BIT ERROR RATE (BER) ANALYSIS OF OFDM SYSTEM

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MAY 2011

Submitted in partial fulfillment of the Degree of

Bachelor of Technology.

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

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CERTFICATE

This is to certify that project report entitled "**BER ANALYSIS OF OFDM SYSTEM**", submitted by **Tanu Kundra** and **Amrit Pal Rattan** in partial fulfillment for the award of degree of Bachelor of Technology in Electronics and Communication Engineering to Jaypee University of Information Technology, Waknaghat, Solan has been carried out under my supervision. This work has not been submitted partially or fully to any other University or Institute for the award of this or any other degree or diploma.

Signature of the Supervisor : ....

Name of the Supervisor: Mr.Bhasker Gupta

Designation: Sr.Lecturer

Date: 23/5/11

Acknowledgement

Apart from the efforts, the success of any project depends largely on the encouragement and guidelines of many others. There fore we take the opportunity to express our gratitude to the people who have been instrumental in the successful completion of this project.

We would also like to show our appreciation to our project guide Mr. Bhasker Gupta without his able guidance, tremendous support ant continuous motivation the project work would not be carried out satisfactory. His kind behavior and motivation provided us the required courage to complete our project.

Special thanks to our project panel because it was their regular concern and appreciation that made this project carried out easily and satisfactory.

Tanu Kundra

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Date: 22.05.2011

SUMMARY

The demand for high speed mobile wireless communications is rapidly growing. OFDM technology promises to be a key technique for achieving the high data capacity and spectral efficiency equirements for wireless communication systems of thw near future. Our project investigates the effectiveness of orthogonal frequency division multiplexing (OFDM) as a modulation technique for wireless radio application.

Several of the main factors affecting the ofdm system are analysed including fading, multipath delay spread, channel noise. The **BIT ERROR RATE (BER)** performance of the ofdm system has been analysed by designing an ofdm transceiver using matlab under different channel conditions and using various modulation techniques eg.bpsk,qpsk,qam etc. finally various plots of different modulation schemes under different channels have been drawn with respect to SNR(sound to noise ratio)

This report represents a better understanding of the basic principle of OFDM design. In this report, we have minimized treatment of more general communication issues. There exist many excellent texts on communication theory and technology. Only brief summary are presented in this report where essential.

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LIST OF FIGURES

CHAPTER 1

INTRODUCTION TO OFDM

1.1 Introduction

OFDM is becoming the chosen modulation technique for wireless communications.OFDM can provide large data rates with sufficient robustness to radio channel impairments. Many reaearch centers in the world have specialized teamsworking in the optimization of OFDM for countless applications.

OFDM is of great research by reasearchers, research universities and research laboratories all over the world. It has already been accepted for the new wireless local area network standards IEEE 802.11a, High Performance LAN type 2(HIPERLAN/2) and Moblile Multimedia Access communication (MMAC) systems. Also, it is expected to be used for wireless broadband multimedia communications.Data rate is really what broadband is about.The new standards specify bit rates of upt o 54 Mbps. Such high rates impose large bandwidth, thus pushing carriers for values higher than UHF band. For instance, IEEE 802.11a has frequencies allocated in the 5- and 17- GHz bands.

OFDM can be seen either as a modulation technique or a multiplexing technique. One of the main reasons to use OFDM is to increase the robustness against frequency selective fading or narrowband interference.OFDM divides the transmission bandwidth into many subchannels, each one occupying a narrow bandwidth. In this way, owing to increase in symbol duration, the effect of dispersion in time of the reflected signal on the receiver is minimized.

The effect of ISI is completely eliminated by inserting a guard band in the resulting composite OFDM symbol. Fast Fourier Transform (FFT) is an efficient way to produce (in the digital domain) is required subcarriers over which the information will be embedded. In practice, OFDM is used in third generation WLANs, WIMAX, and DVB to eliminate ISI.

1.2 History of OFDM:

The concept of using parallel-data transmission and frequency-division multiplexing (FDM) was developed in the mid-1960s [1]. Some early development is traced back to the 1950s [2]. A U.S. patent was filed and issued in January 1970 [3].

In a classical parallel-data system, the total signal frequency band is divided into *N* non overlapping frequency sub channels. Each sub channel is modulated with a separate symbol, and then the *N* sub channels are frequency multiplexed. It seems good to avoid spectral overlap of channels to eliminate inter-channel interference. However, this leads to inefficient use of the available spectrum. To cope with the inefficiency, the ideas proposed in the mid-1960s were to use parallel data and FDM with overlapping sub channels, in which each, carrying a signaling rate *b,* is spaced *b* apart in frequency to avoid the use of high-speed equalization and to combat impulsive noise and multipath distortion, as well as to use the available bandwidth fully.

Figure 1.1 illustrates the difference between the conventional non overlapping multicarrier technique and the overlapping multicarrier modulation technique. By using the overlapping multicarrier modulation technique, we save almost 50% of bandwidth. To realize this technique, however, we need to reduce cross talk between SCs, which means that we want orthogonality between the different modulated carriers.

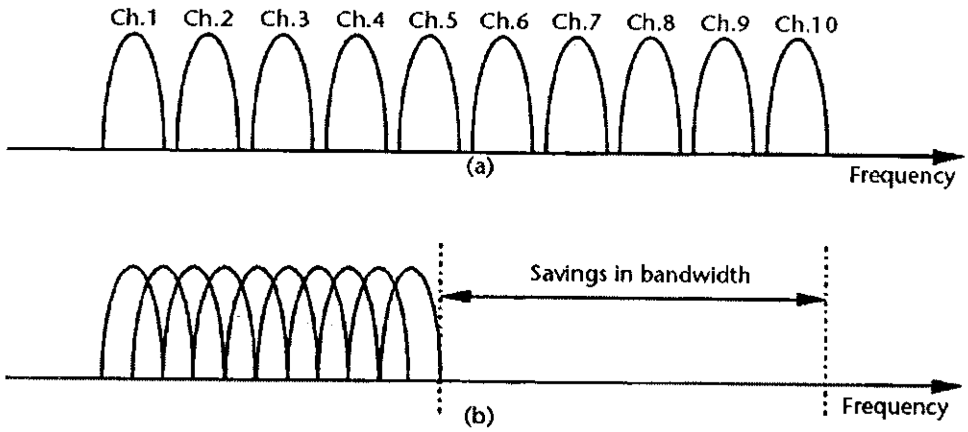


Fig 1.1 Concept of OFDM signal: (a) Conventional Multicarrier technique ;(b) Orthogonal multicarrier modulation technique

In 1971, Weinstein and Ebert[4] applied the discrete Fourier transform (DFT) to parallel-data-transmission systems as part of the modulation and demodulation process.

In the 1960s, the OFDM technique was used in several high-frequency military systems such as KINEPLEX [2], ANDEFT [5], and KATHRYN[6]. For example, the variable-rate data modem in KATHRYN was built for the high-frequency band. It used up to 34 parallel low-rate phase-modulated channels with a spacing of 82 Hz.

In the 1980s, OFDM was studied for high-speed modems, digital mobile communications, and high-density recording. One of the systems realized the OFDM techniques for multiplexed quadrature amplitude modulation (QAM) using DFT [7] also, by using pilot tone, stabilizing carrier and clock frequency control and trellis coding could also be implemented [8]. Moreover, various-speed modems were developed for telephone networks [9].

In the 1990s, OFDM was exploited for wideband data communications over mobile radio FM channels, high-bit-rate digital subscriber lines (HDSL; 1.6 Mbps), asymmetric digital subscriber lines (ADSL; up to 6 Mbps), very-high-speed digital
Subscriber lines (VDSL; 100 Mbps), digital audio broadcasting (DAB), and highdefinition television (HDTV) terrestrial broadcasting [10].

1.3 Choice of the key elements

1.3.1 Useful symbol duration

The useful symbol duration T affects the carrier spacing and coding latency. To maintain the data throughput, longer useful symbol duration results in increase of the number of carriers and the size of FFT (assuming the constellation is fixed). In practice, carrier offset and phase stability may affect how close two carriers can be placed. If the application is for the mobile reception, the carrier spacing must be large enough to make the Doppler shift negligible. Generally, the useful symbol duration should be chosen so that the channel is stable for the duration of a symbol.

1.3.2 Number of carriers

The number of subcarriers can be determined based on the channel bandwidth, data throughput and useful symbol duration. *N*The carriers are spaced by the reciprocal of the useful symbol duration. The number of carriers corresponds to the number of complex points being processed in FFT. For HDTV applications, the number of subcarriers is in the range of several thousands, so as to accommodate the data rate and guard interval requirement. Modulation scheme the modulation scheme in an OFDM system can be selected based on the requirement of power or spectrum efficiency. The type of modulation can be specified by the complex number $Dn=an+jbn$, defined in section *the use of FFT in OFDM.* The symbols *a*n and *b*n can be selected to (□ 1, □ 3) for 16QAM and □ 1 for QPSK. In general, the selection of the modulation scheme applying to each subchannel depends solely on the compromise between the data rate requirement and transmission robustness. Another advantage of OFDM is that different modulation schemes can be used on different sub channels for layered services.

1.3.3 Coded OFDM

By using frequency and time diversity OFDM provides a means to transmit data in a frequency selective channel. However, it does not suppress fading itself. Depending on their position in the frequency domain, individual sub channels could be affected by fading. This requires the use of channel coding to further protect transmitted data. Among those channel techniques, trellis coded modulation (TCM), combined with frequency and time interleaving is considered the most effective means for a selective fading channel. TCM combines coding and

modulation to achieve a high coding gain without affecting the bandwidth of the signal. In a TCM encoder, each symbol of n bits is mapped into constellation of $n+1$ bits, using a set-partitioning rule. This process increases the constellation size and effectively adds additional redundancy to the signal. A TCM code can be decoded with a soft decision Viterbi decoding

algorithm, which exploits the soft decision nature of the received signal. The coding gain for a two dimensional TCM code over a Gaussian channel is about 3 dB for a bit error rate (BER) of 10-5. It should be mentioned that one of the advantages of OFDM is that it can convert a wideband frequency selective fading channel into a series of narrowband and frequency non-selective fading sub channels by using parallel and multicarrier transmission. Coding OFDM subcarriers sequentially by using specially designed TCM codes for frequency non-selective fading channel is the major reason for using the COFDM for terrestrial broadcasting. However, the search of the best TCM code is still on going. Although trellis codes produce improvements in the signal-to-noise ratio (S/N), they do not perform well with impulsive or burst noise. In general, transmission errors have a strong time/frequency correlation. Interleaving plays an essential role in channel coding by providing diversity in the time domain. Interleaving breaks the correlation and enables the decoder to eliminate or reduce local fading throughout the band and over the whole depth of the time interleaving. Interleaving depth should be enough to break long straight errors. Flexibility and scalability based on the information theory, the channel capacity is a function of the signal-to-noise ratio and channel bandwidth. The concept of graceful degradation has been implemented in the analog TV systems. It is believed that the joint source/channel coding is the best way to achieve flexibility and scalability. COFDM has been considered very flexible for the layered and scaleable transmission.

Different groups of COFDM subchannels can be assigned to different orders of modulation, power levels, and channel coding schemes.

CHAPTER 2

PRINCIPLES OF OFDM

2.1 Basic Idea of OFDM

The principles of orthogonal frequency division multiplexing (OFDM) modulation have been in existence for several decades. However, in recent years these techniques have quickly moved out of textbooks and research laboratories and into practice in modern communications systems. The techniques are employed in data delivery systems over the phone line, digital radio and television, and wireless networking systems.

2.2 The Single Carrier Modulation System:

A single carrier system modulates information onto one carrier using frequency, phase, or amplitude adjustment of the carrier. For digital signals, the information is in the form of bits, or collections of bits called symbols, that are modulated onto the carrier. As higher bandwidths (data rates) are used, the duration of one bit or symbol of information becomes smaller. The system becomes more susceptible to loss of information from impulse noise, signal reflections and other impairments. These impairments can impede the ability to recover the information sent. In addition, as the bandwidth used by a single carrier system increases, the susceptibility to interference from other continuous signal sources becomes greater. This type of interference is commonly labeled as carrier wave (CW) or frequency interference.

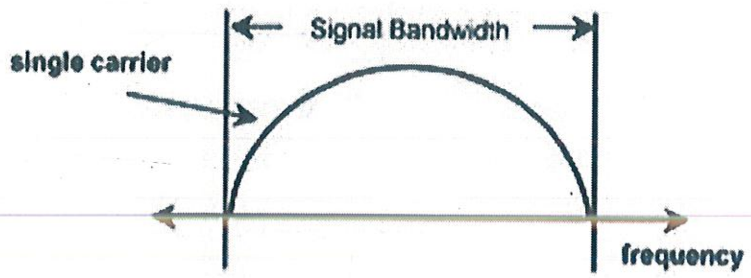


Fig 2.1 single carrier spectrum example

2.2.1 SINGLE CARRIER Vs MULTICARRIER:

Multi carrier modulation has several advantages over single carrier modulation. The primary advantage of OFDM over single sarrier schemes is its ability to cope with severe channel conditions –for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency selective fading due to multipath-without complex equalization filters. Channel equalization is simplified because OFDM may be viewed as using many slowly modulated narrowband signals rather than one rapidly modulated wideband signal.

When the channel is frequency selective that is, using a gurad interval whose duration exceeds the channel's impulse response length, it allows decomposing the channel in a set of independent flat fading subchannels over which equalization amounts to a single phase compensation. As a consequence, the guard protection also diminishes the need for time domain equalization at the receiver,i.e. the inter symbol interference (ISI) is negligible.

In single carrier system the signal representing each bit uses all of the available spectrum. In Multi-Carrier system the available spectrum divided into many narrow bands and data is divided into parallel data streams each transmitted on a separate band as shown in figure 2.2.1

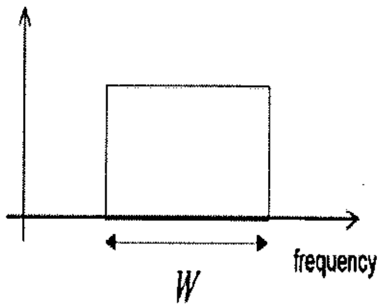


Fig 2.2(a) Single carrier

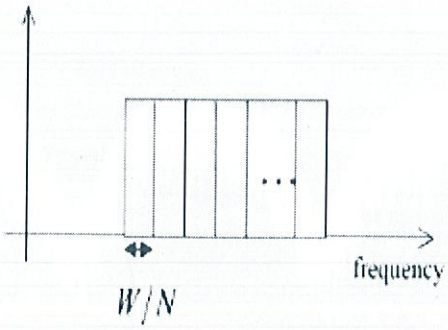


Fig 2.2 (b) Multi carrier

2.3 Frequency Division Multiplexing Modulation:

Frequency division multiplexing (FDM) extends the concept of single carrier modulation by using multiple subcarriers within the same single channel. The total data rate to be sent in the channel is divided between the various subcarriers. The data do not have to be divided evenly nor do they have to originate from the same information source. Advantages include using separate modulation/demodulation customized to a particular type of data, or sending out banks of dissimilar data that can be best sent using multiple, and possibly different, modulation schemes.

Current national television systems committee (NTSC) television and FM stereo multiplex are good examples of FDM. FDM offers an advantage over single-carrier modulation in terms of narrowband frequency interference since this interference will only affect one of the frequency subbands. The other subcarriers will not be affected by the interference. Since each subcarrier has a lower information rate, the data symbol periods in a digital system will be longer, adding some additional immunity to impulse noise and reflections.

FDM systems usually require a guard band between modulated subcarriers to prevent the spectrum of one subcarrier from interfering with another. These guard bands lower the system's effective information rate when compared to a single carrier system with similar modulation.

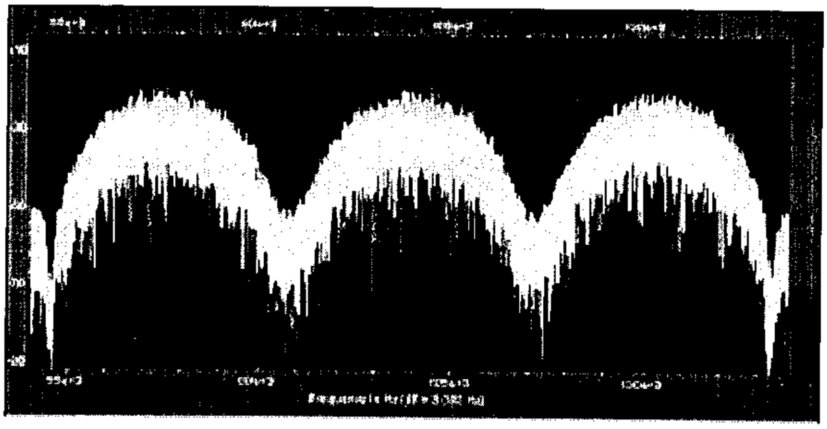


Fig.2.3 FDM signal spectrum example

2.3.1 OFDM Vs FDM :

OFDM is a special case of frequency division multiplexing (FDM). As an analogy , a FDM channel is like water flow out of a faucet, in contrast the OFDM signal is like a shower. In a faucet all water comes in one big stream and cannot be sub divided. OFDM shower is made up of a lotb of little streams as shown in figure.2.3.1

Fig 2.4 (a) A regular FDM single carrier- a whole bunch of water coming in single stream

(b) Orthogonal FDM- same amount of water coming from lot of small streams.

Think about the advantage might be of one over the other ? one obvious one is that if i put my hand over the faucet hole , i can stop the water flow but i cannot do the same for the shower. So although both do the same thing,they respond differently to the interference.

OFDM is similar to FDM but more spectrally efficient by spacing the sub channels much close together (untill they are actually overlapping).OFEM is a special case of FDM called orthogonal FDM. So, whats the reason to establish OFDM !!

As we describe above, we conclude that-

- Data may be lost in two or more subcarriers,but we do not lose the whole stream.
- A clever way to combat frequency selective channels

In older multi channel system using FDM, the total available bandwidth is divided into N non-overlapping frequency sub-channels. Each is sub-divided and modulatedwith a sepeate symbol stream and N sub-channels are frequency multiplexed.

FDM → OFDM

- **Frequency Division Multiplexing**

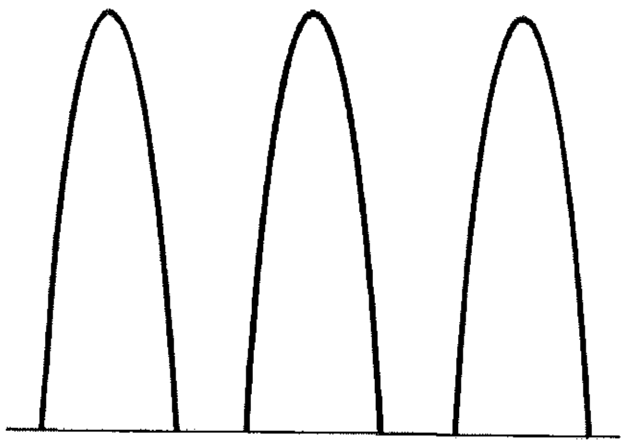


Fig 2.5 (a)

- **Orthogonal Frequency Dividing**

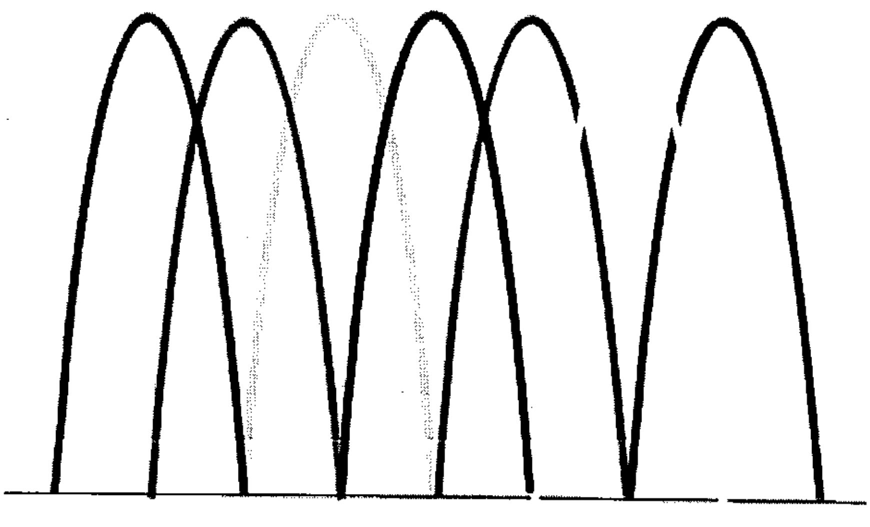


Fig 2.5 (b)

EARN IN SPECTRAL EFFICIENCY

2.4 Orthogonality and OFDM:

If the system above had been able to use a set of sub carriers that were orthogonal to each other, a higher level of spectral efficiency could have been achieved. The guard bands that were necessary to allow individual demodulation of subcarriers in an FDM would no longer be necessary. The use of orthogonal subcarriers would allow the subcarriers spectra to overlap, thus increasing the spectral efficiency. As long as orthogonality is maintained,it is still possible to recover individual subcarriers signals despite their overlapping spectrums.

2.4.1 Orthogonality:

Signals are orthogonal if they are mutually independent of each other. Orthogonality is a property that allows multiple information signals to be transmitted perfectly over a common channel and detected, without interference. Loss of orthogonality results in blurring between these information signals and degradation in communications. Many common multiplexing schemes are inherently orthogonal. Time Division Multiplexing (TDM) allows transmission of multiple information signals over a single channel by assigning unique time slots to each spate information signal. During each time slot only the signal from a single source is transmitted preventing any interference between multiple information sources. Because of this TDM is orthogonal in nature. In the frequency domain most FDM systems are orthogonal as each of the separate transmission signals are well spaced out in frequency preventing interference.

Although these methods are orthogonal the term OFDM has been reserved for a special form of FDM. The subcarriers in an OFDM signal are spaced as close as is theoretically possible while maintaining orthogonality between them.

OFDM achieves orthogonality in the frequency domain by allocating each of the separate information signals onto different sub carriers. OFDM signals are made up a sum of sinusoids, with each corresponding to a subcarrier. The baseband frequency of each subcarrier is chosen to be an integer multiple of the inverse of the symbol time, resulting in all subcarriers having an integer number of cycles per symbol.

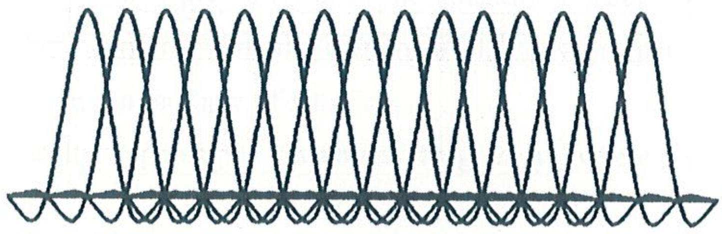


fig. 2.6 frequency domain representation of an OFDM signal

2.4.2 The Importance of Coding

The distribution of the data over many carriers means that selective fading will cause some bits to be received in error while others are received correctly. By using an error-correcting code, which adds extra bits at the transmitter, it is possible to correct many or all of the bits that were incorrectly received. The information carried by one of the degraded carriers is corrected, because other information, which is related to it by the error-correcting code, is transmitted in a different part of the multiplex (and, it is hoped, will not suffer from the same deep fade). This accounts for the "coded" part of the name COFDM.

There are many types of error correcting codes, which could be used.

2.4.3 The Importance of Orthogonality

The "orthogonal" part of the OFDM name indicates that there is a precise mathematical relationship between the frequencies of the carriers in the system. In a normal FDM system, the many carriers are spaced apart in such way that the signals can be received using conventional filters and demodulators. In such receivers, guard bands have to be introduced between the different carriers (Fig. 2.), and the introduction of these guard bands in the frequency domain results in a lowering of the spectrum efficiency. It is possible, however, to arrange the carriers in an OFDM signal so that the sidebands of the individual carriers overlap and the signals can still be received without adjacent carrier interference. In order to do this the carriers must be mathematically orthogonal. The receiver acts as a bank of demodulators, translating each carrier down to DC, the resulting signal then being integrated over a symbol period to recover the raw data. If the other carriers all beat down to frequencies which, in the time domain, have a whole number of cycles in the symbol period (t), then the integration process results in zero contribution from all these carriers. Thus the carriers are linearly independent (i.e. orthogonal) if the carrier spacing is a multiple of 1/t.

Mathematically, suppose we have a set of signals y , where y p is the p-th element in the set.

The signals are orthogonal if

$$\int_{a}^{b} \Psi_p(t)\Psi_q^*(t)dt = \begin{cases} K & for\ p = q \\ 0 & for\ p \neq q \end{cases}$$

where the * indicates the complex conjugate and interval [a,b] is a symbol period. A fairly simple mathematical proof exists, that the series *sin* (*mx*) for *m*=1,2,... is orthogonal over the interval -p to p.Much of transform theory makes the use of orthogonal series, although they are by no means use this theory completely.

2.5 OFDM Generation:

To generate OFDM successfully the relationship between all the carriers must be carefully controlled to maintain the orthogonality of the carriers. For this reason, OFDM is generated by firstly choosing the spectrum required, based on the input data, and modulation scheme used. Each carrier to be produced is assigned some data to transmit. The required amplitude and phase of the carrier is then calculated based on the modulation scheme (typically differential BPSK, QPSK, or QAM). The required spectrum is then converted back to its time domain signal using an Inverse Fourier Transform. In most applications, an Inverse Fast Fourier Transform (IFFT) is used. The IFFT performs the transformation very efficiently, and provides a simple way of ensuring the carrier signals produced are orthogonal.

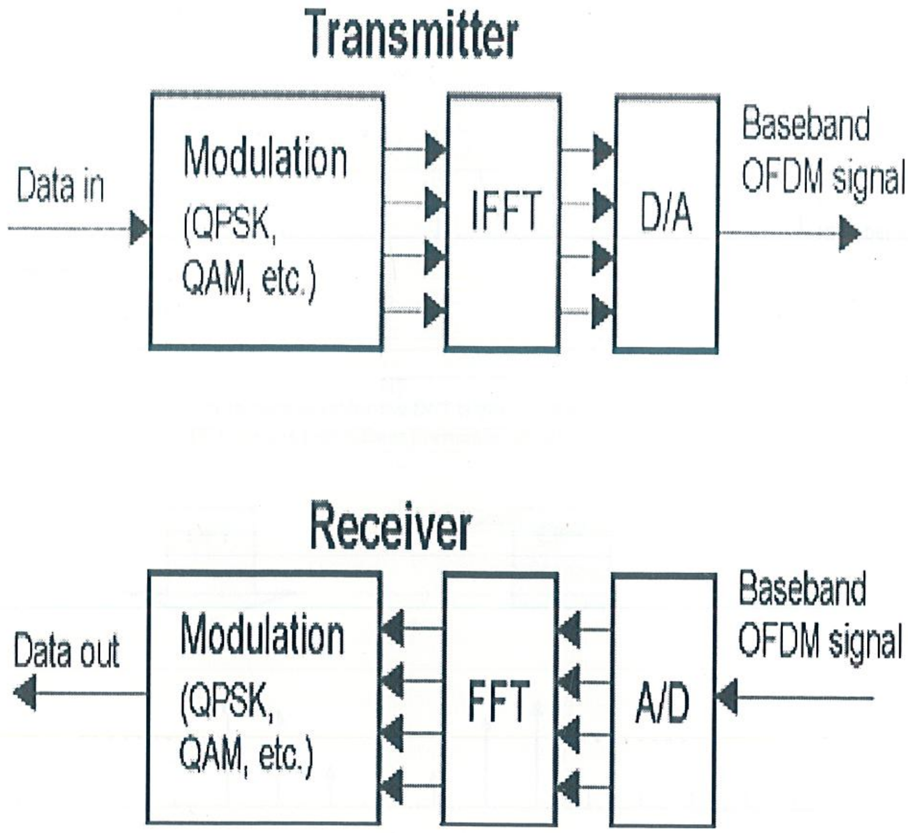


Fig 2.7 OFDM transmitter and reciever

When the DFT (Discrete Fourier Transform) of a time signal is taken, the frequency domain results are a function of the time sampling period and the number of samples as shown in fig. 2.5.1. The fundamental frequency of the DFT is equal to 1/NT (1/total sample time). Each frequency represented in the DFT is an integer multiple of the fundamental frequency. The maximum frequency that can be represented by a time signal sampled at rate 1/T is $f_{max} = 1/2T$ as given by the Nyquist sampling theorem. This frequency is located in the center of the DFT points. All frequencies beyond that point are images of the representative frequencies. The maximum frequency bin of the DFT is equal to the sampling frequency (1/T) minus one fundamental (1/NT).

The IDFT (Inverse Discrete Fourier Transform) performs the opposite operation to the DFT. It takes a signal defined by frequency components and converts them to a time signal. The parameter mapping is the same as for the DFT. The time duration of the IDFT time signal is equal to the number of DFT bins (N) times the sampling period (T).

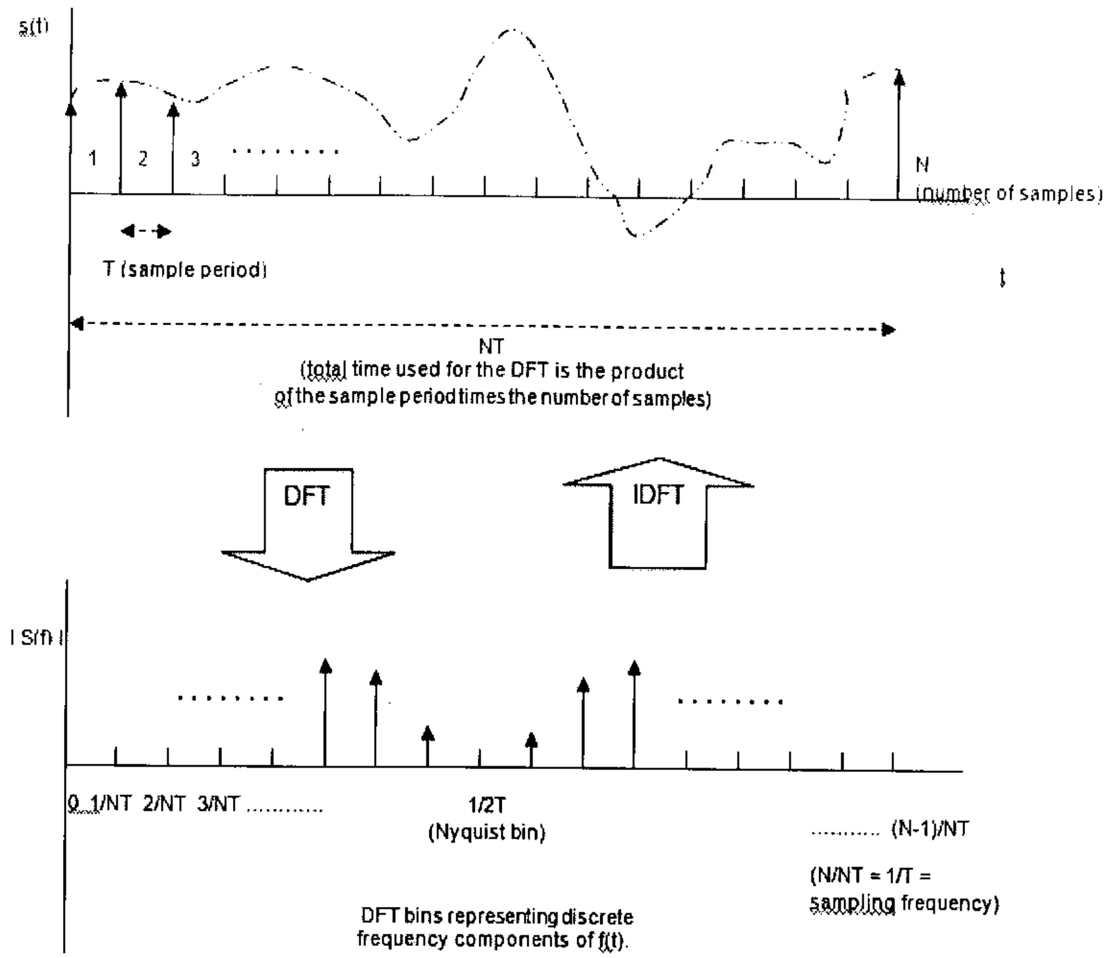


Fig 2.8 signal in time domain and frequency domain

2.5.1 Definition of Carriers

The maximum number of carriers used by OFDM is limited by the size of the IFFT. This is determined as follows in Equation 1:

<u>Equation 1 : OFDM Carrier Count</u>

$$N_{carriers} \le \frac{IFFTsize}{2} - 2 \quad \text{(real - valued time signal)}$$

$$N_{carriers} \le IFFTsize - 1 \quad \text{(complex - valued time signal)}$$

In order to generate a real-valued time signal, OFDM (frequency) carriers must be defined in complex conjugate pairs, which are symmetric about the Nyquist frequency (f_{max}). This puts the number of potential carriers equal to the IFFT size/2. The Nyquist frequency is the symmetry point, so it cannot be part of a complex conjugate pair. The DC component also has no complex conjugate. These two points cannot be used as carriers so they are subtracted from the total available.

If the carriers are not defined in conjugate pairs, then the IFFT will result in a time domain signal that has imaginary components. This must be a viable option as there are OFDM systems defined with carrier counts that exceed the limit for real-valued time signals given in Equation 1. [11] describes a system with IFFT size 256 and carrier count 216. This design must result in a complex time waveform. Further processing would require some sort of quadrature technique (use of parallel sine and cosine processing paths). In this report, only real-value time signals will be treated, but in order to obtain maximum bandwidth efficiency from OFDM, the complex time signal may be preferred (possibly an analagous situation to QPSK vs. BPSK). Equation 1, for the complex time waveform, has all IFFT bins available as carriers except the DC bin.

Both IFFT size and assignment (selection) of carriers can be dynamic. The transmitter and receiver just have to use the same parameters. This is one of the advantages of OFDM. Its bandwidth usage (and bit rate) can be varied according to varying user requirements. A simple control message from a base station can change a mobile unit's IFFT size and carrier selection.

2.5.2 Modulation

Binary data from a memory device or from a digital processing stream is used as the modulating (baseband) signal. The following steps may be carried out in order to apply modulation to the carriers in OFDM:

- combine the binary data into symbols according to the number of bits/symbol selected
- convert the serial symbol stream into parallel segments according to the number of carriers, and form carrier symbol sequences
- apply differential coding to each carrier symbol sequence
- convert each symbol into a complex phase representation
- assign each carrier sequence to the appropriate IFFT bin, including the complex conjugates
- take the IFFT of the result

OFDM modulation is applied in the frequency domain. **Error! Reference source not found.**.5.2 and **Error! Reference source not found.**2.5.3 give an example of modulated OFDM carriers for one symbol period, prior to IFFT. For this example, there are 4 carriers, the IFFT bin size is 64, and there is only 1 bit per symbol. The magnitude of each carrier is 1, but it could be scaled to any value. The phase for each carrier is either 0 or 180 degrees, according to the symbol being sent. The phase determines the value of the symbol (binary in this case, either a 1 or a 0). In the ex ier) is a 1.

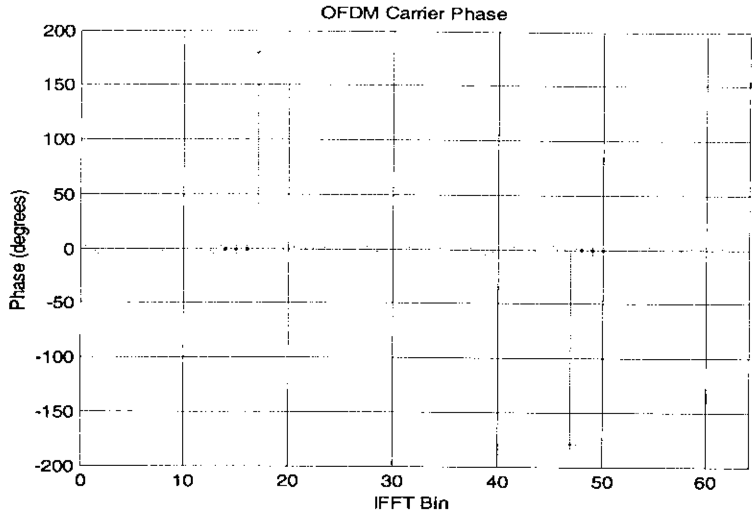


Fig 2.9 modulated carrier phase

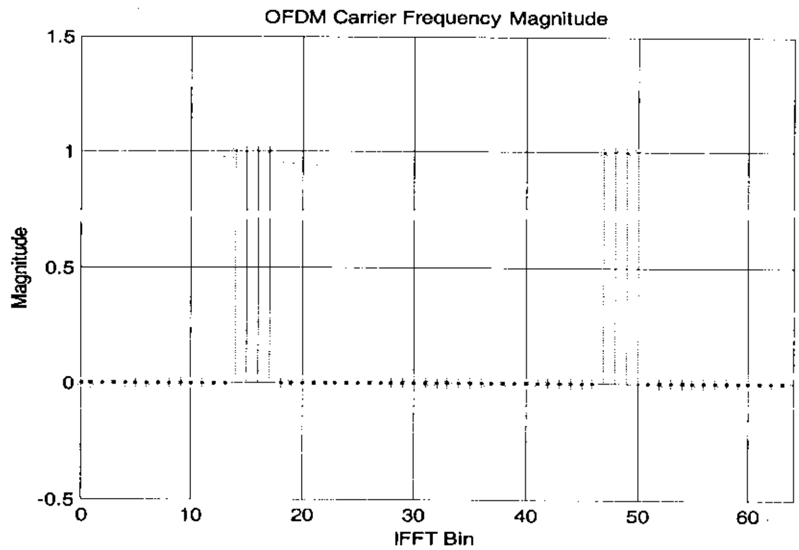


Fig 2.5.3 modulated carrier frequency

Fig 2.10 Modulated carrier Frequency

Equation 2 : OFDM Frequency Domain Representation (one symbol period)

$$S(k) = e^{j\theta_m}\delta\left(k - m - \frac{N}{2}\right) + e^{-j\theta_m}\delta\left(k + m - \frac{N}{2}\right)$$ single (real) OFDM modulated carrier

k = frequency (0 to N - 1)

m = OFDM carrier frequency

N = IFFT bin size

$$S(k)_{ofdm} = \sum_{m=c_{first}}^{c_{last}} \left[e^{j\theta_m}\delta\left(k - m - \frac{N}{2}\right) + e^{-j\theta_m}\delta\left(k + m - \frac{N}{2}\right)\right]$$ composite (real) OFDM modulated carriers

c = OFDM carrier (first thr ough last)

After the modulation is applied, an IFFT is performed to generate one symbol period in the time domain. The IFFT result is shown in **Error! Reference source not found.**. It is clear that the OFDM signal has a varying amplitude. It is very important that the amplitude variations be kept intact as they define the content of the signal. If the amplitude is clipped or modified, then an FFT of the signal would no longer result in the original frequency characteristics, and the modulation may be lost.

This is one of the drawbacks of OFDM, the fact that it requires linear amplification. In addition, very large amplitude peaks may occur depending on how the sinusoids line up, so the peak-to-average power ratio is high. This means that the linear amplifier has to have a large dynamic range to avoid distorting the peaks. The result is a linear amplifier with a constant, high bias current resulting in very poor power efficiency. For a detailed treatment of the peak-to-average power ratio problem in OFDM, see [12].

The IFFT transforms each complex conjugate pair of delta functions (each carrier) into a real-valued, pure sinusoid. **Error! Reference source not found.** shows the separate sinusoids that make up the composite OFDM waveform given in **Error!**

Reference source not found.. The one sinusoid with 180 phase shift is clearly visible as is the frequency difference between each of the 4 sinusoids. Note that this figure is 'zoomed' i.e. all 64 point of the IFFT are not shown. In addition, note that the waveform plots are not very smooth. This is because there are not many samples per cycle for any of the sinusoids.

2.5.3 Transmission

The key to the uniqueness and desirability of OFDM is the relationship between the carrier frequencies and the symbol rate. Each carrier frequency is separated by a multiple of 1/NT (Hz). The symbol rate (R) for each carrier is 1/NT (symbols/sec).

The effect of the symbol rate on each OFDM carrier is to add a sin(x)/x shape to each carrier's spectrum. The nulls of the sin(x)/x (for each carrier) are at integer multiples of 1/NT. The peak (for each carrier) is at the carrier frequency k/NT. Therefore, each carrier frequency is located at the nulls for all the other carriers. This means that none of the carriers will interfere with each other during transmission, although their spectrums overlap. The ability to space carriers so closely together is very bandwidth efficient.

Fig 2.11shows the spectrum of an OFDM signal has following characteristics:

- 1 bit / symbol
- 100 symbols / carrier (i.e. a sequence of 100 symbol periods)
- 4 carriers
- 64 IFFT bins
- spectrum averaged for every 20 symbols (100/20 = 5 averages)

Red diamonds mark all of the available carrier frequencies. Note that the nulls of the spectrums line up with the unused frequencies. The four active carriers each have peaks at carrier frequencies. It is clear that the active carriers have nulls in their spectrums at each of the unused frequencies (otherwise, the nulls would not exist). Although it cannot be seen in the figure, the active frequencies also have spectral nulls at the adjacent active frequencies.

In the OFDM time waveform for the same signal. There are 100 symbol periods in the signal. Each symbol period is 64 samples long (100 x 64 = 6400 total samples). Each symbol period contains 4 carriers each of which carries 1 symbol. Each symbol carries 1 bit. We can also illustrate the large dynamic range of the OFDM waveform envelope.

It is not currently practical to generate the OFDM signal directly at RF rates, so it must be upconverted for transmission. To remain in the discrete domain, the OFDM could be upsampled and added to a discrete carrier frequency. This carrier could be an intermediate frequency whose sample rate is handled by current technology. It could then be converted to analog and increased to the final transmit frequency using analog frequency conversion methods. Alternatively, the OFDM modulation could be immediately converted to analog and directly increased to the desired RF transmit frequency. Either way, the selected technique would have to involve some form of linear AM (possibly implemented with a mixer).

2.5.4 Reception and Demodulation

The received OFDM signal is downconverted (in frequency) and taken from analog to digital. Demodulation is done in the frequency domain (just as modulation was). The following steps may be taken to demodulate the OFDM:

- partition the input stream into vectors representing each symbol period
- take the FFT of each symbol period vector
- extract the carrier FFT bins and calculate the phase of each
- calculate the phase difference, from one symbol period to the next, for each carrier
- decode each phase into binary data
- sort the data into the appropriate order

Fig.2.11 show the magnitude and spectrum of the FFT for one received OFDM symbol period. For this example, there are 4 carriers, the IFFT bin size is 64, there is 1 bit per symbol, and the signal was sent through a channel with AWGN having an SNR of 8 dB. The figures show that, under these conditions, the modulated symbols are very easy to recover.

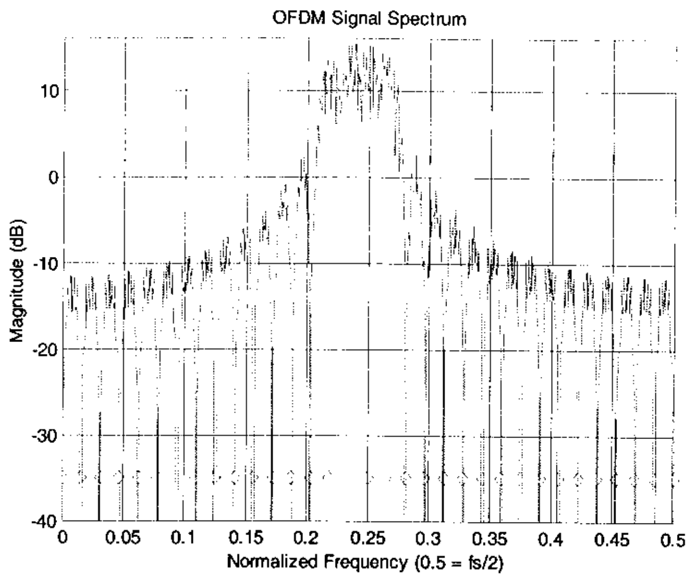


Fig 2.11 spectrum of OFDM signal

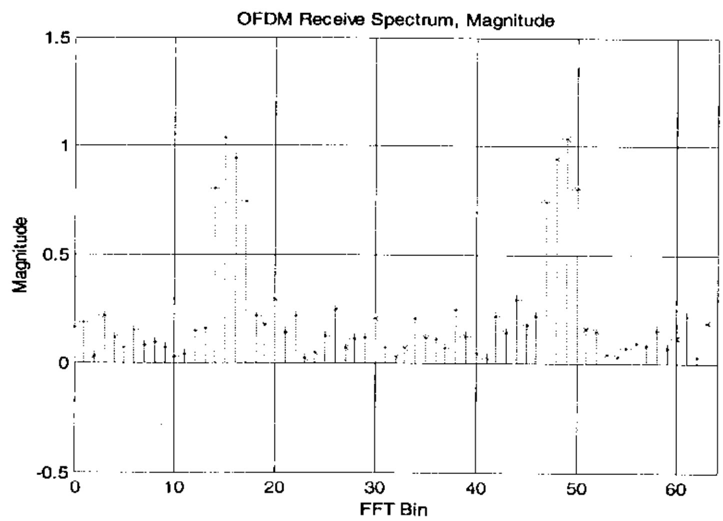


Fig. 2.12 received OFDM spectrum

2.5.5 Guard Interval:

OFDM demodulation must be synchronized with the start and end of the transmitted symbol period. If it is not, then ISI will occur (since information will be decoded and combined for 2 adjacent symbol periods). ICI will also occur because orthogonality will be lost (integrals of the carrier products will no longer be zero over the integration period),[13].

To help solve this problem, a guard interval is added to each OFDM symbol period. The first thought of how to do this might be to simply make the symbol period longer, so that the demodulator does not have to be so precise in picking the period beginning and end, and decoding is always done inside a single period. This would fix the ISI problem, but not the ICI problem.If a complete period is not integrated (via FFT), orthogonality will be lost.

In order to avoid ISI and ICI, the guard period must be formed by a cyclic extension of the symbol period. This is done by taking symbol period samples from the end of the period and appending them to the front of the period. The concept of being able to do this, and what it means, comes from the nature of the IFFT/FFT process. When the IFFT is taken for a symbol period (during OFDM modulation), the resulting time sample sequence is technically periodic. This is because the IFFT/FFT is an extension of the Fourier Transform which is an extension of the Fourier Series for periodic waveforms.

All of these transforms operate on signals with either real or manufactured periodicity. For the IFFT/FFT, the period is the number of samples used [14]provides an excellent explanation of the Fourier Series and its extensions.

With the cyclic extension, the symbol period is longer, but it represents the exact same frequency spectrum. As long as the correct number of samples are taken for the decode, they may be taken anywhere within the extended symbol. Since a complete period is integrated, orthogonality is maintained. Therefore, both ISI and ICI are eliminated.

Note that some bandwidth efficiency is lost with the addition of the guard period (symbol period is increased and symbol rate is decreased).

$$T_{total} = T + T_g$$

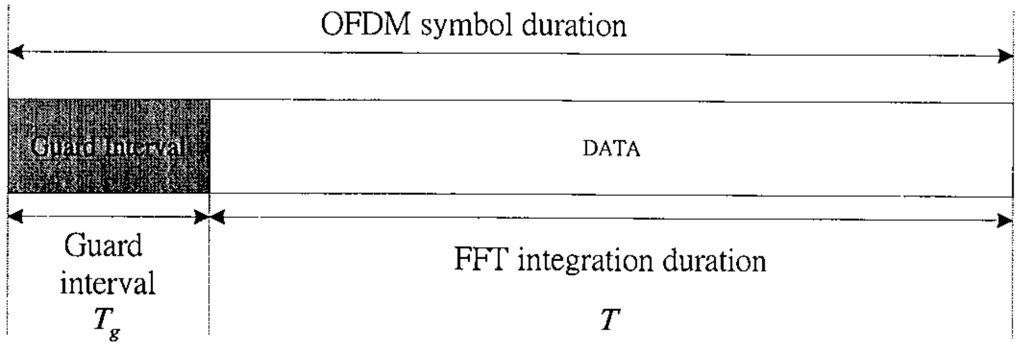


Fig 2.12 Total Symbol duration including guard interval

CHAPTER 3

Factors affecting the OFDM system performance

3.1 Main Factors Influencing the System Performance:

In practical environment there are many factors that leads to the loss in the transmitted signal. They are:

- **fading**
- **ISI (Inter Symbol Interference)**
- **ICI (Inter Carrier Interference)**

3.2 Fading:

Fading is the deviation in attenuation that a carrier modulated telecommunication signal experiences over certain propagation media. The fading may vary with time,geographical position and is often modelled as random process. Basically, there are two types of fading experienced in wireless communication.

Types of Fading:

- Large scale fading
- Small scale fading

Large Scale Fading :

This is the *loss* that propagation models try to account for mostly dependant on the distance from the transmitter to the receiver also known as Large Scale Path Loss, Log-Normal Fading or Shadowing

Small Scale Fading :

Could be 20-30 dB over a fraction of a wavelength.It is Caused by the superposition or cancellation of multipath propagation signals, the speed of the transmitter or receiver or the bandwidth of the transmitted signal.It is also known as *Multipath Fading or Rayleigh Fading*

The type of fading experienced by a signal propagating through a channel can be determined by the nature of the transmitted signal with respect to the characteristics of the channel.

Factors influencing small scale fading:

- Multipath propagation.
- Speed of the mobile.
- Speed of the surrounding objects.
- Transmission bandwidth of the signal.

3.2.1 Multipath Propagation

If the path from transmitter to receiver either has reflections or obstructions,we can get fading effects. In this case, the signal reaches the receiver from many different routes, each a copy of the original. Each of these rays has slightly different delay and different gain.

- The received signal is made up of a sum of attenuated,phase shifted and time delayed versions of the transmitted signal.
- Propagation modes includes diffraction, transmission and reflection.

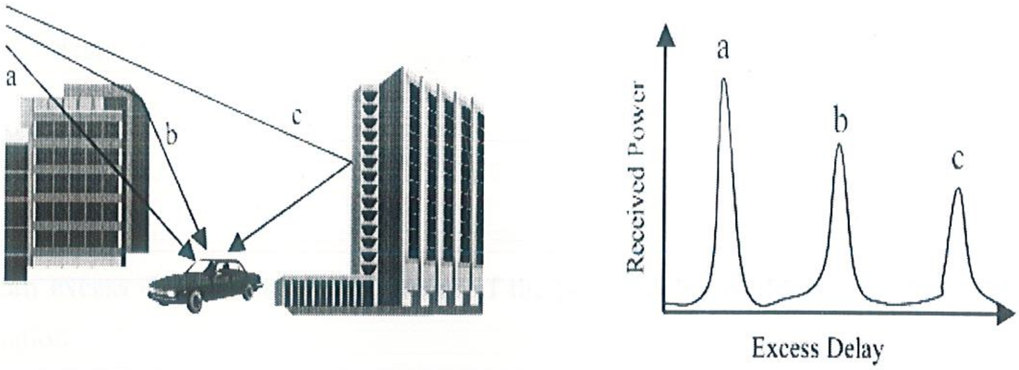


Fig 3.1 Multipath Propagation

Parameters of Mobile Multipath Channels:

In order to compare different multipath channels we need parameters which quantify the multipath channel, they are:

1. Delay spread

2. Coherence bandwidth

3. Doppler spread

4. Coherence time

3.2.2 Delay Spread and Coherence Bandwidth

The different signal paths between a transmitter and receiver corresponds to different transmission times. For an identical signal pulse from the transmitter, multiple copies of signals are received at the receiver at different moments. The signals on shorter paths reach the receiver earlier than those on longer paths. The direct effect of these unsimultaneous arrivals of signal causes the spread of the original signal in time domain. This spread is called delay spread.

· Mean excess delay

· RMS delay spread

· Excess delay spread

Mean excess delay is the first moment of the power delay profile and is defined by the equation

$$\bar{\tau} = \frac{\sum_k a_k^2 \tau_k}{\sum_k a_k^2} = \frac{\sum_h P(\tau_k)\tau_k}{\sum_h P(\tau_k)}$$

RMS delay spread is the square root of the second central moment of the power delay profile and is defined by the equation:

$$\sigma_\tau = \sqrt{\overline{\tau^2} - (\bar{\tau})^2}$$

Where

$$\overline{\tau^2} = \frac{\sum_k a_k^2 \tau_k^2}{\sum_k a_k^2} = \frac{\sum_h P(\tau_k)\tau_k^2}{\sum_h P(\tau_k)}$$

Maximum excess delay is defined as the $\tau_x - \tau_0$ where τ_0 ,is the first arriving signal and is the maximum delay at which a multipath component is within X dB of the strongest arriving multipath signal.

Coherence Bandwidth:

It is the range of frequencies over which two frequency components have a potential for amplitude correlation.

If two sinusoids with a frequency separation of greater than B_c are propagating in the same channel, they are affected quite differently by the channel. Fading effects due to Multipath Time Delay Spread:

Flat Fading

Frequency Selective Fading

3.2.2.1 Flat Fading:

- A received signal is said to have underwent Flat Fading if "*The Mobile Radio Channel has a constant gain and linear phase response over a Bandwidth which is greater than the Bandwidth of the transmitted Signal*"
- Fading in which all frequency components of a received radio signal vary in the same proportion simultaneously.
- Here the multipath structure of the channel is such that spectral characteristics of the transmitted signal are preserved at the receiver
- But due to the fluctuations in the gain of the channel caused by multipath, the signal strength varies with time

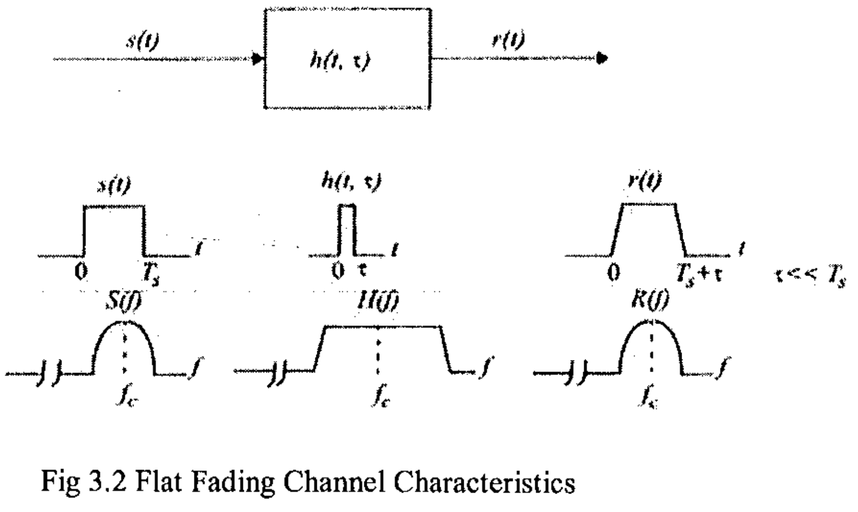


Fig 3.2 Flat Fading Channel Characteristics

- From the figure we can note that if the channel gain varies with time, a change of amplitude of the received signal occurs.
- From the figure we can note that the spectrum of the received signal r(t) is preserved even though there is a change in gain.

- Flat fading channels are also referred as amplitude varying channels or narrow band channels, since the bandwidth of the applied signal is narrow as compared to the channel flat fading bandwidth.
- Typical Flat fading channels cause deep fades.
    - To achieve low bit error rates during times of deep fades, Flat fading channels operate at 20 to 30dB more transmitter power compared to the systems operating over non-fading channels.
- For designing Radio links, the distribution of the instantaneous gain of flat fading channels is important.

Rayleigh distribution is the most common amplitude distribution. According to this distribution, Rayleigh Flat fading channel model assumes that the channel induces an amplitude which varies in time.Signal undergoes Flat Fading if:

- $B_s << B_c$

Where Bs is bandwidth and B_c is the coherence bandwidth of the channel and

- $T_s >> \sigma_\tau$

whereT_s is the reciprocal bandwidth and σ_τ rms delay spread.

3.2.2.2 Frequency Selective Fading:

The channel creates frequency selective fading on the received signal when the channel possesses a constant gain and linear phase response over a bandwidth, which is smaller than the bandwidth of the transmitted signal

- Under these conditions the channel impulse response has a multipath delay spread which is greater than the reciprocal bandwidth of the transmitted message waveform
- So the received signal includes multiple versions of the transmitted waveform, which are attenuated and delayed in time, and hence the received signal is distorted.
- Frequency selective fading is much difficult to model than flat fading channels because each multipath signal must be modeled and the channel must be considered to be a linear filter
- It is for this reason that wideband multipath measurements are made and and models are developed from these measurements
- When analyzing mobile communication systems, statistical impulse response models such as the 2-ray Rayleigh model or computer generated or measured impulse responses are generally used for analyzing frequency selective small-scale fading.

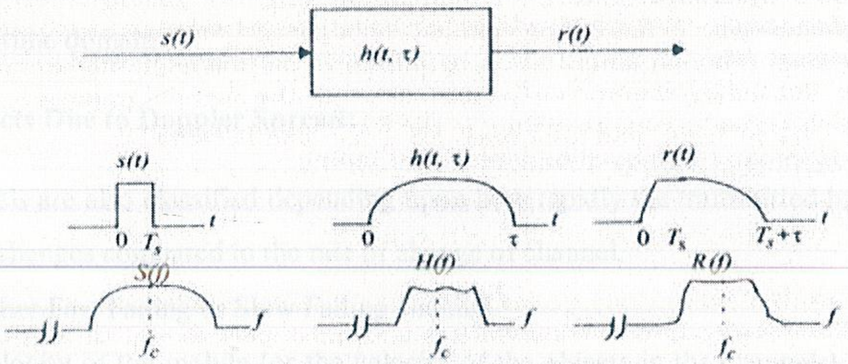


Fig 3.3 Frequency Selective Channel Characteristics

Signal undergoes Frequency Selective fading if:

- $B_s > B_c$

  Where, B_s is bandwidth and B_c is the coherence bandwidth of the channel and

- $T_s < \sigma_\tau$

  where T_s is the reciprocal bandwidth and σ_τ rms delay spread.

3.2.3 DOPPLER SPREAD AND COHERENCE TIME:

Doppler spread and Coherence Time take into account the relative motion between mobile and base station, or by movements of objects in the channel.

They describe the time varying nature of the channel in a small scale region.

Doppler Spread B_d:

When a signal of frequency f_c is transmitted, the received signal spectrum, called the Doppler spectrum, will have components $f_c - f_d$ to $f_c + f_d$, where f_d is the Doppler shift.

Coherence time T_c:

It is used to characterize the time varying nature of the frequency dispersiveness of the channel in the time domain

Fading Effects Due to Doppler Spread:

- Channels are also classified depending upon how rapidly the transmitted baseband signal changes compared to the rate of change of channel.
- It is either Fast Fading or Slow Fading channel.
- The velocity of the mobile (or the velocity of the objects in the channels) and the baseband signaling determines whether a signal undergoes fast or slow fading.

3.2.3.1 Fast Fading: In Fast Fading channel the channel impulse response changes at a rate much faster than the transmitted baseband signal.

- In other words the coherence time of the channel is smaller than the symbol period of the transmitted signal.
- This causes frequency dispersion due to Doppler spreading, which leads to signal distortion.

When viewed in frequency domain, signal distortion due to fast fading increases with increasing Doppler spread relative to the bandwidth of the transmitted signal.

Hence a signal will undergo fast fading if :

$T_s > T_c$ and $B_s < B_D$

When a channel is specified as Fast or Slow fading channel, it does not specify whether the channel is flat fading or frequency selective in nature .

3.2.3.2 Slow Fading:

- In Slow Fading channel the channel impulse response changes at a rate much slower than the transmitted baseband signal
- Here the channel may be assumed static over one or several bandwidth intervals.
- In the frequency domain, this implies that the Doppler spread of the channel is much less than the bandwidth of the baseband channel.

Hence a signal will undergo slow fading if

$T_s << T_c$ and $B_s >> B_D$

Fast and Slow Fading deal with the relationship between the time rate of change in the channel and the transmitted signal, and not with the propagation path loss models.

Small Scale Fading: Different types of transmitted signals undergo different types of fading depending upon the relation between the Signal Parameters: Bandwidth, Symbol Period and Channel Parameters: RMS Delay Spread, Doppler Spread

In any mobile radio channel a wave can be dispersed either in Time or in Frequency. These time and frequency dispersion mechanisms lead to four possible distinct effects which depend on the nature of transmitted signal, the channel and the velocity.

Small-Scale Fading
(Based on multipath time delay spread)

Flat Fading
1. BW of signal < BW of channel
2. Delay spread < Symbol period

Frequency Selective Fading
1. BW of signal > BW of channel
2. Delay spread > Symbol period

Small-Scale Fading
(Based on Doppler spread)

Fast Fading
1. High Doppler spread
2. Coherence time < Symbol period
3. Channel variations faster than baseband signal variations

Slow Fading
1. Low Doppler spread
2. Coherence time > Symbol period
3. Channel variations slower than baseband signal variations

Fig.3.4 fading due to delay spead and doppler spread

3.3 Inter Symbol Interference (ISI):

- ISI arises when energy from one symbol slot is spread out over neighbouring symbol slots.
- ISI is introduced by the channel when the RMS delay spread becomes an appreciable fraction of the bit period (say greater than 10%).

Intersymbol interference (ISI) occurs when a pulse spreads out in such a way that it interferes with adjacent pulses *at the sample instant.*

Example: assume polar NRZ line code. The channel outputs are shown as spreaded (width T_b becomes $2T_b$) pulses shown (Spreading due to bandlimited channel characteristics

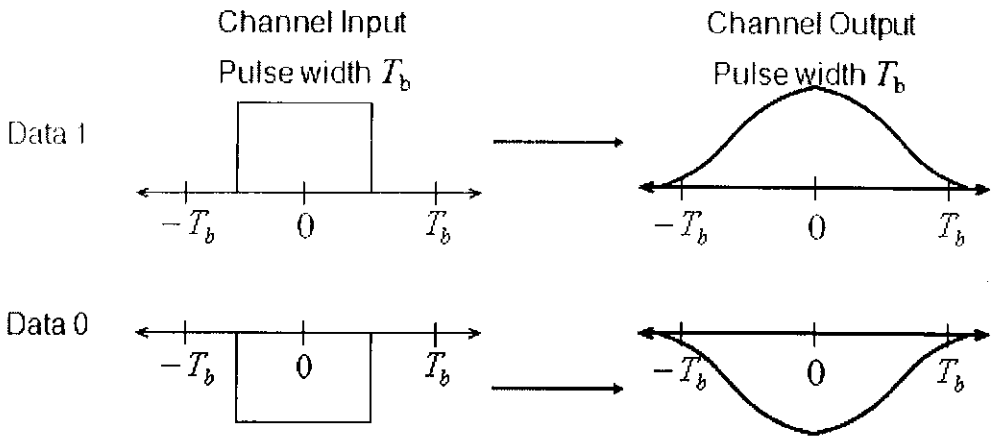


Fig 3.5 (a) ISI due to spreading

For the input data stream:

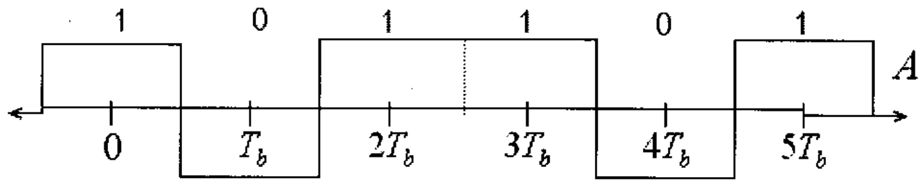


Fig 3.5(b) Input Data Stream

- The channel output is the superposition of each bit's output:

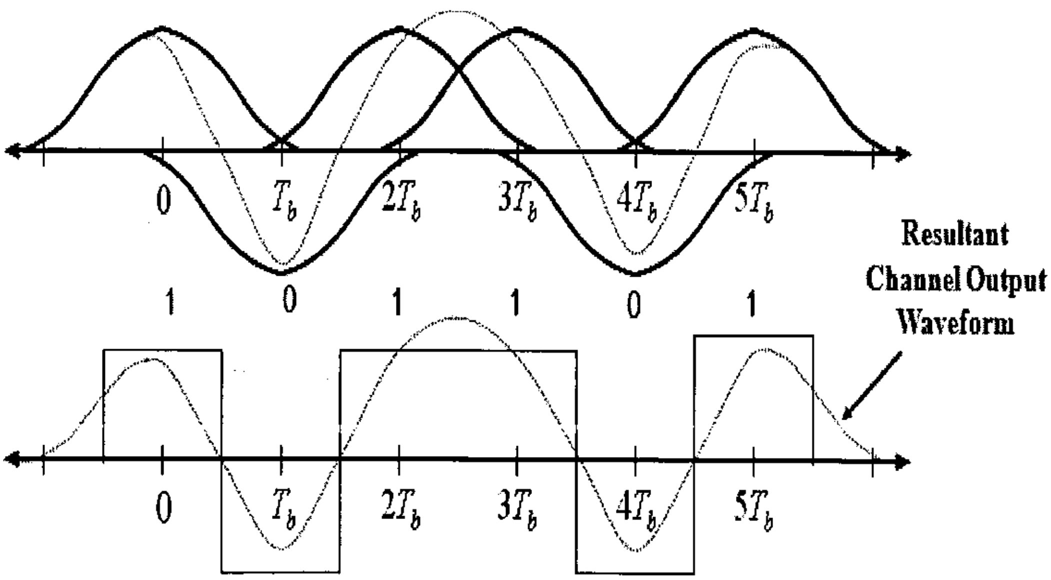


Fig 3.5 (c) resultant output due to superposition

3.4 Inter Carrier Interference (ICI):

It occurs due to loss of orthogonality between the transmitted sub carriers. There are two causes of inter carrier interference:

- Delay spread of radio channel exceeds guard interval

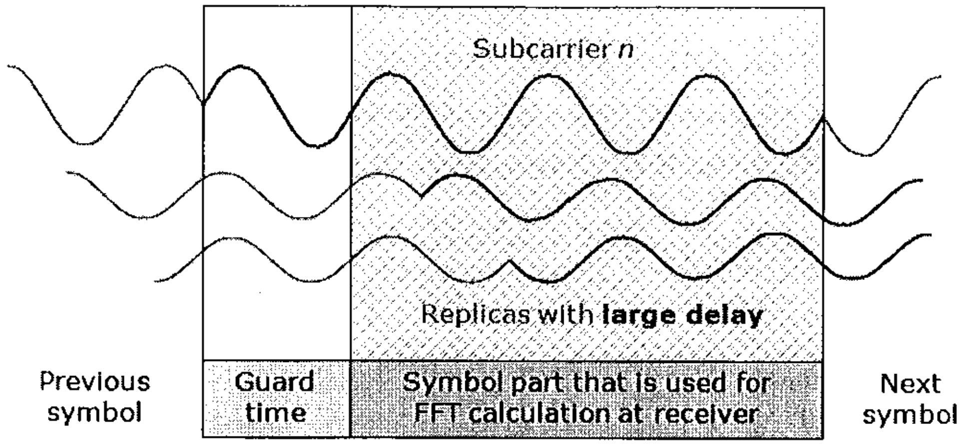


Fig 3.6(a) ICI due to large delay

- Frequency offset at the receiver cause ICI

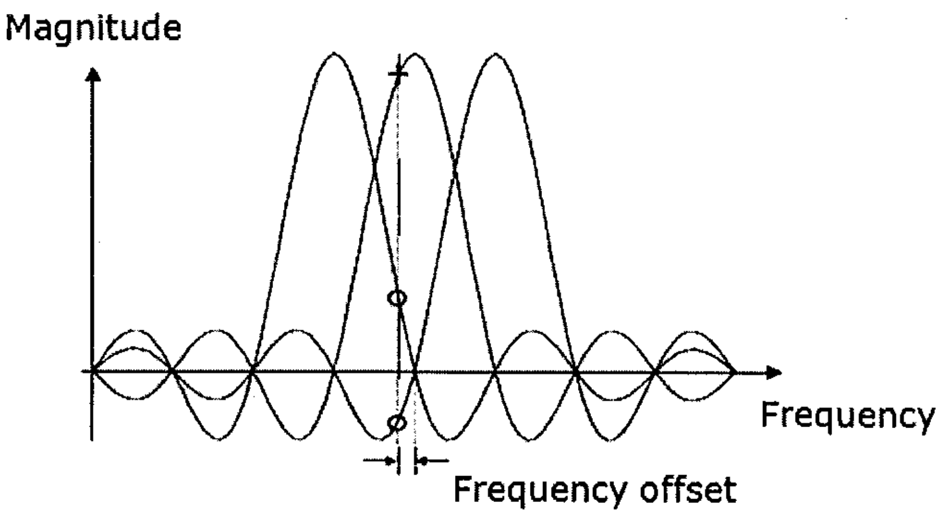


Fig 3.6(b) ICI due to frequency offset

We use cyclic prefix to mitigate the effect of ICI which will be covered in subsequent chapters.

Chapter 4

OFDM TRANSCEIVER SYSTEM

4.1 IMPEMENTATION OF OFDM SYSTEM

Fig shown below is the basic transceiver system of ofdm.It is simulated using matlab tools.Each block has its own function and significance in ofdm generation and reception.it is the most basic system that can be implemented using different modulation schemes and various channel environments.

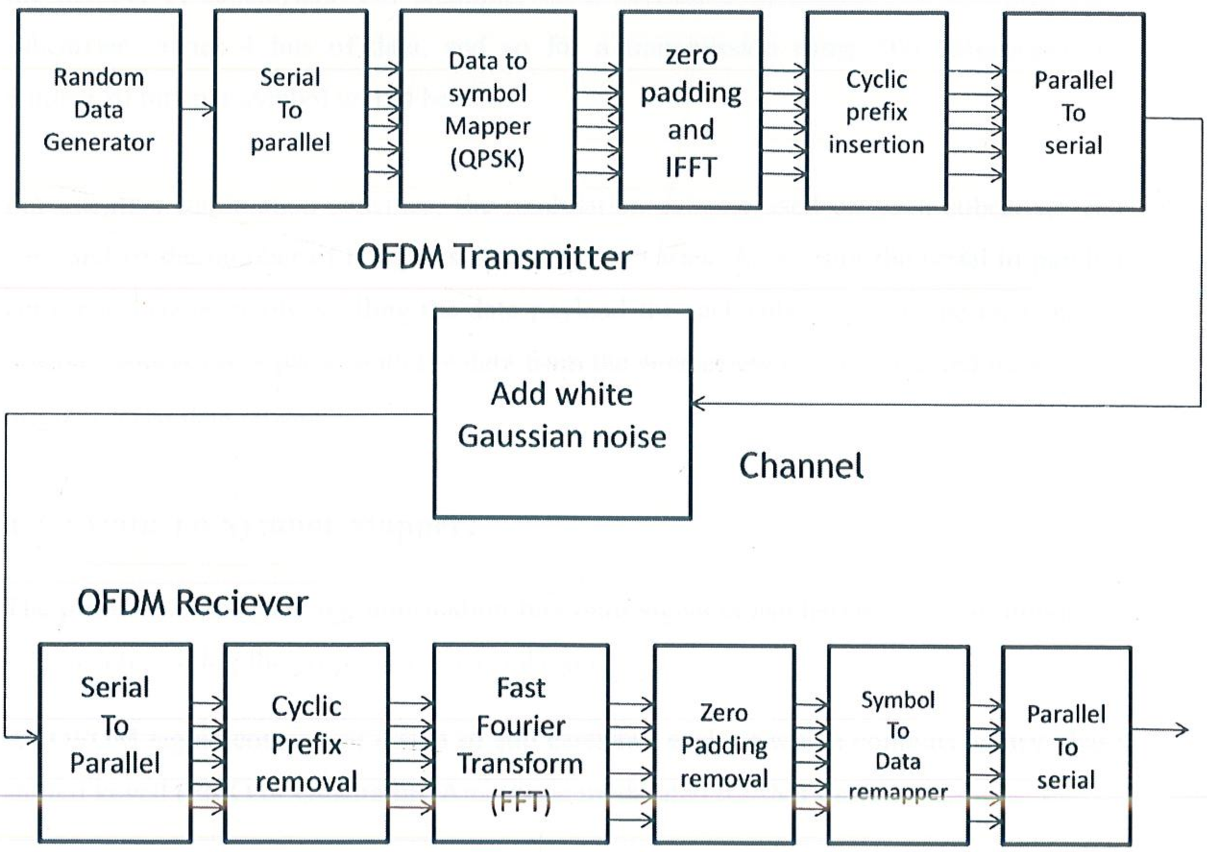


Fig 4.1 OFDM transciever

4.2 Ofdm System Model Descriptions

4.2.1 Radom Data Generator:

Random binary data is generated in this block i.e. it generates zeros and ones with equal probability. It is the most basic step in generation of a one dimensional array of large data stream for further simulation.

4.2.2 Serial To Parallel Conversion:

Data to be transmitted is typically in the form of a serial data stream. In OFDM, each symbol typically transmits 40 - 4000 bits, and so a serial to parallel conversion stage is needed to convert the input serial bit stream to the data to be transmitted in each OFDM symbol. The data allocated to each symbol depends on the modulation scheme used and the number of subcarriers. For example, for a subcarrier modulation of 16-QAM each subcarrier carries 4 bits of data, and so for a transmission using 100 subcarriers the number of bits per symbol would be 400.

For adaptive modulation schemes, the modulation scheme used on each subcarrier can vary and so the number of bits per subcarrier also varies. As a result the serial to parallel conversion stage involves filling the data payload for each subcarrier. At the receiver the reverse process takes place, with the data from the subcarriers being converted back to the original serial data stream.

4.2.3 Data To Symbol Mapper:

The process of mapping the information bits onto signal constellation plays an important role in determining the properties of modulation.

An OFDM signal consists of a sum of sub carriers , each of which contains M-ary phase shifted keyed (PSK) or Quadrature Amplitude modulated (QAM) signals.

Modulation types over OFDM systems:

- Phase Shift Keying (PSK)
- Quadrature Amplitude Modulation (QAM)

Phase Shift Keying:

In this method, the phase of the carrier signal is shifted by the modulating signal with the phase measured relative to the previous bit interval. The binary 0 is represented by sending a signal of the same phase as the preceding one and 1 is represented by sending the signal with opposite phase to the previous one.

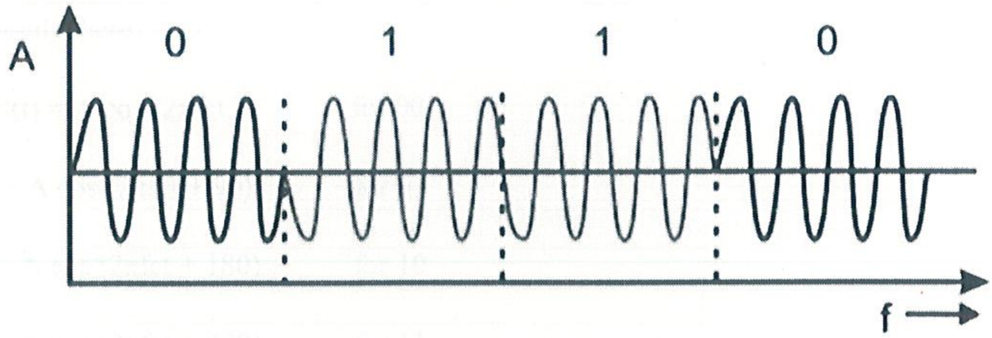


Fig 4.2 Phase Shift Keying

In 2-PSK the carrier is used to represent 0 or 1

$s(t) = A \cos(2\pi fct + \pi)$ for binary 1

$s(t) = A \cos(2\pi fct)$ for binary 0

M-ary Modulation: instead of just varying the phase, the frequency or amplitude of the RF signal , modern modulation techniques allow both(envelope) and (phase) orfrequency of RF carrier to vary. Because the envelope and phase provide two possible degrees of freedom,such modulation techniques map baseband data into four or more possible RF carrier signals. Such modulation techniques are known as M-ary modulation techniques. . In M-ary modulation scheme, two or more bits are grouped together to form

symbols and one of possible signals S1(t), S2(t), …, Sm(t) is transmitted during each symbol period Ts. Normally, the number of possible signals is M = 2^n , where n is an integer. Depending on whether the amplitude, phase or frequency is varied, the modulation is referred to as M-ary ASK, M-ary PSK or M-ary FSK, respectively. M-ary modulation technique attractive for use in bandlimited channels, because these techniques achieve better bandwidth efficiency at the expense of power efficiency. For example, an

8-PSK technique requires a bandwidth that is log28 = 3 times smaller than 2-PSK (also known as BPSK) system. However, M-ary signalling results in poorer error performance because of smaller distances between signals in the constellation diagram. Several commonly used M-ary signalling schemes are discussed below.

QPSK:

For more efficient use of bandwidth Quadrature Phase Shift Keying(QPSK) can be used,where

$S(t) = A \cos(2\pi f_c t)$ for 00

$= A \cos(2\pi f_c t + 90)$ for 01

$= A \cos(2\pi f_c t + 180)$ for 10

$= A \cos(2\pi f_c t + 270)$ for 11,

Here phase shift occurs in multiple of 90 degrees.

Bits	Phase
00	0
01	90
10	180
11	270

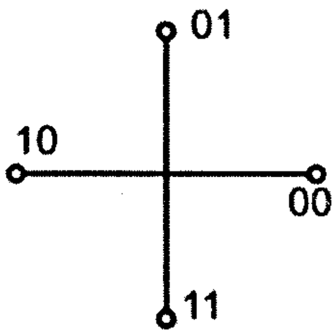


Fig 4.3 constellation diagram for QPSK

QAM (Quadrature Amplitude Modulation): Ability of equipment to distinguish small differences in phase limits the potential bit rate. This can be improved by combining ASK and PSK. This combined modulation technique is known Quardrature Amplitude Modulation (QAM). It is possible to obtain higher data rate using QAM. The constellation diagram of a QAM signal with two amplitude levels and four phases is shown in Fig. 4.2.3 . It may be noted that M-ary QAM does not have constant energy per symbol, nor does it have constant distance between possible symbol values.

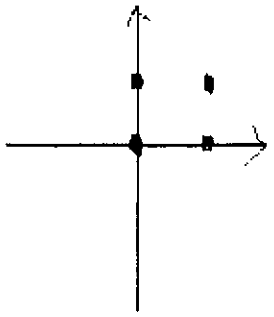


Fig (a)

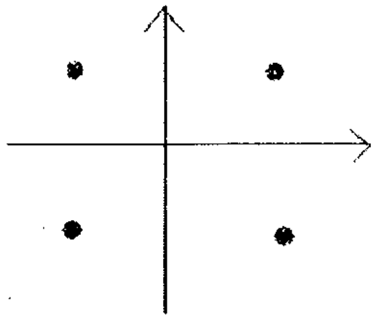
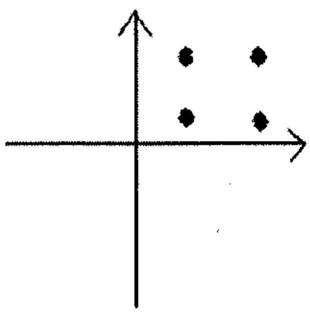


Fig (b)



Fig(c)

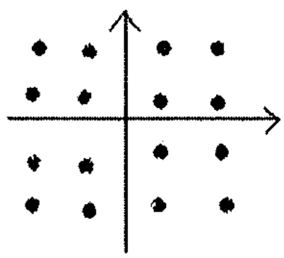


Fig (d)

Fig (a) 4.4 shows the simplest 4-QAM scheme (four different signal element types) using a unipolar NRZ (non-return to -zero) signal to modulate each carrier. Fig (b) shows another 4-QAM using polar NRZ, but this is exactly the same as QPSK. Fig(c) shows another 4-QAM.Finally, fig (d) shows that a 16-QAM constellations of a signal with eight levels, four positive and four negative.

4.2.4 Zero Padding and Ifft:

In zero padding we add zeroes in front and end of the data coming from data to symbol mapper block , so as to make it compatible to 64 ponit IFFT block.

An inverse Fourier transform converts the frequency domain data set into samples of the corresponding time domain representation of this data. Specifically, the IFFT is useful for OFDM because it generates samples of a waveform with orthogonal frequency components i.e. it introduces orthogonality.

4.2.5 Cyclic Prefix:

- **What is Cyclic Prefix?**

Let us consider one subcarrier (subcarrier +1 specified in IEEE 802.11a specification) alone. In the figure shown below, the blue line corresponds to the original sinusoidal where one cycle of the sinusoidal is of duration 64 samples ($3.2\mu s$ with 20MHz sampling), corresponding to subcarrier of frequency 312.5kHz.

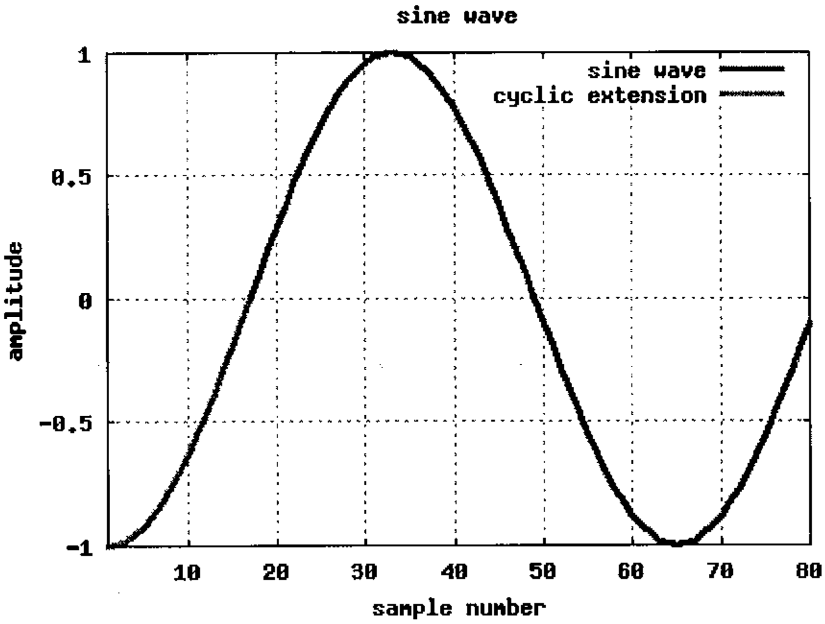


Fig 4.5 cyclic prefix

To add the cyclic prefix, 16 samples ($0.8\mu s$) from the end of the sinusoidal are appended to the beginning of the sinusoidal (shown in green colour). As can be seen, appending of cyclic prefix does not cause any discontinuities and we still have the original sinusoidal of frequency 312.5 kHz.

Further, after adding cyclic prefix, as the sinusoidal is of duration $4\mu s$, we now have a bigger window for choosing one period of the sinuosidal. Ofcourse, depending on which set of $3.2\mu s$ is chosen, the phase needs to be corrected, but that will be a trivial operation in a typical implementation.

- **Use of cyclic prefix in multipath channel:**

Cyclic prefix acts as a buffer region where delayed information from the previous symbols can get stored. The receiver has to exclude samples from the cyclic prefix which got corrupted by the previous symbol when choosing the samples for an OFDM symbol. Further, from the previous section, we learned that a sinusoidal added with a delayed version of the same sinusoidal does not affect the frequency of the sinusoidal it only affects the amplitude and phase).

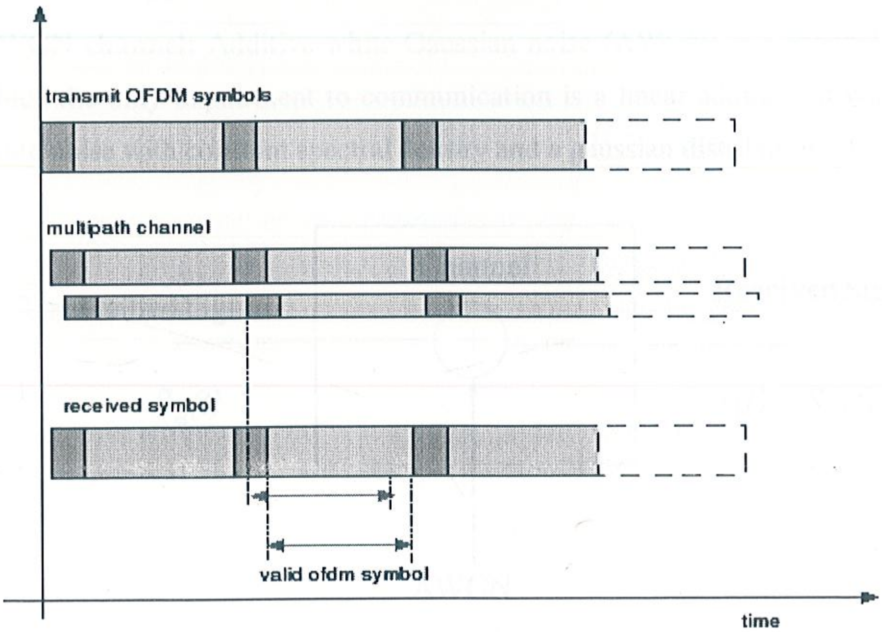


Fig 4.6 OFDM symbol with multipath

Given so, for demodulating the received symbol, the receiver can chose $3.2\mu s$ samples from a region which is not affected by the previous symbol. As shown in the figure above, the samples can be chosen from the blue-arrow region OR the orange-arrow region OR somewhere in between

Then, the parallel to serial block creates the OFDM signal by sequentially outputting the time domain samples.

4.2.6 Channel Simulation

The channel simulation will allow examination of the effects of noise, multipath, and clipping. By adding random data to the transmitted signal, simple noise can be simulated. Multipath simulation involves adding attenuated and delayed copies of the transmitted signal to the original. This simulates the problem in wireless communication when the signal propagates on many paths. For example, a receiver may see a signal via a direct path as well as a path that bounces off a building. Finally, clipping simulates the problem of amplifier saturation. This addresses a practical implementation problem in OFDM where the peak to average power ratio is high.

➢ **Different Types of Channel Environment:**

- **AWGN channel:** Additive white Gaussian noise (AWGN) is a channel model in which the only impairment to communication is a linear addition of wideband or white noise with constant spectral density and a gaussian distribution of amplitude.

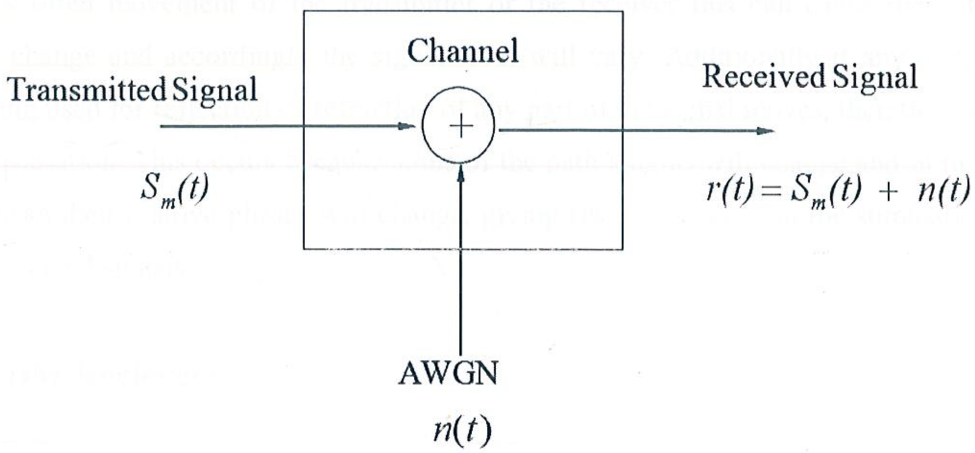


Fig 4.7 AWGN channel model

Where n(t) represents the sample function of AWGN process.

- **Rayleigh fading channel:** The Rayleigh fading model is particularly useful in scenarios where the signal may be considered to be scattered between the transmitter and receiver. In this form of scenario there is no single signal path that dominates and a statistical approach is required to the analysis of the overall nature of the radio communications channel.

Rayleigh fading is a model that can be used to describe the form of fading that occurs when multipath propagation exists. In any terrestrial environment radio signal will travel via a number of different paths from the transmitter to the receiver. The most obvious path is the direct, or line of sight path.

However there will be very many objects around the direct path. These objects may serve to reflect, refract, etc the signal. As a result of this, there are many other paths by which the signal may reach the receiver.

When the signals reach the receiver, the overall signal is a combination of all the signals that have reached the receiver via the multitude of different paths that are available. These signals will all sum together, the phase of the signal being important. Dependent upon the way in which these signals sum together, the signal will vary in strength. If they were all in phase with each other they would all add together. However this is not normally the case, as some will be in phase and others out of phase, depending upon the various path lengths, and therefore some will tend to add to the overall signal, whereas others will subtract.

As there is often movement of the transmitter or the receiver this can cause the path lengths to change and accordingly the signal level will vary. Additionally if any of the objects being used for reflection or refraction of any part of the signal moves, then this too will cause variation. This occurs because some of the path lengths will change and in turn this will mean their relative phases will change, giving rise to a change in the summation of all the received signals.

4.2.7 OFDM Reciever:

The receiver performs the inverse of the transmitter. First, the OFDM data are split from a serial stream into parallel sets. The Fast Fourier Transform (FFT) converts the time domain samples back into a frequency domain representation. The magnitudes of the frequency components correspond to the original data. Finally, the parallel to serial block converts this parallel data into a serial stream to recover the original input data.

4.3 OFDM Advantages and Disadvantages:

4.3.1 Advantages:

OFDM enjoys several advantages over other solutions for high speed transmission and possesses some inherent advantages for wireless communications. These advantages are few of the most important reasons on why OFDM is becoming more popular in the wireless industry today.

- Makes efficient use of spectrum by allowing overlap.
- By dividing the channel into narrowband flat fading sub-channels, OFDM is more resistant to frequency selective fading then single carrier systems are.
- Eliminates ISI and ICI through the use of cyclic prefix.
- Using adequate channel coding and interleaving one can recover symbols lost due to frequency selectivity of the channel.
- Channel equalization becomes simpler than by using adaptive equalization with single carrier systems.
- It is possible to use maximum likelihood decoding with reasonable complexity, as discussed in OFDM is spectrally efficient by using FFT techniques to implement the modulation and demodulation functions.
- In conjunction with differential modulation,there is no need to implement a channel estimator.
- Is less sensitive to sample timing offsets,than single carrier systems are
- Provides good protection against cochannel interference and impulsive parasitic noise
- Used as a multiple access scheme.
- Suitable for coherent demodulation and direct detection.
- Multiple access using OFDM is highly flexible

TDMA: scheduled access in time

FDMA: scheduled access in frequency

CSMA: random access using carrier sense

OFDMA:assigning multiple users to different subcarriers

4.3.2 Disadvantages:

- Sensitive to Doppler shift.
- Sensitive to frequency synchronization problems.
- High Peak to average ratio(PAPR),requiring linear transmitter circuitry,which suffers from poor power efficiency.
- Loss of efficiency caused by Cyclic Prefix/Guard Interval.

4.4 OFDM Applications:

- The initial applications were in the military communications. In the telecommunications field, the terms of discrete multi tone (DMT) , multi channel modulation, multi carrier modulation are widely used and sometimes they are interchangeable with OFDM.

- It has already been accepted for new wireless local area network(LAN) standards IEEE 8011.2a, high performance LAN type 2 (HIPERLAN/2), the IEE 802.16a Metropolitan area network(MAN) starndard andMobile Multimedia Access communication(MMAC) systems.

- For fixed-wire applications, OFDM is employed in asynchronous digital subscriber line(ADSL) and high bit rate digital subscriber line(HDSL) systems and it has also been suggested for powerline communications systems due to its resilience to time dispersive cannel and narrowband interferers.

- OFDM is also being pursued for dedicated short range communications (DSRC) for road side to vehicle communications and as a potential candidate for 4G mobile wireless systems.

- In optical communication, optical OFDM which combines the merits of the coherent detection and OFDM technology has arrived in time for next generation optical networks.

The following list is the summary of existing OFDM based standards and products:

Cable:

- ADSL and VDSL broadband access via POTS copper wiring
- Power line communication (PLC)
- MultiMedia Over Coax Alliance (MoCA) home networking

Wireless:

- The wireless radio interfaces IEEE 802.11a,g,n and HIPERLAN/2
- The digital radio systems DAB/ EUREKA 147
- The terrestrialdigital tv system DVB-T
- The cellular communication systems Flash OFDM
- The mobile broadband 3GPP long term evolution air interface named high speed OFDM packet access (HSOPA).

4.5 OFDM Challanges:

- OFDM/DMT consists of multiple sinusoids summed together, can have a large peak-to-average power ratio (PAPR), which leads to amplifier inefficiencies.
- PAPR compensated through clipping or coding.
- Timing and frequency off sets cause subchannels to interfere with each other.
- Interference between subchannels mitigated by minimizing the number of subchannels and using pulse shapes robust to timing errors.

CONCLUSION

We designed an OFDM transmitter and receiver system and analysed its BER performance under various channel environment using several modulation schemes like BPSK, QPSK and 16-QAM etc. The simulations are based upon IEEE 802.11a standard. Based on simulated OFDM model we can conclude that:

- BER for given range of SNR is more in Rayleigh channel as compared to AWGN channel because the Rayleigh channel exhibits more practical behavior than AWGN channel..

- BER curve for AWGN monotonically falls down to zero, whereas in case of Rayleigh it attains a certain minimum value instead of falling down to zero.

- As far as modulation schemes are concerned, BER performance is best in case of BPSK but QPSK and 16-QAM support higher data rates. So, we have to trade off between system performance and higher data rates.

Finally, we can conclude that OFDM promises to be a suitable modulation technique for high capacity along with high data rate wireless communications and will become an dominant technology in future on which wireless networks can be relied on.

FUTURE SCOPE

Future telecommunication systems must be very efficient spectrally to support more number of users with high data rate. OFDM uses the available spectrum very efficiently due to its orthogonal nature. This is very useful for multimedia communications. Thus, OFDM stands a good chance to become the prime technology for 4G. can be Work can be carried out to improve the OFDM system performance by mitigating ISI as well as ICI. Performance can be further enhanced by alleviating PAPR along with time and frequency offsets.

Appendix A

S. No.	Parameter	Value
1	Carrier modulation used	QPSK and 16-QAM
2	Number of data subcarriers	48
3	Number of pilot-subcarriers	None
4	IFFT size	64
5	Guard period type	cyclic extension of the symbol
6	Cyclic prefix length	16
7	Window type	No windowing used
8	Bandwidth	20MHz
9	Number of channel Taps	18 (Freq. selective channel) 10 (Freq. Flat channels)
10	Sub-carrier frequency spacing	20 MHz/64 = 0.3125 MHz
11	T_{FFT} : IFFT/FFT period	3.2μsec
12	T_{CP} : cyclic prefix duration	0.8μsec
13	Total OFDM symbol duration	$T_{FFT} + T_{CP}$ = 4μsec
14	Symbol Rate	Number of carrier/ symbol duration = 48/3.2 μsec, 15Msps

Simulation parameters for OFDM Transceivers

Data rate (Mbits/s)	Modulation	Coding rate (R)	Coded bits per subcarrier (N_{BPSC})	Coded bits per OFDM symbol (N_{CBPS})	Data bits per OFDM symbol (N_{DBPS})
6	BPSK	1/2	1	48	24
9	BPSK	3/4	1	48	36
12	QPSK	1/2	2	96	48
18	QPSK	3/4	2	96	72
24	16-QAM	1/2	4	192	96
36	16-QAM	3/4	4	192	144
48	64-QAM	2/3	6	288	192
54	64-QAM	3/4	6	288	216

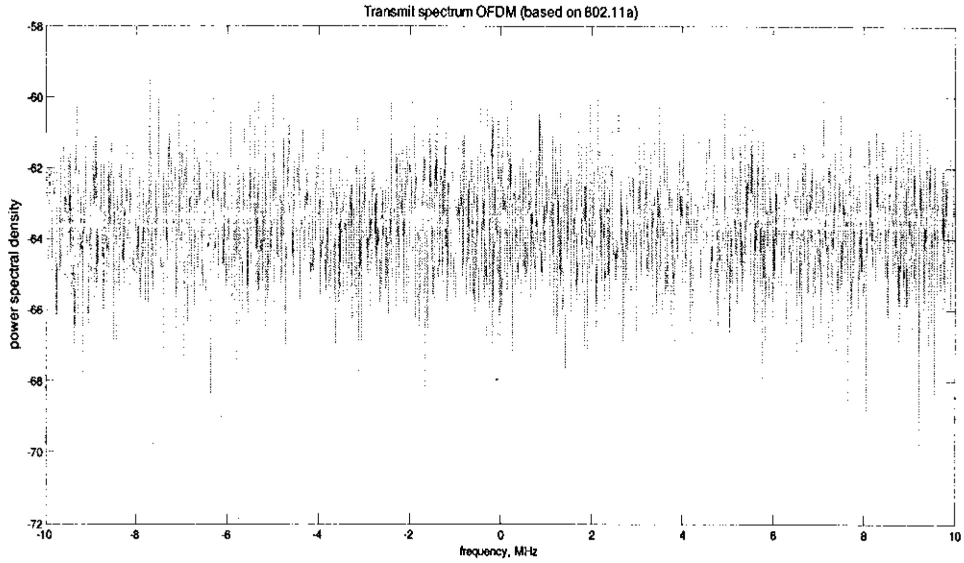
Rates Supported By OFDM Transceivers

Appendix B

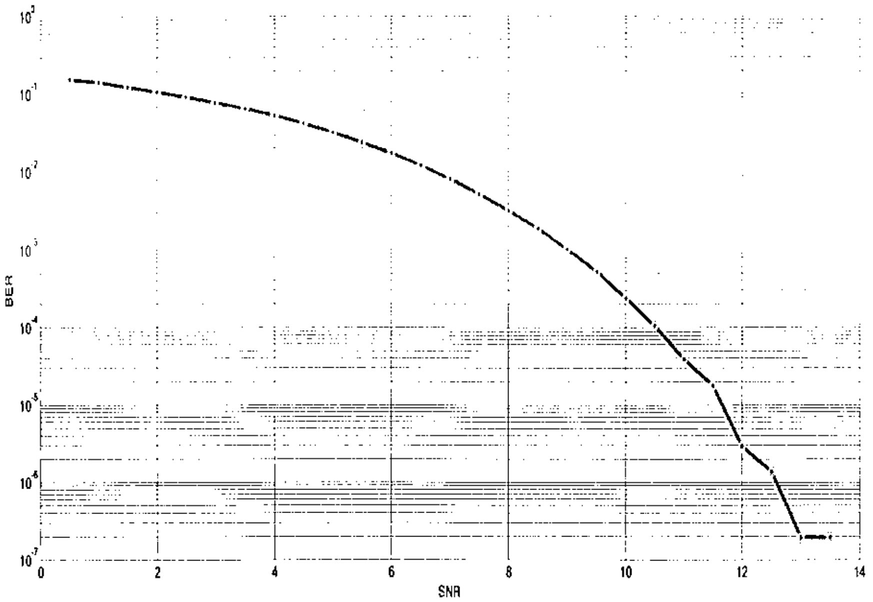
Matlab code for OFDM transmitter and receiver using QPSK under AWGN channel

```
snr=.5:.5:15;% defining snr level

%transmitter
x=randint(5200000,1,4);%random binary data
r1 = reshape(x,100000,52);%s to p
m=(modulate(modem.pskmod(4),r1));%modulation 4 psk
m1=[zeros(100000,6) m zeros(100000,6)];% adding zeropadding bits
m2=ifft(m1);%ifft
m6=reshape(m2,6400000,1);
m3=[m2(:,49:64)];%filter signal for prefixing
m4=[m3 m2];%cycling prefixing
m5=reshape(m4,8000000,1);%parallel to serial

%channel added white gaussian noise variying 1 to 12
number=[];
ratio=[];
for i=1:length(snr)
% for i=1:5:30
 y = awgn(m5,snr(i),'measured');%intoducing white gaussian noise

%receiver
y1=reshape(y,100000,80);%s to p
n=[y1(:,17:80)];%remove cycling prefixing
n1=fft(n);%fft
```

```
n2=[n1(:,7:58)];%remove zero padding bits and filter the signal
n3=(demodulate(modem.pskdemod(4),n2));%demodulation or symbol to bit convertion
r=reshape(n3,5200000,1);%p to s
%r is the output signal in ofdm system
[number(i),ratio(i)]=biterr(r,x);
end
% plot(ratio,snr);hold on;
% xlabel('semilog plot')
% ylabel('linear plot')
 grid on
semilogy(snr,ratio)
```



Matlab Figure showing Power spectral density (PSD)

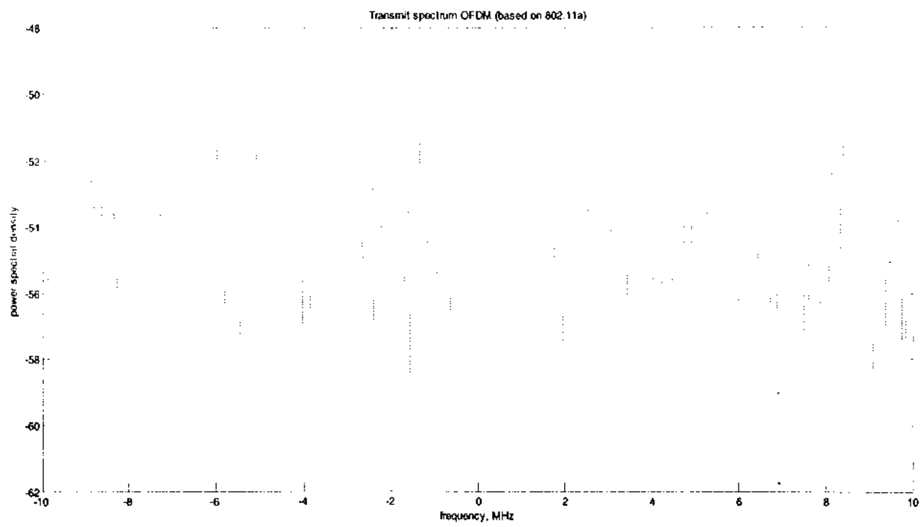


Matlab figure showing BER vs SNR curve

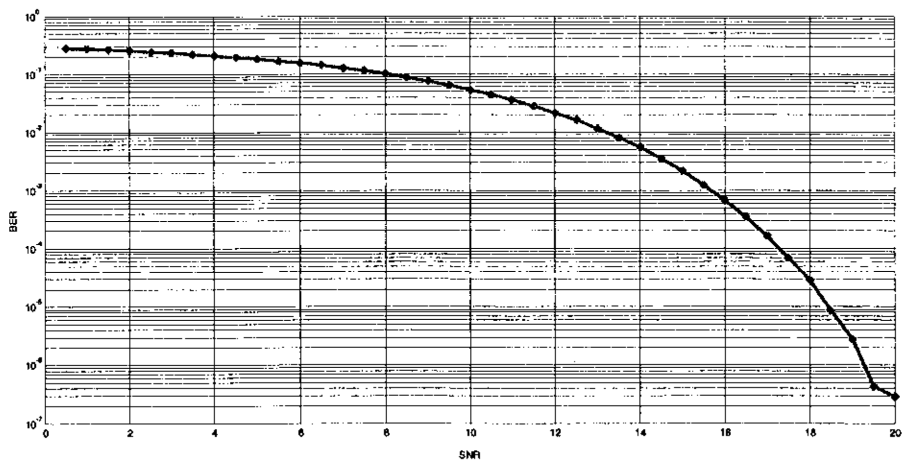
Matlab Code for OFDM transmitter and receiver using 16QAM under AWGN channel

```
snr=.5:.5:20;% defining snr level

%transmitter
x=randint(5200000,1,16);%random binary data
r1 = reshape(x,100000,52);%s to p
m=(modulate(modem.qammod(16),r1));%modulation 4 psk
m1=[zeros(100000,6) m zeros(100000,6)];% adding zeropadding bits
m2=ifft(m1);%ifft
m6=reshape(m2,6400000,1);
m3=[m2(:,49:64)];%filter signal for prefixing
m4=[m3 m2];%cycling prefixing
m5=reshape(m4,8000000,1);%parallel to serial
```

```
%channel added white gaussian noise variying 1 to 12
number=[];
ratio=[];
for i=1:length(snr)
% for i=1:5:30
 y = awgn(m5,snr(i),'measured');%intoducing white gaussian noise

%receiver
y1=reshape(y,100000,80);%s to p
n=[y1(:,17:80)];%remove cycling prefixing
n1=fft(n);%fft
n2=[n1(:,7:58)];%remove zero padding bits and filter the signal
n3=(demodulate(modem.qamdemod(16),n2));%demodulation or symbol to bit
convertion
r=reshape(n3,5200000,1);%p to s
%r is the output signal in ofdm system
[number(i),ratio(i)]=biterr(r,x);
end
% plot(ratio,snr);hold on;
% xlabel('semilog plot')
% ylabel('linear plot')
 grid on
semilogy(snr,ratio)


% ofdm spectrum
fs_MHZ=20;
[Pxx,W] = pwelch(m6,[],[],4096,20);  plot([-
2048:2047]*fs_MHZ/4096,10*log10(fftshift(Pxx)),'g')
xlabel('frequency, MHz')
ylabel('power spectral density')
title('Transmit spectrum OFDM (based on 802.11a)')
```



Matlab figure showing power spectral density for 16 QAM



Matlab figure showing BER vs SNR plot for 16 QAM

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