

An Adaptive Narrowband Interference Excision Filter with Low Signal Loss for GPS Receivers

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Abstract: As the low power GPS signal is susceptible to interference, interference can seriously degrade the performance of GPS receiver. This paper designs a ANIEF(Adaptive Narrowband Interference Excision in Frequency domain) filter that removes narrow band interferences with low signal loss. This filter uses the pre-correlation technique and attempts to filter out the interference in the frequency domain. The interference excision performance of the designed filter is evaluated for various interferences using the ANIEF filter inserted GPS software receiver and the interference generator. Interferences considered in this paper are single-tone CWI(Continuous Wave Interference), multi-tones CWI, pulsed CWI, and swept CWI. The narrowband interference excision filter in frequency domain is very effective against various interferences and the strong interference with a simple structure. However, the signal power loss is unavoidable while transforming. In this paper, the hamming window and overlap technique are adopted to reduce the signal power loss. Finally, the interference excision performance and the reduced signal power loss of the ANIEF filter are shown.

Keywords: Interference suppression, Adaptive narrowband filter, Frequency-domain excision, Anti-jamming

1. INTRODUCTION

The low power GPS signal is susceptible to the interference. Therefore, interference can seriously degrade the performance of GPS receiver. Interference excision techniques can be classified into the time domain, frequency domain and amplitude domain technique. This paper designs the ANIEF(Adaptive Narrowband Interference Excision in Frequency domain) filter that removes narrow band interference from the GPS spectrum. This filter attempts to filter out the interference before correlation in the GPS receiver. The interference excision technique in the frequency domain transforms the received GPS signal containing interference into the signals in the frequency domain and computes the signal statistically to determine an excision threshold. And then, it removes all spectrums exceeding the threshold, and restores the remaining signal without interference to the signals in the time domain. This paper proposes the ANIEF filter scheme that adopts the hamming window and 50 % overlap technique to reduce the signal power loss which is unavoidable while transforming. To simulate the performance of the proposed filter, the GPS IF signal generator and the software receiver are implemented.

Section 2 summarizes effects of RF interference on GPS receivers. Section 3 describes the structure of the proposed the interference excision filter. Section 4 shows some interference excision performance results. Finally, summary and concluding remarks will be given in section 5.

2. EFFECTS AND MEASURES OF RF INTERFERENCE

The interference can result in degraded navigation accuracy or complete loss of receiver tracking. Therefore, the receiver requires countermeasure for removing impact of interference.

Table 1 summarizes various types of RF interference[1].

Table 1 Type of RF Interference and Typical Sources

Type	Typical Sources
Wideband-Gaussian	Intentional noise jammers
Wideband phase / frequency modulation	Television transmitter's harmonics or near-band microwave link transmitters overcoming front-end filter of GPS receiver
Wideband-spread spectrum	Intentional spread spectrum jammers or near-field of pseudolites
Narrowband-pulse	Radar transmitters
Narrowband phase / frequency modulation	AM stations transmitter's harmonics or CB transmitter's harmonics
Narrowband-swept continuous wave	Intentional CW jammers or FM stations transmitter's harmonics
Narrowband-continuous wave	Intentional CW jammers or near-band unmodulated transmitter's carriers

Fig. 1 shows a basic GPS receiver architecture with the interference effects on the receiver. The interference can result in degraded navigation accuracy or complete loss of receiver tracking[2].

Fig. 2 shows all potential mitigation techniques which can be applied to the GPS receiver would occur.

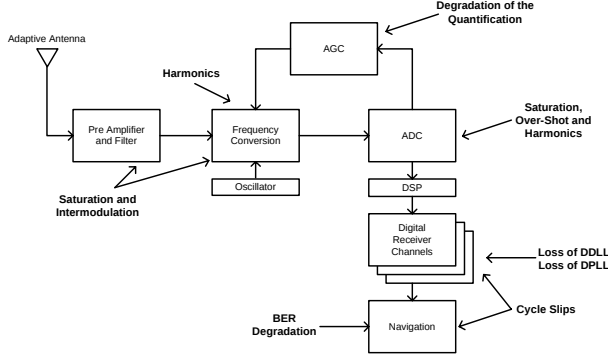


Fig. 1 Interference Effects on a GPS receiver

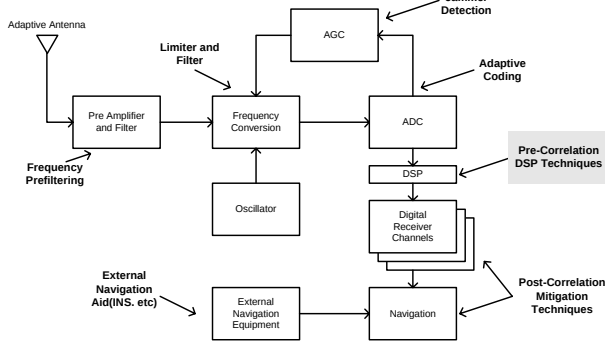


Fig. 2 Position of the Interference Mitigation Techniques in a GPS receiver

The ANIEF filter belongs to the pre-correlation technique and attempts to filter out the interferences in the frequency domain.

3. ANIEF FILTER STRUCTURE AND INTERFERENCE EXCISION TECHNIQUE

The structure of ANIEF is shown in Fig. 3.



Fig. 3 The structure of ANIEF Filter

The received GPS signal is transformed to the frequency domain one by the FFT(Fast Fourier Transform) of 256-samples and analyzed by the Interference Excision block to determine an excision threshold. The interference excision block removes all spectrums exceeding the excision threshold. The received GPS signal, $x(n)$ is composed of the transmitted GPS signal, the AWGN(Adaptive White Gaussian Noise) and the interference (see Eq. (1)).

$$x(n) = s(n) + w(n) + j(n), \quad n = 0, 1, \dots, N_p - 1 \quad (1)$$

In equation, $s(n)$ is the transmitted GPS signal, $w(n)$ is AWGN, and $j(n)$ is interference signal.

The FFT output of N_p samples, $X(k)$, is given in Eq. (2)[3][4].

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$$X(k) = \sum_{n=0}^{N_p-1} x(n) e^{-j2\pi kn / N_p}, \quad k = 0, 1, \dots, N_p - 1 \quad (2)$$

If the magnitude of spectrum of each frequency bin is larger than the magnitude of AWGN, it can be regarded as the interference and will be rejected. Because the power of GPS signal is much smaller than that of AWGN, the GPS signal is not likely to be rejected. The remaining signal is restored in the time domain through IFFT (see Eq. (3)).

$$x(n) = \frac{1}{N} \sum_{k=0}^{N_p-1} X(k) e^{j2\pi kn / N_p}, \quad k = 0, 1, \dots, N_p - 1 \quad (3)$$

The FFT processing without window brings the spectral leakage[3]-[5]. Windowing smooths the discontinuities at the block boundary and lessens the effect of spectral leakage. The signal energy will be spread across the spectrum proportional to the width of the main-lobe and the height of the side-lobes of the window. Selecting a window with lower side-lobes will reduce the amount of spectral leakage. However, a window with lower side-lobes usually has a wider main-lobe.

For the GPS application, the objective is to minimize the frequency spreading of each CW tone in order to minimize the number of frequency bins that will be excised[6]. At the same time, it is also required to minimize the degradation of the GPS signal when the interference is not present. The window selection requires a tradeoff between the reduction in SNR due to the signal attenuation incurred by multiplying the data sequence by a window and the effectiveness of the spectral containment for a CW tone. The degradation of the SNR can be expressed as Eq.(4).

The SNR loss may exceeds high as 3dB for some window functions with extremely low side-lobes.

$$\text{SNR degradation} = \frac{\left\{ \sum_{n=0}^{N-1} w(n) \right\}^2}{N \sum_{n=0}^{N-1} w^2(n)}, \quad w(n) \text{ window} \quad (4)$$

In Table 2, the characteristics of Rectangular window, Blackman-Harris window, Hamming window are compared [3][4].

Table 2 Window Weighting Characteristics in FFT Analysis

Parameter	Side-lobe Height	Worst Case Processing Loss	Frequency Containment
Rectangular	-13dB	3.92dB	25 bins
Blackman-Harris	-92dB	3.47dB	6 bins
Hamming	-43dB	3.10dB	4 bins

The most filters with OFFT(Overlap Fast Fourier Transform) structure use Blackman-Harris window. This paper will use the Hamming window since it has the smallest the frequency containment and the least processing loss are shown in table 2. The Hamming window can be expressed as Eq. (5).

$$w(n) = 0.54 - 0.46[\cos(2\pi n / (N - 1))](0 \leq n < N) \quad (5)$$

In this paper, the hamming window and 50% overlap technique are adopted to reduce the signal power loss. 50% overlap processing is of complex structure, but it reduces the effect of the signal attenuation from the window on the output SNR [6][7]. The SNR loss is reduced from 0.6dB to 3dB using the hamming window and overlap technology. Each path in the processing chain produces one-half of the usable output sequence as shown in Fig. 4. This figure shows the contribution of each data path to the overall result.

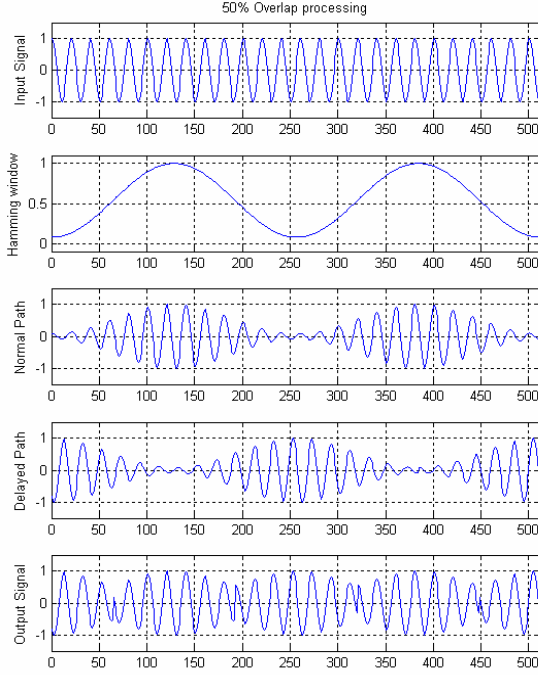


Fig. 4 50% Overlap Processing

The overlap function unfortunately doubles the processing since it requires a second processing path that includes the Hamming Window, FFT, Interference Excision, and IFFT, as shown in Fig. 5.

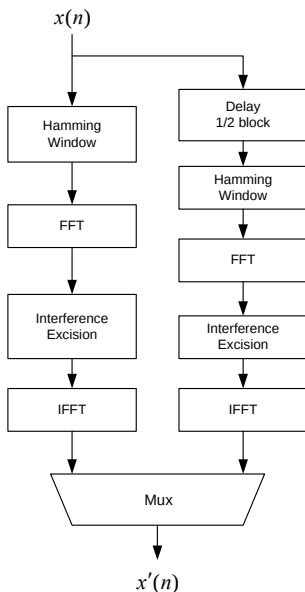


Fig. 5 Block Diagram of the Narrow band Interference Excision Filter

CW interferences occupy relatively few frequency bins, and their amplitudes are above the noise floor[6][8]. Therefore, interference excision block determines the excision threshold and then removes all spectrums exceeding the excision threshold every 256 samples.

The Interference Excision block firstly transforms the magnitude of the FFT output into the magnitude in decibels for each frequency bin to determine the excision threshold which is the boundary between the interference and the AWGN. Then, it calculates the standard deviation ($\sigma_{n-block}$) and mean ($\mu_{n-block}$) of the magnitudes of 256 samples. The standard deviation and the mean are parameters that determine the excision threshold. The excision threshold can be expressed as Eq. (6).

$$\text{Threshold}_{n-block} = \mu_{n-block} + N \cdot \sigma_{n-block} \quad (6)$$

Where N is to be chosen are one of five reference points considering the mean and the standard deviation. The larger standard deviation indicates the presence of interferers and results in a smaller scale factor N to maintain the threshold at the level of the noise floor. If the magnitude of a sample is larger than this threshold, then the magnitudes of 4-samples is set to zero. The 4-samples is chosen by the characteristics of the hamming window

The functional description of the Interference Excision block is shown Fig. 6.

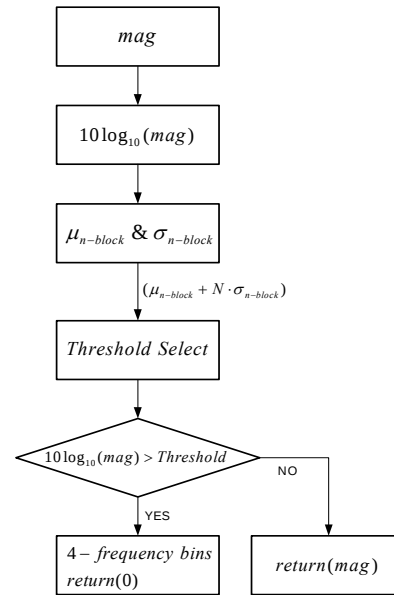


Fig. 6 Functional Description of the Interference Excision Block

4. PERFORMANCE EVALUATION

This section shows simulation results using the test environment shown in Fig. 7. The simulated GPS signal consists of IF GPS signal, AWGN and interference. The GPS signal generator outputs the signal with 1.405MHz center frequency which is sampled by 5.714MHz and quantized for 12bits. The output signal is applied to the GPS software receiver. The ANIEF filter has been inserted in front of the correlator in the software GPS receiver.

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Interferences considered in the test are single-tone CWI, multi-tones CWI, pulsed CWI and swept CWI. Against these interferences, it is checked whether the GPS receiver with ANIEF can acquire the GPS signal. In additional, the maximum J/S is also tested.

Condition 1 : Lock indicator condition ($I^2 + Q^2$)

Condition 2 : Loss of lock threshold condition (3dB above the noise floor)

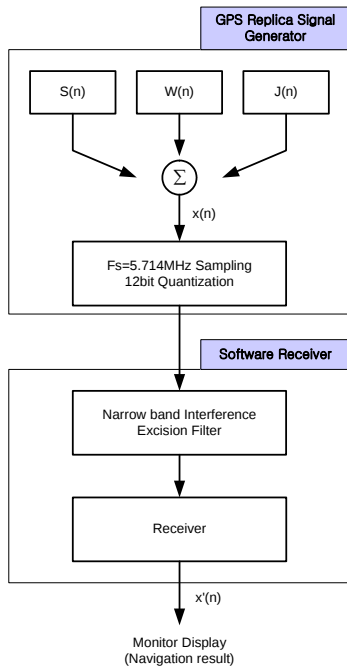


Fig. 7 The test environment setup for simulation

First check up on SNR loss after filter is inserted in software GPS receiver. Table 3 is result that compare to output SNR after processing that process the simulative GPS signal not included interference with the receiver without the ANIEF filter, receiver with the ANIEF filter except the overlap processing and receiver with the ANIEF filter. SNR loss is 3.4dB when the signal transforms frequency domain for the interference excision. At this time gain is 2.3dB which use 50% overlap for minimize SNR loss. Table 4 compare to SNR loss of software receiver for various windows to reduce signal loss by window function. Because of the result in Table 4, the ANIEF filter structure used the hamming window that it has small SNR loss.

Table 3 The SNR loss due to ANIEF

Parameter	No the filter inserted receiver	The filter except overlap inserted receiver	The filter inserted receiver
SNR	14.6dB	11.2dB	13.5dB

Table 4 The SNR loss due to window

Parameter	Rectangular Window	Blackman-Harris Window	Hamming Window
SNR	5.8dB	6.9dB	7.2dB

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The signal spectrum of single-tone CWI in 900kHz bandwidth is shown in Fig 8. Then the result that the single-tone CWI is rejected after ANIEF filtering is shown in Fig. 9. At the frequency domain appears power distribution of signal. Therefore it is easy to detect the CWI. So the ANIEF filter will be shown high performance that excises single-tone CWI and multi-tones CWI of high power level.

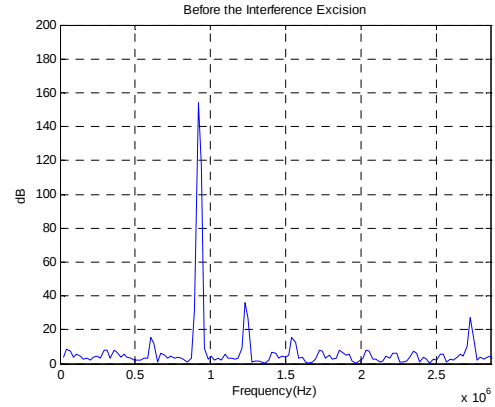


Fig. 8 The power spectral density before the ANIEF filter

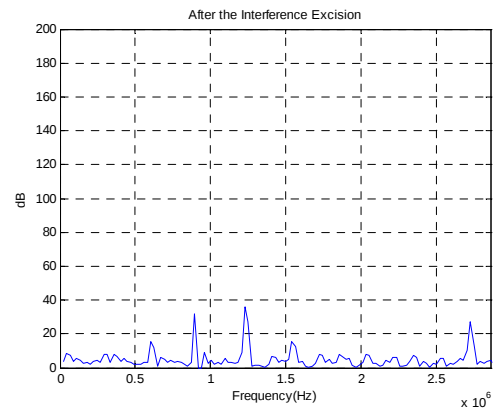


Fig. 9 The power spectral density after the ANIEF filter

This paper evaluates the filter performance against interference power level of single-tone CWI, multi-tones CWI, pulsed CWI and swept CWI. The acquisition of signal to evaluate the filter performance is determined according to conditions. The interference removal performance evaluates by comparing maximum J/S. Table. 5 defines parameter of interference used this test.

Table 5 Parameters of the interferences.

Interference Parameter	Frequency	Duration
Single-tone CWI	0.9MHz	-
Multi-tones CWI	0.5MHz, 1MHz, 1.5MHz	-
Pulsed CWI	1.5MHz	400,000samples : On 100,000samples : Off
Swept CWI	100Hz ~ 1MHz	Increase 100Hz every 100samples

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Fig. 10-11 are an example to evaluate filter performance when the single-tone CWI($J/S=23.8372\text{dB}$) is inputted like Fig. 8-9. Some power loss is shown in Fig. 11, but the acquisition of signal is possible.

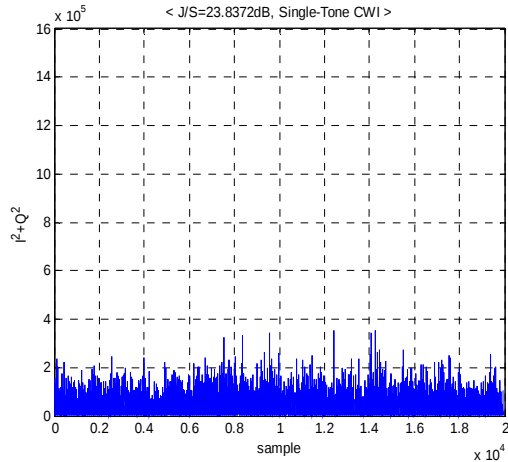


Fig. 10 The software GPS receiver without the ANIEF filter

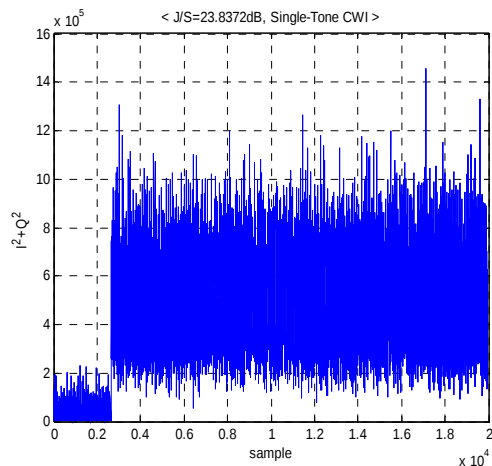


Fig. 11 The software GPS receiver with the ANIEF filter

Fig. 12 compares performance of filter about various interferences. This is the maximum J/S to be able to excise the interference in the ANIEF filter inserted receiver and the ANIEF filter not inserted receiver. Fig. 12 can check up high the excision performance of the narrowband interference in frequency domain.

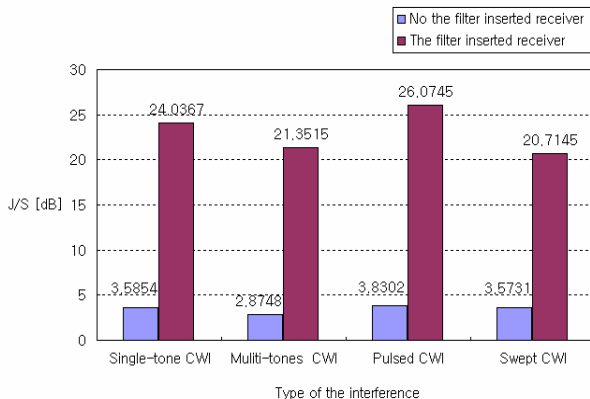


Fig. 12 Performance comparison according to the interference

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Above the test checked up the effective performance about various interferences of the ANIEF filter.

5. SUMMARY AND CONCLUSION

This paper shows that the performance of designed anti-jamming filter is excellent against CW interferences and that such time-variant interferences as pulsed CWI and swept CWI are also excised efficiently. Although the performance of the designed filter varies a little bit according to the type of interference, the designed filter excises all of the interferences with the minimum J/S of 20dB so that the signal acquisition and tracking are maintained in spite of the presence of such interferences. Furthermore, the designed filter reduces the signal power loss of at least 2.3dB using overlap technique with hamming window.

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