HIGH PERFORMANCE OFDM COMMUNICATION SYSTEM

By:

NC Sundeel Bin Haleem

NC Usama Javed

NC Mobeen Sarwar

NC Shehryar Malik

Submitted to the Department of Electrical Engineering in Partial Fulfillment of the Requirements for the Bachelor's Degree in Electrical (Telecom) Engineering

JUNE 2016

ABSTRACT

OFDM is used in high speed communication systems like LTE. It works by dividing the available spectrum in orthogonal overlapping sub-carriers or by dividing a higher data rate link into low data rate links. Thus OFDM, using orthogonal sub-carriers, achieve high data rates at low bandwidth. However, OFDM is highly sensitive to carrier frequency interferences. And, if carrier position is affected by noise, orthogonality property is lost, which in turn severely affects system performance. The main aim of the project is to apply carrier synchronization for OFDM. Our goal will be to maximize the system performance by applying carrier synchronization on the receiver side.

The prototype for the project was initially developed on Xilinx Virtex 5 FPGA using VHDL. After that the project was shifted on NI-USRP 2922 for simulation and real time data transmission. The OFDM model is first simulated on NI LabVIEW Communications System Design Suite and the real time communication is then communicated between two NIUSRPs 2922 for demonstration purposes. The CFO elimination and channel estimation is done on the receiver side.

CERTIFICATE OF CORRECTNESS AND APPROVAL

It is certified that the work contained in the thesis titled "High Performance OFDM Communication System", carried out by Sundeel Bin Haleem, Usama Javed, Mobeen Sarwar and Sheryar Malik under the supervision of Dr. Mir Yasir Umair in partial fulfilment of Degree of Bachelor of Electrical (Telecom) Engineering, is correct and approved.

Approved by:

____

Dr. Mir Yasir Umair

EE Department

Military College of Signals, RWP

DEDICATION

We dedicate this thesis to our beloved parents, whose constant belief in us made us achieve our goals and dreams.

ACKNOWLEDGEMENTS

We would like to thank our supervisor Dr. Mir Yasir Umair who believed in us and was continuously supporting us in every problem that occurred during the project. We especially thank him for his encouragement and his accurate comments which were of critical importance, during this work. Our cooperation was truly an inspiring experience.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADC	Analog to Digital Converter
CFO	Carrier Frequency Offset
CP	Cyclic Prefix
DAC	Digital to Analog Converter
FPGA	Field Programmable Gate Array
FFT	Fast Fourier Transform
GNU	GNU's Not **Unix**
IFFT	Inverse Fast Fourier Transform
IQ	In Phase and Quadrature Phase
MIMO	Multiple Input Multiple Output
MSps	Mega Samples per seconds
NI	National Instruments
OFDM	Orthogonal Frequency Division Multiplexing
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
SISO	Single Input Single Output
USRP	Universal Software Radio Peripheral

1. INTRODUCTION

1.1. Background:

OFDM is a multicarrier modulation technique, which employs several carriers, within the allocated bandwidth, to convey the information from source to destination. Each carrier may employ one of the several available digital modulation techniques like QPSK. Using a large number of parallel narrow-band sub- carriers instead of a single wide-band carrier to transport information.

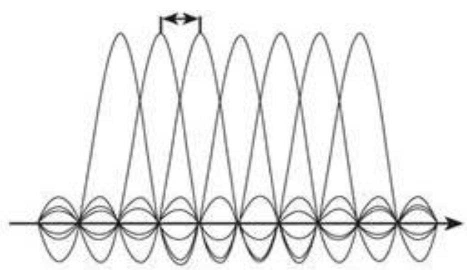

Fig.1. OFDM Spectrum

1.2. Problem Statement:

As, CFO destroys orthogonality, in result, Inter Carrier Interference takes place. There is a need for an algorithm that eliminates the effect of CFO and improves the system performance. Therefore, an intelligent OFDM receiver is required.

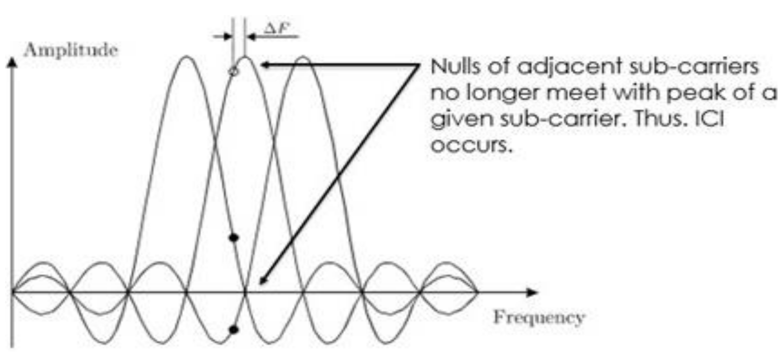

Fig.2. Effects of Frequency Offset. Retrieved June 1, 2016

1.3. Project description and salient features:

The aim of the project is to apply carrier synchronization for an OFDM system. The project has been done to better understand the real time effects of noise and degradation on signals and to counter these effects. Through this project we can achieve reliable and fast digital communication through OFDM in a non-reliable transmission environment.

Some features regarding the OFDM technique are:

- Since numerous sub channels are used, the system is immune to frequency selective fading caused by delayed waves in certain sub channels.
- Long symbols intervals and guard intervals of OFDM reduce the effects of delayed wave interference.
- The closed spaced sub channels in OFDM result in high spectral efficiency and greater the number of sub channels, the better the system meets Nyquist minimum bandwidth.
- Information can be arbitrarily assigned to specific sub channels. Sub channels where interference is expected can be avoided adding more flexibility to the system.

A general OFDM model is shown below:

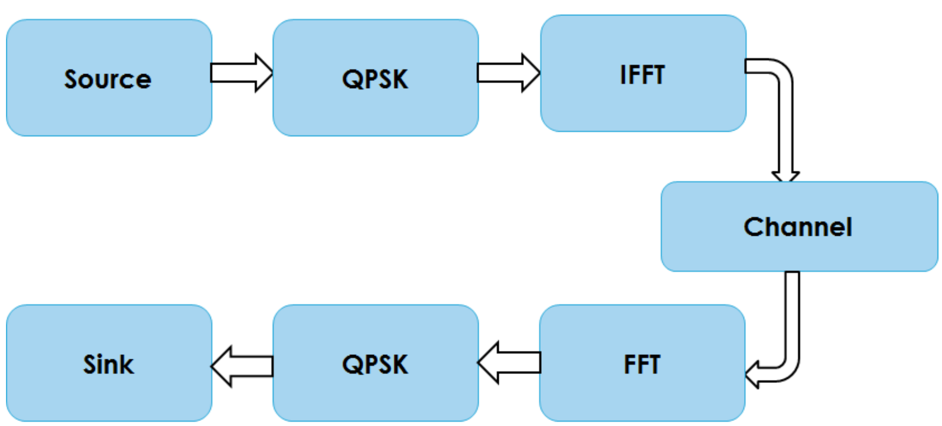

Fig.3. General OFDM System

1.4. Scope:

The bandwidth capability of OFDM gives it a significant advantage. Therefore, it is used in high speed communication systems like LTE.

1.5. Objectives and deliverables:

Carrier Frequency Offset results in the disturbance of orthogonality property of OFDM that results in poor performance. We aim to eliminate the noise due to Carrier Frequency Offset by using signal processing algorithms and to improve the reliability of OFDM system.

The final deliverable of this project is OFDM transceiver system with CFO elimination capability on a NI-USRP 2922 using NI LabVIEW Communications System Design Suite.

2. LITERATURE REVIEW OF OFDM SYSTEM

An OFDM transmission symbol is given by the N point complex modulation sequence implemented by IFFT. S (k) is the modulated data on the kth subcarrier and N is the number of total subcarriers.

$$s_{n,j} = \frac{1}{N}\sum_{k=0}^{N-1} S_{k,j}\, e^{\frac{j2\pi nk}{N}} \ldots\ldots\ldots\ldots\ldots\ldots.. n = 0,1,2,\ldots\ldots., N-1 \qquad (2.1)$$

2.1. General OFDM System:

A typical OFDM system has been depicted above in Figure. 3. QPSK modulation is used to modulate data. IFFT/FFT is used for performing Fast Fourier Transform.

2.1.1. Advantages:

- OFDM **divides a higher data rate link into multiple low data links**, such low data rate links are less complex and inexpensive to build.
- As there are multiple carriers, OFDM is **robust again narrow-band interference**.
- It achieves **high spectral efficiency** because it used overlapping carriers.
- As modern DSP hardware has become very sophisticated, **FFT can be performed easily** using DSP, or as ASIC.
- OFDM **eliminates Inter Symbol Interference (ISI)** through the use of a cyclic prefix.

2.1.2. Disadvantages:

- OFDM is particularly sensitive to CFO.

- CFO destroys orthogonality among overlapping carriers which results in higher BER.
- Peak-to-average problem reduces the power efficiency of RF amplifier at the transmitter.

2.2. Sensitivity of OFDM to Carrier Offset

OFDM is highly sensitive to carrier frequency interferences. And, if carrier position is affected by noise, orthogonality property is lost, which in turn severely affect system performance. The sources of carrier frequency offset (CFO) are as following:

2.2.1. Mismatched oscillators:

CFO occurs when the local oscillators used for up-conversion or down-conversion at the transmitter or the receiver are not synchronized with each other. In practical life, no two oscillators are synchronized perfectly in time domain as well as frequency domain.

2.2.2. Doppler Effect:

Change in frequency of a wave for an observer moving relative to source of wave is called Doppler Effect. CFO happens due to Doppler Effect when user is moving in a vehicle or train.

2.3. Literature Study on CFO and its estimation:

An OFDM signal having CFO is given by the equation below.

$$r(n) = \frac{1}{N}\left[\sum_{k=0}^{N-1} S(k)H(k)\, e^{\frac{j2\pi n(k+\varepsilon)}{N}}\right] e^{j\Theta} + w(n) \qquad (2.2)$$

Where r (n) is received samples, N is the length of training sequence, H (k) is the transfer function of the channel at the frequency of the kth subcarrier, Ɛ is the relative frequency offset of the channel (the ratio of the actual frequency offset to the inter-carrier spacing), w (n) is the complex envelope of additive white Gaussian noise (AWGN) with mean zero and variance σ^2. The offset can be in two categories:

- **Integral Frequency Offset**
- **Fractional Frequency Offset**

Integral Frequency Offset also known as **Coarse Frequency Offset** is the offset which is integer multiple of carrier spacing, Δf. And, **Fractional Frequency Offset** also known as **Fine Frequency Offset** is the offset which is Fractional multiple of carrier spacing, Δf.

Coarse Frequency Offset results in distortion of constellation and severe noise. And Fractional Frequency Offset results in loss of orthogonality between sub-carriers which generate Inter-Carrier Interference (ICI).

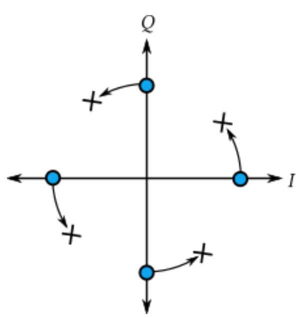

Fig.4. Distortion due to Coarse CFO

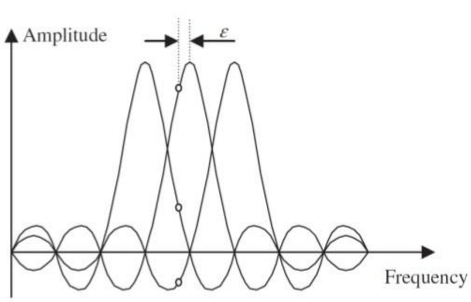

Fig.5. ICI due to Fine CFO

As discussed in [1], we employ two known time domain Pseudo Noise sequences and two OFDM symbols to estimate CFO in this project. Algorithm can be subdivided into two parts: **Coarse CFO Estimation** and **Fine CFO Estimation.**

2.3.1. Coarse CFO Estimation:

The transmitted preamble PN1 and PN2 are all composed of PN-sequence m (n). After passing through a band pass channel, the received preamble sequence becomes r(n) due to effect of CFO. The first-step frequency offset estimation can be implemented by correlating the repeated data whose distance is d in r(n):

$$\hat{\varepsilon} = \frac{N}{2\pi d}\arg\left[\sum_{k=0}^{N_n-1} r^*(n)\ \text{x}\, r(n+d)\right] \tag{2.3}$$

2.3.2. Fine CFO Estimation:

The two OFDM modulated symbols are used to estimate residue due to Fine CFO after the coarse CFO. The two OFDM symbols, denoted as symbols $r_1(n)$ and $r_2(n)$, along with the frequency components for the two symbols are R1(k) and R2(k), respectively are used to calculate the Fine CFO.

As QPSK modulation is used for each sub-carrier, the valid phases difference P between the sub-symbols in symbols $r_1(n)$ and $r_2(n)$ will be in the set 0, π/2, π, 3π/2, and 2π. There will also be a phase difference caused by the CFO. If the phase difference is multiplied by 4, then the effect of the QPSK modulation will be removed since it will be a multiple of 2π, and the only phase difference remaining will be phase due to CFO. This phase difference caused by CFO will be eliminated.

$$\Theta = angle\left(\sum_{k=0}^{N-1} (R_{1k}{}^{*}.R_{2k})^4\right) * \frac{1}{4} \tag{2.4}$$

The overall estimation of frequency offset by the proposed three steps method is

$$\hat{\varepsilon} = \hat{\varepsilon}_{coarse} + \hat{\varepsilon}_{fine} \tag{2.5}$$

The training frame consists of two PN (Pseudo Noise) based preamble each having $\boldsymbol{K}$ samples and two OFDM modulated symbols $\boldsymbol{N_s}$ samples. The two PN sequences are same and consist of a known certain repeated pattern, while phase change in two OFDM modulated symbols is monitored to calculate CFO.

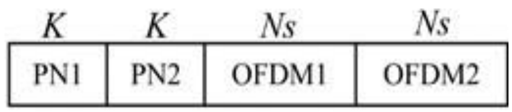

Fig.6. Structure of Training Frame

3. DESIGN AND DEVELOPMENT

The system design is first implemented and simulated on LabVIEW Communications System Design Suite. After the simulation the design was added to include real time transmission between USRPs for real world analysis.

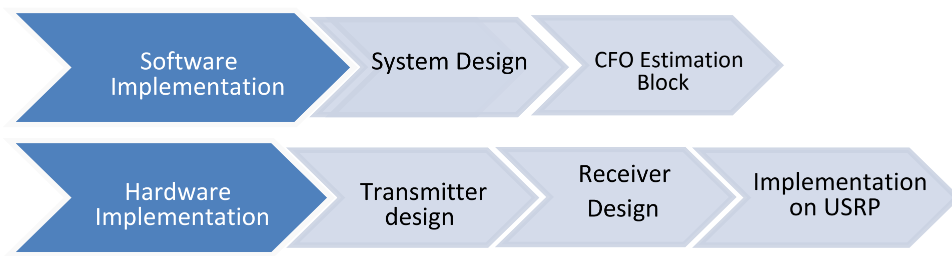

Fig.7. Design Steps

3.1. Design overview:

A brief description about LabVIEW Communications System Design Suite and NI-USRP2922 has been discussed below.

3.1.1. LabVIEW Communications System Design Suite:

LabVIEW communications system design suite provides a design environment closely integrated with NI-USRP hardware for rapidly prototyping of communication systems the designs created can be easily deployed to processors and FPGAs to jump-start research in LTE applications.

The LabVIEW Communications work environment is shown below:

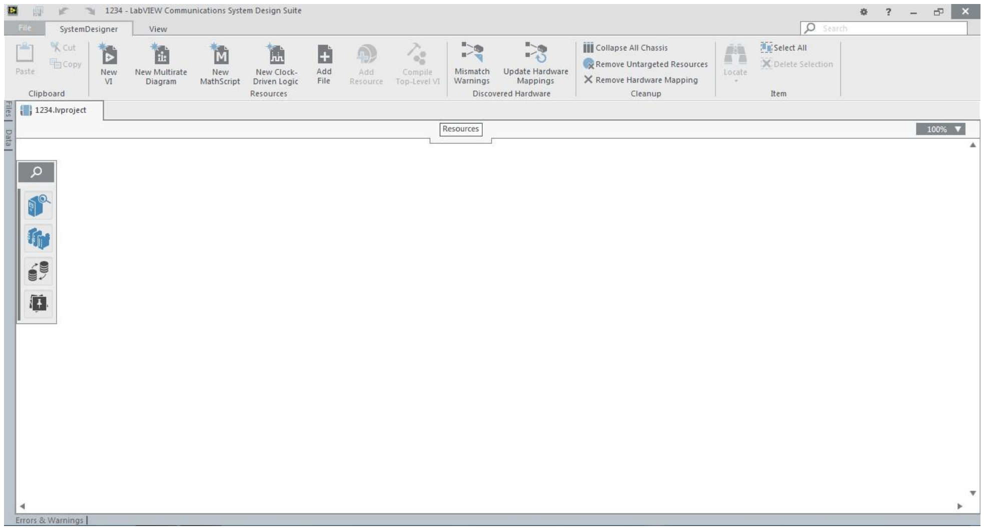

Fig.8. LabVIEW Communications System Design Suite Interface

3.1.2. USRP:

USRP, or Universal Software Radio Peripheral, is the hardware used with LabVIEW Communications System Design Suite for the design and implementation of OFDM transceiver system.

The USRP 2922 is shown below:

Fig.9. USRP 2922

Transmitter Specifications:

Frequency Range	400MHz-4.4GHz
Max Output Power	50mW-100mW
Gain Range	0dB-31dB
Max IQ rate	16-bit sample=>25MS/s 8 bit sample=>50MS/s
DAC	2 channels, 400MS/s, 16 bit

Receiver Specifications:

Frequency Range	400MHz-4.4GHz
Max Input Power	0dBm
Gain Range	0dB-31.5dB
Max IQ rate	16-bit sample=>25MS/s 8 bit sample=>50MS/s
ADC	2 channels, 100MS/s, 14 bit

3.2. Detailed Hardware/Software Design

The detailed design consists of hardware configuration and its interfacing with the software.
The next headings discuss these steps in detail.

3.2.1. Configuration of USRP:

Before using the USRP with LabVIEW the USRP has to be configured properly to be used by the host PC. For this the following steps are followed:

First of all, USRP device is connected with the host PC through Gigabit Ethernet cable.

The IP address of NI-USRPs is 192.168.10.2 by default, so IP of host PC must be different than USRP device, for example 192.168.10.10 with the subnet mask 255.255.255.0.

After setting the IP address of host, the NI USRP configuration utility is run.

The following display is shown:

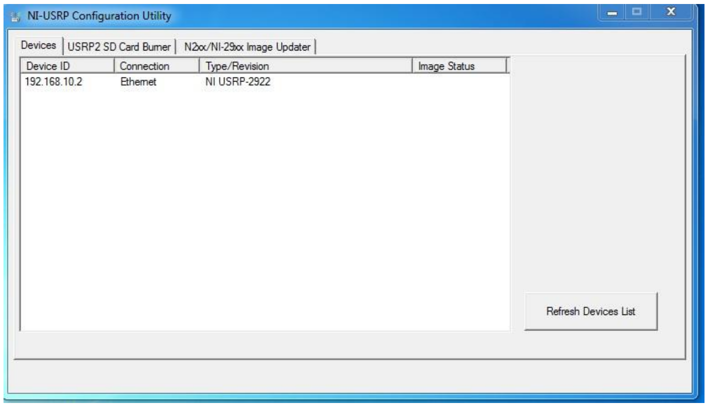

Fig.10. NI USRP Configuration Utility 1

After opening the utility, the proper USRP firmware and FPGA image is need to be loaded on the device as shown below:

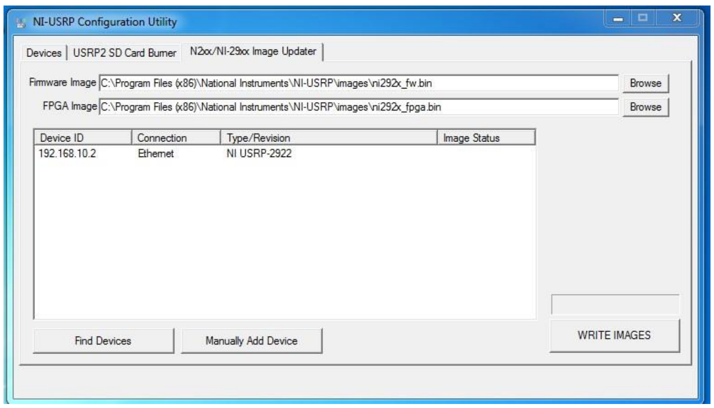

Fig.11. NI USRP Configuration Utility 2

After loading the images, the USRP device is ready to be used with LabVIEW communication system design suite.

3.2.2. LabVIEW System Design:

The LabVIEW system design of OFDM Communication System is mainly divided into two parts mainly the transmitter and the receiver. Given below is a brief explanation and working of both parts of the system.

3.2.2.1 Transmitter Side:

1. First USRP is initialized using parameters like gain, IP address, Carrier Frequency, IQ rate,

   Antenna Name the number of bits and QAM map locations as shown below:

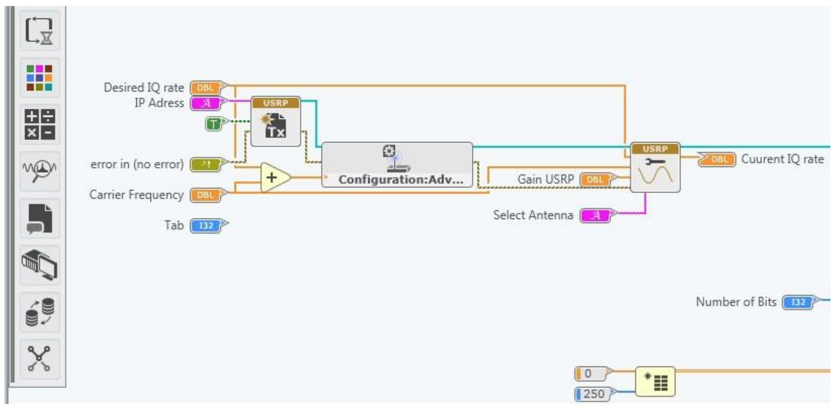

Fig.12. LabVIEW USRP Tx Configuration

2. A PN sequence is generated for given number of bits (125 bits for this scenario).

3. Bits are mapped to symbols using “MT Map bits to QAM symbols” blocks (625 bits are mapped to symbols using QAM-4).
4. The array of symbols is divided into 5 sets of 125 points data sets each and is build OFDM symbols (125 data points per OFDM symbol)
5. Pilot carrier is inserted after every 6th data symbol (25 pilot carrier per OFDM symbol, Total symbol length is 150 now)
6. Total 106 Null carriers are inserted in OFDM symbol. 52 Null carries at the either edge of the band and at 2 zero at DC (Making 256 total carriers per OFDM symbol)
7. Inverse FFT is taken to convert the frequency domain design to a time domain signal (256 point IQ time domain waveform)
8. A 64-point Cyclic Prefix is inserted by duplicating the last 64 points of the array at the beginning (320 point IQ time domain waveform)

9. OFDM waveform is scaled down to a complex magnitude below 1, 0.7 for each IQ signal (1600 point IQ time domain waveform).

   The figure for steps 2-9 is shown below:

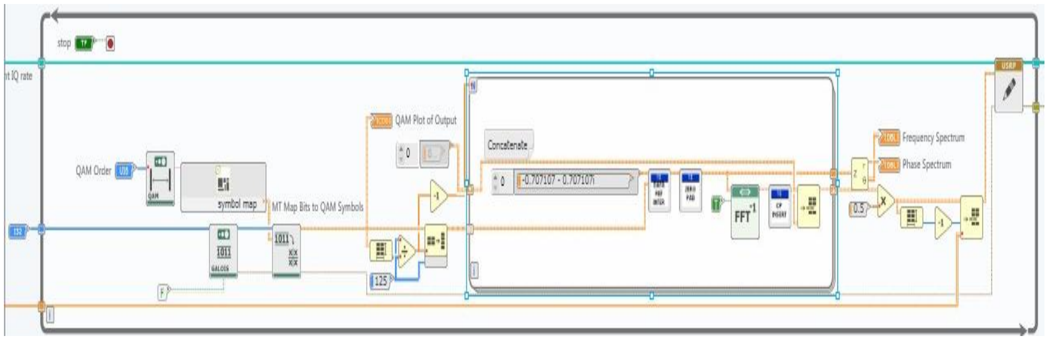

Fig.13. LabVIEW Tx Circuit

10. The data is transmitted using NI USRP interface.

Fig.14. LabVIEW USRP Tx Session Close

3.2.2.2. Receiver Side:

1. NI USRP interface is initialized using Antenna Name, IP address, Carrier Frequency, IQ rate, Gain, and Number of samples as shown below:

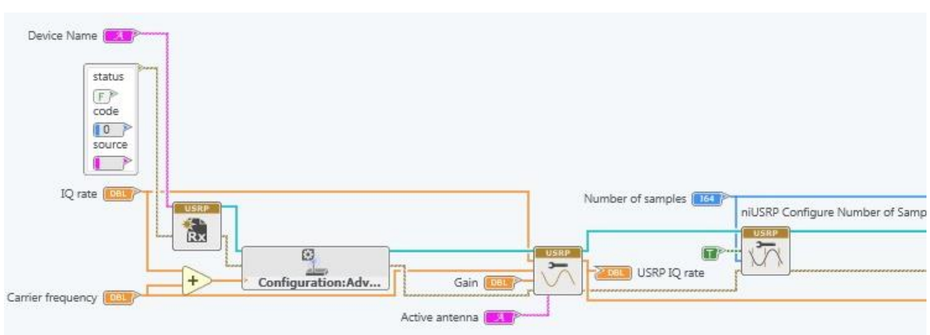

Fig.15. LabVIEW USRP Rx Configuration

2. IQ data from ADC is fed into CFO Algorithm block. CFO is estimated. Correlation is used to estimate CFO.

3. Cyclic Prefix is removed.
4. Now the FFT is calculated of data converting the time domain OFDM symbol to the frequency domain.
5. Null Carriers are deleted.
6. Data bits, Pilot carriers are removed.
7. Equalization is done using for IQ based on Pilot symbols.
8. Data symbols are mapped back to data bits using QAM-4.

The figure for steps 2-8 is shown below:

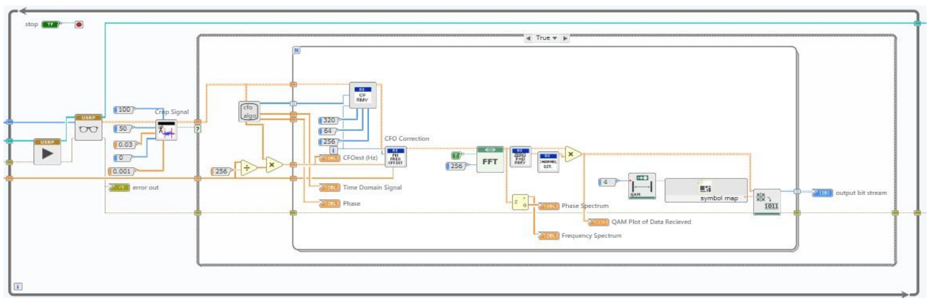

Fig.16. LabVIEW Rx Circuit

9. The receiver session is closed automatically if cancelled or the transmitter is shut down.

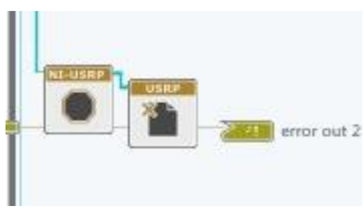

Fig.17. LabVIEW USRP Session Close

4. PROJECT ANALYSIS AND EVALUATION

The system was designed in LabVIEW and was evaluated via simulations and afterwards tested on USRPs.

4.1. Simulation Results:

Before implanting the system design on hardware is has to be analyzed in software simulation environment first.

First of all, the system is analyzed in ideal conditions when there is no CFO. The results for this simulation are shown below:

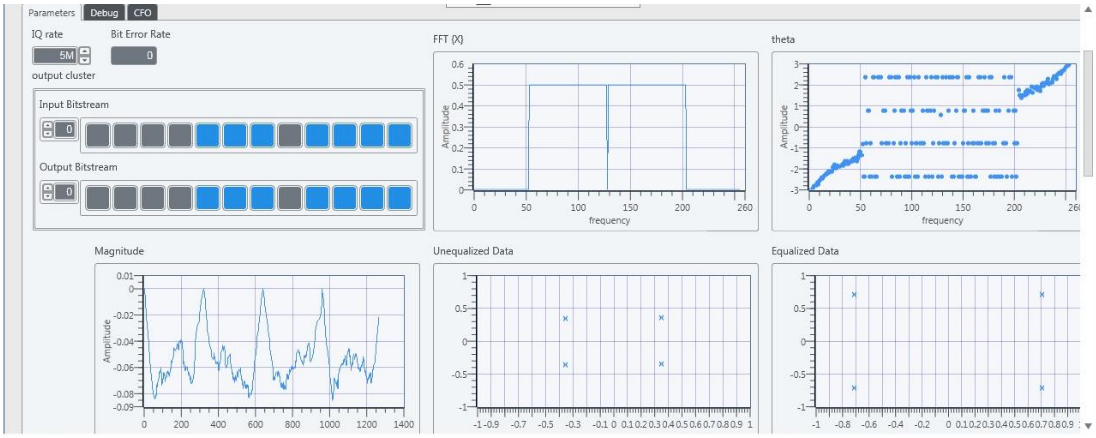

Fig.18. LabVIEW Simulation No CFO

Since there is no CFO, this results in 0 BER, which does not affect the orthogonality of the system and the data before and after the equalization is the same.

But if we introduce some CFO the results would not be as accurate as ideal scenario. For example, consider the figure below:

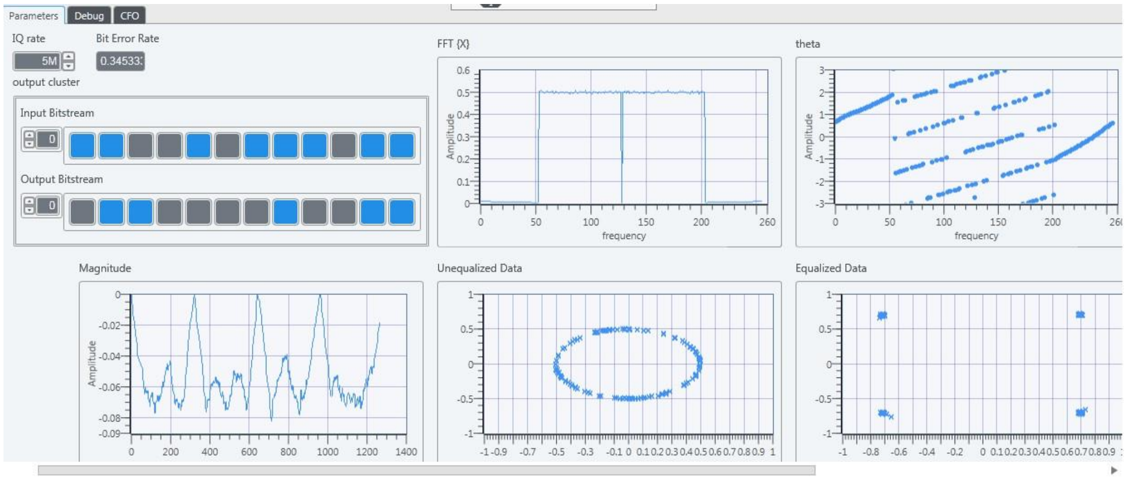

Fig.19. LabVIEW Simulation with CFO

From the figure we can clearly see that due to introduction of CFO the theta gets shifted, due to which the orthogonality property is lost which results is mixing of symbols as shown in the un-equalized data graph. But after applying CFO correction Algorithm the property is somewhat restored, with a little bit of BER.

4.2. Hardware Analysis:

After completing our analysis on simulations the system is implemented on NI-USRP hardware devices. Both the devices are connected to different host PCs, one acts as transmitter and the other as a receiver. The hardware setup is shown below:

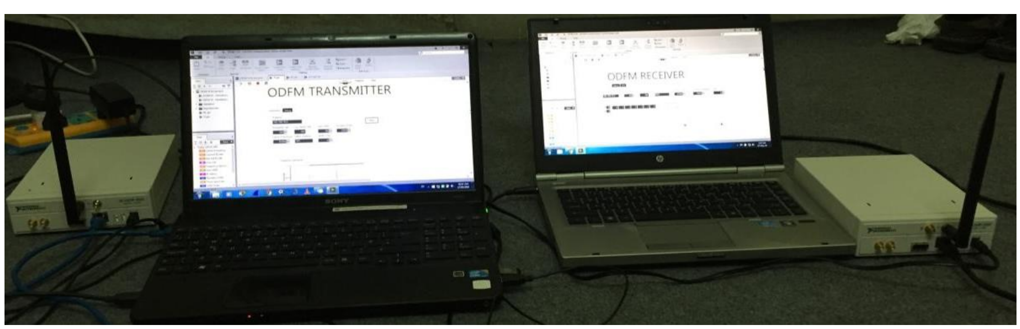

Fig.20. Hardware Setup

Both the transmitter and receiver and set to 5M IQ rate and transmission and reception frequency at 910MHZ. The results from real time transmission are shown below:

Transmitter Settings:

Fig.21. LabVIEW USRP Tx Configuration Parameters

Transmitter Plots:

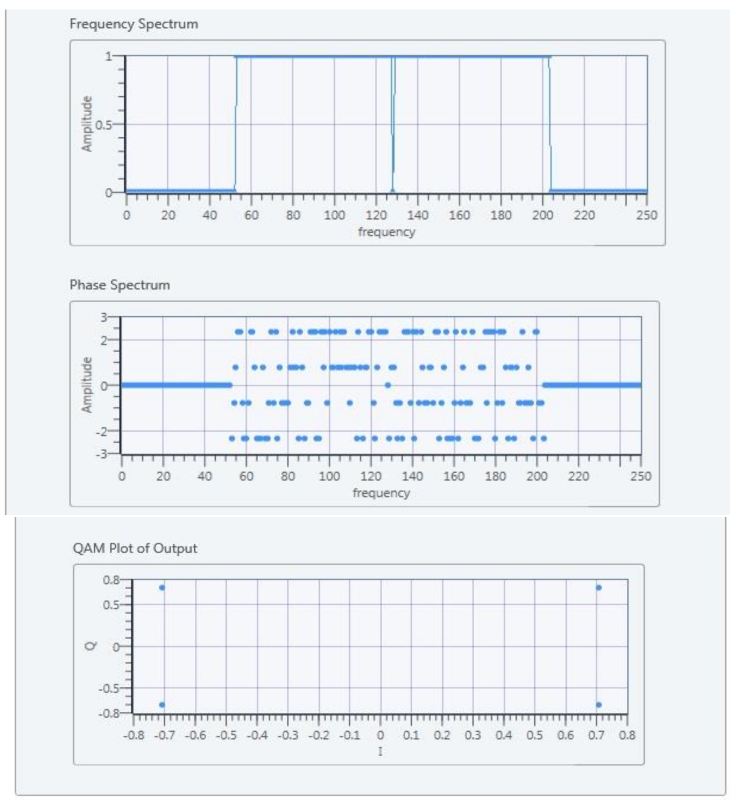

Fig.22. LabVIEW USRP Tx Result Plots

Receiver Settings:

Fig.23. LabVIEW USRP Rx Configuration Parameters

Receiver Plots:

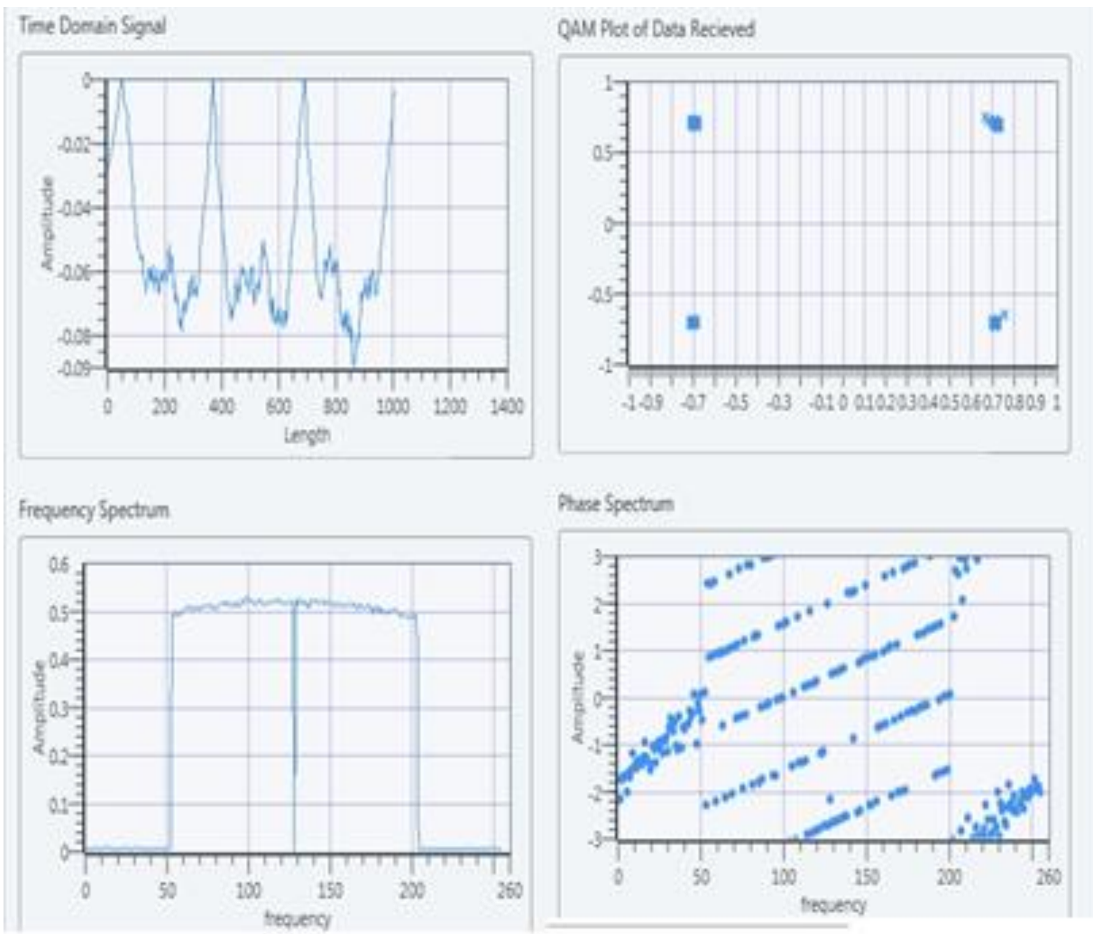

Fig.24. LabVIEW USRP Rx Result Plots

5. RECOMMENDATIONS FOR FUTURE WORK

This Project deals with the physical layer of the data communication model, it is strongly recommended that to build the MAC layer for reliable transmission of different file formats.

The project covers CFO correction for SISO system, future work can further be extended for a MIMO system. Also, automatic switching among different order QAM schemes can be implemented depending upon SNR to build an efficient and adaptive system.

6. CONCLUSION

An OFDM communication system is built using NI LabVIEW and USRP. It transmits data efficiently and have the capability to eliminate the CFO. System was first evaluated by simulations in LabVIEW and later was tested on USRP platform.

To harness even greater bandwidth, MIMO technique can be used.

Project can be upgraded in the future to MIMO Communication since it is limited to SISO communication.

Our design is built at Physical layer only. Though the system can eliminate CFO, it does not have a MAC layer. Therefore, typical operations, like flow control, Segmentation and Re-assembly, are not supported.

An intelligent approach can be used to switch between Different order QAM schemes depending upon Signal-to-Noise ratio.

The system can be employed in communication systems like LTE, Power Line Communication.

REFERENCES

[1] D. Zhang, L. Yu, P. Zhou, Q. Huang and W. Chen, "A high performance frequency offset estimation method for OFDM," Proc. 3rd international Conference on Intelligent System Design and Engineering Applications, pp.73-76, 2013.

[2] Cho, Kim, Yang & Kang, "MIMO-OFDM WIRELESS COMMUNICATIONS WITH MATLAB"

[3] R. Prasad, "OFDM for Wireless Communications Systems"

[4] Y.B. Bereket, K. Langat, and E.K. Ndungu, "Maximum Likelihood CFO Estimation in OFDM Based Communication Systems", Proceedings of 2014 International Conference on Sustainable Research and Innovation, vol.5, pp.285-289,2014.

[5] IEEE Standards Association; http://standards.ieee.org/getieee802/download/802.11-2012.pdfhttp://standards.ieee.org/about/get/802/802.11.html

[6] P. H. Moose, "A technique for orthogonal frequency division multiplexing frequency offset correction" Communications, IEEE Transaction on Oct 1994, volume 42, issue 10, pages 2908-2914

[7] Pollet, T., Van Bladel, M. Moeneclaey; "BER sensitivity of OFDM systems to carrier frequency offset and Wiener phase noise" Communications, IEEE Transactions on Feb/Mar/Apr 1995 pages: 191-193

[8] Muschallik, C "Influence of RF oscillator on an OFDM signal" IEEE Transaction on Aug 1995, volume 41, issue 3, pages: 592–603

[9] Minn, H., Zeng M., and Bhargava V. K., "On Timing Offset Estimation for OFDM Systems", IEEE Transaction Communication Volume 4, No. 7 2000

[10] Schmidl, T.M., Cox, D.C. "Low-overhead, low-complexity [burst] synchronization for OFDM", IEEE, Communications, 1996. ICC '96,

Conference Record, Converging Technologies for Tomorrow's Applications, 1996 volume 3, pages: 1301-1306

[11] Shekar, Amal. http://Image.Slidesharecdn.Com/Ofdmfinal-111125032200-Phpapp01/95/Ofdm-Final-20-728.Jpg?Cb=1322192367. 2016. Print.

APPENDEIX A

High Performance OFDM Communication System

Extended Title: ***Implementation of Carrier Synchronization Algorithm for OFDM***

Brief Description of the Project: OFDM systems works by dividing the available spectrum in orthogonal subcarriers. Thus OFDM, using orthogonal sub-carriers, achieve high data rates, and conserve bandwidth. However, OFDM is highly sensitive to carrier frequency interferences. And, if carrier is affected by noise, orthogonality property is lost, which in turn severely affect system performance. The main aim of the project is to apply carrier synchronization for an OFDM system. The algorithm will be first simulated in MATLAB and then implemented on hardware kit. Our goal will be to maximize the system performance by applying synchronization.

Scope of Work: OFDM is used by all LTE systems. And, our project will target at solving real world problems of such systems which will result in overall better performance. Secondly, we will gain experience in Signal Processing Techniques and Systems.

Academic Objectives: This project will help us in following way:

- Wireless Communication & OFDM systems
- Digital Signal Processing
- Programming & Algorithm Implementation

Application / End Goal Objectives: At the end of the project we will be able to improve OFDM performance. This communication will be least effected by the frequency interferences. This project will be applicable to the modern communication system for reliable data delivery.

Previous Work Done on The Subject:

- *OFDM-Based Broadband Wireless Networks (Design and Optimization)* by Hui Lui and Gouqing Li
- *MIMO OFDM Wireless Communication with Matlab* by Yong Soo Cho, Jaekwon Kim, Wong Young Yang, Chung-Gu Kang

Material Resources Required:

USRP/2x Raspberry Pi/ FPGA kits**,** MATLAB/C

No of Students Required :4

Special Skills Required:

USRP, Signal Processing, LabVIEW