

# An Efficient Improving Of dm Receiver Performance in an Impulsive Noise Environment with Blanking Nonlinearity

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**ABSTRACT**-The aim of this paper is to investigate the effect of impulsive noise on the performance of the OFDM (orthogonal frequency division Multiplexing) system. The employed model of impulsive noise consists of Bernoulli distributed impulsive arrivals and Gaussian distributed amplitudes of the impulses. A simple method of improving OFDM receiver performance in an impulsive noise environment is to precede a conventional OFDM demodulator with blanking nonlinearity. The effect of changing impulsivity of noise and different relative power of impulsive noise are investigated and are compared with Additive Whit Gaussian Noise (AWGN) case. Also the performance of the OFDM receiver with blanking nonlinearity in the presence of impulsive noise will be studied. Closed form analytical expressions for the signal-to-noise ratio (SNR) at the output of blanking nonlinearity and the optimal blanking threshold that maximizes SNR are derived.

## 1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) also called Multicarrier (MC) technique is a modulation method that can be used for high-speed data communications. In this modulation scheme transmission is carried out in parallel on different frequencies. This technique is desirable for transmission of the digital data through the multipath fading channels. Since by the parallel transmission, the deleterious effect of fading is spread over many bits, therefore, instead of a few adjacent bit completely destroyed by the fading, it is more likely that several bits are only slightly affected by the channel. The other advantage of this technique is its spectral efficiency. In

the MC method the spectra of subchannels overlap each other while satisfying orthogonality, giving rise to the spectral efficiency [1].

One of the challenging problems in practical applications of wireless digital communication techniques is a data transmission over channels with man-made noise that appears in typical urban environments. The man-made noise created by vehicle ignition systems, power lines, heavy current switches and other sources cannot be assumed to be Gaussian, and has to be represented by impulsive models [2-4].

In this paper, a Bernoulli-Gaussian model for the impulsive noise is employed and is shape by a proper filter. The bit error rate performance results are provided using different impulsivity of the noise and different relative power of impulsive noise. Besides from impulsive noise, AWGN is also considered. The problem of optimal threshold selection and performance characterization of the OFDM receiver that uses blanking nonlinearity for impulsive noise cancellation is also considered.

## 2. Basic Principles of OFDM

OFDM is a parallel transmission scheme, where a high-rate serial data stream is split up into a set of low-rate sub streams, each of which is modulated on a separate subcarrier (SC) (frequency division multiplexing). Thereby, the bandwidth of the subcarriers becomes small compared with the bandwidth of the channel [9]. Using digital modulation format, the transmitted OFDM symbol waveform can be represented as [9]

$$S(t) = \text{Re} \left\{ \sum_{k=0}^{N-1} d(k) \exp(j2\pi f_k t) \right\} \dots\dots\dots (1)$$

where:

$d(k)$ : is the modulated data symbol

$f_c$ : is subcarrier frequency of  $k^{th}$  subcarrier which is equal to  $(f_c + k\Delta f)$ .

$\Delta f$ : is subcarrier spacing (bandwidth) equal to  $(1/NT)$ .

$f_c$ : is the carrier frequency.

This expression represents the passband OFDM signal, if the equivalent complexbaseband notation is used which is given by [9]

$$S(t) = \sum_{k=0}^{N-1} d(k) \exp(j2\pi k \Delta f t) \dots\dots\dots (2)$$

Equation (2) represents the general form of complex baseband OFDM signal. At the receiver, all operations in the transmitter are reversed. It is shown that an OFDM signal is effectively the inverse Fourier Transform of original data stream, and the bank of coherent demodulators is effectively the Fourier Transform.

If the signal is sampled at a rate of  $(T)$ , then  $(t=nT)$ , and for orthogonality  $(\Delta f = 1/NT)$ , then Equation (2) can be rewritten as [9]:

$$s(n) = \sum_{k=0}^{N-1} d(k) \exp(j2\pi kn/N) \dots\dots\dots (3)$$

Equation (3) is exactly the Inverse Discrete Fourier Transform (IDFT) of the data sequence  $d(k)$  [9]. Further reductions in complexity are possible by using the Fast Fourier Transform (FFT) algorithm to implement the DFT.

### 3. Impulsive Noise Model

The model discussed in the following is a Bernoulli-Gaussian (BG) model of an Impulsive Noise (IN) process. The random time of occurrence of the impulsive is modeled by a Bernoulli process  $b(k)$ , where  $k$  is the time point and  $b(k)$  is a binary-valued process that takes a value of “1” with a probability of  $\alpha$  and a value of “0” with probability of  $(1 - \alpha)$ . The amplitude of the impulsive is modeled by a Gaussian process  $g(k)$  with mean zero and variance  $2\sigma$ . Each

impulsive is shaped by a filter with the impulsive response  $h(k)$ . The Bernoulli-Gaussian model of impulsive noise is illustrated in Fig.(2). The IN can be expressed as [1]:

$$n(k) = \sum_{i=0}^{P-1} h(i)g(k-i)b(k-i) \dots\dots\dots (4)$$

where:

$P$ : is the length of the impulsive response of the impulsive shaping filter.

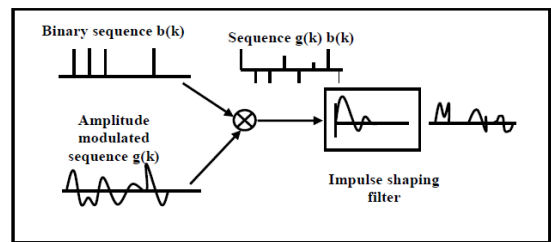


Figure (2) Impulsive noise model

In a Bernoulli-Gaussian model the probability density function (pdf) of impulsive noise

$n(k)$  is given by [1]:

$$\text{pdf}_N^{BG}(n(k)) = (1 - \alpha)\delta(n(k)) + \alpha \text{pdf}_N(n(k)) \dots\dots\dots (5)$$

where:

$\delta(n(k))$ : is the Kronecker delta function and:

$$\text{pdf}_N(n(k)) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{1}{2} \left(\frac{n(k)}{\sigma}\right)^2} \dots\dots\dots (6)$$

is the probability density function of a zero Gaussian process. In this regard we also define a parameter that controls the power ratio of the AWGN part and the “impulsive” part of the total noise as [1]:

$$\gamma = \text{power (AWGN\_component) / power (impulsive\_component)} \dots\dots\dots (7)$$

with the definition of  $\gamma$  the noise impinging the system consists of IN and AWGN with a manageable ratio of power.

### 4. System Model

Figure (3) shows the block diagram of a typical OFDM transceiver. In the transmitter section, the input serial data stream is formatted into the word size required for transmission, e.g. 2 bits/word for QPSK, and shifted into a parallel format. The data is then transmitted in parallel by assigning each data word to one carrier in the transmission. Then the information bits are mapped into baseband symbols  $S_k$  using DQPSK scheme.

An IFFT is then used to convert this signal to the time domain, and to produce the orthogonality between subcarriers, allowing it to be transmitted. In practice, these samples are not enough to make a real OFDM signal. The reason is that there is no oversampling present, which would introduce intolerable aliasing if one would pass these samples through a digital-to-analog converter. To introduce oversampling, a number of zeros can be added to the input data vector. Hence, if oversampling is used, the zeros should be added in the middle of the data vector rather than appending them at the end. These are also used to center the spectrum. This ensures the zero data values are mapped onto frequencies close to plus and minus half the sampling rate, while the nonzero data values are mapped onto the subcarriers around 0Hz [9].

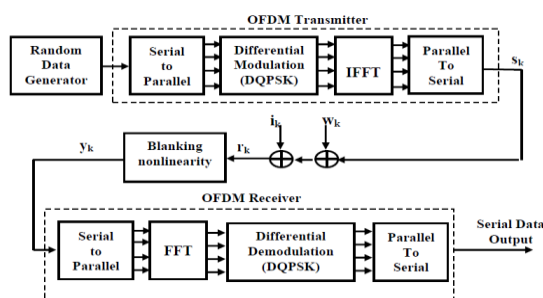


Figure (3) Block diagram of OFDM transceiver

It then digital-to-analog conversion is applied to the complex baseband OFDM signal as Equation (2). The time-domain received signal after down-conversion, analog-to-digital conversion, and perfect synchronization can be expressed as [11]:

$$r = s + w + i, \quad k=0,1,\dots,N-1 \quad (8)$$

where:

$$s_k = s(kT/N).$$

$w_k$ : is the additive white Gaussian noise (AWGN), and  $i_k$ : is the impulsive noise ( $s_k$ ,  $w_k$  and  $i_k$  are assumed to be mutually independent).

The noise term  $u_k = w_k + i_k$  in Equation (8), can also be expressed in terms of the two-component mixture-Gaussian model, which is widely accepted and frequently used for performance analysis of various transmission schemes in impulsive noise environment. To reduce energy of the impulsive noise, the *blanking nonlinearity* can be applied to the received baseband signal  $r_k$  before the conventional OFDM demodulator [11]:

$$y_k = \begin{cases} r_k & \text{if } |r_k| < \lambda \\ 0 & \text{otherwise} \end{cases} \quad (9)$$

where:

$\lambda$  : is threshold value.

Nonlinearity of Equation (9) reduces the effect of large received signal values as these are assumed to be the result of impulsive noise. The receiver performs the reverse operation of the transmitter. Fast Fourier Transform (FFT) is used to analyse the signal in the frequency domain. The amplitude and phase of the subcarriers are then picked out and converted back to digital data, then decoded to produce binary output data.

## 5. Signal to Noise Ratio at the Output of Nonlinearity

### 5.1 SNR Definition

To assess the receiver performance we should first represent the output of nonlinear preprocessor Equation (9) as:

$$y_k = K_0 s_k + d_k, \quad k = 0, \dots, N-1 \quad (10)$$

where: the first term on the right-hand side of Equation (10) represents the scaled replica of information-

bearing signal,  $d_k$  is the cumulative noise/distortion term, and  $K_0$  is the appropriately chosen scaling factor. It is usually desirable to have a zero-mean noise process

$$(d_k = y_k - K_0 s_k) \text{ uncorrelated with the useful signal, i.e. } E[d_k s_k^*] = 0.$$

The optimal scaling factor in Equation (10), which

satisfies  $E[d_k s_k^*] = 0$  can be found as [11]:

$$K_0 = \frac{E[y_k s_k^*]}{E[s_k^2]} = \frac{1}{2} E[y_k s_k^*] \dots\dots\dots (11)$$

When  $K_0$  is chosen in accordance with Equation (11), the signal-to-noise ratio (SNR) after impulsive noise preprocessing can be expressed as [11]:

$$\psi = \frac{E[K_0 s_k^2]}{E[y_k - K_0 s_k^2]} = \left( \frac{E[y_k^2]}{2K_0^2} - 1 \right)^{-1} \dots\dots\dots (12)$$

where:

$E[y_k^2]$ : represent the total signal power (i.e. useful signal power plus noise/distortion power) at the output of blanking nonlinearity.

In accordance with the system model presented in Section (4),  $s_k$ ,  $w_k$  and  $g_k$  are mutually uncorrelated white spectrum sequences. Therefore, the noise process  $d_k$  is also white, and SNR is constant for all OFDM subchannels. Note that  $\psi$  can also be used to characterize output of OFDM demodulator, since SNR at the input of OFDM demodulator (DFT) and SNR at its output are equal [12].

The following analysis relies on the assumption that the number of OFDM subcarriers is sufficiently large ( $N \rightarrow \infty$ ), and the OFDM signal can be modeled as a complex Gaussian process with Rayleigh envelope distribution [11,12].

### 5.2 Optimal Scaling Factor and the Total Signal Power at the Output of Blanking Nonlinearity

Using representation of the signal at the output of blanking nonlinearity given by

Equation (9), it is straightforward to express Equation (11) as [11]:

$$K_0 = \frac{1}{2} E[(s_k + w_k) s_k^* | \bar{C}, \bar{I}] P(\bar{C}, \bar{I}) + \frac{1}{2} E[(s_k + w_k + g_k) s_k^* | C, I] P(C, I) \\ = \frac{1}{2} E[s_k^2 | \bar{C}, \bar{I}] P(\bar{C}, \bar{I}) + \frac{1}{2} E[s_k^2 | C, I] P(C, I) \\ + \frac{1}{2} E[w_k s_k^* | \bar{C}, \bar{I}] P(\bar{C}, \bar{I}) + \frac{1}{2} E[(w_k + g_k) s_k^* | C, I] P(C, I) \dots\dots\dots (13)$$

where:

$C$ : is the event of clipping a signal above level  $\lambda$ ,

$\lambda$ : is threshold value,

$g_k$ : is a Gaussian process with mean zero and variance  $2\sigma$  (see Equation (4)) and

$I$ : is the event of impulsive noise occurring (and  $C$  and  $I$  are their complements).

$$P(\bar{C}, \bar{I}) = P(A_r < T | \bar{I}) (1 - \alpha) = (1 - \alpha) \left( 1 - e^{-\frac{\lambda^2}{2(1+\sigma_g^2)}} \right) \dots\dots\dots (14)$$

On the other hand, if received sample is affected by impulsive noise,  $A_r$  has a Rayleigh distribution with parameter  $\sigma^2 = 1 + \sigma_w^2 + \sigma_g^2$ , and, as a consequence,  $P(C, I)$  is expressed as:

$$P(C, I) = P(A_r > T | I) \alpha = \alpha \left( 1 - e^{-\frac{\lambda^2}{2(1+\sigma_w^2+\sigma_g^2)}} \right) \dots\dots\dots (15)$$

The closed-form expression for  $K_0$  <sup>(1)</sup>:

$$K_0 = 1 - \left( 1 + \frac{\lambda^2}{2(1+\sigma_w^2)} \right) (1 - \alpha) e^{-\frac{\lambda^2}{2(1+\sigma_w^2)}} \\ - \left( 1 + \frac{\lambda^2}{2(1+\sigma_w^2+\sigma_g^2)} \right) (1 - \alpha) e^{-\frac{\lambda^2}{2(1+\sigma_w^2+\sigma_g^2)}} \dots\dots\dots (16)$$

It is worth noting that the optimal  $K_0$  is a real constant, which means that the signal constellation at the input of the decision device is not rotated. On the other hand, there is constellation shrinking after blanking nonlinearity, since  $K_0 \leq 1$ . The total signal power at the output of blanking nonlinearity can be expressed as:

$$E[|y_k|^2] = E[|y_k|^2 | \bar{C}, \bar{I}] P(\bar{C}, \bar{I}) + E[|y_k|^2 | \bar{C}, \bar{I}] P(\bar{C}, \bar{I}) \dots \dots \dots (17)$$

Finally, substituting Equation (16) and Equation (17) in Equation (12), immediately results in a closed-form expression for SNR at the output of blanking nonlinearity [11].

The closed-form expression for  $E[|y_k|^2]$  is:

$$E[|y_k|^2] = 2(1 + \sigma_w^2 + \alpha \sigma_i^2) - (1 - \alpha) \left( \lambda^2 + 2(1 + \sigma_w^2) \right) e^{-\frac{\lambda^2}{2(1 + \sigma_w^2 + \alpha \sigma_i^2)}} - \alpha \left( \lambda^2 + 2(1 + \sigma_w^2 + \sigma_i^2) \right) e^{-\frac{\lambda^2}{2(1 + \sigma_w^2 + \sigma_i^2)}} \dots \dots \dots (18)$$

### 7. Simulation Results

After the proposed system for the OFDM has been designed as shown in Fig.(3), the simulation of this system using MATLAB version 7 is achieved. Simulations of the OFDM system with various impulsivities ( $\alpha$ ) and power of impulsive noise to respect to AWGN ( $\gamma$ ) are considered and the BER performance is evaluated. Typical values for  $\alpha$  are 0.1, 0.01, 0.001, and 0.0001 and that for  $\gamma$  are 1, 5 and 10. The impulse response of the filter  $h(t)$  is 9<sup>th</sup> order low pass filter with cutoff frequency 5MHz. In this simulation the OFDM signal have subcarriers number  $N=1024$ , transmitted in AWGN and impulsive noise channel, number of transmission bits are about 30000 bits. **Figure (4)** shows the flowchart of blanking nonlinearity that is used in this work. **Figure (5)** shows BER performance versus the threshold value as percentage of maximum absolute value of the received signal for SNR=15 dB,  $\gamma=10$  and different values of  $\alpha$ . It can see from this figure for  $\alpha=0.001$  the best chosen of threshold when it equals 90% of maximum absolute received signal with BER= $4 \times 10^{-4}$ , while BER=0 when blanking nonlinearity is used. Similarly for  $\alpha=0.1$  where the best chosen of threshold equals 40% of maximum absolute received signal with BER=0.1089, while BER=0.1095 when blanking nonlinearity is used. This means that threshold values depends on the level of the received signal and parameters of the impulsive noise and blanking nonlinearity gives good estimation for the optimum threshold.

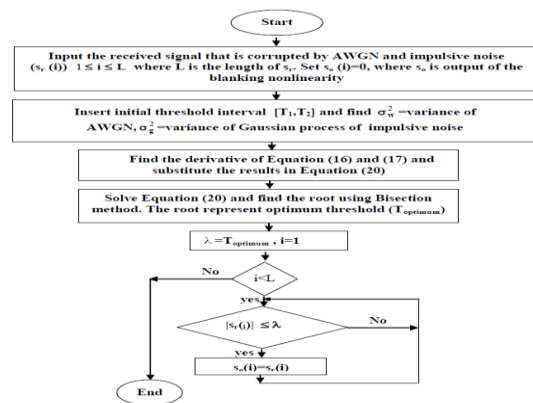


Figure (4) Flowchart of blanking nonlinearity

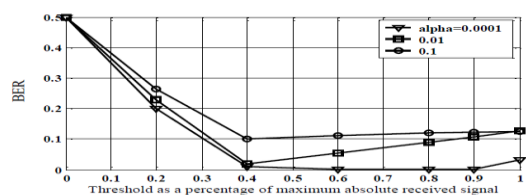


Figure (5) BER performance versus threshold value for SNR=15 dB  $\gamma=10$  and different values of  $\alpha$

**Figures (6, 7 and 8)** show the influence of  $\alpha$  on the BER performance of an OFDM system with  $\gamma=1, 5$  and 10 respectively. **Figure (9)** show the effect of  $\gamma$  on the BER performance of an OFDM system with  $\alpha=0.001$ . From these figures can be noticed that: For high impulsivity ( $\alpha=0.0001$ ), BER increase and required more SNR to obtain BER about 10-4 comparing with AWGN only (i.e. about 2 dB is required for  $\gamma=1$  and about 6 dB for  $\gamma=5$ ). Any further increase of  $\alpha$  value will increase BER. For given  $\gamma$ , when  $\alpha$  increase more and more has no effect (or small effect) on BER performance (as can be seen for  $\alpha=0.01$  and 0.1). Any increase in  $\gamma$ , will increase BER.

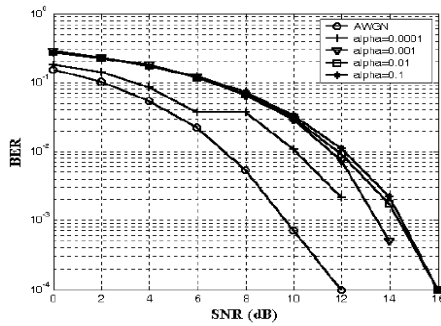


Figure (6) The influence of  $\alpha$  on BER performance of an OFDM system with  $\gamma=1$

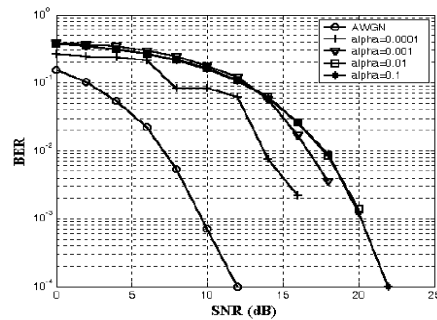


Figure (7) The influence of  $\alpha$  on BER performance of an OFDM system with  $\gamma=5$

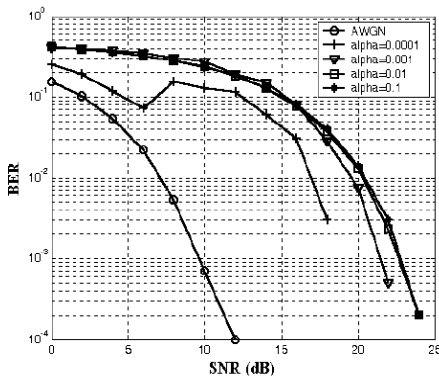


Figure (8) The influence of  $\alpha$  on BER performance of an OFDM system with  $\gamma=10$

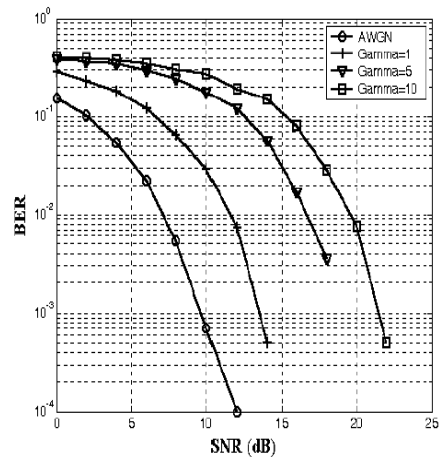


Figure (9) The influence of  $\gamma$  on BER performance of an OFDM system with  $\alpha=0.001$

Figures (10-12) show the influence of blanking nonlinearity on the BER performance of an OFDM system with different values of  $\alpha$  and  $\gamma=1,5$  and 10 respectively. Figures (13-16) show comparison results of an OFDM system with and without blanking non linearity method.

for  $\gamma=10$  and  $\alpha=0.0001, 0.001, 0.01$  and 0.1 respectively. From these figures some points can be noticed:

For  $\alpha=0.0001$  and 0.001, the impulsive noise can be suppressed by using blanking nonlinearity method, even though  $\gamma$  is increased. For  $\alpha=0.01$ , the impulsive noise can be minimized but not fully suppressed. This minimizing becomes less when SNR is increased. For  $\alpha=0.1$ , the minimizing is very small and special for high SNR.

For high values of  $\alpha$  the characteristics of impulsive noise reaches from Gaussian noise and therefore blanking nonlinearity is failed to suppress the impulsive noise. In general, the blanking nonlinearity is very good method when is used with an OFDM system with high noise impulsivity ( $\alpha$  is small), for every value of  $\gamma$

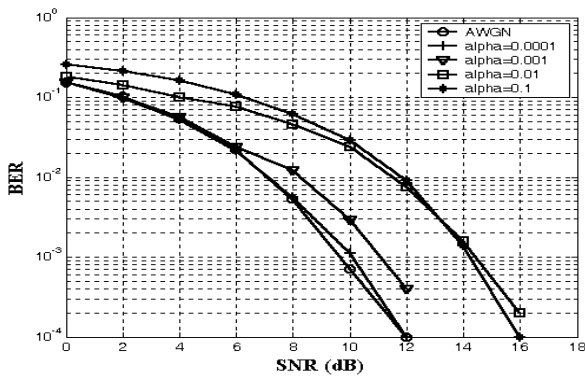


Figure (10) The influence of the blanking nonlinearity on the BER performance of an OFDM system for different values of  $\alpha$  and  $\gamma = 10$

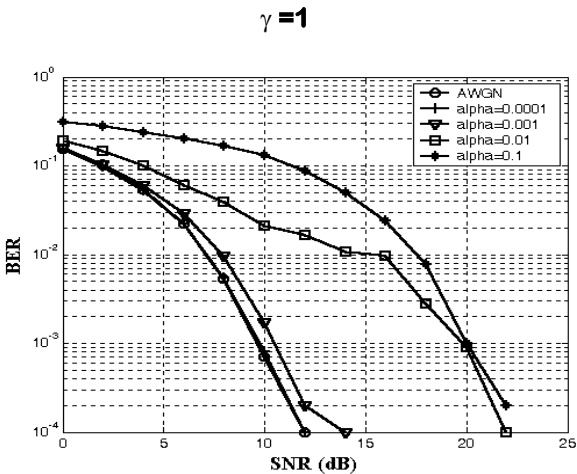


Figure (11) The influence of the blanking nonlinearity on the BER performance of an OFDM system for different values of  $\alpha$  and  $\gamma = 5$

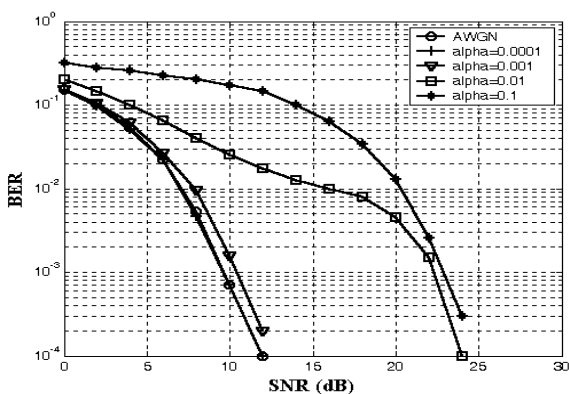


Figure (12) The influence of the blanking nonlinearity on the BER performance of an

OFDM system for different values of  $\alpha$  and

$\gamma = 10$

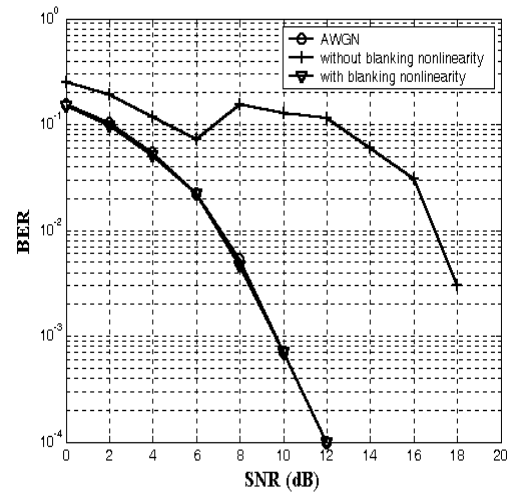


Figure (13) Comparison results of an OFDM system with and without blanking nonlinearity for  $\gamma = 10$  and  $\alpha = 0.0001$

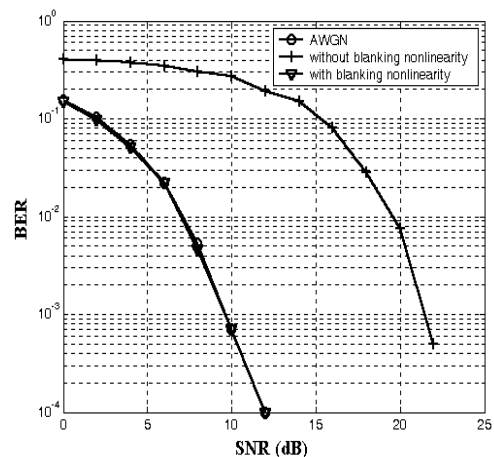
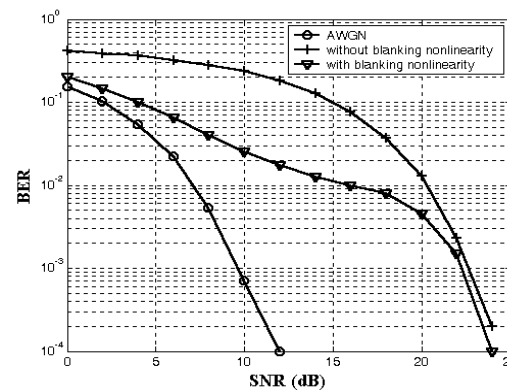
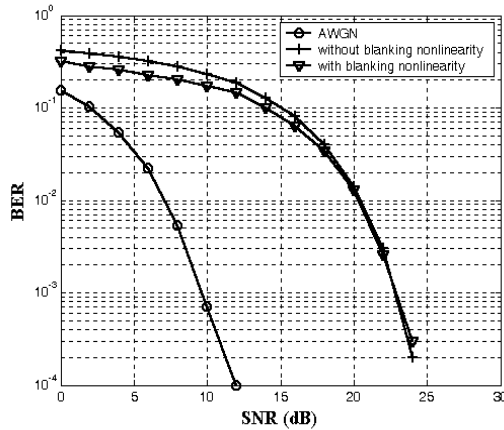


Figure (14) Comparison results of an OFDM system with and without blanking nonlinearity for  $\gamma = 10$  and  $\alpha = 0.001$



**Figure (15) Comparison results of an OFDM system with and without blanking nonlinearity for  $\gamma = 10$  and  $\alpha = 0.01$**



**Figure (16) comparison results of an OFDM system with and without blanking nonlinearity for  $\gamma = 10$  and  $\alpha = 0.1$**

### 8. Conclusion

Simulation results show that the performance of an OFDM system in the impulsive noisy environment depends on the impulsivity of the noise ( $\alpha$ ) and its power relative to the AWGN ( $\gamma$ ). The impulsive noise can be suppressed in an OFDM system by using blanking nonlinearity. But this method is not perfect method for high value of  $\alpha$ .

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