1. Introduction:

Orthogonal frequency division multiplexing (OFDM) is one of the multi-carrier Modulation (MCM) techniques that transmit signals through multiple carriers these Carriers (subcarriers) have different frequencies and they are orthogonal to each other orthogonal frequency division multiplexing techniques have been applied in both wired and wireless communications, such as the asymmetric digital subscriber line (ADSL) and The IEEE 802.11 standard.

It is well known that Chang proposed the original OFDM principles in 1966[1], and successfully achieved a patent in January of 1970 Later on, Saltsburg analyzed the OFDM performance and observed that the crosstalk was the severe problem in this System. Although each subcarrier in the principal OFDM systems overlapped with the Neighborhood subcarriers, the orthogonally can still be preserved through the staggered QAM (SQAM) technique.

However, the difficulty will emerge when a large number of Subcarriers are required. In some early OFDM applications, the number of subcarriers can be chosen up to 34. Such 34 symbols will be appended with redundancy of a guard time Interval to eliminate inter symbol interference (ISI) [2].

However, should more subcarriers be required, the modulation, synchronization, and coherent demodulation would induce a very complicated OFDM requiring additional Hardware cost in 1971, Weinstein and Ebert proposed a modified OFDM system[3] in which the discrete Fourier Transform (DFT) was applied to generate the orthogonal Subcarriers waveforms.

Their scheme reduced the implementation complexity significantly, by making use of the IDFT modules and the digital-to-analog converters in their proposed model, baseband signals were modulated by the inverse DFT (IDFT) in the transmitter and then demodulated by DFT in the receiver.

Therefore, all the Subcarriers were overlapped with others in the frequency domain, while the DFT Modulation still assures their orthogonally.

Moreover, the windowing technique was introduced in this paper to attack the Inter-symbol interference (ISI) and inter-carrier interference (ICI) problems Thanks to These evolutions, modern low-cost OFDM systems have become plausible cyclic prefix (CP) or cyclic extension was first introduced by Peled and Ruiz in 1980 For OFDM systems. In their scheme, conventional null guard interval is substituted by cyclic extension for fully-loaded OFDM modulation. As a result, the orthogonally among the subcarriers was guaranteed.

With the trade-off of the transmitting energy Efficiency, this new scheme can result in a phenomenal ICI reduction. Hence it has been adopted by the current IEEE standards in 1980[4], Hirosaki introduced an equalization algorithm to suppress both ISI and ICI, which may have resulted from a channel distortion, synchronization error, or Phase error [5].

In the meantime, Hirosaki also applied QAM modulation, pilot tone, and Trellis coding techniques in his high-speed OFDM system, which operated in voice-band Spectrum in 1985, [6] Camino introduced a pilot-based method to reduce the interference emanating from the multipath and co-channels. In 1989, Kalet suggested a Subcarrier-selective allocating scheme [7].

He allocated more data through transmission of "good" subcarriers near the center of the transmission frequency band; these Subcarriers will suffer less channel distortion.

In the 1990s, OFDM systems have been exploited for high data rate Communications. In the IEEE 802.11 standard, the carrier frequency can go up as high as 2.4 GHz or 5 GHz. Researchers tend to pursue OFDM operating at even much higher Frequencies nowadays. For example, the IEEE 802.16 standard proposes yet higher Carrier frequencies ranging from 10 GHz to 60 GHz.

1.2 Motivation:

The demand for future higher data rate communications always provides the Impetus for this research.

It is obvious that a parallel system is capable of carrying more Information than a cascade system, simply because it uses a variety of frequency bands however, the significant advantage of OFDM is that it is robust in frequency-selective Channels, which result from either multipath fading's or other communication interferences.

The interference problem is severe especially for some systems working in The Unlicensed National Information Infrastructure (U-NII) operating frequency range, Such as the IEEE802.11a standard under any of these conditions, the channel has non-Uniform power gains, as well as nonlinear phases across frequencies [8].

1.3Related Work:

In this paper there have proposed a self-cancellation method which uses for sub carriers for a particular data transmission to reduce the Phase Rotation of the received signal there have compared the phase rotation of the received signal with respect to the Carrier Frequency Offset (CFO) of their proposed scheme with the ICI Self Cancellation Schemes. From our simulation, there find that their proposed scheme provides less rotation to the received data for a particular CFO than any other schemes [9].

In this paper among different ICI self-cancellation methods, the data-conjugate method shows the best performances compared with the original OFDM, and the data-conversion method since it makes CPE to be zero along with its role in significant reduction of ICI [10].

This paper investigate the three main methods of suppressing the ICI produced during transmission i.e. Extended kalman filter method of ICI reduction, Self-cancellation method of ICI reduction and Maximum likelihood method of ICI reduction a simulation program has been designed to investigate the performance of these methods of ICI reduction under noisy environment[11].

There analyze the frequency diversity of inter carrier interference (ICI) reduction methods in the presence of phase noise over multipath fading channels. Based on analysis, there propose an enhanced symmetric data conjugate (ESDC) method to exploit the frequency diversity in multipath fading channel there derive carrier-to-interference ratio (CIR) expression of proposed ICI reduction scheme.

The BER performance of the proposed system is compared with conventional ICI reduction methods such as adjacent data conjugate and symmetric data conjugate methods Simulation results show that the proposed ICI reduction scheme provides an improvement in BER performance over a fading channel and it is also better than conventional ICI reduction techniques in the presence of ICI due to phase noise [12].

The study in this paper highlights different problems or issues of OFDM system like high PAPR, synchronization, and Inter-Carrier-Interference (ICI). This review also summarizes the methods available in the literature to overcome these problems [13].

There compare two methods to combat ICI Self Cancellation (SC) and Extended Kalman Filter (EKF) method these methods are compared in terms of bit error rate and bandwidth efficiency. EKF method performs better than SC method this will be shown by simulations [14].

This paper proposes an efficient ICI self-cancellation scheme to combat the impact of ICI on OFDM systems. In this scheme at the transmitter side, one data symbol is modulated onto four subcarriers with appropriate weighting coefficients. At the receiver side, the linear combination of the received signals on these subcarriers leads to a sufficient reduction in ICI.

A detailed analysis and simulation over AWGN channel proves that the proposed scheme achieves better BER (Bit Error Rate) performance and CIR improvement than the existing self-cancellation schemes [15].

There compare two methods to combat ICI: ICI Self Cancellation (SC) and Maximum likelihood (ML) method. These methods are judge against in terms of bit error rate and bandwidth efficiency. ML method performs enhanced than SC process this will be exposed by simulation [16].

When it is combined with OFDM systems; it eliminates the fading effect and with requirement of lower Bandwidth it provides high Throughput. Yet having a number of advantages; it suffers from some limitations like ISI, ICI and PAPR these are the factors which degrades the System Performance [17].

In this paper the effect of ICI has analyzed and different techniques has been used to reduce the ICI effect. The first method is a self-cancellation scheme and other one is using an extended kalman filter [18].

In this paper the effect of ICI has analyzed and different techniques has been used to reduce the ICI effect. The first method is a self-cancellation scheme and other one is using an extended kalman filter. We also analyze the ICI without reduction [19].

In this paper, First OFDM system is modeled and simulated under different channel conditions such as AWGN and Rayleigh fading. Subsequently pulse shaping technique for ICI power reduction in OFDM systems is investigated. A number of pulse shaping functions such as Rectangular pulse shape, Sinc power pulse (SP) and Improved sinc power pulse (ISP) have been considered for ICI power reduction. The performance of each pulse shaping function is evaluated and compared with each other using the parameters such as ICI power, SIR (Signal to Interference Ratio) and BER (Bit Error Rate). It is found that ISP pulse shape outperforms to all other pulse shaping functions by the above parameters [20].

There compare two methods to combat ICI: ICI Self Cancellation (SC) and Maximum likelihood (ML) method. These methods are compared in terms of bit error rate and bandwidth efficiency. ML method performs better than SC method this will be shown by simulations [21].

Ne IC redo&on of the technique is comparable to the rate-half technique while the throughput of the former is higher than that of the latter. In Paper, three suboptimal methods, i.e.9 the random seleaion9 the modified pFs9 and the recursive partial sequence methods, are also proposed to lower the Mutational complete. Their performances are evaluated and camped by simulations [22].

1.3 Problem statement:

Orthogonal frequency division multiplexing (OFDM) is considered as a one of the best modulation schemes in wireless communications however, OFDM suffers from the sensitivity to frequency offset. This frequency offset introduces the problem of inter-carrier interference (ICI) in OFDM system.

1.5 Scope:

The project will implement the modified self-cancellation technique by using MATLAB (code), in 4th generation of mobile communication system in downlink direction (OFDM) and comber but to self-cancellation technique.

1.6 Objective:

This project presents compare but self-cancellation technique and (modified self-cancellation technique).

In proposed technique a zero sub-carriers carries are used in order to mitigate the interference occurred by the main – lobe of the two adjacent sub-carriers, in addition to zeros sub-carrier, the proposed technique used *self-cancellation* in order to mitigate the effect of the side-lobes of other sub-carriers.

1.7 Methodology:

MATLAB will be to implement the ICI reduction technique (self-cancellation zero-gab) by generating code.

In order to compare between the proposed scheme and the *self-cancellation* scheme, the *BER* curves were used to evaluate the performance of each schemes

Modulation scheme of quadrature amplitude modulation (QAM) was chosen, different values of normalized frequency (0.1, 0.5, 0.8 and 1.1 were used).

BER performance of the proposed system is outperformed the *BER* performance of the two other systems While the *BER* performance for the OFDM using the *self-cancelation* technique is outperformed the *BER* performance of the standard OFDM system.

The *CIR* is used in order to compare and evaluate the performance of the two different cancellation schemes the results of the *CIR* curves are shown.

1.8 Research out line:

In the 1st chapter the study concerns and their relatives are introduce.

In the 2nd chapter the literature of topics related to the project is reviewed, and link adaptation concept and its implementation in OFDMA transceiver are summarized.

In the 3rd chapter, the proposed methodology that is used for modulation and coding schemes technique a zero sub-carriers carries are used in order to mitigate the interference occurred by the main – lobe of the two adjacent sub-carriers, in addition to zeros sub-carrier, the proposed technique used *self-cancellation* in order to mitigate the effect of the side-lobes of other sub-carriers.

In chapter 4, Using MATLAB to implement the ICI reduction technique (self-cancellation zero-gab) by generating code In order to compare between the proposed scheme and the *self-cancellation* scheme, the *BER* curves were used to evaluate the performance of each schemes the *CIR* is used in order to compare and evaluate the performance of the two different cancellation schemes the results of the *CIR* curves are shown.

Finally, in the 5th chapter the conclusion and recommendations for future studies are summarized.

2. Literature review:

In OFDM, the subcarrier frequencies are chosen so that the subcarriers are orthogonal to each other, meaning that crosstalk between the sub channels is eliminated and inter-carrier guard bands are not required. This greatly simplifies the design of both the transmitter and the receiver. In conventional FDM, a separate filter for each sub-channel is required.

In some respects, OFDM is similar to conventional frequency-division multiplexing (FDM). The difference lies in the way in which the signals are modulated and demodulated. Priority is given to minimizing the interference, or crosstalk, among the channels and symbols comprising the data stream. Less importance is placed on perfecting individual channels.

OFDM is used in European digital audio broadcast services. The technology lends itself to digital television, and is being considered as a method of obtaining high-speed digital data transmission over conventional telephone lines. It is also used in wireless local area networks.

Orthogonal frequency-division multiplexing (OFDM) is a method of digital modulation in which a signal is split into several narrowband channels at different frequencies. The technology was first conceived in the 1960s and 1970s during research into minimizing interference among channels near each other in frequency.

OFDM is used in WiMAX 802.16a as a radio access scheme in fixed communication scenarios, it uses 256 FFT length, and channel bandwidth up to 10 MHz [23].

2.1Channel

When a study involved with high frequencies radio transmission, we are often challenged to a multipath environment. Such environments are found mostly in urban areas where buildings reflect waves.

2.1.1Frequency selectivity:

One problem of multipath is that the consequent of waves from different paths can be constructive or destructive depending on the position, so signal change over time when moving.

Generally we speak of a frequency selective channel. Characteristics may change fast when moving. That's why the channel is also time varying [24].

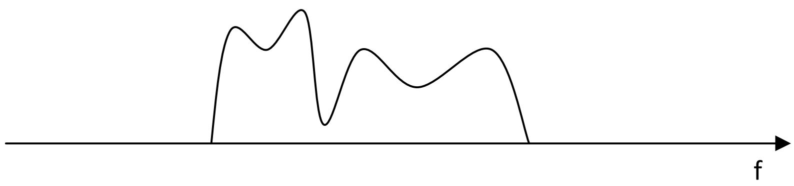


Figure (1.2): Typical frequency response of a channel suffering from multipath propagation

The aim of equalization is to compensate the problems introduced by frequency selectivity [25].

2.1.2 Delay spread:

Another impact that affects digital transmission is that the signal coming from different paths has different time delays depending on the length of path. A result of that is affecting the memory of channel which cause an Inter Symbol Interference (ISI) between symbols received.

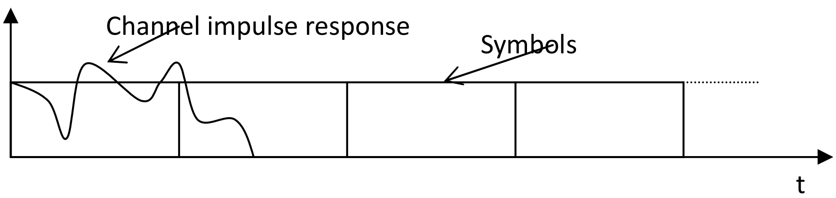


Figure (2.2): Inter Symbol Interference (ISI)

2.2 Specification description:

This section is inspired and established as the time line of OFDM appearance and development requirements.

2.1.1 Single-carrier wideband transmission problem:

Equalization is performed in order to avoid inter-symbol interference when transmitting wideband on frequency selective channels. Equalisation used to introduce more flatness to the channel. In order to do that channel state information (CSI) is needed. Training sequences have then to be transmitted periodically to estimate channel. Channel estimation is CPU time consuming that because it performed by several calculations. So when data rate is high and when characteristics of channel change rapidly CPU power needed is high and system becomes more complex expensive [26].

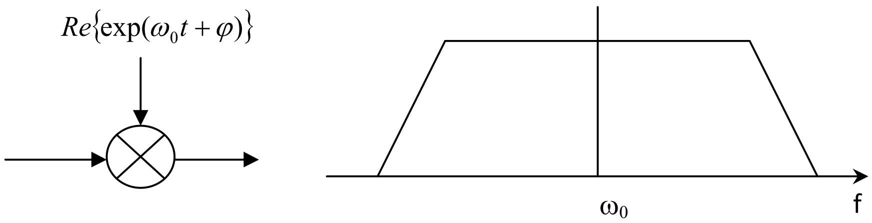


Figure (2.3): Single carrier system

Also the symbol period is very small compared to the channel memory. That cause strong Interference (ISI) and equalization is needed to correct that problem [27].

2.1.2 Multicarrier transmission:

The idea of multicarrier transmission is to divide the bandwidth in several narrow-band transmissions so that the channel looks flat on each carrier. The data stream to transmit is then split among the carriers instead of being transmitted on one carrier with large signal bandwidth. That's what is meant by Frequency Division Multiplex (FDM) the advantage is that no or less complex equalization is needed [28].

The symbol period on each carrier become large and the effect of channel memory (length of channel impulse response) become less destructive on the symbols, so Inter Symbol interference (ISI) is reduced and less equalisation is needed [29].

Each carrier is modulated using any known modulation scheme like QAM and PSK schemes.

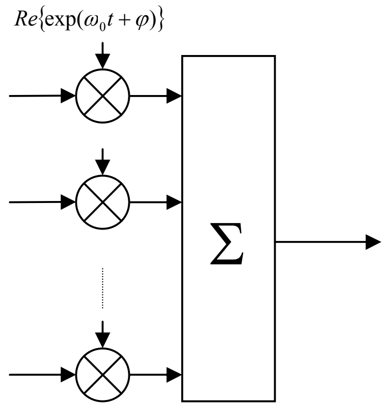
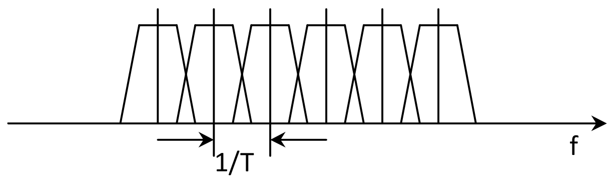


Figure (2.4): Multi carrier system

2.1.3Orthogonality:

In a transmission system, we want the occupied bandwidth on the channel to be as small as possible. For that, in a multicarrier system, we try to set a minimum frequency space between carriers without having inter-carrier interference (ICI). The minimum space is reached when carriers are orthogonal to each other, signal from each can have a small overlap on the other without causing interference. That's what is meant by the « O »



(Orthogonal) of OFDM. We'll see further that the inverse Fourier transform has that orthogonality property [30].

Figure (2.5): orthogonality

Consider the time-limited complex exponential signal $\left\{e^{j2\pi f_k t}\right\}_{k=0}^{N-1}$ which represent the different subcarriers at $f_k = k/T_{sym}$ in the OFDM signal, where $0 \le t \le T_{sym}$. These signals are defined to be orthogonal if the integral of the products for their common (fundamental) period is there, mathematically [31]:

$$\frac{1}{T_{sym}}\int_0^{T_{sym}} e^{j2\pi f_k t}\, e^{-j2\pi f_i t} dt = \frac{1}{T_{sym}}\int_0^{T_{sym}} e^{j2\pi \frac{k}{T_{sym}} t}\, e^{-j2\pi \frac{i}{T_{sym}} t} dt =$$

$$\frac{1}{T_{sym}}\int_0^{T_{sym}} e^{j2\pi \frac{(k-i)}{T_{sym}} t}\, dt = \begin{cases} 1, & \forall\ integer\ k = i \\ 0, & otherwise \end{cases} \quad 2.1$$

Taking the discrete samples with the sampling instances at $t = nT_s = nT_{sym}/N$, where $n = 0,1,2,\ldots,N-1$, the equation above can be written in the discrete time domain as [6]:

$$\frac{1}{N}\sum_{n=0}^{N-1} e^{j2\pi \frac{k}{T_{sym}} .nT_s}\, e^{-j2\pi \frac{i}{T} .nT_s} = \frac{1}{N}\sum_{n=0}^{N-1} e^{j2\pi \frac{k}{T_{sym}} . \frac{nT}{N}}\, e^{-j2\pi \frac{i}{T_{sym}} . \frac{nT_{sym}}{N}} =$$

$$\frac{1}{N}\sum_{n=0}^{N-1} e^{j2\pi \frac{(k-i)}{N} n} = \begin{cases} 1, & \forall\ integer\ k = i \\ 0, & otherwise \end{cases} \quad 2.2$$

The orthogonality above is an essential condition for the OFDM signal to be ICI-free [6].

2.1.3 The guard interval:

One way to avoid Inter-symbol interference is to set a small gap equal to the duration of delay spread between the symbols. So, each symbol does not affect the next one. We'll also see later that this interval plays an important role in the implementation.

2.2Mathematical description:

Let us consider the general problem of transmitting a signal $S(t)$ over the time-varying channel $c(t, \tau)$. The sampling version of $S(t)$ is a bit stream S[n] that is de-multiplexed onto N carriers.

2.2.1 Multicarrier approach:

The bit stream S[n] is shared onto all carriers, each one to be produced some data to transmit. Then the bit stream is divided in sub-stream $(X_n[k])_{0 \le k \le N-1}$ called OFDM symbol, we use two indexes n being time index and k the sub-stream index (index used for carrier recognition). The carriers do not receive an amount of bit since the bit stream is pre modulated, the required amplitude and phase of the carrier is then calculated using

BPSK, QPSK or QAM before de-multiplexing. A variant of OFDM is COFDM (coded orthogonal frequency division multiplexing), where forward error coding is applied to the signal before transmission, to overcome errors due to lost carriers from frequency selective fading, channel noise and other effects of propagation. But the main focus of this project is OFDM.

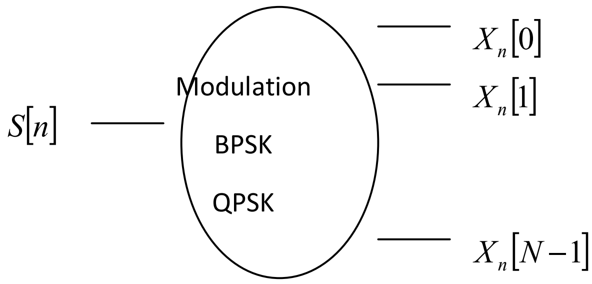
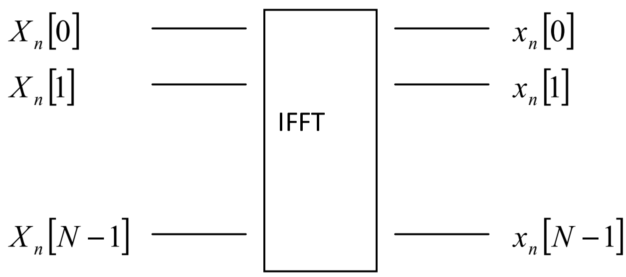


Figure (2.6): Modulation

2.2.2Inverse Fourier Transform:

OFDM uses the available spectrum efficiently by spacing the channels much closer together. This is achieved by making all the carriers orthogonal to one another, preventing interference between the closely spaced carriers. To generate OFDM successfully the relationship between all carriers must be carefully to maintain the orthogonality of the carriers. For that, after choosing the spectrum required, we have to



convert it back to its time domain signal using an Inverse Fourier Transform. In most applications, an Inverse Fast Fourier Transform is used; it performs the transformation very efficiently, and provides a simple way of ensuring the carrier signals produced are orthogonal.

Figure (2.7): Inverse Fourier Transform

$$x_n[l] = \frac{1}{N}\sum_{k=0}^{N-1} X_n[k]\exp\left(j2\pi l\frac{k}{N}\right)$$ For l = 0, 1… N-1 2.3

Adding a guard interval:

One of the most important properties of OFDM transmissions is the robustness against multipath delay spread. This is achieved by having a long symbol period, which minimizes the inter-symbol interference. The level of robustness can in fact be increased even more by addition of a guard interval between transmitted symbols. The guard period allows time for multipath signals from the previous symbol to die away before the information from the current symbol gathered. The most effective guard interval to use is a cyclic extension of the symbol. Why?

The Fast Fourier Transform that we will be use at the receiver transforms a cyclic time domain signal into its equivalent frequency spectrum. The signal $x_n[k]$ is not necessary cyclic… Let form a cyclic signal of $N + L - 1$ samples by repeating the last $L - 1$ samples $x_n[k]$ at the beginning of the signal. This technique is called guard interval by cyclic prefix. The number L of samples to repeat is taken more than the memory of the channel. So we the resulting cyclic prefixed signal is:

$$(x_n[N-L+1],\ldots,x_n[N-1],x_n[0],x_n[1],\ldots x_n[N-1])(4)$$

Limitation of bandwidth:

The frequencies used in OFDM are regularly spaced in the spectrum required so, the time domain signal $x_n[k]$ has to be limited in the frequency domain. For this reason we will make a convolution between the signal and a window function that has a spectrum limited exactly on the required one. (All window functions have a limited spectrum). We have chosen to use the raised cosine function to limit our signal spectrum and we will note it $g_*(t)$. The signal to send over the channel is:

$x^{\sim}[m] = \sum_{i=0}^{N+l-1} x_n[l]g + [m-l]$ 2.5

$$g_*(t) = \sin\ c(t/T)\frac{\cos(\propto \pi t/T)}{1-4\alpha^2 t^2/T^2}$$

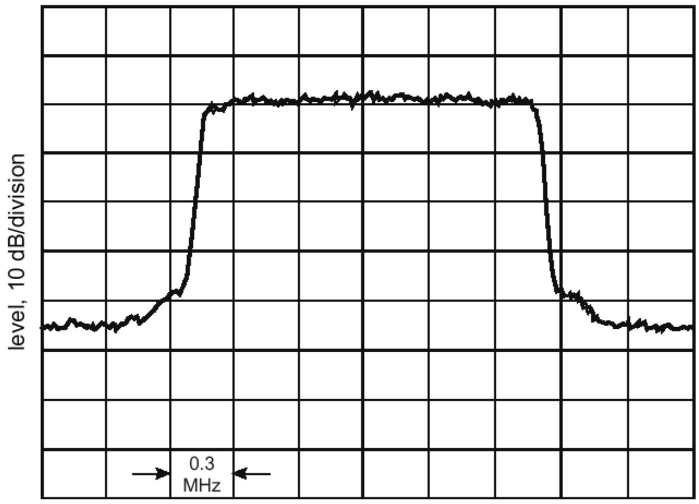


Figure (2.8): Example of an OFDM spectrum

Channel and receiver parts:

Let consider the problem of transmitting the signal $\tilde{x}_n[m]$ over the time-varying linear channel $c(t,\tau)$ without additional noise. If we call $c[m]$ the sampling version of the channel, then the output of obtained by the channel is [6]:

$$y_n^{\sim}[m] = \sum_{i=0}^{N+L-1} x_n^{\sim}[l]c[m-l] \quad \text{, where m = 0,1,…, N+L-1}$$

The receiver basically does the reverse operation to the transmitter. The signal received is $\tilde{y}_n[m]$ that has N+L-1 samples, before the demodulation, we have to drop the L last samples of the received signal, and then remove the guard period, in order to use correctly the Fourier Transform properties. Indeed the demodulation operation is a simple FFT according to the IFFT used as modulation. We need to find out N samples (one per carrier) as at the modulator input, let apply an FFT to the signal $\tilde{y}_n[m]$.

$Y_n^{\sim}[k] = \sum_{i=0}^{N-1} y_n^{\sim} \exp\left(-2\pi jk\frac{l}{N}\right)$ 2.6

$$Y_n^{\sim}[k] = \sum_{l=0}^{N-1}[\sum_{m=0}^{N+L-1} x_n^{\sim}[m]c[l-m]\exp\left(-2\pi jk\frac{l}{N}\right) \quad 2.7$$

$$\widetilde{Y}_n[k] = \left(\sum_{m=0}^{N+L-1}\widetilde{x}_n[m]\right)\sum_{l=0}^{N-1}c[l-m]\exp\left(-2\pi jk\frac{l}{N}\right) \quad 2.8$$

$$\widetilde{Y}_n[k] = \left(\sum_{m=0}^{N+L-1}\widetilde{x}_n[m]\exp\left(-2\pi jk\frac{m}{N}\right)\right)\Im(c[k]) \quad 2.9$$

The first term of the multiplication above looks like a Fourier Transform expression. In fact, if we restrict the summation index from m = 0 to m = N-1 it is equivalent to drop the L last samples of the signal $\widetilde{y}_n[m]$. So the signal produces by the demodulator is:

$$\widetilde{Y}_n[k] = \left(\sum_{m=0}^{N-1}\widetilde{x}_n[m]\exp\left(-2\pi jk\frac{m}{N}\right)\right)\Im(c[k]) \quad 2.10$$

$$\widetilde{Y}_n[k] = \Im(x_n[k])\Im(c[k]) \quad (11)$$

$$\widetilde{Y}_n[k] = X_n[k]C[k] \quad (12)$$

A simple division by the channel frequency response gets back the transmitted signal. This modulation does not need any equalization and the data samples are then combined back to the same size as the original data.

2.4OFDMdisadvantages:

2.4.1 Orthogonality issues

As seen above the fact to have several carriers is actually advantageous whenever they are mathematically orthogonal. So carrier's orthogonality is constrain that can leads to a wrong operation of OFDM systems if not respected. The orthogonality is provided by IFFT that a numerical manipulation, an error of computation could change lightly spacing between two consecutive carriers and break the orthogonality of the whole system. In this case OFDM loses all its efficiency, because the notion of orthogonality is an absolute one [].

2.4.2 Synchronization issues

One of the crucial problems in the receiver is to sample the incoming signal correctly. If the wrong sequence of samples is processed, the Fast Fourier Transform shall not correctly recover the received data on the carriers. The problem is more embarrassing when the receiver is switched on. There is therefore a need for acquiring timing lock. If the signal transmitted is really time domain periodic, as required for the FFT to be correctly applied, then the effect of the time displacement is to modify the phase of all carriers by a known amount. This is due to the time shift theorem in convolution transform theory.

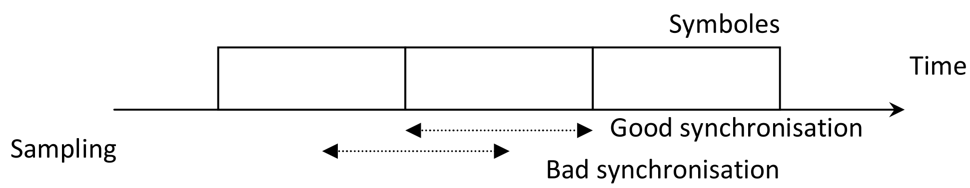


Figure (2.9): Symbols Synchronization

However, the signal is not really repetitive, we have cheated and performed the mathematical transform as if it were repetitive, but then chosen different symbols and transmitted them one after the other. The effect of the time shift would then be not only to add the phase shift referred to above, but also to add some Inter Symbol interference with adjacent symbols. This interference could hardly degrade reception [32].

To avoid these problems, we decide to transmit more than one complete sequence of time samples in order to increase the tolerance in timing. It's an additional data guard interval. It is built by repeating a set as long as channel memory of last samples taken in the original sequence. The longer guard interval size the more system weakness, but guard interval does not carry any useful information and its transmission leads to a reduction of power [32].

One technique used to obtain good synchronization is to add between each OFDM symbol a null (zero samples) symbol. This technique is used in DAB for time synchronization [33].

2.4.3 Peak Average Power Ratio (PAPR):

When the phase of different subcarriers adds up to form large peaks, an important complication comes in OFDM systems. This problem is called Peak Average Power Ratio (PAPR) and it is defined for each OFDM signal on a time interval $[n, n + Ts]$ by the following formula: For continuous signals

$$\chi_n = \frac{\max_{t\in[n,n+T_s]} |x(t)|^2}{\int_n^{n+t_s} |x^2(t)| dt} \quad 2.13$$

$$x_n = \frac{te_{[n,n+T]}^{max} |x(t)|^2}{\int_n^{n+t} |x^2(t)| dt} \quad 2.14$$

For sampled signals:

$$x_n = \frac{k^{max} |x_n[k]^2}{E\{\ \ |x_n[k]|^2\}} 2.15$$

In OFDM systems PAPR can have very high values for certain input sets of sample $(X_n[k])$ and overload non-linear characteristics of systems, causing inter-modulations among different carriers and undesired out-of-band radiation.

Another main drawback of PAPR can be seen as quantization noise domination towards the performance of system. This domination can be excited by avoiding the clipping effect of the maximum level of the Digital to Analogy Converter (DAC) that is set too high.

Various techniques are proposed to reduce PAPR in OFDM signals, but that reduction is not obvious because PAPR and SNR are closely linked. We will not expound those techniques in this paper, they can be found in reference [34].

2.4.4 Effect of clipping in OFDM signals:

When transmitted signals have high PAPRs, amplifiers may produce “clipping”. In some way, clipping can be regarded as peaks of the input signal being simply cut-off by amplifiers. Consequences of clipping are out-of-band radiation and inter symbol interference between subcarriers. In order to avoid these undesired effects that reduce

OFDM performances, one has either to use amplifiers with dynamic range, or try to reduce PAPR. The first alternative is expensive; the second one is more often used.

Phase noise:

At the receiver, a local oscillator can add phase noise to an OFDM signal, for example. The phase noise could so have two effects those are: Common Phase Error (CPE) due to a rotation of the signal constellation and, Inter Carrier Interference (ICI), similar to additive Gaussian noise. The BBC R&D have made analysis of the effects of phase noise on an OFDM signal, this analysis shows that CPE arises simultaneously on all carriers. Indeed, the signal constellation within a given symbol is subject to the same rotation for all carriers and this effect can be corrected by using reference information within the same symbol. Unfortunately, ICI is more difficult to overcome, due to the additive noise, which is different for all carriers. This difference can be interpreted as a loss of orthogonality.

2.4.5 Frequency error:

An OFDM system can be subject to two types of frequency error. They are Frequency offset (as might be caused by the tolerance of the local oscillator frequency) and, Error in the receiver master clock frequency (which will cause the spacing of the demodulating carriers to be different from those transmitted). Before to find solutions to those problems, the system designer needs to determine how much residual frequency error is permissible, and understand exactly how errors affect the received signal.

Both of these error situations have been analysed so, a frequency offset affects most carriers equally, with the very edge carrier less affected. ICI resulting from a fixed absolute frequency offset increases with the number of carriers, if the system bandwidth is kept constant. About error in the receiver clock frequency, in absence of frequency offset, it affects carriers unequally (the centre carrier suffers a little while the worst affected carrier lies close to, but not at, the edge).

2.4.6 General structure of an OFDM transmission system:

Implementation of OFDM modulation nowadays is almost every time performed digitally. Here’s a model of an OFDM transmission system

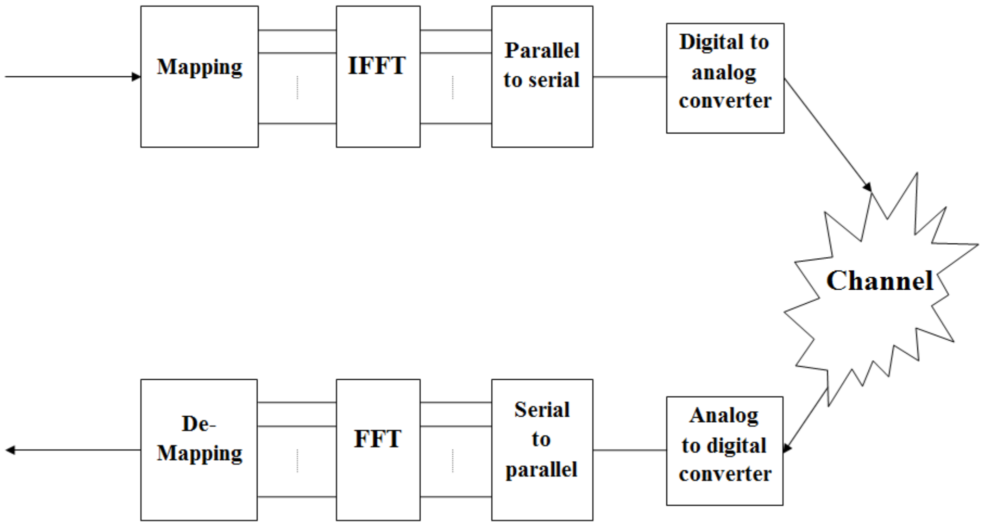


Figure (2.10): General OFDM structure

- Data coming from the input are arranged into vectors with number of components equal to the number of $\widetilde{N}$ carriers. Each component is composed by a number of bits depending on the alphabet of the modulation scheme used on the next stage. For example, if we use a 1536 carriers system with BPSK, we'll have vectors of 1536 component each one composed by 1 bit (BPSK is 2-ary).

- Each component (group of bits) is mapped into a complex symbol depending on the alphabet of the modulation scheme used. For example, with BPSK the alphabet is $\{ -1 ; +1 \}$.

- In order to obtain real samples after IFFT, a 2*Number of carrier points IFFT is done with :

$$X_{N-k} = X_k^*, k = 1, \dots, \widetilde{N} - 1$$
$$X_0 = \mathrm{Re}(X_0), X_{\widetilde{N}} = \mathrm{Im}(X_0)$$

- The Inverse Fast Fourier Transform algorithm (IFFT) is applied to the vector giving a real samples vector.

- The guard interval is added at the beginning of the vector by repeating the components of the end. Vectors are concatenated to form a time signal (parallel/serial conversion)
- Windowing the signal is necessary to limit the bandwidth. Most used window is the raised cosine.
- The signal is then passed through the channel. Channel is modelled by a linear system with frequency response c(t) together with a source of additive Gaussian noise.
- At the reception, signal is rearranged again into vectors (serial/parallel conversion) and guard interval is dropped.
- Fast Fourier Transform (FFT) is computed in order to get back the complex vector of symbols.

3.1 Complex coefficient:

A discrete time situation is considered. In any symbol interval, N symbols XX_0, XX_0, $\cdots XX_{NN-1}$ will be transmitted using N sub-carriers $\phi_0[n]$, $\phi_1[n]$, $\cdots\phi\phi_{NN-1}[nn]$, the resulting signal is:

$$[nn] = XX_0\phi\phi_0[nn] + XX_1\phi\phi_1[nn] + \cdots XX_{NN-1}\phi\phi_{NN-1}[nn] \qquad 3.16$$

In OFDM system this sub-carrier takes the following values:

$[n] = \frac{1}{-} * \exp$ NN = number of symbols and sub-carriers.

ll = discrete frequency.

nn = time symbol.

By substituting eq. (17) in eq. (16) the result will be:

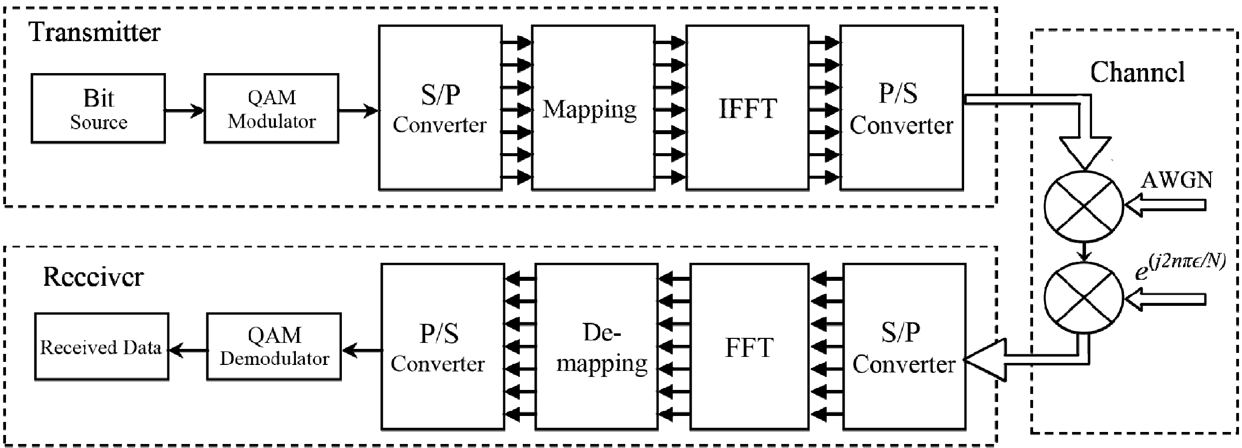


Figure (1): A block diagram of an OFDM system.

$$y[n] = 1/N \sum_{i=0}^{n-1} Xi * \exp\left(\frac{j2\pi/n}{N}\right) \qquad 3.18$$

Eq. (3.19) represents the transmitted signal if the impulse response of the transmission filter is ignored. It is assumed that: the channel introduces only shift in frequency and ignoring the effects of random noise, impulse response of the channel and impulse response of the receiver filter. So the received signal will be:

$$y[n]=1/N\sum_{i=0}^{N-1} xi \quad * \exp\left(\frac{j2\pi(i+€)/n}{N}\right) \qquad 3.19$$

Whereϵ is normalized frequency shift which occurs due to frequency miss-match between local oscillator in the sender and receiver or the *Doppler shift*.

ϵcan be defined as: $\epsilon = \Delta f T$, $\epsilon = 0$ means there is no shifting in frequency, $\epsilon = 1$ means that the frequency shift is equal to the difference between two adjacent subcarrier [1/(Symbol period)]. For example, data sent in sub-carrier (0) will be received in sub-carrier (1). At the receiver, FFT is applied to convert the received signal from time-domain to frequency-domain. The received signal in sub-carrier *k* can be represented as follow:

$$Y_k=1/N\sum_{i=0}^{N-1} y[n] * \exp\left(\frac{-j2\pi Kn}{N}\right) \qquad 3.20$$

By defining complex weighting coefficients (1), (2) $\cdots(N-1)$, which give the contribution of each of the inputs $X_1, X_2 \cdots X_{mm-1}$ to the output value YY_{kk} , eq. (20) can be rewritten as follow:

$$Y_k = X \cdot S(0) + \sum_{\substack{i=0 \\ i\neq k}}^{N-1} X \cdot S(l-k) \qquad 3.2$$

The first term in the right side of eq. (21) represents the wanted signal and the second term represents unwanted signal (ICI components).

3.2 Carrier to Interference Ratio:

Carrier to interference ratio (*CIR*) can be defined as a ratio between the wanted power and unwanted power. It increases when normalized frequency shift ($\epsilon\epsilon$) decreases and vice versa. It is used to determine the performance of the whole system. The goal of all ICI reduction algorithms is to get a larger value of CIR. The theoretical *CIR* for standard OFDM can be written as:

$$CIR = abs(S(0)) \div \sum_{\substack{i=0 \\ i\neq k}}^{N-1} abs((l-k)) \qquad 3.22$$

This equation can be applied for all kinds of modulation and any number of subcarriers; but the derivation assumes that: the standard transmitted data has zero mean, the symbols transmitted on the different subcarriers are statistically independent, and the additive noise is omitted. This equation is verified by simulation results as shown later.

3.3 Contribution (Adjacent sub-carriers):

Figures (12) and (13) show how each sub-carrier contributes in sub-carrier 0 and the figures (14) and (15) shows the case for sub-carrier 3.

In the both cases, the desired signal decreases and the undesired signals increases when the normalized frequency shift (ϵ) is increased. And the desired signal increases and the undesired signals decreases when the normalized frequency shift (ϵ) is decreased.

It can also be noticed that the adjacent carrier has the maximum contribution in the ICI. When normalized shift (ϵ) is negative, the maximum contribution in the ICI component comes from the left sub-carrier as shown in the figures (12) and (14). When (ϵ) is positive, the maximum contribution to the ICI component comes from the right sub-carrier as shown in the figures (13) and (15).

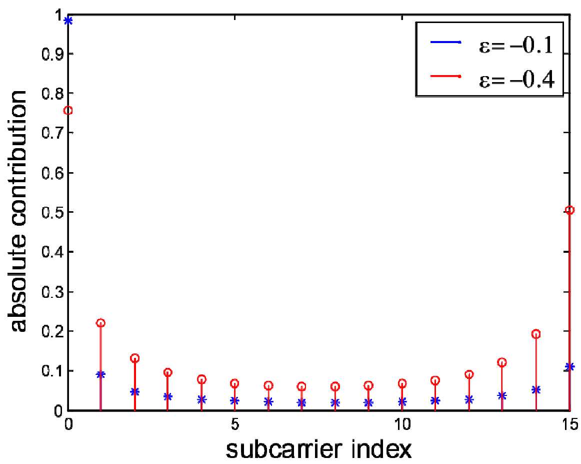


Figure ((3.12): Coefficient contribution in sub-carrier 0 for negative ($\epsilon\epsilon$).

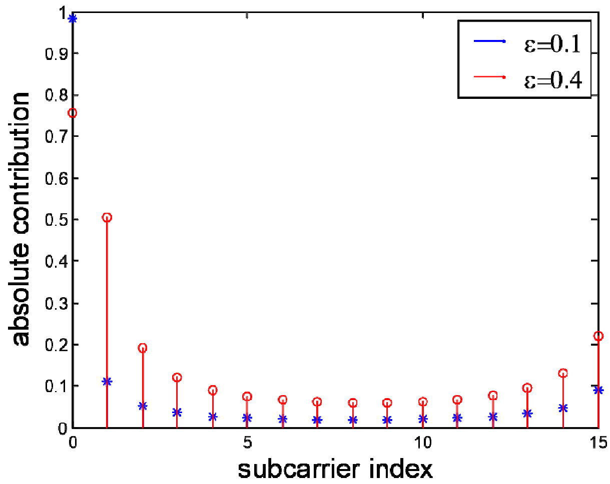


Figure (3.13): Coefficient contribution in sub-carrier 0 for positive (ϵϵ).

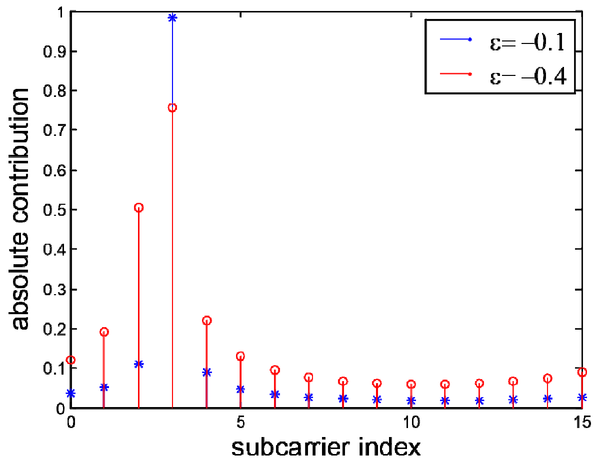


Figure (3.14): Coefficient contribution in sub-carrier 3 for negative (ϵϵ).

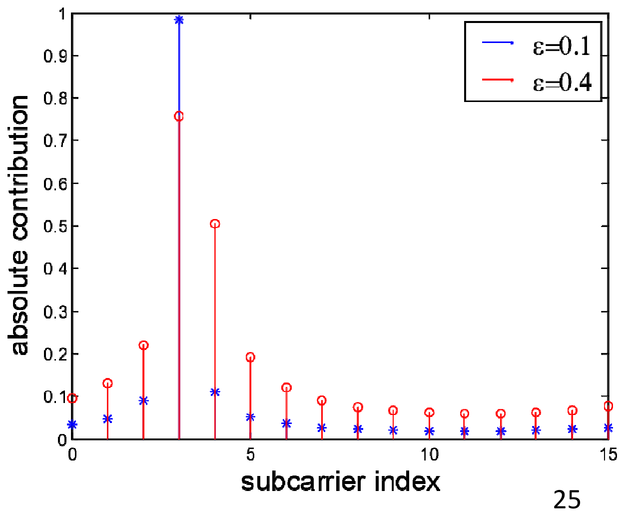


Figure (15) Coefficient contribution in sub-carrier 3 for positive ($\epsilon\epsilon$).

3.4 Self-Cancellation:

The self-cancellation technique was introduced by Zhao and Sven-Gustav Häggmanin [27]. In this method the input symbol is assigned in a pair of subcarriers, where in the standard OFDM each symbol is mapped into a single carrier. For example, if symbol *X* is transmitted, then it will be mapped into two adjacent sub-carriers with (X, -X) values. By this substitution; the received signal will be:

$$Y'_k \quad = \sum_{i=0,2,4\ldots}^{N-2} x(i)[s(i-k) - s(i+1-k)] + n_k \qquad 3.23$$

Where nn_{kk} denotes the additive noise symbol introduced in sub-carrier k , and $YY_{kk}{}'$ denotes the received symbol in sub-carrier *k*.

The received symbol in sub-carrier k+1 is represented by:

$$Y_k \quad = \sum_{i=0,2,4\ldots}^{N-2} x(i)[s(i-k-1) - s(i-k)] + n_{k+1} \qquad 3.24$$

And the ICI coefficient *S*'(l-*k*) is referred to as:

$$s'(i-k) = s(i-k) - s(i-k+1)$$

Which is better than the original one? Better coefficient can be achieved by subtracting the two adjacent carriers, the result will be:

$$Y''(k) = Y'(k) - Y'(k+1) = \sum_{i=0,2,4\ldots}^{N-2} x(i)[-s(i-k-1) + 2s(i-k) - s(i-k+1) + n_k \; - n_{k+1}$$

ll=0, 2, 4, ⋯ 3.25

Subsequently, the ICI coefficients for the received signal become:

$$s''(i-k) = -s(i-k-1) + 2s(i-k) - s(i-k+1) \qquad 3.26$$

Eq. (18) represents the received signal at sub-carrier *k*. In the right side of Eq. (18) there are three parts: first part represents the wanted signal, the second part represents the unwanted signal, and the last part represents the Gaussian noise. From Eq. (26) it can be derived that the *CIR* for self-cancellation is given by:

$$Y''(k) = x(k)\big(-s(-1) + 2s(0) - s(1)\big) \quad 3.27$$

The derivation assumes that: the standard transmitted data has zero mean, the symbols transmitted on the different sub-carriers are statistically independent, and the additive noise is omitted.

In addition, this equation (Eq. 27) will be verified by simulation as shown later.

3.4 Modified Self Cancellation:

In the OFDM spectrum, each carrier consists of a *main-lobe* followed by a number of *side-lobes* with degraded amplitudes, as shown in figure (11).

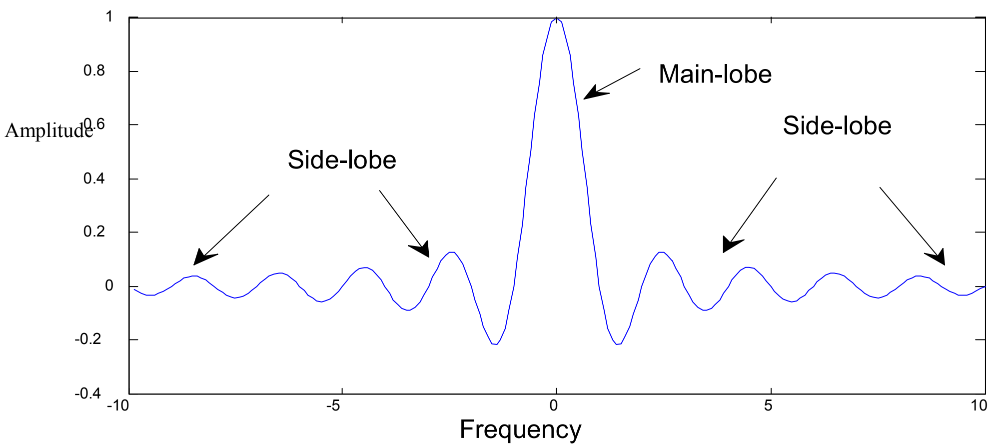


Figure (3.16): Frequency domain of a single carrier

The proposed method (modified self-cancellation) using a zero gab in order to mitigate the noise that comes from the main-lobe (of adjacent sub-carrier) and using the conventional self-cancellation technique in order to mitigate the effect of side-lobes. Using these two techniques together achieve better *CIR* and *BER* results as it will be shown in the next section.

The input symbol is modulated into three sub-carriers, one sub-carrier carries zeros so as to cancel the main-lobe power comes from adjacent sub-carrier. The role of the remaining two sub-carriers is to reduce the ICI components come from side-lobes.

The main disadvantage of this method is the bandwidth inefficiency, but it can be overcome by increasing the level of QAM, or by increasing the number of subcarriers (reducing frequency separation between sub-carriers). This method introduces redundancy in the symbol since each three of subcarriers transmit only one data symbol. Then the following symbols are generated:

$$\sum_{i=0,2,4\ldots}^{N-2} x(1)[-s(i-k-1)+2s(i-k)-s(i-k+1)+n_k\ -n_{k+1}(28)$$

If the signal is shifted in frequency and affected by an AWGN noise then the received signal at sub-carrier *k* is expressed as follows:

$$CIR=\frac{-S(-1)+2S(0)-S(1)}{(-S(i-K-1)+2S(i-k)-s(i+1-k)}(3.29)$$

And the received signal at sub-carrier sub-carrier$k$+1 is:

$$Y'_{k+1}=\sum_{i=0,3,6\ldots}^{N-3} x(i)[s(i-k-1)-s(i-k)]+n_{k+1} \qquad 3.30$$

At this point the effect of main-lobe noise which consumes in carrier k+2 and k-1 is mitigated and neglected at the receiver. The main-lobe noise represents a large component in the unwanted signal. Moreover, the effect of the side-lobe can be reduced by subtracting Y'_k from Y'_{k+1}:

$$Y''_k=Y'_k-Y'_{k+1}\ (31)$$

By substituting the values of Y'_k and Y'_{k+1} in eq. (3.32)

$Y_k'' = \sum_{i=0,3,6\ldots}^{N-3} x[-s(i-k-1) + 2s(i-k) - s(i-k+1) + n_k - n_{k+1}$ 3.33

Eq. (33) can be rewritten as follow:

$$Y'(k) = x(k)\big(-s(-1) + 2s(0) - s(1)\big) \quad 3.34$$

$Y_k' = X_k\big(-S(-1) + 2S(0) - S(1)\big) \quad +$

Eq. (34) represents the received signal after *de-mapping*. In the right side of this equation there are three parts: the first one represents the wanted signal, the second part represents the unwanted signal and the last part represents the Gaussian noise. In this method, the unwanted components are reduced by removing $S(-1)$ &$S(1)$ from the unwanted signal, which are the largest complex component. Moreover, this represents the effect of the main-lobe.

The coefficient in eq. (3.34) is similar to the coefficient in the self-cancellation, but there are two differences: the coefficient (1) and (-1) (it can be noted that $(-1) = (NN - 1)$ where NN is the number of sub-carriers) does not appear in the unwanted signal. The second difference is that the total number of interferer signals is one third of which standard OFDM has.

From eq. (34) it can be derived that the CIR for this proposed method is given by:

$$CIR = \frac{-S(-1) + 2S(0) - S(1)}{\sum_{i=3,6,..}^{N-3}(-S(i-K-1) + 2S(i-k) - s(i+1-k)} \quad 3.35$$

The derivation assumes that: the standard transmitted data has zero mean, the symbols transmitted on the different subcarriers are statistically independent, and the additive noise is omitted. In addition, eq. (3.35) will be verified by simulation as shown later.

4.1 Results and Discussion:

In order to compare between the proposed scheme and the self-cancellation scheme, the BER curves were used to evaluate the performance of each schemes. The OFDM transceiver shown in figure (1) was employed and simulated using MATLAB. Modulation scheme of quadrature amplitude modulation (QAM) was chosen, different values of normalized frequency (0.2, 0.4, 0.6 were used and the results are shown in figures (17), (18), (19) and (20) respectively. In these figures the blue dashed curve represent the standard OFDM system, the red dot-dashed curve represent the OFDM system using self-cancelation technique and the black sold curve represent the OFDM system using the proposed scheme.

It can be observed from these figures the BER performance of the proposed system is outperformed the BER performance of the two other systems. While the BER performance for the OFDM using the self-cancelation technique is outperformed the BER performance of the standard OFDM system. Moreover, it can be seen from these figures that as frequency offset increases the BER performance is degraded.

Table (4.1): SIMULSTION PARAMETERS.

Permeates	value
N	128
sym_no	1000
Normalized frequency(ep)	0.2,.0.4,0.6
SNR	[0:0.5:20]
Transmission mode	MIMO=4

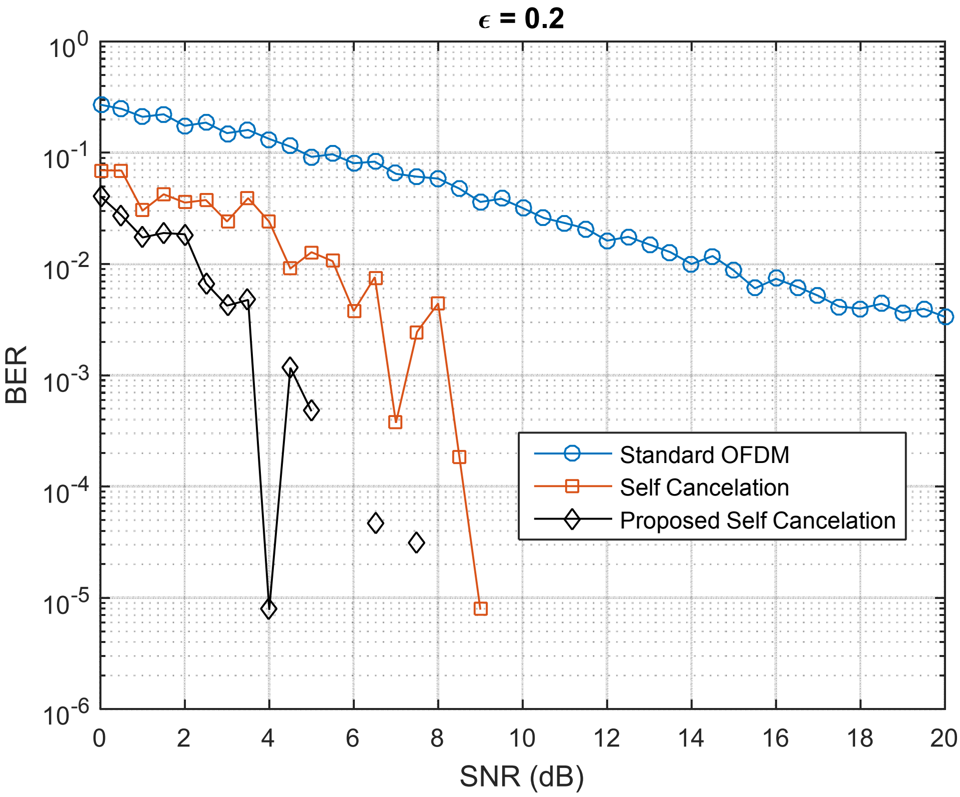


Figure (4.17): ***BER*** **performance of the considered systems using:** $\epsilon\epsilon = 0.2$, $MM = 4$

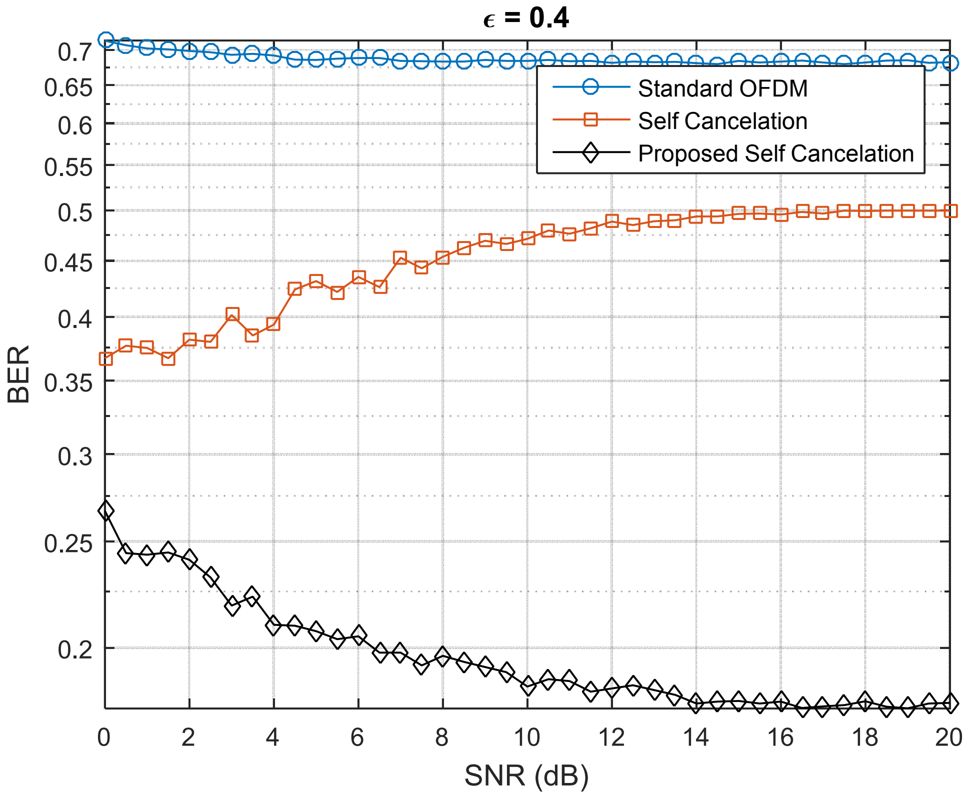


Figure (18): ***BER*** **performance of the considered systems using:** $\epsilon\epsilon = 0.4$, $MM = 4$

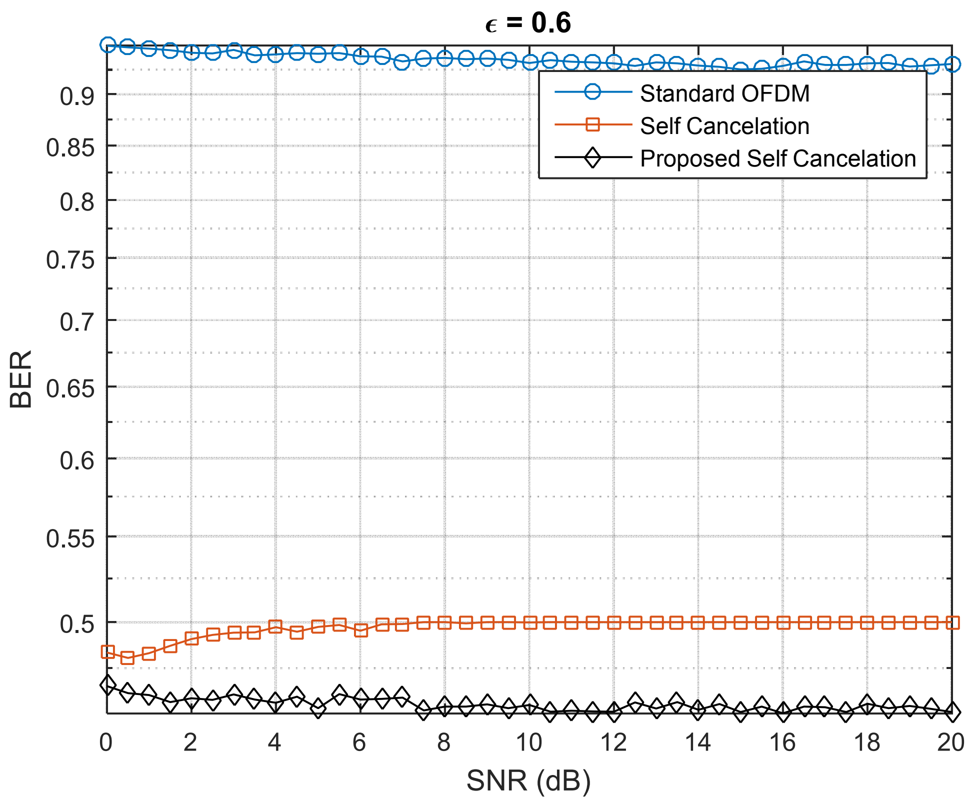
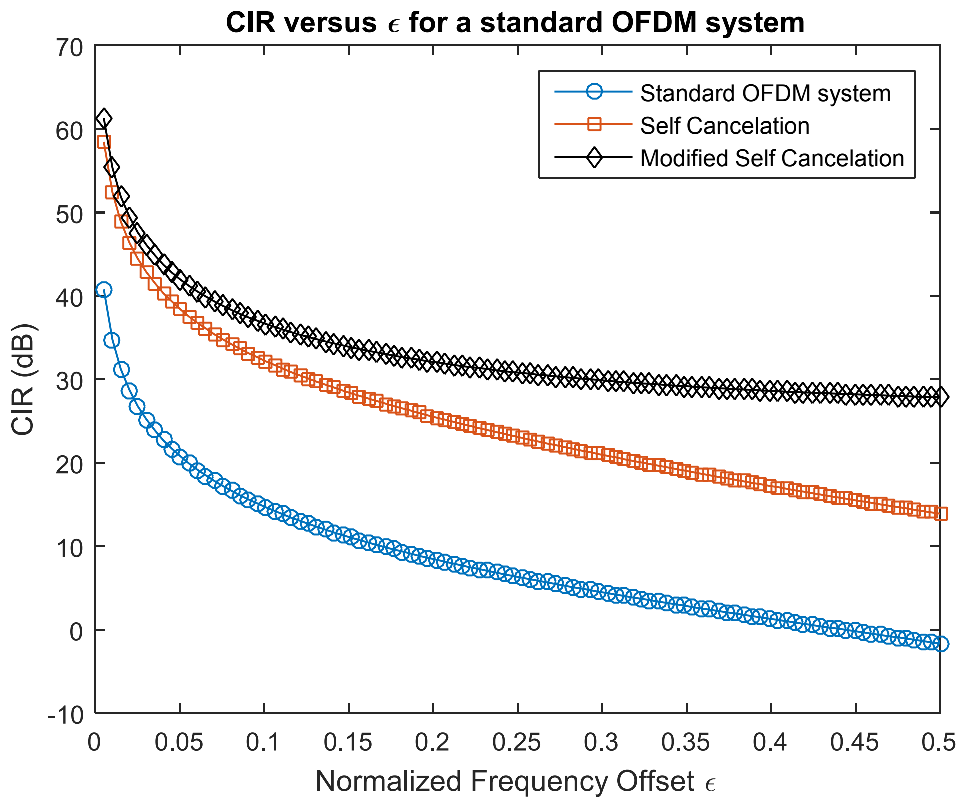


Figure (3.19): ***BER*** **performance of the considered systems using: $\epsilon\epsilon$ = 0.6, MM = 4**

The *CIR* is used in order to compare and evaluate the performance of the two different cancellation schemes. The results of the *CIR* curves are shown in figure (11) (16) Below.



Normalized frequency offset

Figure (4.20): CIR curve for different schemes. (Theo ≡ theoretical).

Figure (4.20) shows the theoretical *CIR* curves for standard OFDM, self-cancellation and the proposed method which are calculated by eq. (4.12), () and (4.25) respectively. Also figure (4.21) shows that all the theoretical and simulation results are identical, so these results verify the simulation and verify the theoretical expression for the proposed method.

From figure (4.21) and table (4.1), it is noted that the best method which gives better *CIR* value is the proposed method followed by the conventional self-cancellation, and finally the standard OFDM. It has been found that when the frequency offset is increased, the *CIR* values will decrease.

5.1 CONCLUSION:

This research proposed a new self-cancellation technique (modified self-cancellation). In this research, a comparison was done between standard OFDM, OFDM using conventional self-cancellation technique and OFDM using modified self-cancellation technique. In term of *CIR*, the proposed scheme gives better results than standard OFDM. Also in term of *BER* the proposed method outperforms the conventional self-cancellation and standard OFDM. Moreover, the theoretical *CIR* equations for the proposed method, the conventional self-cancellation and standard OFDM were also verified.

5.2 Recommendations for Future work:

By the end of this study many understood and open the mind by asking a question, which is; what is the next? And the answer is already known, which is; the next is now. As we can see the growth of the broadband wireless networks as in the 4G technologies there are more techniques and features which makes it possible and already implemented in the real world.

So as an improvement of this work Recommended using the same methodology of this study to evaluate the spectral efficiency with 5G networks such as Long Term Evolution LTE.

Also implement Modified Self Cancelation for Reduction of Inter Carrier Interference in OFDM System in OPENT and analyze the performance of the system in different value of frequency offset and different channel conditions (AWGN, Rayleigh and Rican fading

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Interference Due to Carrier Frequency Offset in OFDM," *IEEE transactions on communications ,* vol. 47, 1999.

Appendix A:

```
clear all;
clc;
N=128;
sym_no=1000;
bit_no=N*sym_no;
Ncp=N/4;
Ns=N+Ncp;
ep=0.2;
T=3.2*10^-3;
Ts=T/N;
% ch_len=10;    % channel length
% setting
% win_scmm=winfx(1,N);
% err_loca_win1=[];
% trun_len=300;        % truncation length
% const=[1 -1];        % constellation
% art_ch1=[1 -1];      % artificial channel
t=(0:Ns-1)-(Ncp+1);
freq_drift=exp(j*2*pi*ep*Ts*t/T);
% --- Frequency Drift Generation --- %
SNR=[0:0.5:20];
N0=10.^(-SNR/10);
L=[];
L1=[];
% modulation
M=4;                                % 2 for BPSK ; 4 for  QPSK(QAM)
for przt_snr=1:length(SNR)
  current_snr=SNR(przt_snr);
  err=0;
  err_inver=0;
  err_conj=0;
  err_sym_conj=0;
  err_win=0;
  x_inver_f=zeros(1,N);
  x_conj_f=zeros(1,N);
  x_sym_conj_f=zeros(1,N);
  noise=sqrt(N0(przt_snr)/2/N)*(randn(1,Ns)+j*randn(1,Ns));

    pre_symbol_1=randint(1,N);
    pre_symbol_2=pre_symbol_1;
    pre_symbol_1_t=ifft(pre_symbol_1,N);
    pre_symbol_2_t=ifft(pre_symbol_2,N);
    pre_symbol_1_tx=[pre_symbol_1_t(N-Ncp+1:N) pre_symbol_1];
    pre_symbol_2_tx=[pre_symbol_2_t(N-Ncp+1:N) pre_symbol_2];
```

```
        pre_symbol_1_rx=pre_symbol_1_tx.*freq_drift+noise;
        pre_symbol_2_rx=pre_symbol_2_tx.*freq_drift+noise;
        pre_symbol_1_f=fft(pre_symbol_1_rx(Ncp+1:Ns),N);
        pre_symbol_2_f_t=fft(pre_symbol_2_rx(Ncp+1:Ns),2*N);
        pre_symbol_2_f=pre_symbol_2_f_t(N+1:2*N);
        alpha=pre_symbol_2_f.*conj(pre_symbol_1_f);
        fo_est=angle(sum(alpha))/(2*pi);
        L=[L fo_est];
        freq_drift_e=exp(j*2*pi*(ep-abs(L(1)))*Ts*t/T);
        L1=[L1 freq_drift_e];
    for s=1:sym_no
          b_1=randint(1,N,M);                % standard ofdm
          b_1_tx=de2bi(b_1)';
          b=qammod(b_1,M);
          x_t=ifft(b,N);
          x_tx=[x_t(N-Ncp+1:N) x_t];

          b_2=randint(1,N,M);                % self_cancellation
          b_2_tx=de2bi(b_2(:,1:N/2))';
          b_3_tx=de2bi(b_2)';
          b_c=qammod(b_2(1:N/2),M);
          b_c_a=qammod(b_2,M);
          x_inver_f(1:2:N-1)=b_c;
          x_inver_f(2:2:N)=-(b_c);
          x_inver_t=ifft(x_inver_f,N);
          x_inver_tx=[x_inver_t(N-Ncp+1:N) x_inver_t];

          x_conj_f(1:2:N-1)=b_c;             % self_cancellation_Modidied
          x_conj_f(2:2:N)=-conj(b_c);
          x_conj_t=ifft(x_conj_f,N);
          x_conj_tx=[x_conj_t(N-Ncp+1:N) x_conj_t];
          x_sym_conj_f(1:1:N/2)=b_c;
          x_sym_conj_f(N:-1:N/2+1)=-conj(b_c);
          x_sym_conj_t=ifft(x_sym_conj_f,N);
          x_sym_conj_tx=[x_sym_conj_t(N-Ncp+1:N) x_sym_conj_t];

    % channel
          y_rx=x_tx.*freq_drift_e+noise;
          y_inver_rx=x_inver_tx.*freq_drift_e+noise;
          y_conj_rx=x_conj_tx.*freq_drift_e+noise;
          y_sym_conj_rx=x_sym_conj_tx.*freq_drift_e+noise;
    %         y_win_rx=x_win_tx.*freq_drift+noise;
    % FFT
          y_f=fft(y_rx(Ncp+1:Ns),N);
          y_inver_rx_f=fft(y_inver_rx(Ncp+1:Ns),N);
          y_conj_rx_f=fft(y_conj_rx(Ncp+1:Ns),N);
```

```
        y_sym_conj_rx_f=fft(y_sym_conj_rx(Ncp+1:Ns),N);
%         y_win_rx_f=fft(y_win_rx(Ncp+1:N),N);
        %% DeModulation
% standard ofdm demod
        y_d=de2bi(demapper(y_f,M))';
% Self Cancelation demod
        y_1=y_inver_rx_f(1:2:N-1);
        y_2=y_inver_rx_f(2:2:N);
        y_inver_d_temp=(y_1-y_2)/2;
        y_inver_d=de2bi(demapper(y_inver_d_temp,M))';
% Modified Self Cancelation  demod
        y_conj_1=y_conj_rx_f(1:2:N-1);
        y_conj_2=y_conj_rx_f(2:2:N);
        y_conj_d_temp=(y_conj_1-conj(y_conj_2))/2;
        y_conj_d=de2bi(demapper(y_conj_d_temp,M))';
% Sym Self Cancelation  demod
        y_sym_conj_1=y_sym_conj_rx_f(1:1:N/2);
        y_sym_conj_2=y_sym_conj_rx_f(N:-1:N/2+1);
        y_sym_conj_d_temp=(y_sym_conj_1-conj(y_sym_conj_2))/2;
        y_sym_conj_d=de2bi(demapper(y_sym_conj_d_temp,M))';

%         y_win_deco=mlseeq(y_win_rx_f,art_ch1,const,trun_len,'rst');
%         y_win_d=de2bi(demapper(y_win_deco,M))';
% BER calculation
        err=err+sum(b_1_tx(:)~=y_d(:));
        err_inver=err_inver+sum(b_2_tx(:)~=y_inver_d(:));
        err_conj=err_conj+sum(b_2_tx(:)~=y_conj_d(:));
        err_sym_conj=err_sym_conj+sum(b_2_tx(:)~=y_sym_conj_d(:));
%         err_win=err_win+sum(b_3_tx(:)~=y_win_d(:));
end
    ber(przt_snr)=err/bit_no;
    ber_inver(przt_snr)=err_inver/bit_no;
    ber_conj(przt_snr)=err_conj/bit_no;
    ber_sym_conj(przt_snr)=err_sym_conj/bit_no;
%       ber_win(przt_snr)=err_win/bit_no;
end
% end ,'Modified Self Cancelation ' , ,SNR,real(ber_conj),'-+ r'

figure;
semilogy(SNR,ber,'-o',SNR,real(ber_inver),'-s',SNR,real(ber_sym_conj),'-d k');

legend('Standard OFDM','Self Cancelation','Proposed Self Cancelation')
title(['\epsilon = ' num2str(ep)])
xlabel('SNR (dB)')
ylabel('BER')
grid on
% t_end=cputime-t_begin
% end
```

Appendix B:

```
N=128;
n = (0:N-1);


ep = linspace(0,.5, 100);%A sample of 100 points is generated between 0 and 0.5

for i = 1:100
S = sin(pi*(-n+ep(i)))./(N*sin(pi/N*(ep(i)-n))).*exp(j*pi*(1-1/N)*(ep(i)-n));
CIR(i) = abs(S(1))^2/sum(abs(S(2:N)).^2);
end
for i = 1:100
S_0 = sin(pi*(ep(i)))./(N*sin(pi/N*(ep(i)))).*exp(j*pi*(1-1/N)*(ep(i)));
S_1 = sin(pi*(-1+ep(i)))./(N*sin(pi/N*(ep(i)-1))).*exp(j*pi*(1-1/N)*(ep(i)-1));
S_2 = sin(pi*(1+ep(i)))./(N*sin(pi/N*(ep(i)+1))).*exp(j*pi*(1-1/N)*(ep(i)+1));
Stt = 0;
for l = 2:2:N-1
St = -sin(pi*(l-1+ep(i)))./(N*sin(pi/N*(ep(i)+l-1))).*exp(j*pi*(1-1/N)*(ep(i)+l-1))+2*sin(pi*(l+ep(i)))./(N*sin(pi/N*(ep(i)+l))).*exp(j*pi*(1-1/N)*(ep(i)+l))-sin(pi*(l+1+ep(i)))./(N*sin(pi/N*(ep(i)+l+1))).*exp(j*pi*(1-1/N)*(ep(i)+l+1));
Stt = abs(St).^2 + Stt;
end
CIR_SC(i) = abs(-S_1-S_2+2*S_0).^2/Stt;
end
for i = 1:100
S_0 = sin(pi*(ep(i)))./(N*sin(pi/N*(ep(i)))).*exp(j*pi*(1-1/N)*(ep(i)));
S_1 = sin(pi*(-1+ep(i)))./(N*sin(pi/N*(ep(i)-1))).*exp(j*pi*(1-1/N)*(ep(i)-1));
S_2 = sin(pi*(1+ep(i)))./(N*sin(pi/N*(ep(i)+1))).*exp(j*pi*(1-1/N)*(ep(i)+1));
Stt = 0;
for l = 2:3:N-2
St = -sin(pi*(l-1+ep(i)))./(N*sin(pi/N*(ep(i)+l-1))).*exp(j*pi*(1-1/N)*(ep(i)+l-1))+2*sin(pi*(l+ep(i)))./(N*sin(pi/N*(ep(i)+l))).*exp(j*pi*(1-1/N)*(ep(i)+l))-sin(pi*(l+1+ep(i)))./(N*sin(pi/N*(ep(i)+l+1))).*exp(j*pi*(1-1/N)*(ep(i)+l+1));
```

```
Stt = abs(St).^2 + Stt;
end
CIR_SC2(i) = abs(-S_1-S_2+2*S_0).^2/Stt;
end
figure
plot(ep, 10*log10(CIR+eps),'-o')
hold on
plot(ep, 10*log10(CIR_SC+eps),'-s')
hold on
plot(ep, 10*log10(CIR_SC2+eps),'-d k')
xlabel('Normalized Frequency Offset \epsilon')
ylabel('CIR (dB)')
title('CIR versus \epsilon for a standard OFDM system')
legend('Standard OFDM system', 'Self Cancelation', 'Modified Self Cancelation')
```