NARROWBAND INTERFERENCE MITIGATION IN UWB SYSTEMS

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ABSTRACT

In this paper we propose a scheme for mitigation of narrowband interference (NBI) in OFDM ultra wideband (UWB) systems, employing simple adaptive narrowband filtering for the detection and suppression of the interfering signal. The scheme employs a low sensitivity second order filter with adaptive independent tuning of the central frequency and bandwidth on the basis of LMS algorithm, with low computational complexity and a very fast convergence. Simulation results show that the proposed scheme could significantly improve the performance of UWB systems.

1 INTRODUCTION

UWB employing OFDM has recently been attracting attention as a technology for short range high data rate communications [1], [2]. However, since it occupies a very wide frequency band and low transmission power, UWB systems are subject to different types of narrowband interferences, which could deteriorate and even block communications. Therefore, NBI suppression is of primary importance for these systems [3]. The issue of avoidance or cancellation of NBI for UWB systems has been studied extensively in the last years. NBI avoidance methods are based on avoiding the transmission over frequencies with strong narrowband interferers, while the cancellation methods aim at eliminating the effect of NBI on the received UWB signal [4].

One of the major limitations of most digital NBI suppression schemes is the need of high precision analog-to digital converters (ADC) and high complexity digital signal processing (DSP) elements [5,6]. Due to their huge bandwidths, UWB receivers usually employ low-bit ADCs. On the other hand, a NBI might significantly increase the level of quantization noise at the output of ADCs, hence higher precision ADCs are required in order to ensure a negligible loss in the performance of the receiver. Usually to improve the efficiency of the finite precision ADC, a variable-gain amplifier (VGA) is used to normalize the power of the signal to a desirable level. Therefore, for UWB systems it is necessary to develop NBI mitigation schemes with relatively low complexity DSP, that take into account the effects induced by the NBI.

One solution is this part of the signal, or those frequency bins in an OFDM system, which are corrupted by NBI to be excised. But in most cases the degradation in an OFDM based UWB receiver is beyond the reach of the frequency excision method when the SIR is less than 0dB. Usually increase in the NBI leads to smaller gain for the useful signal in the VGA and hence lower Signal-to-Interference plus AWGN Ratio (SINR) in the ADC. The reason for this is that the gain of the VGA is set accordingly to the power of the interference, which as a result leads to an increase in the quantization noise of the ADC. This is why it is important to remove the interference signal before it enters the AGC and ADC.

A method for removing the NBI before the VGA is proposed in [7], using an adaptive analog notch filter to filter the NBI out of the received signal. Besides this digital frequency excision is applied for the filtered frequency bins. In addition to the use of an analog notch filter, a relatively complex DSP part based on banks of Operational Transconductance Amplifiers for the detection of the NBI is employed. One question which is not discussed is the policy for monitoring the existence or absence of the NBI.

In this paper a scheme for suppression of NBI employing adaptive digital filtering using the LMS algorithm to adapt to the central frequency of the NBI, is presented. Compared with the desired wideband signal the interference occupies a much narrower frequency band, but with a higher power spectral density. On the other hand the UWB signal has autocorrelation properties quite similar to that of AWGN, so filtering in the frequency domain could be realized. The filtering is performed at the input of the OFDM demodulator. To do this, a simple variable filter section with independent tuning of the central frequency and the bandwidth is used which is then turned into adaptive to implement it in an OFDM receiver. The realization of the filter structure, the evaluation of its parameters and the adaptive algorithm are presented.

The study shows that the proposed scheme could be applied to combat NBI which causes the signal-to-interference ratio (SIR) to drop significantly and deteriorate the performance of the UWB system. Advantage of the proposed scheme is that mitigation of the NBI is performed at the input of the OFDM receiver, before the variable gain amplifier (VGA) and monitoring of the NBI is straightforward.

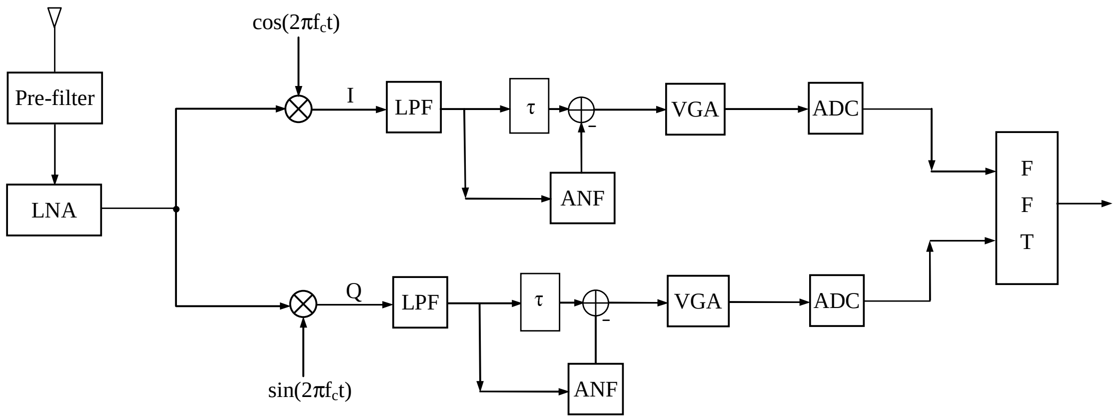

Fig.1. UWB-OFDM receiver with NBI cancellation

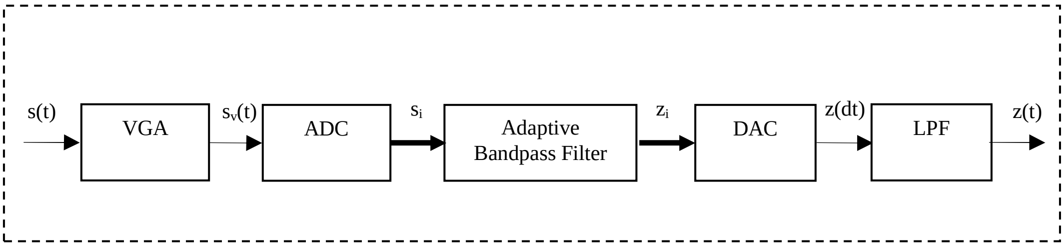

Fig.2. Adaptive NBI Filtering scheme (ANF)

2 NBI CANCELLATION SCHEME

In an UWB-OFDM receiver, the received signal first is pre-filtered and amplified with a low noise amplifier (LNA) and then down–converted to baseband. The inphase and quadrature components are low-pass filtered (LPF), amplified by a variable gain amplifier and converted by an analog-to-digital converter (Fig.1). In a standard OFDM system the signal from the output of the ADC is fed to the OFDM demodulator, where the output data signal is obtained after removing cycle prefix, FFT, deinterleaving, demapping, channel decoding, etc.

Important issue for such a scheme is the value of the NBI to be constantly monitored, as it could appear at different frequencies, change or vanish. This is done via the adaptive narrowband interference digital filtering scheme (ANF), shown in Fig.2. The VGA and ADC in the filtering scheme are designed for better monitoring of the interference signal. They could be different from the ones used in a standard demodulator, as the parameters there are designed in accordance with the useful signal.

3 ADAPTIVE NARROWBAND FILTERING

A realization based on second-order Gray-Markel lattice circuit is used [8] – Fig. 3. Using that circuit it becomes possible to implement a second-order notch/bandpass filter illustrated in Fig. 4.

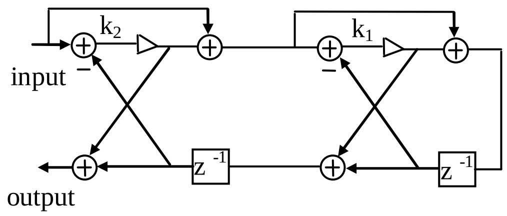

Fig.3. Second-order lattice Gray-Markel circuit realizing all-pass function A(z)

This implementation has two very important advantages: first extremely low passband sensitivity that means resistance to quantization effects, second independent control of central frequency and filter bandwidth.

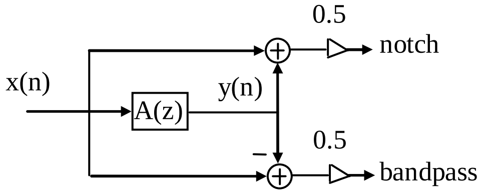

Fig.4. Second-order notch/bandpass filter

Thus if the allpass function A(z) is

$$A(z) = \frac{k_2 + k_1(1+k_2)\, z^{-1} + z^{-2}}{1 + k_1(1+k_2)\, z^{-1} + k_2 z^{-2}} \quad (1)$$

then k_1 controls the central frequency ω_0 while k_2 is related to the bandwidth BW via

$$k_1 = -\cos\omega_0 \quad (2)$$

$$k_2 = \frac{1-\tan(BW/2)}{1+\tan(BW/2)}. \quad (3)$$

BW is directly connected to the distance from the pole to the unity-circle and transforming the structure in Fig.4 into an adaptive filter, it is possible to fix the bandwidth and implement an adaptive IIR filter free of stability problems. Adapting k_1 the central frequency can be shifted around the unity-circle.

For the adjustment of filter coefficient a Least Mean Squares (LMS) algorithm is applied as follows

$$k_1(n+1) = k_1(n) - \mu e(n)[x(n-1) - y(n-1)] \quad (4)$$

where e(n) is the error signal and μ is the step size controlling the convergence speed.

In order to ensure the stability of the adaptive algorithm the range of the step size μ should be set according to [9]

$$0 < \mu < \frac{K}{L\sigma^2}. \quad (5)$$

In this case L is the filter order, σ^2 is the power of the signal [x(n-1) – y(n-1)] and K is a constant depending on the statistical characteristics of the input signal. In most of the practical situations K is approximately equal to 0.1.

4 SIMULATION MODEL

To evaluate the performance of the NBI suppression scheme simulations relative to baseband were conducted assuming standard MB-OFDM receiver.

The information source is modeled by a generator of uniformly distributed random integers based on the modified version of Marsaglia's “Subtract with borrow algorithm” [10]. This classes of non-linear random number generators, called add-with-carry (AWC) and subtract-with-borrow (SWB), are capable of quickly generating very long-period pseudo-random number sequences using very little memory. These sequences are essentially equivalent to linear congruential sequences with very large prime moduli. So, the AWC/SWB generators can be viewed as efficient ways of implementing such large linear congruential generators. This method can generate all the double-precision values in the closed interval $[2^{-53}, 1-2^{-53}]$. Theoretically, it can generate over 2^{1492} values before repeating itself.

The channel encoder is implemented as a convolutional encoder. Several code rates are possible: 1/2, 2/3, 1/4. In the simulation, the code rate: Rc = 1/2 is chosen. In the receiver, a Viterbi hard threshold convolutional decoder is implemented.

A block interleaver - deinterleaver is implemented in the simulation which chooses a permutation table randomly using the initial state input that is provided.

The digital modulator is implemented as 256-point IFFT. The OFDM symbol consists of 128 data bins and 2 pilot tones. Each OFDM data can use different modulation formats. In the experiments Grey encoded 64-QAM (Fig.5 - 10) and QPSK (Fig.12,13,14) modulation formats are used. After the IFFT process, the prefix and postfix guard intervals are added. Finally, to minimize the spectrum leakage and limit the frequency bandwidth, a Raised Cosine Window with row-off factor Beta = 0.025, is applied to the complex OFDM symbol.

The impact of the channel is modeled as an equivalent signal at the input of the OFDM receiver. This signal product consists of three terms: faded multipath signal, broad-band white Gaussian noise (AWGN) and Narrow Band Interference (NBI) signal. For the UWB simulation experiments IEEE 802.15.3a channel models CM1 and CM2 are applied [11,12].

The NBI suppression adaptive filter is connected at the receiver’s input. An adaptation algorithm tunes the filter in such a way that its central frequency and bandwidth match to the NBI signal spectrum. In the simulations, the central frequency of the filter is chosen in such a way that it is equal to the NBI central frequency, while its bandwidth is equal to 50% of the bandwidth between two adjacent OFDM sub-carriers.

At the receiver side, in the digital demodulator the guard prefix and postfix intervals are removed. The signal is windowed and 256-point FFT is applied. The pilot tones are removed and respective channel equalization of the OFDM symbol is applied. Finally, corresponding QPSK or 64-QAM demodulation is performed.

Using this general simulation model different experiments where performed, estimating the bit error ratio (BER) in function of the Signal to Interference Ratio (SIR) and/or Signal-to-Interference and AWGN ratio (SINR).

5 EXPERIMENTAL RESULTS

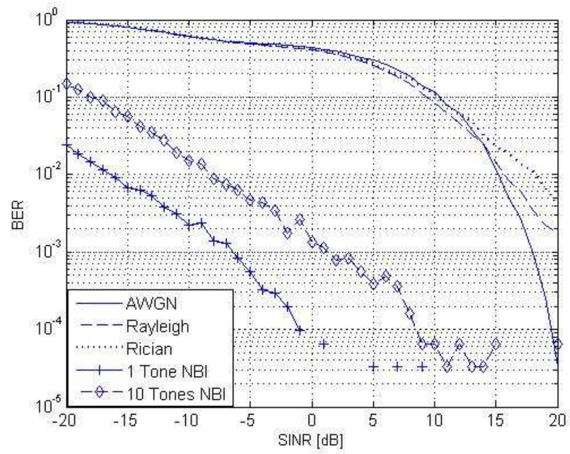

Fig. 5. BER versus SINR for fading channels

In Fig.5, the three top curves, illustrate typical simulation scenarios – AWGN, Rayleigh and Rician channel. The bottom two curves represent a ten tone NBI signal (no AWGN or fading) that occupies about 50% of the frequency band between two adjacent OFDM sub-carriers and a single NBI signal with frequency which is in between of two adjacent OFDM sub-carriers. It is seen that for low levels of NBI (SIR > 0 dB), the BER is almost constant i.e. the introduced errors by the NBI are completely recovered by the error correction coding and interleaving applied in the OFDM system model. In real OFDM channels, the above three main types of disturbing phenomenon (AWGN, Fading, NBI) coexist, thus causing significant degradation of system performance.

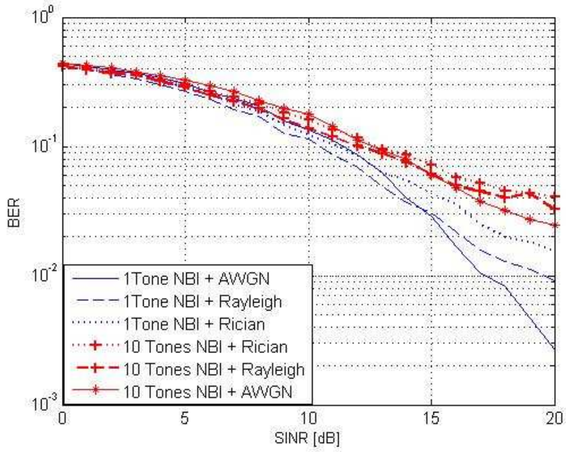

Fig.6. BER for constant level NBI

Another test scenario is given in Fig.6. The constant level NBI (SIR = -10 dB) is added to the channel, thus obtaining two families of curves, for one single tone NBI signal between two neighboring OFDM carriers, and for a 10 tone NBI signal. It can be observed that for SINR<15dB the predominant factor of BER performance is AWGN or fading phenomena (Rayleigh or Rician) as the NBI level is fixed to -10 dB. For SINR levels higher than 16 dB, where the power of the signal is significantly higher than the noise power, the predominant deterioration factor is the level of NBI, fixed to -10 dB. For example, having SINR = 20 dB for one tone NBI curve gives BER = $2.10^{-3.}$ If this result is compared to the results from Fig.5 for the one tone NBI curve and BER = 2.10^{-3}, the corresponding SIR is about -10 dB, which is exactly the test case for Fig.6.

In Fig.7 simulation for two main cases are illustrated – when the NBI signal coincides with the OFDM tone, and NBI signal is between adjacent OFDM tones. For each case, four different fading channels are simulated: Ideal, AWGN, Rayleigh and Rician. The SNR of the channel is fixed and equal to 15 dB (AWGN). The SIR is varied from -20 dB to +10 dB. The results show that when the NBI tone coincides with the OFDM sub-carrier, the BER is about to be constant. In the simulation example two levels of error correction are used: convolutional coding with code rate Rc = ½ and block interleaving. The results point out that for ideal channel, when the NBI coincides with the OFDM sub-carrier, the errors due to NBI are corrected.

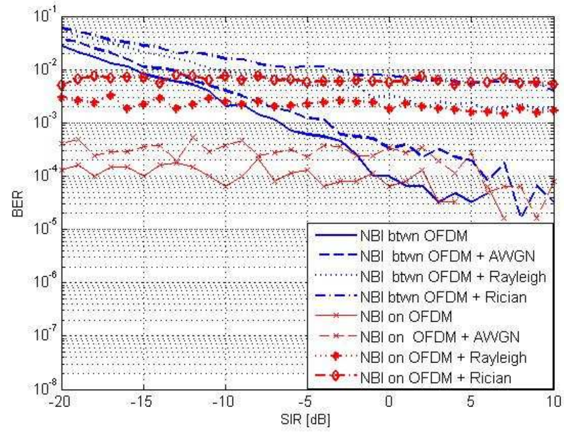

Fig.7. BER versus SIR with different NBI spectral position

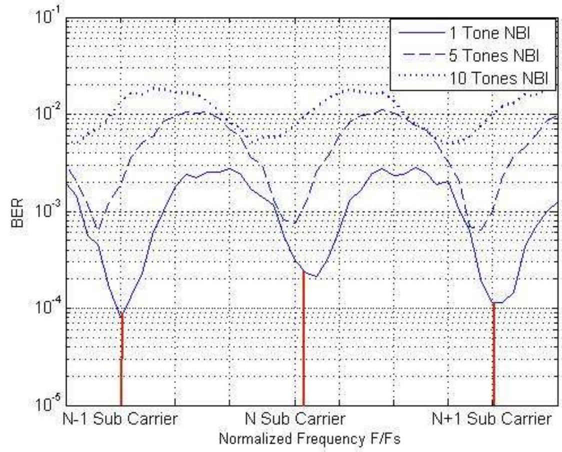

Fig.8. BER of ideal channel as function of NBI position

The BER performance of an ideal OFDM channel with NBI signal, as a function of NBI position in the spectrum of the OFDM signal, is plotted in Fig.8. Three curves are given: for single tone NBI signal, for five tones NBI signal and for ten tones NBI signal respectively. The level of NBI is fixed to: SIR = -10 dB. It is observed that when the single tone NBI has the same frequency as the OFDM sub-carrier, the BER has minimum with the aid of the error correction codes applied in the model. When the frequency of the interfering signal is being shifted in between the two adjacent OFDM sub-carriers, the BER increases and comes to the maximum at the middle between the sub-carriers. This effect is due to the spectrum leakage during the FFT process in the demodulator. Increasing the number of NBI tones causes direct increase of the spectrum leakage energy.

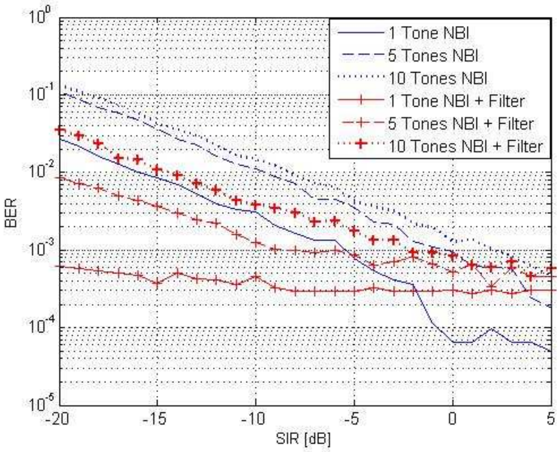

Fig.9. BER versus SIR with and without ANF

Fig.9 plots BER performance curves of an ideal OFDM channel with and without ANF scheme. The central frequency of the NBI signal is fixed at the middle between two adjacent OFDM sub-carriers. The NBI filter is tuned by the adaptation algorithm, in the way that, its central frequency coincides with the center frequency of the NBI signal. The SIR is being varied from -20 dB to 5 dB. It is seen that for lower SIR the performance of the ANF scheme is better. For SIR > 0 dB, the BER is almost constant due to the used error correction codes. However, this result is not in contrast with the simulation results given in Fig.7, because for SIR > 0 dB, the BER for the "NBI+Filter" case is higher than the BER for the "NO Filter" case, due to the amplitude and phase distortion introduced by the NBI Filter. In the case of multi-tone NBI, further improvement of the BER could be obtained by using a windowing technique before the FFT process in the demodulator.

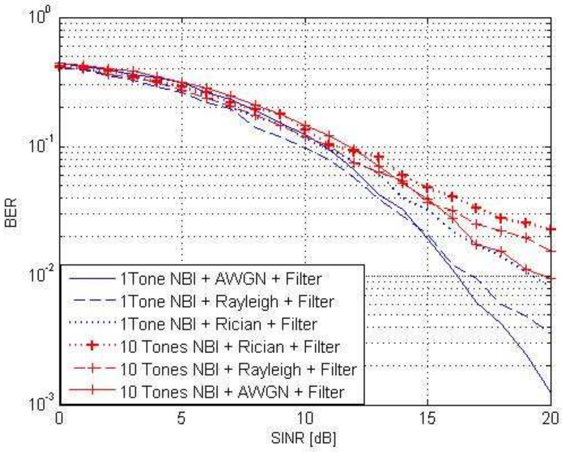

Fig.10. BER versus SINR for channels with SIR=-10dB

Fig.10 shows the simulation results for different fading channel plus NBI signal. The NBI Filter is applied to the OFDM signal. The modeled NBI signal has a constant level, such that SIR = -10 dB and frequency that is in between the adjacent OFDM sub-carriers. Observation of the simulation results and comparison to Fig.6 shows that the NBI filtering is especially efficient for middle and high SNR, a case when the NBI is predominant factor for BER performance. The application of the NBI filter leads to an extra gain of about 9 dB in BER performance.

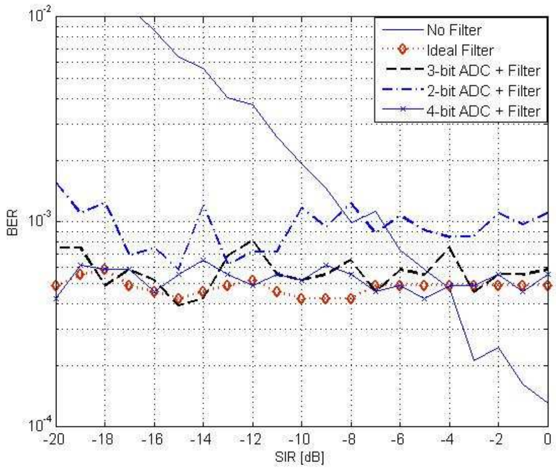

Fig.11. BER versus SIR for different ADC

Fig.11 presents the results for a possible realization of the ANF- the "feed-forward correction" topology. The effect of quantization and the length of the ADC word are modeled. Several test scenarios of an ANF realization are plotted: No filter, ideal filter, 2-bit ADC, 3-bit ADC and 4-bit ADC. The simulation results show that successful NBI suppression can be achieved using a 4-bit ADC and sufficient quality of NBI mitigation is achieved by using 3-bit ADC.

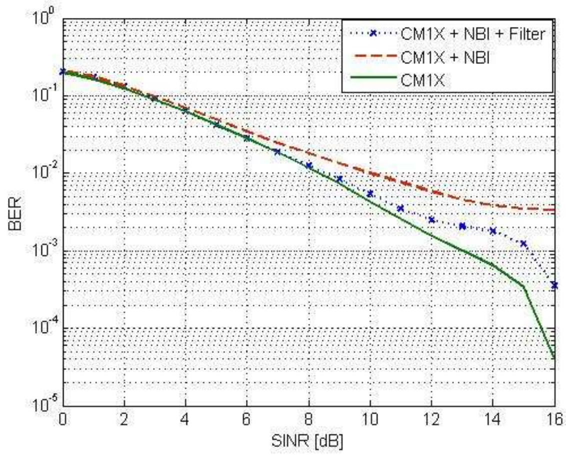

Fig.12. BER versus SINR for UWB channel CM1

More realistic scenarios for MBV-UWB systems are illustrated in Fig.12,13,14. Fig.12 shows the BER in function of the SINR for UWB channel model 802.15.3a, type CM1, QPSK modulation and 1 tone NBI, with constant SIR=-10dB. It could be seen that the filtering scheme improves the overall performance for SINR>10dB.

The reason for this is the fact that for lower SINR the AWGN is predominant. Fig.13 shows the experimental results for BER as function only of the SIR, for CM1 UWB channel model. The AWGN SNR is constantly set to 16dB. The filtering scheme performs very well for SIR<0dB, as expected. The same experiment for CM2 channel model is shown in Fig.14. It could be seen that for SIR>0, there is a performance degradation due to the amplitude and phase distortion of the filter, as commented previously for Fig.9. This could be improved by the implementation of a higher-order notch filter or simply by switching off the ANF when SIR>0. This is easily realizable as the amplitude of the NBI can be monitored from the bandpass output of the filter (Fig.4).

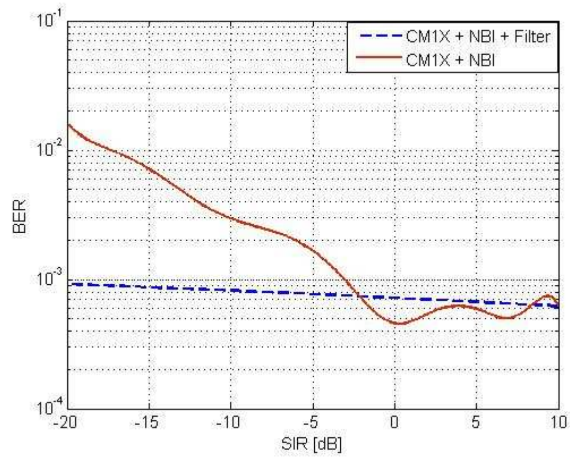

Fig.13. BER versus SIR for UWB channel CM1

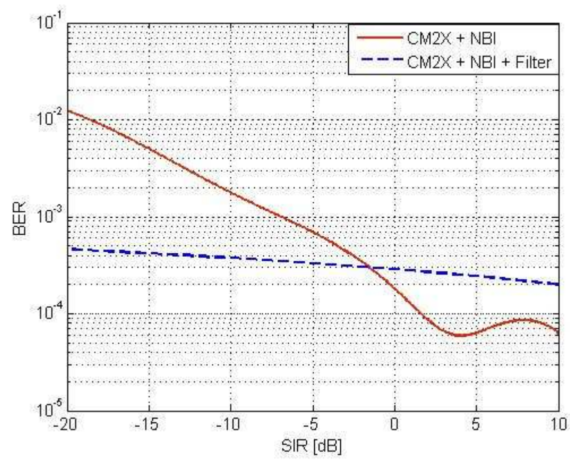

Fig.14. BER versus SIR for UWB channel CM2

6 CONCLUSIONS

A scheme for the mitigation of narrowband interference in OFDM ultra wideband systems has been proposed using an adaptive narrow-band digital filter section. Main advantage of the proposed scheme is that NBI cancellation is performed at the input of the UWB-OFDM receiver. The adaptive narrowband filtering exhibits low computational complexity and fast convergence. Simulation experiments have been performed for different types of scenarios, including MB-UWB system performance for different channel models. The results show that considerable improvement of the performance is obtained for SIR lower than 0 dB, using this relative simple adaptive filter section.

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