MATLAB BASED TESTBENCH IMPLEMENTATION OF DIGITAL COMMUNICATION OVER AN ACOUSTIC CHANNEL USING OFDM

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Abstract

This paper presents the implementation of an OFDM based modem for the transmission of digital signal over an acoustic channel between the speaker and the microphone in MATLAB. The features of OFDM modulation scheme such as its robustness towards intersymbol interferences and multipath interference at the receiver side is also discussed. An analog data converted into digital bits is sent from the transmitter and the output is recorded at the microphone. The study implements 16 quadrature amplitude modulation schemes on each of the carriers. The OFDM symbols are separated with insertion of cyclic prefix that makes the system more resistant to multipath effects. The frequency domain channel estimation and equalisation has been carried out in order to have better BER performance and avoid ISI and ICI. Clipping at the receiver has been overcome by direct scaling of the signal. The effect of the distance on the channel capacity has also been studied by changing the distance between the speaker and the microphone. The performance of the OFDM system with different SNR and constellation points [illegible] presented.

Key Words : OFDM, acoustic channel, ISI, BER and SNR.

1. INTRODUCTION

It is more challenging to maintain reliable communications over wireless (radio signal) channels than over wired channels as the propagation paths or the channel are in most situations unpredictable and susceptible to even a small change in the environment. Therefore, signal processing techniques plays an extremely important role to overcome these problems.

The idea of OFDM was proposed in mid-1960s used initially for the military purpose. The Discrete Fourier transform was applied to parallel data transmission systems in 1971 by Weinstein and Ebert. In 1980s it was studied as the high speed modem digital mobile communication (anoynomous, nd). Recently, the use of Orthogonal Frequency Division Multiplexing (OFDM) has emerged as a technology for high data rates. Many wireless standards such as Wi-Max, IEEE802.11a, LTE, and DVB have adopted OFDM technology as a mean for increasing future wireless communications. OFDM is well suited for frequency selective channels and high data rates. It transforms a frequency-selective wide-band channel into a group of non-selective narrowband channels by preserv-ing orthogonality and it makes it robust against large delay spreads.

In an OFDM scheme, a large number of orthogonal, overlapping, narrowband sub-channels or carriers transmitted in parallel divide the available transmission bandwidth. Attraction of the OFDM is mainly due to how the system handles the multipath interference at the receiver. The presence of ISI in the system introduces errors in the decision device at the receiver output. So in order to remove this ISI adaptive equalizer and error correcting code (adding of guard symbol) are used. Although the sidebands from each carrier overlap, they can still be received without the interference that might be expected because they are orthogonal to each other. This is achieved by having the carrier spacing equal to the reciprocal of the symbol period (Rodriguez & Jover, 2007).

New applications are emerging not only in the wired environment but also in the mobile one. The presences of low bit- rate data services are inefficient for the transmission. The usage of adaptive equalization could be the solution but operating equalization in real time are practically difficult. Therefore OFDM can be used to meet the need of complex equalizers. It can be used in adverse channel condition and can give high spectral efficiency. It has an advantage of handling multipath interference.

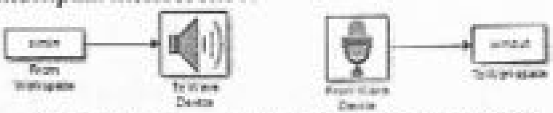

Fig 1 : Simulink model (backbone for all the Matlab programs implemented in this project).

Simulink model is used for simultaneous audio recording and playing back. The audio signal is taken from a Matlab workspace variable (simin) and saved in another workspace variable (simout). And this Simulink scheme will be the backbone for the completion of project. Input signal "toplay" (a vector that contains the samples of an audio signal) is created at sampling frequency of 16000Hz at which the playback/recording operates.

2. CHANNEL CHARACTERISTICS

Simulink model was created and a channel was modelled for transmitting digital data between speaker (transmitter) and microphone (receiver) which is connected to a PC. The spectrogram and Power spectral density (PSD) of input signal and the recorded output signal is plotted. The impulse response and the frequency response of the system is plotted to get the system response. In order to get better response of the system its impulse response is estimated.

2.1 Spectrogram

It is a graph representing the amount of energy content in the signal and is expressed as a function of frequency and the time. It is built by piling the sequence of spectra in time and the amplitude is compressed into a grey scale. The time is plotted along the horizontal axis, frequency along the vertical axis and the amplitude is represented by the grey colour at any given time and frequency. The dark color indicates the strong energy content while light indicates the least energy content. The degree of darkness is proportional to the strength of the signal.

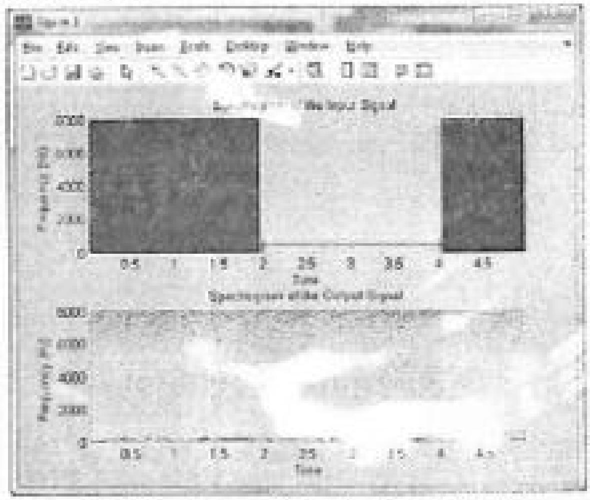

Fig 2 *Spectrogram of input and output signal*

The figures above depict the spectrogram of the input signal "simin" which is the sine-wave of frequency 440Hz at sampling frequency 16000Hz, which runs for 2 seconds. And the other figure shows the spectrogram of the recorded signal "simout" which is collected by "out". The length of the playback/recording is 5seconds. From the figure it can be seen that the beside the fundamental frequency (440Hz) there are other frequencies present and this frequencies are known as Harmonic frequencies. Harmonic frequencies are the multiplication of the fundamental frequency (440Hz) which are equally spaced by the width of the fundamental frequency.

2.2 Power Spectal Density

This graph shows the variation or strength of energy as a function of frequency.

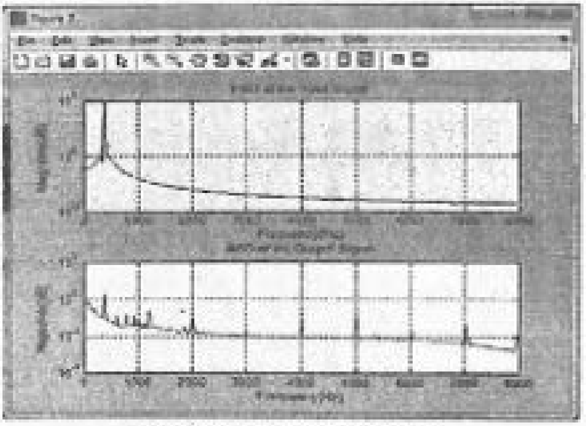

Fig 3 : PSD of input and output

The above figures show the Power Spectral Density (PSD) of the input signal "simin" and the output signal "out". The first figure is the PSD of the input signal with one spike at the fundamental frequency of 440Hz. The second figure is the PSD of the output signal containing spikes at fundamental frequency and multiples of the fundamental frequency.

3. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

Orthogonal Frequency Division Multiplexing (OFDM) is a method of multi-carrier modulation in which carrier spacing is so chosen that all the sub-carriers are orthogonal to each other. Orthogonality can be assured by cautious selection of the sub-carrier frequencies. By choosing sub-carrier frequencies that are harmonious to each other, orthogonality can be achieved.

The presence of a multipath channel is the major problem in most wireless system. The presence of multipath channel causes the transmitted signal to reflect off the several objects resulting in multiple delayed versions of the transmitted signal at the receiver. This causes distortion to the received signal. The multiple signals cause two problems for the OFDM system. The first problem faced is inter-symbol interference and it occurs due to the distortion in received signal caused by the transmitted OFDM symbol. The effect of inter-symbol interference is same as that of the single carrier system. However, in single carrier system the interference is due to the several other symbols instead of just the previous symbol. In single carrier system, the symbol period is much shorter than the time span of the channel but in OFDM system symbol period is much longer than the time span of the channel. The second problem is intra-symbol interference and is caused due to the interference among a given OFDM symbol's own subcarriers (Marcheti, n.d).

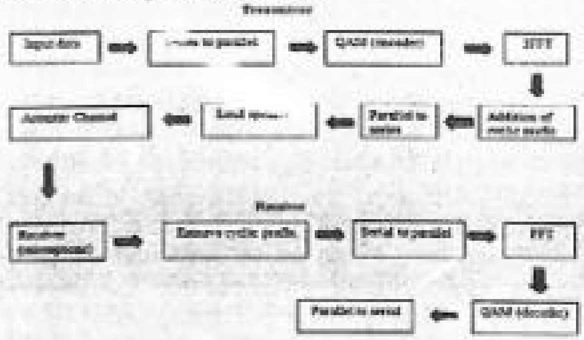

Fig 4 OFDM Block Diagram

3.1 Serial to Parallel

Each channel is broken down into various sub-carriers in an OFDM system. The sub-carriers make optimal use of the frequency spectrum but this requires additional processing by the transmitter and receiver. This additional processing is necessary to convert a serial bit-stream into several parallel bit-streams to be divided among the individual carriers (John, n.d). Once the bit-stream has been divided among the individual sub-carriers, each sub-carrier is modulated as if it was an individual channel before all channels are combined back together and transmitted as a whole. The receiver performs the reverse process to divide the incoming signal into appropriate sub-carriers and then demodulating these individually before reconstructing the original bit-stream (Simon, n.d).

3.2.QAM

Amplitude Shift Keying (ASK) is also combined with Phase Shift Keying (PSK) to create hybrid systems such as Quadrature Amplitude

Modulation (QAM) where both the amplitude and the phase are changed at the same time. QAM is a modulation scheme which conveys data by changing (modulating) the amplitude of the two carrier waves (Jagadeesh, 2007). These two waves usually sinusoids are known as quadrature carriers and are out of phase with each other by 90°. In QAM, the constellation points are usually arranged in a square grid with equal vertical and horizontal spacing. By moving to a higher-order constellation it is possible to transmit more bits per symbol (Rappaport, n.d).

3.3. FFT & IFFT

An OFDM system treats the source symbols (e.g., the QPSK or QAM symbols that would be present in a single carrier system) at the transmitter as though they are in the frequency-domain. These symbols are used as the inputs to an IFFT block that brings the signal into the time domain. The IFFT takes in N symbols at a time where N is the number of subcarriers in the system. Each of these N input symbols has a symbol period of T seconds. We know that the basic functions for an IFFT are N orthogonal sinusoids. These sinusoids each have a different frequency.

Each input symbol acts like a complex weight for the corresponding sinusoidal basis function and the value of these symbols determines both the amplitude and phase of the sinusoid for that subcarrier. The output from the IFFT is the simulation of all N sinusoids. The block of N output samples from the IFFT make up a single OFDM symbol. The length of the OFDM symbol is NT where T is the IFFT input symbol period.

The time-domain signal that results from the IFFT is transmitted across the channel to the receiver. At the receiver, an FFT block is used to process the received signal and bring it into the frequency domain. The FFT output will be the original symbols that were sent to the IFFT at the transmitter (Chide Nilesh: Deshmukh, 2009).

3.4. Cyclic Prefix Insertion

Wireless communication systems are susceptible to multi-path channel reflections; a cyclic prefix is added to reduce ISI. A cyclic prefix is a repetition of the first section of a symbol that is appended to the end of the symbol. In addition, it is important because it enables multi-path representations of the original signal to fade so that they do not interfere with the subsequent symbol (Lathi, n.d).

Cyclic prefix insertion allows the signal to be decoded even if the packet is detected after some delay. Cyclic prefix acts as a buffer region where delayed information from the previous symbols can get stored (Litwin, 2001).

3.5. Digital to Analog Conversion, Analog to Digital Conversion

Digital-to-Analog Converter is an electronic device, often an integrated circuit that converts a digital number into a corresponding analog voltage or current. It involves transforming the computer's binary output in 0's and 1's into an analog representation of the binary data.

Analog-to-Digital Converter is an electronic integrated circuit which transforms a signal from analog (continuous) to digital (discrete) form. ADC Provides a link between the analog world of transducers and the digital world of signal processing and data handling (Ancynomouse, n.d).

3.6. Parallel to Serial Conversion

After the cyclic prefix has been added to the sub-carrier channels, they must be transmitted as one signal. Thus, the parallel to serial conversion stage is the process of summing all sub-carriers and combining them into one signal. As a result, all sub-carriers are generated perfectly simultaneously (Hanzo, Webb, & Keller, n.d).

3.7. OFDM Principle

Its basic principle is that it split the channel bandwidth into many narrow sub-channels which are transmitted in parallel. Since each sub-channels are narrow enough to experience a flat fading, coding for the error correction and mapping of bits onto the symbols is done on the source data. The symbols are modulated using IFFT onto the orthogonal sub-carrier.

Orthogonality between the sub-carrier is maintained and it is done by adding a cyclic prefix to the frame. The cyclic prefix placed at the beginning of the frame is the copied L last sample of the frame. The start of the frame can be detected from the insertion of cyclic prefix. At the receiver side FFT is used to demodulate the received signal.Training sequence or pilot symbol can be used for channel equalization.

4. Quadature Amplitude Modulation (QAM)

The different types of QAM modulation was experimented to understand their trade-offs in terms of bit rate, signal to noise ratio(SNR) and error bits. A pseudo random binary data stream wass generated. A sequence of bits was modulated into M-ary QAM format where M is an integer power of 2, i.e., $M = 2^{N_s}$. The maximum value of N_s for the targeted OFDM system was kept as 6, corresponding to 64-QAM. The constellation diagrams for the generated QAM symbol sequence is shown below:

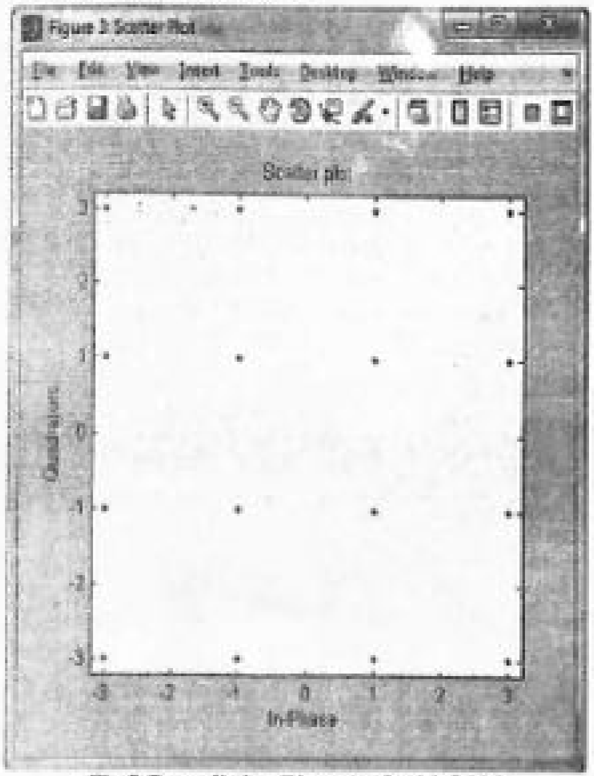

Fig 5 Constellation Diagrams for 16-QAM

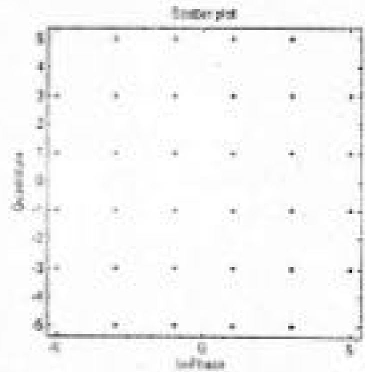

Fig 6 Constellation Diagrams for 32-QAM

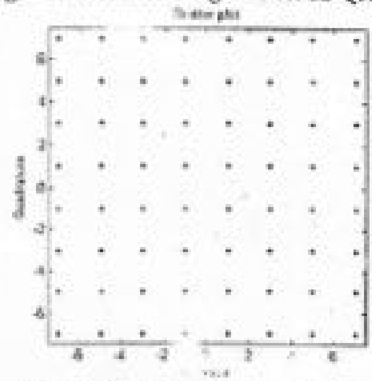

Fig 7 Constellation Diagrams for 64-QAM

The constellation points for different QAM modulation are usually arranged in square grid with equal vertical and horizontal spacing. The commonly used constellation points are 16QAM, 64QAM and 256 QAM. When using higher QAM modulation, there will be more points on the constellation which enables more bits per symbol to be transmitted. But when there are more points on the constellation, the points becomes closer to each other and they are prone to noise and data errors.The main advantage of choosing high order modulation formats is to transmit more bits per symbol.Hence the high modulation formats are used only when there is high signal to noise ratio. Basically 16QAM is used as the lowest order QAM . For 16QAM the bit rate is 4bits per symbol and the symbol rate is ¼ bit rate. For 32QAM the bit rate is 5 bits per symbol and the symbol bit is 1/5 bit rate.The bit rate for 64QAM is 6 bit per symbol and the symbol bit is 1/6 bit rate. As the order of modulation formats increases from 16QAM to 32QAM and 64QAM, the points on the constellation become narrow, thereby it becomes susceptible to noise and interference and there bit per symbol also increases. The average signal power increases when the modulation formats is increased.

5. Effect of AWGN on OFDM

Noise exists in all the communication systems operating over an analog physical channel. The main sources of noise are found to be electrical noise and thermal background noise at the receiver and inter-cellular interference. As a result of inter-symbol interference (ISI), inter-carrier inference (ICI), and inter-modulation distortion (IMD) it can also generate internal noise to the communication system. All these sources of noise decreases the signal to noise ratio (SNR) which in turn results in decreased spectral efficiency of the system. In communication system, noise in all its forms is the negative effect limiting the efficiency of the system (Amasa, 2009).

Hence it becomes important to study the noise effect on the communication error rate and the existence of the tradeoffs between the spectral efficiency of system and level of noise. An additive white Gaussian noise is used so to model the types of noise present in communication systems. It is also used because of its property of having uniform spectral density and having Gaussian distribution in its amplitude. Since the transmission being OFDM, the sources of noise have properties of AWGN. Therefore almost all the noise present in OFDM system has AWGN properties, which enables them to be modelled accurately with AWGN (phillip, 2001).

The effect of additive white Gaussian noise on the QAM symbol sequence is depicted as below:

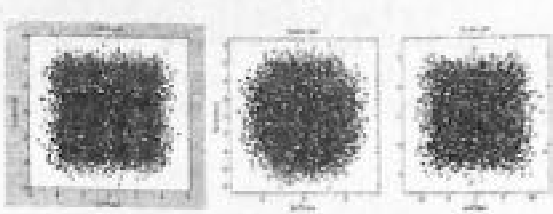

Fig 6 Scatter Plot Showing Effect of White Gaussian Noise on the QAM Symbol

From the above diagram it is observed that when there is more constellation point on the QAM symbol more of the noise appears on the plot.

QAM symbol sequences are now demodulated back to a binary sequence for different values of M. Two binary sequences are taken from transmitted and received sequence to calculate the bit error rate (BER).The number of bit errors is the number of received bits of a data stream over a communication channel that have been altered due to noise, interference, distortion or bit synchronization errors (Lim, 2010).

Each time a bit-error-rate simulation is done; it transmits and receives a fixed number of bits. It determine how many of the received bits are in error, and then compute the bit-error-rate as the number of bit errors divided by the total number of bits in the transmitted signal (Gilley, 2003).

The calculated BER for different QAM is found to be as follow:

Constellation points	16 QAM	32 QAM	64 QAM
BER	0.0789	0.1683	0.2197

It is found that the BER increases as the M-ary QAM constellation is increased resulting in decreased in SNR. The BER versus SNR for different QAM constellation is plotted in figure 7.

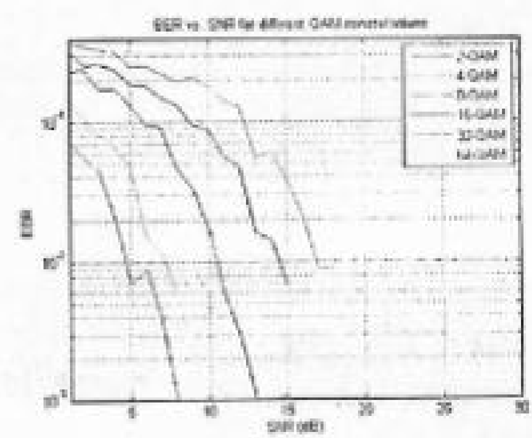

Fig 7 BER vs SNR for different QAM constellation

6. OFDM Over Acoustic Channel

Now an OFDM modulation is being implemented and OFDM based transmitter is simulated. Firstly in order to simulate OFDM transmitter, a packet of P OFDM frames are generated. Each frame consists of N complex numbers, of which two numbers are equal to zero (corresponding to the DC frequency and the Nyquist frequency), and other numbers are equal to QAM symbols taken from a QAM symbol sequence.Then to each OFDM frames an IFFT is applied which is followed by serial to parallel conversion. At the receiver side, serial to parallel conversion is being implemented and in order to regenerate the transmitted OFDM frames and QAM symbol FFT is performed.The transmitter and receiver are extended with box that add and remove a cyclic prefix to every data frame. The length of the cyclic prefix is user defined which is much shorter than the length of the frame.

Here instead of sending random bit sequence the image will be send over the channel. To start with the QAM modulator and demodulator created in chapter four are now added to obtain a QAM symbol sequence. Similarly in order to obtain OFDM frame sequence, OFDM modulator and demodulator created in previous chapter is added. Then AWGN is added to the received OFDM frame sequence and the signal received after transmission.

The image received is observed to be distorted by the noise present in the channel. SNR is set to ∞ dB and a channel with a transfer function of $H(z)= h_0+ h_1z^{-1}+ \ldots +h_Lz^{-L}$ is inserted between the transmitter and the receiver having random numbers as the channel coefficient . The cyclic prefix inserted is longer than the length of the channel impulse response. The components of FFT output are scaled with the inverse of the channel frequency response.

7. FUTURE WORKS

Increasing ability to achieve capacity, high data rate, minimum bit error rate (BER), spectral efficiency and minimum power requirements are the main reasons behind future research efforts in OFDM. By coping up with few drawbacks associated with OFDM, there can be many prospects for future research. Some of the possibilities for future work are given below:

- Channel estimation and equalization with diversity techniques and/or coding to compensate the effect(s) of channel with delay/Doppler shifts and try to achieve optimum values of capacity, BER etc.

- Appropriate combination of waveform shaping and frame overlap in time limited OFDM without destroying orthogonality.

- Dynamic selection of phase shifts, data sequences and signal clipping or either of the combination of those to reduce PAPR.

- Design of channel estimator with time / frequency correlations with adaptation.

- Adaptive subcarrier, bit, and power allocation to each sub-band to achieve optimum values of capacity, BER, minimum power requirement etc.

- Any other combined approaches like OFDM-CDMA, OFDM-SDMA.

- Blind estimation techniques for symbol timing and carrier frequency offset.

- OFDM application specific DSP architectures.

And lastsy efforts to make OFDM user-centered technology for improvement of quality of life of the individual can be one of the many future works.

8. CONCLUSION

Efficient communication with less interfernces as far as possible is what everybody expects from a communication scheme. Therefore, in this paper, a digital communication over acoustic channel using OFDM has been demonstrated which highlights why OFDM has emerged as a technology for high data rates. Digital data from a transmitter, in this project a speaker was transmitted over an acoustic channel to the receiver which is a microphone using OFDM scheme and the output obtained was compared with the input. OFDM has been used because of its property of being able to handle multipath interference at the receiver.

8. ACKNOWLEDGMENT

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9. REFERENCES

Anoynomous. (nd). Chapter 1: ..torduction to Orthogonal frequecy division multiplexing technique. *Wireless comm Lab*, 6-7.

Anoynomouse. (2003). Acoustic of speech and hearing. *psychology and language scheme.*

Anoynomouse. (n.d). digital to analog conversion.
Bell, D. A. (2004). *Operational Amplifiers and Linear ICs* (4th ed.). (Prentice-Hall, Ed.) New Delhi, India.

Berman, H. L., & Hills, L. A. (1972, Nov 21). *USA Patent No. 3,73,718.*

Chide Nilesh: Deshmukh, S. (2009). Implementation of OFDM system using IFFT and FFT. *Internation journal of engineering research and applications.*

Hanzo, L., Webb, W., & Keller, T. (n.d). Multicarrier modulation: Principles and applications. *IEEE computer science.*

Jagadeesh, D. (2007). *Simulation of wireless communication system using OFDM principle.*

Khedr, M. (2007). Orthogonal Frequency Division Multiplexing and Related Technology. *OFDM basics.*

Lathi, P. B. (n.d). *Modern digital and analog communication systems.*

Litwin, L. P. (2001). RF signal processing: The principle of OFDM.

Marcheti, N. R. (n.d). OFDM: principle and challenges.

Rappaport, t. S. (n.d). *wireless communication.*

Rodriguez, M. L., & Jover, R. P. (2007). Resiliency of OFDM to Multipath Fading in Wireless Communications.

Simon, H. (n.d). *communication system.*

Sonoran. (2010, June). *Cudde Back Digital.* Retrieved December 2012, from Tech Note: http://cuddeback.com/pdf/Troubleshooting/Tech%20 Note: %20-%20Motion%20Heat%20Sensor%20&%20Setup.pdf