Effect Analysis of GNSS Traditional Interference Suppression Method on Fast Chirp Interference

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Abstract. With the wide use of the global navigation satellite system (GNSS), its vulnerability has become an increasing serious problem. More specifically, interference is one of the severe challenges faced by GNSS applications. There are relatively mature detection and excision methods for the simple interference currently, such as pulse interference, single-tone interference, and narrow-band interference. On contrary, for complicating interference, such as fast chirp interference, there are a few effective suppression methods. In this paper, the model of periodic fast chirp signal is built first. Then, several traditional interference suppression methods of GNSS receiver are used to excise fast chirp interference to analyse their feasibility. Finally, both theoretical analysis and simulation results show that traditional interference suppression methods for the GNSS receiver do not perform well on fast chirp interference.

1. Introduction
GNSS signal is so vulnerable that it is critical to take measures to eliminate or mitigate the impact of interference, considering the complex and variable interference is harmful to the performance of GNSS receivers [1]-[3].

The chirp signal is a common type of interference signal in GNSS field, which is also a typical non-stationary interference [4]. Unintentional chirp interference, which has various sources, mainly comes from radar, sonar, and mobile communications. When the chirp interference is applied to intentional interference, the range of frequency sweep can be set according to the target signal. In addition, the sweep width can also be increased in the case of uncertain target signal frequency, so that the target falls within the frequency band of the interference spectrum and the target signal is suppressed. Fast chirp frequency interference is a kind of chirp interference which has a wide bandwidth and short scan period. Therefore, it has a greater impact on GNSS signals and requires effective means of suppression.

At present, some researches on GNSS fast chirp interference based on time-frequency analysis have been done [5]-[8]. Nevertheless, few studies of the effect of traditional interference suppression methods on fast chirp interference are made. In this paper, the model of the fast chirp interference is built according to its characteristics. Then, the applicability of traditional interference suppression methods to fast chirp interference are analysed by simulation. Finally the conclusion is that the traditional interference suppression methods do not perform well on fast chirp interference.

2. Model of Fast Chirp Interference
Chirp interference is widely found in systems such as radar, sonar and mobile communications [4]. Due to its wide range of sources, chirp interference has been a common unintentional interference to
GNSS receiver. Its mature interference effects also make it a common form of interference in radio countermeasures. When it is used as intentional interference, the interference equipment periodically scans each channel in a certain frequency band. Then, all target signals in its frequency band are suppressive interfered. If the sweep speed is moderately selected, multiple electronic devices whose frequencies are in the sweep range will periodically experience strong interference. Figure 1 shows a chirp signal with a length of 30μs and a span of 10.23MHz, and Figure 2 shows its time-frequency distribution.

\[ I_{\text{chirp}}(t) = A \cos \left( 2\pi f_{\text{chirp}}(t) t + \phi_0 \right) \]  

Where \( \phi_0 \) is the initial phase of the signal and \( f_{\text{chirp}}(t) \) is the instantaneous frequency of the fast chirp signal. The frequency span is typically between 7 MHz and 60 MHz and the scanning time is approximately tens of microseconds. This type of interference can be considered as a broadband interference as it repeatedly scans a wide frequency during a coherent integration period of a typical receiver. In addition, the jammer can change the amplitude of interference signal according to actual situation, so that it can enhance the interference effect. Therefore, for a fast-sweep jammer that operates continuously, the periodic interference signal generated can be expressed as following,

\[ J(t) = \sum_{n=0}^{\infty} [u(t - nT) - u(t - (n + 1)T)]A(t - nT) \cos \left( 2\pi f_{\text{chirp}}(t - nT)(t - nT) + \phi_0 \right). \]  

Where \( T \) is the period of the signal and \( A(t) \) is the function of the signal amplitude as a function of time.

3. Traditional interference suppression method for fast chirp interference effect

The traditional interference suppression methods used in commonly GNSS receivers are mainly time and frequency domain interference suppression techniques [9], [10].

3.1. Effect of traditional frequency domain interference suppression method on fast chirp interference

The frequency domain interference suppression technique [9]-[12] is one of traditional anti-jamming techniques. The method identifies and suppresses interference spectrum based on the difference between desired signal and interference on the spectral characteristics. Two algorithms are commonly used in frequency domain interference suppression technology. One of these is to set a threshold to zero, average, or whiten the frequency components whose amplitude exceeds the threshold in the spectrum, that is, the threshold-based notch algorithm [8]. The other is an adaptive filtering method.
that adaptively filters the frequency domain signal after the N point FFT to filter out the interference frequency components (Figure 3).

Figure 3. Adaptive filtering in frequency domain.

Figure 4. Comparison of single-tone interference power spectrum between before and after processed by frequency domain interference suppression method.

Figure 4 is the comparison of the signal power spectrum between before and after filtering single-tone interference using frequency domain interference suppression filtering. This method performs well on pulse interference, single-frequency interference, narrow-band interference, etc. However, it is not applicable to broadband interference.

The fast chirp interference exhibits the same characteristics as the wideband interference in the spectrum for its wide band and short period. Therefore, suppressing the fast chirp interference by the traditional frequency-domain interference suppression technology is difficult.

3.2. Effect of traditional time domain interference suppression method on fast chirp interference

Time domain interference suppression technique [9]-[10], [12], [13] is also one of traditional anti-jamming techniques. The desired signal and the interference have different correlations in time domain, and the time domain interference suppression technology uses this feature to detect and suppress interference. The autocorrelation property of interference is used to estimate the signal. Then, the interference is cancelled from the received signal. This method is usually implemented by adaptive filtering algorithms, such as LMS algorithm, RLS algorithm and the expansion of the former two.

Taking the LMS algorithm [9] as an example, the algorithm is based on the steepest descent principle of gradient estimation. The signal is represented in digital form and the error signal at the output of the array is as follows,

\[ e(k) = d(k) - y(k) = d(k) - \mathbf{w}^H(k)\mathbf{x}(k) \]  \hspace{1cm} (3)

The iteration formula is

\[ \mathbf{w}(k+1) = \mathbf{w}(k) + 2\mu\mathbf{x}(k)e^+(k) \]  \hspace{1cm} (4)

Where \( \mathbf{x}(k) \) is the input vector, \( d(k) \) is the wanted output, \( y(k) \) is the actual output, \( e(k) \) is the error vector, \( \mathbf{w}(k) \) is the weight vector, and \( \mu \) is the convergence factor, which controls the convergence speed of the algorithm.
Figure 5 shows the comparison of the signal power spectrum between before and after narrow-band interference filtering by the LMS algorithm. This method performs well on single-frequency interference and narrow-band interference. Nevertheless, it is not suitable for broadband interference. Because the fast chirp interference period is extremely short and the frequency changes rapidly, the adaptive filtering algorithm cannot estimate the correct interference signal due to the slow convergence speed. And it cannot effectively detect and suppress the interference signal as well.

4. Simulation Analysis
In practice, the GNSS signal strength is much smaller than the noise and is usually submerged under the noise. Therefore, the method that replaces the GNSS signal with the bandpass-filtered white noise, which is used in [8] to analyse the effect of the time-frequency filter, can be used in this simulation. First, the fast chirp interference is added to the noise signal. Then the interfered signal is processed by traditional single antenna interference suppression methods. Finally, the effect of methods are analysed by the power spectrum and histogram of the processed signal. The simulation parameters are shown in Table 1.

| Table 1. Simulation parameters. |
|---------------------------------|
| Intermediate frequency          | 16.84MHz |
| Sampling frequency              | 65MHz    |
| Signal bandwidth                | 10.23MHz |
| Signal length                   | 1ms      |
| Interference signal period      | 30μs     |
| Interference frequency range    | 11.725–21.955MHz |
| JSR                             | 40dB     |
| Intermediate frequency          | 16.84MHz |

The parameters in Table 1 are used to generate the simulated signals. Then the frequency domain and the time domain interference suppression technology are used to process the interfered signals respectively. Finally the processing performance of two methods can be analysed.
Figure 6. Comparison of power spectrum between before and after using LMS algorithm to filter narrowband interference.

Figure 6 is a histogram of the useful signal. Since the wanted signal used in this section of the simulation is white noise, the signal histogram exhibits a normal distribution.

Figure 7. The waveform of interference signal in one cycle.

Figure 8. The power spectrum interference signal.

Figure 9. The histogram of interference signal.

Figures 7 and 8 show the waveforms (within one cycle) and the power spectrum of the interfering signal. The power spectrum of the interfering signal appears in the form of wideband interference. Figure 9 is a histogram of the interfered signal which is no longer in a normal distribution.
4.1. Simulation of processing the fast frequency chirp interference by frequency domain interference suppression method

In this section, a threshold-based notch algorithm is used to process the interfered signal. Firstly, we make a 1024-point FFT on the interfered signal, then plot its spectrum, and compare it to the spectrum of the wanted signal (as is shown in Figure 10).

![Figure 10. 1024-point FFT spectrogram within the bandwidth of the interfered signal.](image1)

![Figure 11. The histogram of the processed signal.](image2)

When dealing with the interfered signal, the frequency domain interference suppression algorithm needs a significant difference between the interference signal and the useful signal on the spectral line. Therefore, for the broadband interfered signal, the frequency domain interference suppression algorithm cannot detect the spectrum line of the interference signal, and cannot set the component of the interference signal to zero by setting a threshold naturally as well. Figure 10 shows the spectrum of the interfered signal. The spectrum of the interfered signal exhibits the characteristics of interfered by broadband interference. Figure 11 is a histogram of the signal processed by the frequency domain interference suppression method. It can be seen that if the signal is notch-processed, a large number of frequency components of the wanted signal are lost. It results in a large difference between the IFFT signal and the originally wanted signal and the processed signal is unable to track. Therefore, we have confirmed that in the GNSS receiver, the traditional frequency domain interference suppression method cannot effectively identify and suppress fast-chirp interference.

4.2. Simulation of processing the fast frequency chirp interference by time domain interference suppression method

In this section, the LMS algorithm is used to process the interfered signal. The power spectrum of the interfered signal before processing is shown in Figure 12.

![Figure 12. The power spectrum of the interfered signal.](image3)

![Figure 13. Comparison of signal power spectrum between before and after processing.](image4)
We perform time domain adaptive filtering on the interfered signal to suppress the interference signal, and then compare the power spectrum and histogram of the signal between before and after processing.

Figure 13 shows the signal power spectrum between before and after the time domain interference suppression processing. The difference between the two is small, but the interference still exists.

Figure 14 shows the histogram of the processed signal. Similar to the histogram before signal processing, it also does not exhibit the characteristics of a normal distribution. It can be considered that the method of using the time domain interference suppression does not remove the fast chirp interference in the signal. The analysis shows that the traditional time domain interference suppression method in the GNSS receiver cannot effectively identify and suppress fast-chirp interference.

5. Conclusion
In this paper, we make a study of the effect of traditional interference suppression methods of GNSS receiver on fast chirp interference. Firstly, the model of the fast chirp interference in practical applications is built. Then, the applicability of two traditional interference suppression methods to fast-chirp interference is analysed, and traditional interference suppression methods cannot effectively detect and suppress fast-chirp interference. In addition, the performance of traditional interference suppression methods on signals interfered by fast-sweep signal is analysed. Both theoretical analysis and simulation results show that traditional interference suppression methods have a low-performance effect on fast-chirp interference. Further study will be carried out on how to suppress fast chirp interference in a signal on a single-antenna GNSS receiver.

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