

# NARROW-BAND INTERFERENCE REJECTION USING TRANSFORM DOMAIN SIGNAL PROCESSING IN A HYBRID DS/FH SPREAD-SPECTRUM SYSTEM

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## ABSTRACT

*In this paper the performance of a narrow-band interference rejection scheme using the transform domain signal processing is studied in a hybrid DS/FH spread-spectrum system. The signal of interest can be considered to be a BPSK modulated direct-sequence spread-spectrum signal within one frequency hopping period. The interference itself is a narrow-band signal with high power level and with a bandwidth relatively much narrower than the bandwidth of the wide-band signal. The interference can be located either intentionally or unintentionally within the DS-bandwidth which is centered according to the hopping frequency in question. The influence of the narrow-band interference will be reduced by using transform domain filtering. The interference excision takes place in the frequency domain after which the signal is transformed back to the time domain where the rest of the signal processing takes place. To avoid the dissemination of the interferer's energy over a wide frequency range, windowing is used prior to the transformation process. The transformations from the time domain to the frequency domain and vice versa are made by fast Fourier transform (FFT) and inverse fast Fourier transform (IFFT), respectively. The criterion used for the evaluation of the performance of the interference rejection algorithm is the bit error probability as a function of  $E_b/N_0$  and SJR. The bit error rates were obtained by Monte-Carlo simulations.*

## I INTRODUCTION

When the power of the narrow-band interference is much higher than the power of the wide-band signal in a spread-spectrum communication system, it might happen that the inherent processing gain of the spread-spectrum system is not high enough to overcome the performance degradation due to the interference. The performance

degradation can be reduced by using additional techniques to cancel the influence of the narrow-band interference. The most often used methods for the narrow-band interference rejection are adaptive filtering in the time domain and interference excisers in the frequency domain. The both methods are applied in spread-spectrum receivers prior to the despreading operation. When using adaptive time domain filtering, two-sided transversal filters or one-sided prediction error filters can be used with adaptively weighted tap coefficients. The most widely used way to update the filter tap coefficients is to use the Widrow-Hoff LMS algorithm. Since the number of the coefficients in the time domain interference rejection filter can be quite high, the convergence rate of the tap coefficients when using the LMS algorithm can be relatively small. This is mainly the reason why the time domain filtering can not be used in the applications where high adaptivity rate is required. In the fast applications so called transform domain filtering can be used to suppress the narrow-band interference. In this type of filtering the interference, of which there is no apriori information, can be considered to be adaptively suppressed without any adaptive algorithm resulting in faster operation rate.

In a hybrid DS/FH spread-spectrum receiver the narrow-band interference rejection can be applied after frequency hopping demodulation, prior to direct-sequence demodulation. Basically, this means that the interference rejection in a DS/FH system can be handled as a interference rejection from a DS spread-spectrum signal, which has a center frequency corresponding to the hopping frequency in question. Since the frequency hopping period can be of the order of tens or hundreds of micro seconds the narrow-band interference must be estimated and suppressed relatively fast. For that reason the transform domain based interference rejection scheme is more preferable in DS/FH system than the time domain rejection filter with LMS algorithm.

## II SYSTEM MODEL

In a hybrid DS/FH spread-spectrum communication system both direct-sequence and frequency hop spreading are employed simultaneously throughout the transmission. The modulated data sequence is first spread by multiplication with the DS spreading wave form generated by PN code generator. After the direct-sequence spreading modulation the signal is up converted by FH-modulator which changes the frequency of the carrier periodically. The carrier frequency is chosen from a set of frequencies which are controlled by a code sequence generated by the FH-code generator.

In the receiver the received signal is first down-converted by the FH-demodulator and then the DS-despreading is applied by multiplying the received signal with a local replica of the PN code sequence. To make the despreading operation occur properly both DS- and FH-code sequences generated in the receiver must be synchronized with the sequences generated in the transmitter. The block diagram of the DS/FH system is presented in figure 1.

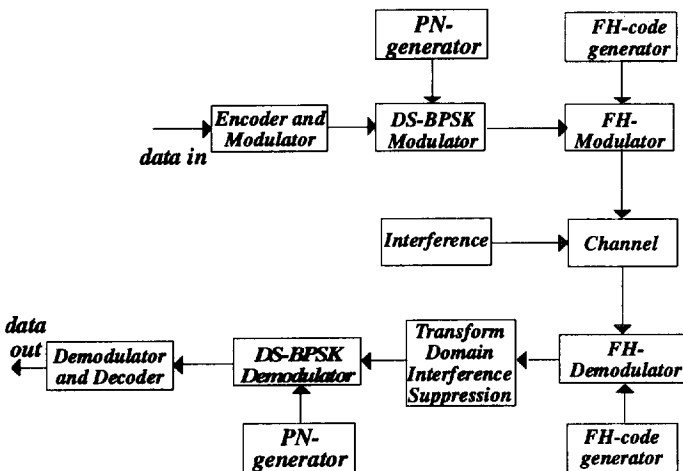


Figure1. DS/FH spread-spectrum communication system with transform domain interference suppression.

The influence of the narrow-band interference in the system described in figure 1 can be reduced by transform domain filtering. The interference excision in that type of filtering takes place in the frequency domain after which the signal is transformed back to the time domain where the rest of the signal processing takes place. To avoid the dissemination of the interferer's energy over a wide frequency range, a windowing function can be used prior to the transformation processes. After the windowing, the input signal is Fourier transformed. The transform is then

multiplied by the transfer function of some appropriate filter, after which the inverse Fourier transform takes place. The block diagram of the transform domain filter is presented in figure2.

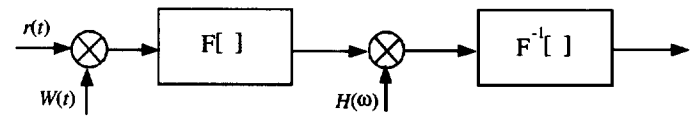


Figure 2. Transform domain filter block diagram

Assuming that the input signal  $r(t)$  consists of a DS spread-spectrum signal, high level but narrow-band interference and white Gaussian noise, the output of the Fourier transform can be presented as in figure 3 a) [1]. The above mentioned assumption holds also in the hybrid DS/FH system, since after the frequency down conversion the received signal can be considered to be direct-sequence spread-spectrum signal within one frequency hopping interval. By multiplying the transformed output by the wave form (notch filtering) shown in figure 3. b), significant amount of the interference power should be suppressed while the power of the desired signal is only slightly reduced.

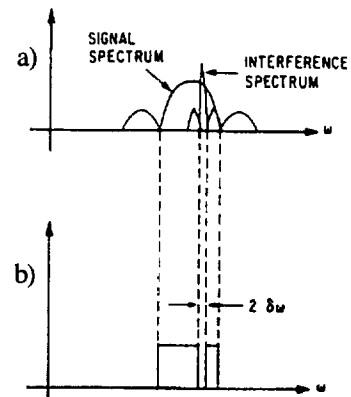


Figure 3. Function of the notch filter [1]

In practice, the statistics of the interference can not be known apriori, and hence the structure described in figure 2 is difficult to implement since the center frequency and the bandwidth of the interference are unknown. An adaptive version of the transform domain filter can be implemented to suppress narrow-band interference that is unknown to the receiver. The block diagram of an adaptive transform domain filter is presented in figure 4.

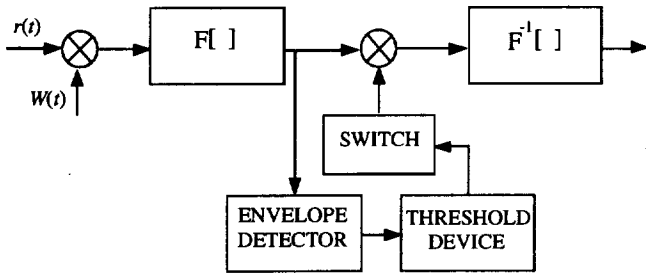


Figure 4. Adaptive transform domain filter structure

In the lower branch in figure 4 the Fourier transformed input is fed to the envelope detector, and the output of the envelope detector is then fed into a switch controlled by a threshold device. The upper branch, in turn, passes the Fourier transformed input directly to the multiplier. The switch in the lower branch is set so that when the output of the envelope detector exceeds a predetermined level, the output of the switch is forced to zero, and hence the lower input to the multiplier is zero. By this manner the adaptive type of notch can be implemented. Since the interference cancellation based on transform domain processing can be made adaptively without the need of adaptive algorithm, it has certain advantages over the receivers employing the time domain adaptive algorithms. For that reason it is preferable to use the transform domain filters in the applications where rapid adaptivity is required like in DS/FH spread-spectrum systems.

Function  $w(t)$  in figures 2 and 4 represents the windowing function which is used to avoid the leaking of the energy of the interferer over a wide frequency range. In simulations the windowing is obtained by using discrete time Hamming window, by which the input signal samples are weighted as follows [4]

$$w(n) = 0.54 + 0.46 \cos(2n\pi / K), \quad (1)$$

where  $K$  is the length of the window.

### III SYSTEM SIMULATIONS

To find out what is the capability of the transform domain processing to suppress the narrow-band interference, a simulation program was written. The simulation system was considered as a DS-spread spectrum system having a finite time period to operate limited by the frequency hopping interval. The BPSK modulated spread-spectrum signal is centered in the frequency domain according to the hopping frequency and the interference suppression is assumed to be fast enough to make the interference cancellation before the next frequency hop.

In simulations, the data sequence is modulated by a PN code sequence of length 63 chips. The length of one code sequence corresponds to the length of one data bit, and one data bit is spread exactly by one spreading code sequence. The received signal in the input of the transform domain interference suppression block consists of DS-spread spectrum signal, white Gaussian noise and narrow-band interference. The interference is either a single tone or partial band interference with respect to the DS-signal.

After windowing, the transformation from the time domain to the frequency domain is made by the fast Fourier transform (FFT). The length of the FFT is one of the simulation parameters and it was selected to be 512. After the FFT, the exciser removes the frequency components that exceed a given threshold. In simulations the threshold is selected to be a fixed value. The exciser output samples are then fed to the inverse FFT (IFFT) which transforms the signal samples back to the time domain. The number of the samples taken from one chip is a selectable parameter and it was chosen to be two throughout the simulations.

To make it possible for FFT to handle long input sequences block-by-block basis, the overlap-and-save method is used. In overlap-and save method a long input sequence is divided into smaller blocks. Each new block consists of the last  $N$  samples from the previous block followed by  $M$  new samples resulting in block size of  $M+N$  samples. Also the number of the overlapping samples in overlap-and-save process is a selectable simulation parameter. Description of the overlap-and-save method is shown in figure 5 [4].

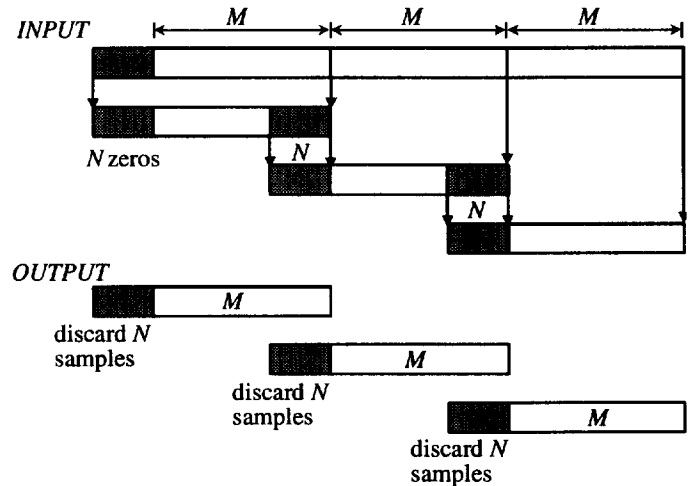


Figure 5. Principle of the overlap-and-save method

After returning back to the time domain and completing the overlap-and-and-save process the

correlation process takes place to despread the DS-signal. The correlation is made by multiplying the output of the interference suppression block by the local replica of the spreading code sequence. The synchronization in the transmitter is assumed to be ideal, meaning that there is no performance degradation due to the despreading operation. Finally, after the despreading, bit decisions are made by hard decision approach and the recovered bits are then compared to the transmitted ones. Based on the bit comparisons bit error rates (BER) were calculated for the two types of interference mentioned earlier in this chapter.

#### IV SIMULATION RESULTS

Simulations in this stage of research were performed to find out what is the performance of the transform domain based interference suppression method against tone and partial band interference.

In figure 6 there is a set of curves showing the BER results for tone jamming and partial band jamming when signal-to-jammer ratio (SJR) is -15 dB. Interference in both cases is located 0.5 times  $R_c$  (chip rate) off from the center frequency of the DS-signal. The band width of the partial band interference is 1/10th of the band width of the wide band signal. This means that the partial band interference occupies 20 % of the one-sided DS-signal bandwidth. The threshold of the exciser was set to cut out the energy of the frequency bins exceeding power spectral density value of 22 dB. The processing gain with respect to DS spreading in simulations was 63.

Curve 1 in figure 6 represents the performance when tone jamming is use with no suppression while curve 2 represents the same situation when exciser has been used. Curves 3 and 4 represents cases for partial band interference without suppression and with exciser type of interference suppression, respectively. First of all, based on curves 1 and 3 it can be seen that the tone interference causes more performance degradation than the partial band interference. Furthermore, when comparing curves 3 and 4 it can be seen that there is no big difference in performance weather the suppression is used or not for partial band interference when SJR is -15 dB. This is quite obvious since the power density of the interference is spread to a wider frequency range and the inherent processing gain can reduce the influence of the interference. The reason why the exciser type of suppressor does not help in partial band interference is that the threshold of the exciser is exceeded within wider frequency range witch means that the larger part of the signal energy is also removed.

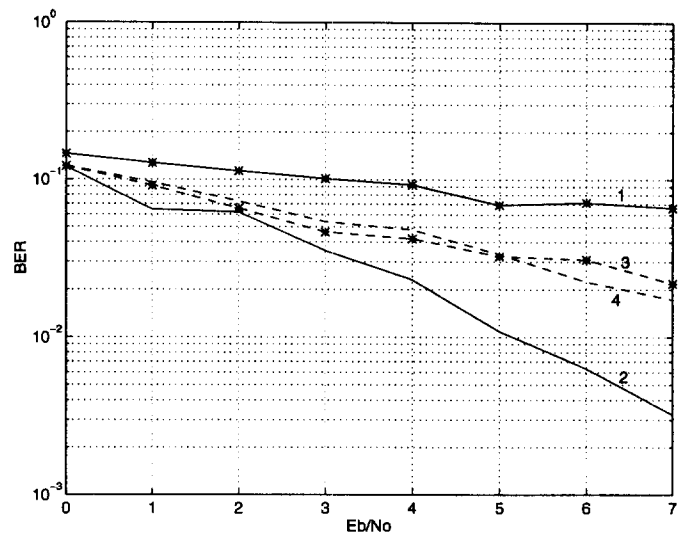


Figure 6. BER results for SJR = -15 dB.

The curves shown in figure 7 represents the cases where the parameters except the SJR value are the same as for figure 6. The SJR value for the curves in figure 7 was -20 dB. Again, curves 1 and 2 are for tone interference with no suppression and with exciser as suppressor, respectively. Curves 3 and 4 represent cases for partial band in interference without suppression and with exciser, respectively.

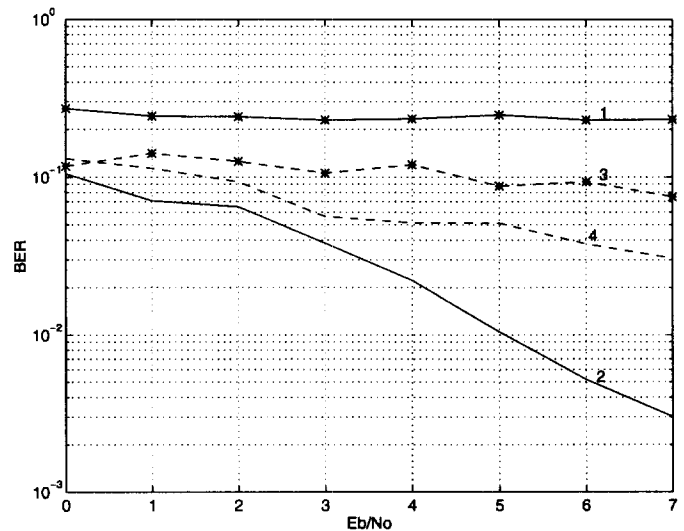


Figure 7. BER results for SJR = -20 dB

From figure 7 it can be seen that the performance with no suppression with both type of interference is very poor. With exciser there is now a little performance improvement in the case of partial band interference. The improvement is still quite small, and the reason for that is the same as mentioned before. Just like shown in figure 6,

the exciser type of suppressor works quite well against tone interference also with lower SJR value. These results are expected. Since the bandwidth of the tone interference is very narrow, the exciser removes now only small amount of signal energy.

In figure 8 a set of BER curves is presented as a function of the SJR for the fixed value of  $E_b/N_0$  of 7 dB. Number of the curves presents the same cases as in the previous figures. Now the interference is located 0.25 times  $R_c$  (chip rate) off from the center frequency of the DS-signal.

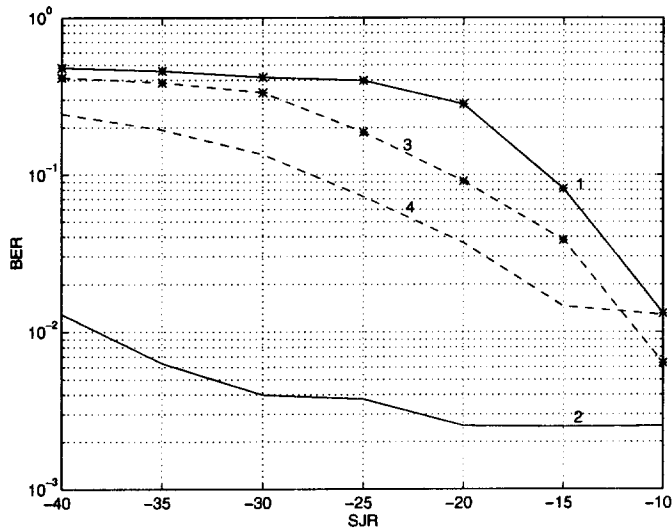


Figure 8. BER results as a function of SJR,  $E_b/N_0=7$  dB

From figure 8 it can be seen again that the exciser type of interference suppression method works quite well against tone interference with different SJR values. It can also be noted that with tone interference the performance of the exciser is quite reasonable also with low SJR values.

## V SUMMARY AND CONCLUSION

In this paper we have presented a narrow-band interference suppression algorithm which is based on transform domain signal processing. This type algorithm is suitable for applications where fast adaptivity is required and that is the reason why it can be used in a hybrid DS/FH spread-spectrum communication system.

The performance analysis of the transform domain based interference suppression algorithm has been made by Monte-Carlo simulations. The criterion used to evaluate the performance was the bit error probability as a function of  $E_b/N_0$  and as a function of SJR. Based on the results it can be said that the transform domain based interference suppression method can cope quite well against the tone jamming even with low SJR values. For example when  $SJR = -20$  dB and  $E_b/N_0 = 7$  dB the bit error rate was  $3.01 \cdot 10^{-3}$ . This can be considered to be quite good result since in simulations there was no error correcting coding in use. By using for example some simple convolutional coding the bit error rate can be reduced significantly.

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