 20.

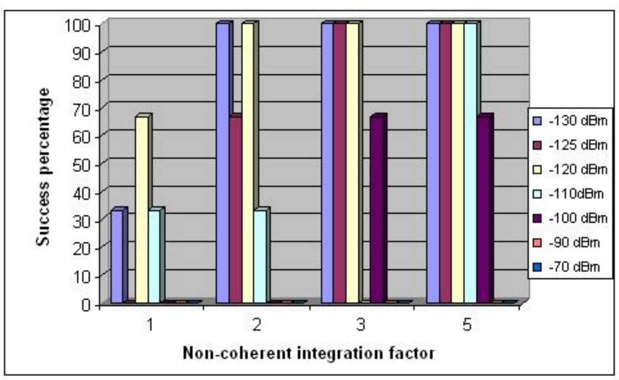


**Figure 20: Percentages of acquisition success for different non-coherent integration times at a broadband noise bandwidth of 100 KHz**

By increasing the non-coherent integration factor, the acquisition success increases. But even by increasing the non-coherent integration factor to five, the signal gets jammed for an interference power of 30 dB more than the signal power.

### 4.3 Pulsed Interference

The third type of interference analyzed is the pulsed interference. Pulsed interference was analyzed for different pulse durations with various duty cycles at several interference powers. The pulse signal can cause problems to hardware components in the GPS receiver by exceeding the power level specifications of the hardware components [ibid]. The Signal Tap RF front end has a power specification of +10 dB; hence the interference power for the pulse was limited to –40 dBm before the low noise amplifier (LNA). GPS receivers should use an RF power limiter to protect the hardware components from pulsed interference. Apart from effects on the hardware components, the effect of pulsed interference on the GPS acquisition process was analyzed through testing as described below.

The pulse interference power was tested in the low power range to prevent damage to the Signal Tap. Pulsed interference at high power is expected to cause saturation of ADC and correlator loops.

#### 4.3.1 Noise Power Analysis

The noise powers obtained for different pulse durations at various duty cycles are shown in Figure 21. The noise power obtained for the reference signal is considered as the reference noise power. Variations in the noise power give indications about the possibility of acquisition. The results show that the noise power ratio is close to one indicating that the noise power does not vary much with the pulsed interference duration or the duty cycle. This indicates that pulsed interference does not have much influence on the signal spectrum and hence very little effect on the acquisition process.

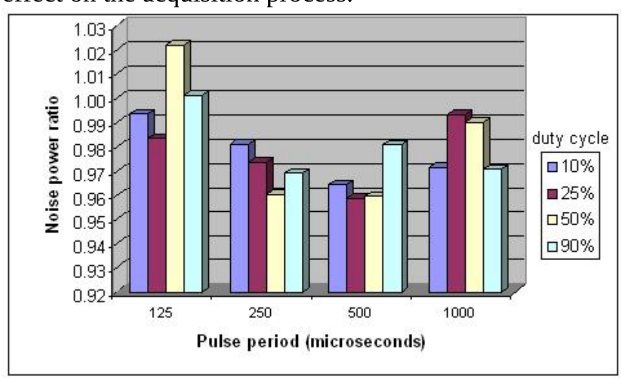


**Figure 21: Noise power ratios for different pulse durations and duty cycles at an interference power of -130 dBm and a coherent integration time of 10 ms**

The noise power was found to vary by a negligible amount with variations in the pulsed duration or the duty cycle. The effect of the coherent integration time on the pulsed interference power levels was also found to be negligible. The noise power varies by about 1-2% compared to the noise power of the reference signal. Non-coherent integration also does not affect the noise power variation and hence the effect of pulsed interference on the noise power is nearly zero.

#### 4.3.2 Signal-to-Noise Analysis

The noise power does not vary with the pulsed interference power levels, duration or duty cycle. The SNR is analyzed to determine if the pulsed interference has any effect on the signal peak. SNR results at different pulse durations and duty cycles for a 10 ms coherent integration time are shown in Figure 22.

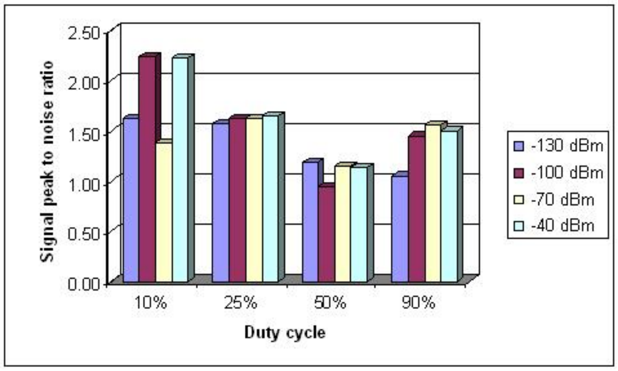


**Figure 22: SNRs for different duty cycle for 125 microsecond pulse duration at coherent integration of 10 ms with non-coherent integration factor of 1**

The results show that the SNR is greater than one for different duty cycles and interference powers. The increase in interference power has no effect on the SNR allowing the acquisition process to acquire the GPS signal at the correct peak. The same effect is observed for different coherent integration times and non-coherent integration factors. This indicates that low power pulsed interference has no effect on the GPS signal processing section. However during the design of the GPS receiver hardware, protection from pulsed interference must be considered [ibid].

## 5 CONCLUSIONS

Different interference sources were analyzed to determine the effect on the GPS acquisition process. Narrow in-band continuous wave interference can jam the GPS signal with only 15 dB more power than the GPS signal power. A continuous wave signal can be easily generated but since it is a directional signal, the antenna gain in that direction determines the amount of signal captured by the receiver.

A broadband interference signal is potentially more dangerous than the continuous wave interference signal as it is much more difficult to detect. Broadband interference depends on the noise bandwidth and easily jams the GPS signal with 30 dB more interference power than the GPS signal. A longer predetection integration time can tolerate more interference power.

Low power pulsed interference does not affect GPS signal spectrum and has no effect on acquisition process. Pulsed interference can damage hardware components of the GPS receiver and must be considered during hardware design. High power pulsed interference needs to be analyzed to determine the effects on the GPS acquisition process.

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