Air Interface for LTE (4G) Radio: Physical Layer Design and Implementation on PXI-1045

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ABSTRACT

AIR INTERFACE FOR LTE (RADIO): PHYSICAL LAYER DESIGN AND IMPLEMENTATION ON PXI-1045

In recent years mobile communication has evolved rapidly and demand for mobile devices with new and higher quality services is increasing. The existing 2.5G and 3G standards, Universal Mobile Telecommunication System (UMTS), is currently being upgraded with High Speed Packet Access (HSPA) to meet current demands. However, in the longer term this will not be sufficient.

The 3rd Generation Partnership Project (3GPP) has investigated the long term evolution of UMTS (LTE) to meet future demands and ensure the competitiveness of the standard. The objective is a radio access technology with higher data rates, lower latencies and optimal support for packet services such as multimedia, games and internet services. Telephony shall be supported by means of Voice over IP (VoIP) with at least as good quality as circuit switched telephony.

LTE promises to deliver an unrivalled user experience with ultra fast broadband, very low latency, services while also delivering a very compelling business proposition for operators with flexible spectrum bandwidth, smooth migration and the ability to deliver low cost per bit voice and data services. With LTE's ability to interconnect with other access technologies, operators will be able to converge their LTE and fixed line broadband networks giving them the ability to provide subscribers with a seamless experience.

Radio frequency is a valuable and finite resource and, today, there is simply not enough to satisfy demand. The need for spectrum is being driven by the pervasive convenience of mobile communications and increased penetration combined with improved performance and the falling costs of wireless devices & services. Existing and new Mobile Broadband networks will quickly consume existing spectrum allocations as they deliver a highly compelling user experience by allowing multimedia applications anywhere. This thesis will cover the technology and architecture of LTE. The focus is on Physical Layer of LTE functionality. The specifications of LTE are not yet finalized. Therefore, the implementation is based on work in progress specifications and meeting protocols from 3GP work groups.

CERTIFICATE OF CORRECTNESS AND APPROVAL

It is certified that the work contained in the thesis titled “Air Interface for LTE: Physical Layer Design and Implementation on PXI-1045”, carried out by Saad Siddique, Muhammad Sabih, Dileep Kumar, Sardar Asfand Yar under the supervision of Dr. Arif Wahla in partial fulfillment of the degree of Bachelor of Telecommunication Engineering, is correct and approved.

Approved by

Dr. Arif Wahla

Project Supervisor

Military College of Signals, NUST

بسم الله الرحمن الرحيم

DEDICATION

To Almighty Allah, for Whose greatness we do not have enough words,

To our parents and friends, whose undaunted support, made a work of this magnitude possible

Acknowledgements

This project work proved to be a challenging task for us as we started to learn about 3GPP LTE technology after getting impressed from continuously rising popularity in the cellular broadband world. We learnt many things about LTE and were very confuse in selection about the topic for Final Year Project.

Then luckily we met **Associate Professor Dr Arif Walah**, our supervisor at Department of Electrical Engineering, Military College of Signals (NUST) who provided us guidelines on selection of topic for project. We really appreciate his precious recommendations which helped us a lot in moving ahead with our project and his continuous support on project.

We would like to express our most humble gratitude to **Associate Prof. Dr. Nadeem Lehrasab**, and **Lecturer Mr. Khurram** , Department of Avionics Engineering Air University. They supported us technically and morally and pushed us continuously to complete this project work and of course, we couldn't be able to complete this work without their efforts.

Special thanks to **Mr. Ahmed Bilal** , Application engineer National Instruments for providing us valuable advice and skillful suggestions.

We express our good feelings to our group members for their moral and hardwork throughout the entire course of project. We would also like to acknowledge the lab attendants for their patience and help during this work.

Our deepest love and thanks to our parents whose heartiest cooperation, kindness, prayers and noble guidance was a great source of strength to us, who motivated us to complete our work.

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List of Abbreviations

3GPP LTE	3rd Generation Partnership Project Long Term Evolution
E-UTRAN	Evolved-UMTS Terrestrial Radio Access Network
HSDPA	High Speed Downlink Packet Access
CS	Circuit Switched
PS	Packet Switched
QoS	Quality of Service
eNodeB	Evolved Node Base station
OFDMA	Orthogonal Frequency Division Multiplexing
SISO	Single Input Single Output
MIMO	Multiple Input Multiple Output
L2, L3	Layer 2, 3
UE	User Equipment
SC-FDMA	Single Carrier – Frequency Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
PAPR	Peak to Average Power Ratio
BPSK	Binary Phase Shift Keying
QPSK	Quadratic Phase Shift Keying
QAM	Quadratic Amplitude Modulation
DFT	Discrete Fourier Transform
IDFT	Inverse Discrete Fourier Transform
FFT/IFFT	Fast / Inverse Fast Fourier Transform
RRM	Radio Resource Management
MAC	Medium Access Control
FDD/TDD	Frequency Division Duplex / Time Division Duplex
SFN	Single Frequency Network
CP	Cyclic Prefix
CQI	Channel Quality Indicator
ARQ/HARQ	Automatic Repeat Request / Hybrid Automatic Repeat Request
AMC	Adaptive Modulation Coding

CHAPTER 1

INTRODUCTION

Telecommunication has developed from old obsolete analog telephones to latest technologies such as 3G and 4G wireless cell phones in the past few decades. This growth has revolutionized our world in the way we work, think and interact. With these developments in wireless networking, the freedom to access information and data anytime and anywhere is in the offing, thereby redefining the old concept of connectivity.

Simultaneously there is a bandwidth detonation taking place in mobile communications and in IT sector. Due to this fast growth of communication sector Therefore, by converging to the future belongs to and "IP everywhere and over everything era" and packed with wireless interfaces and intensive networking.

However, there are many challenges that arise for this convergence in this interconnected world some of them are conserving user security, routing of data, enhancement in the multimedia networking and other applications, will higher data rates and many more. So to cater for all these challenges extensive research and hard work is required.

The basic objectives of this network evolution is to provide these services with a quality at least similar to what an end-user can enjoy today using their existing fixed broadband access at home, and another objective is to reduce operational expenses by means of introducing flat IP architecture and complete packet based network.

1.1. Problem Description

Many books and research paper outlined the performance of the physical layer performance of LTE. Depending on the parameters i.e. system bandwidth, multi antenna schemes etc different values are stated as LTE performance. The maximum data rate of LTE ranges from 100 Mbps to 300 Mbps. There is no sufficient information is provided on of how this value is calculated.

The basic objective of this study is to determine physical layer throughput of LTE according to Release 8 in different scenarios for both uplink and downlink, as the system bandwidth of LTE varies from 1.4 to 20 MHz which is scalable and different amount of physical resources (from 10080 to 168000) are available during one singleradio frame. Both the physical and reference signalsaremappedtothese available resources. By calculating the overhead of reference signals that do not carry any useful data, we can find out the number of resource elements allotted for data transmission. Based on different parameter such as modulation schemes, code rates, and number of antenna, the throughput for data channels can be calculated.

The project focuses on implementing physical layer of LTE Air Interface as system on national instruments PXI-1045 modules.

1.2. Purpose

We chose this project because, LTE is a new and an emerging technology and we hope that in the near future many countries in the world including Pakistan will switch over it. We are eager to study and learn this new technology.

The main goal is Implementation of Uplink PHY layer for LTE radio on PXI-1045 according to release 8 standards to meet the requirnments

It should have scalable bandwidths of 1.25,2.5 to 20 MHz

The end peak data rate that scales with the available system bandwidth in efficient way.

It will supported uplink configurations SISO   Uplink :1x1

And it will have spectrum efficiency

1.3. Evolution to LTE

The latest technology "LTE" provides a path for the further evolution to true 4G which will have all the features of LTE with verymany improvements such as improvement in functionality, have higher speeds and general much better performance then many other wireless technologies.

Table 1.1: Comparison Among Different Technologies

	WCDMA (UMTS)	HSPA HSDPA / HSUPA	HSPA+	LTE
Max downlink speed bps	384 k	14 M	28 M	100M
Max uplink speed bps	128 k	5.7 M	11 M	50 M
Latency round trip time approx	150 ms	100 ms	50ms (max)	~10 ms
3GPP releases	Rel 99/4	Rel 5 / 6	Rel 7	Rel 8
Approx years of initial roll out	2003 / 4	2005 / 6 HSDPA 2007 / 8 HSUPA	2008 / 9	2009 / 10
Access methodology	CDMA	CDMA	CDMA	OFDMA / SC-FDMA

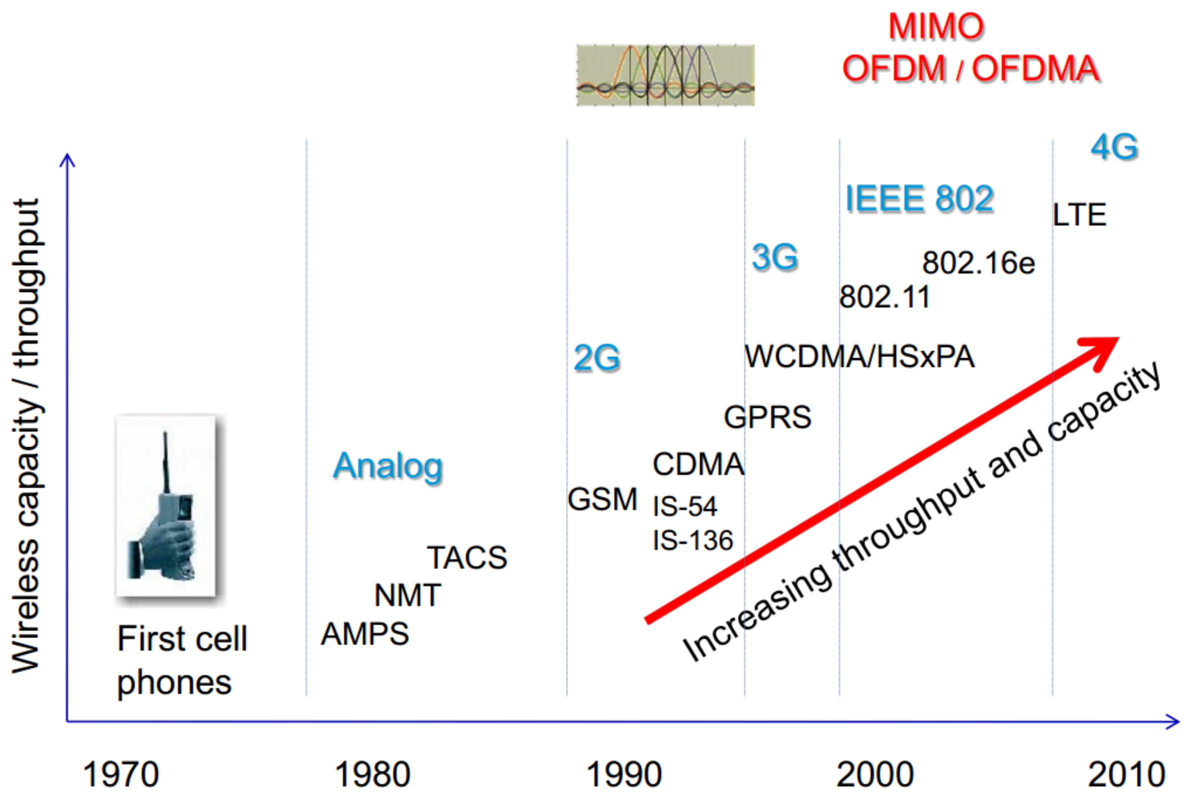


Figure 1.1: Evolution to LTE

In addition to all discussed above, LTE is a complete IP based network (AIPN), which support both IPv6 and IPv4.

CHAPTER 2

LTE Technical Background

It is very useful to view the very preliminary details of these technologies in understanding of LTE Physical Layer

2.1. LTE Basic Concepts

According to release 8 specification, the download link of the LTE uses OFDM and for the uplink transmission SC-FDMA is used. OFDM is a new modulation technique but it is now being employed in new emerging technologies.

Original message signal can be distorted due to multipath. In addition to that line one line of sight path, there are so many other paths created by signal itself by reflection from various sources as shown in Figure 1. And this reflected signals traveling along these multiple paths all reach the one same receiver, but each received signal is shifted in terms of time. In other word we can say time shift is directly proportional to the distance signal travelled.

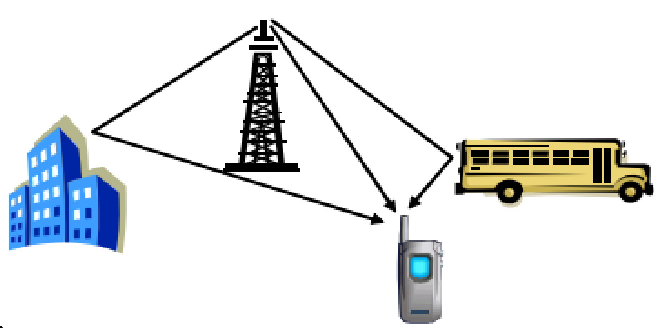


Figure 2.1 Multipath is caused by Reflections off Objects Such as Building and Vehicles.

2.2. Single Carrier Modulation and Channel Equalization

Unlike the other modulation schemes that has been in use, in the previous technologies usually employ single modulation but the LTE employ the OFDM as per specified by the release of 3GPP.

Delay spread is actually the time delay at the receiver when the signal travels from the transmitter when it takes different paths. It is usually in micro second. The main cause of this delay is the multipath effect. Figure 2.2 shows exactly the time delay due to the multipath effect.

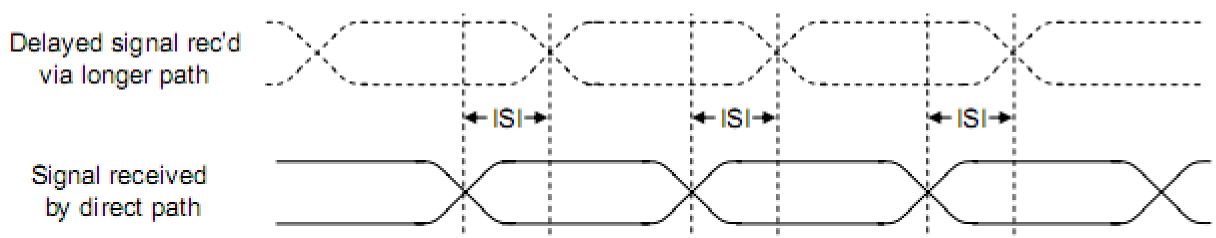


Figure 2.2 Multipath-Induced Time Delays Result is ISI

Phase shift is directly proportional to path length andreflection. As all the signals which have been received at the receiver which undergoes multipath fading, some of the signals undergo the constructive interference and some of them have destructive interference. So at the end the aggregative signal undergoes frequency selective fading.

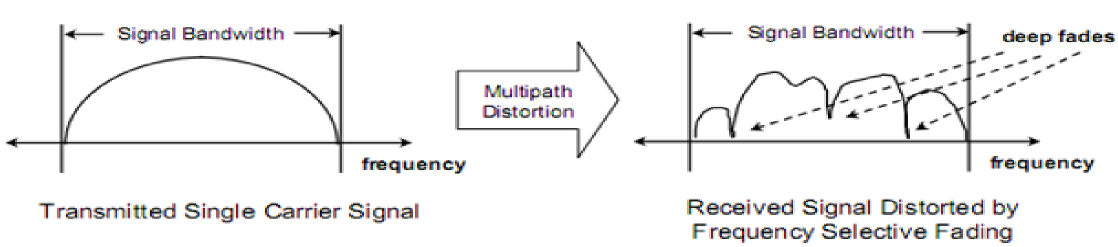


Fig 2.3 Longer Delays Spreads Result in Frequency Selective Fading

It is already discussed that Single carrier systems which are used in existing cellular network compensate for channel and other type of distortion bye using time domain equalization.

2.3. OFDM

OFDM is a new multiplexing scheme that has been introduced in the new technologies. With the help of OFDM we can have a high data rate by utilizing optimum bandwidth, so our bandwidth efficiency would increase giving more data rate. OFDM basically employ orthogonal frequencies so all the frequencies in the OFDM will be orthogonal to each other.

According to the release 8, LTE employ OFDM in QPSK, 64QAM, 16QAM and QAM. And it is employed in the downlink (DL).

There are basically two main advantages of OFDM over various other techniques which are used in cellular world. First, we use cyclic prefix before each OFDM symbol, which contain no useful data but it is basically used to effectively eliminate ISI. Second major aspect related of OFDM, all the sub-carriers are very much tightly spaced so making very efficient use of the bandwidth; this is very unique feature of OFDM.

The figure 2.4 shows two major things, the first one is OFDM utilizes longer symbol period so that they should be minimum inter-symbol interference. The other thing is the use of cyclic prefix. Cyclic prefix is actually the head of the next symbol added to symbol in order to reduce ISI. And it carries no useful data.

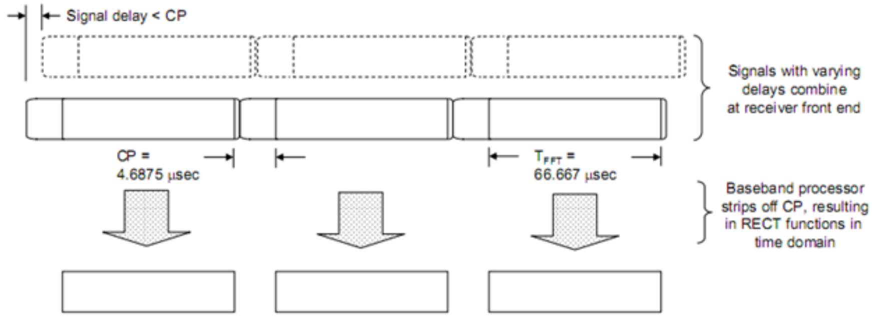


Figure 2.4 OFDM Eliminates ISI via Longer Symbol Periods and a Cyclic Prefix

The figure shows the distant subcarrier that is used in the OFDM. The end result of this is actually our required data that is within each subcarrier have constant amplitude because of digital system over FFT system.

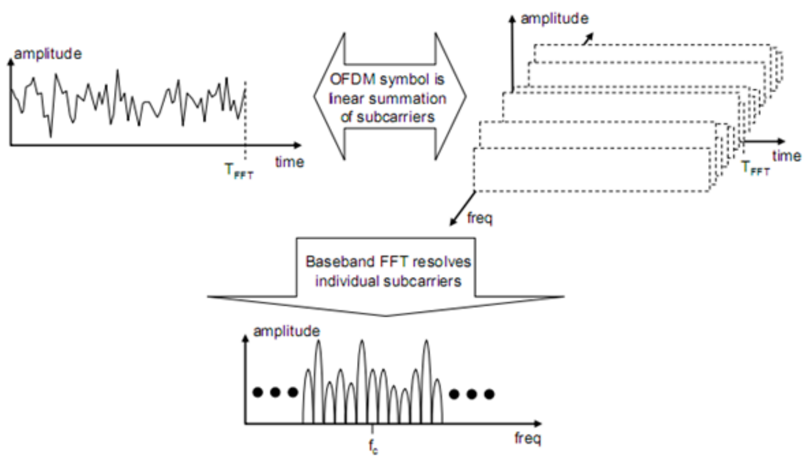


Figure 2.5 FFT of OFDM Symbol Reveals Distinct Subcarriers

2.4. OFDM Transceiver

The diagram below show the block use in OFDM Transmitter and Receiver, each block perform it unique function and pass the data to upper block.

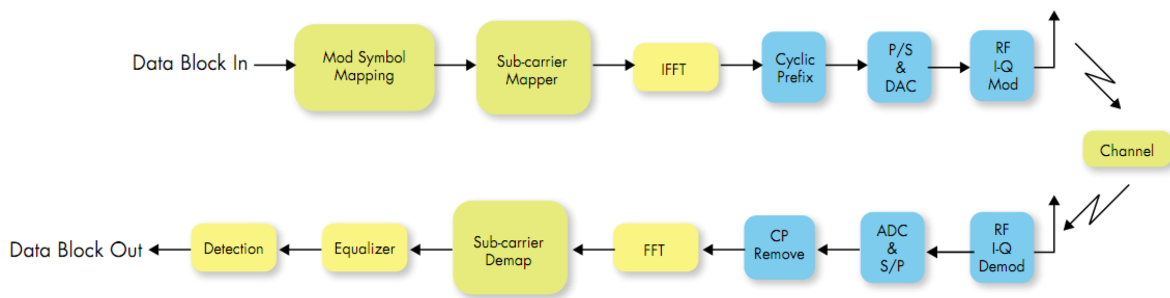


Figure 2.6 OFDM Transceiver

2.5. Disadvantages of OFDM

By concluding the previous discussion we cannot say, the OFDM does not come with any disadvantage. It has two main disadvantages:

The first one is, it may have the error in the carrier frequencies this due to the offset of the local oscillator or due Doppler shift

The main disadvantage is the high peak to average power ratio (PAPR).

2.6. SC-FDMA

LTE employ SC-FDMA in the uplink, SC-FDMA is basically single carrier frequency division multiplexing technique. Which is almost same as OFDM but differs in certain respect which is that it eliminates the problem of height peak to average power ratio, so the user equipment doesn't have to waste a lot of power in the transmission and reception of the signal.

Figure 2.8 shows the basic architecture of SC-FDMA system it is much like same to OFDM with slightly difference that before the modulation the DFT of the carriers are taken.

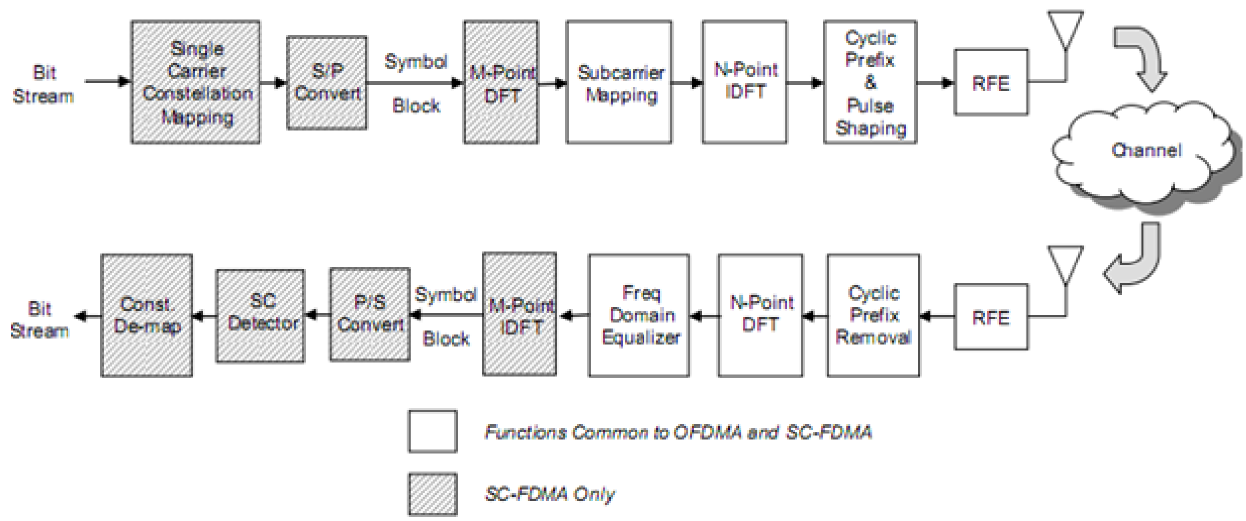


Figure 2.8 SC-FDMA and OFDMA Signal Chains

2.7. Downlink Vs Uplink Transmission

As we have already mention in previous sections Physical layer downlink (DL) transmission is implemented using OFDMA while the uplink (UL) transmission uses SC-FDMA technique. There are many similarities between OFDMA and SC-FDMA such as both of them uses the same time-frequency grid, same time slots, sub-frames, frames, sub-carrier etc.

Besides of upper mention similarities there are few differences between these two techniques. The major differences in both techniques i.e. OFDMA and SC-FDMA are

In SC-FDMA sub band is made using the adjacent sub-carriers so no need of Cyclic Prefix (CP), where as in OFDMA random available sub carriers combines to make sub band so that it can achieve frequency diversity.

Another major difference is in the transmission of control signals. In OFDMA to carry data transmission one subcarrier uses 7 OFDM symbols in one time slot, while in SC-FDMA two short blocks are reserved to carry only pilot signal and rest 6 blocks are used for data transmission.

LTE is upcoming technology that also supports its co-existence with the lower generation mobile standards such GSM and thus it also has special Time Division Duplex frame structure to support Low-Chip-Rate (TDD-LCR).

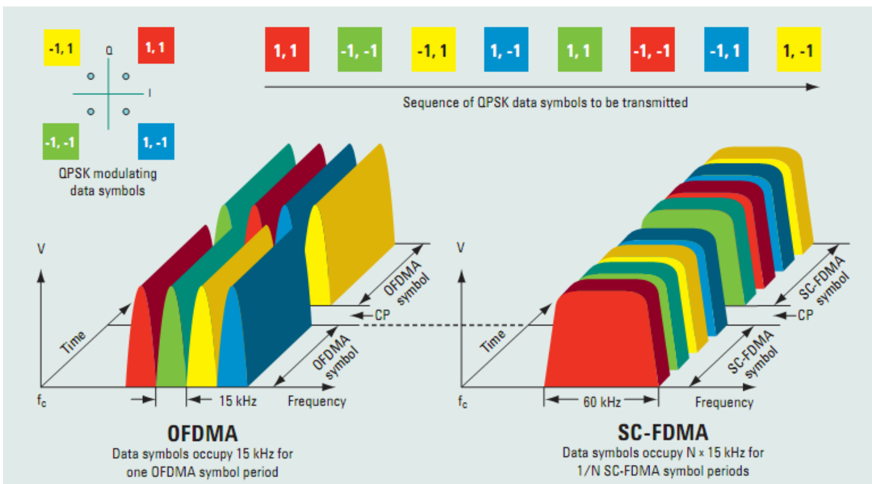


Figure 2.10: Difference b/w OFDMA and SC-FDMA

2.8. Convolution Codes/Turbo Codes

Turbo codes are basically derived from convolution codes.

Convolution code is a type of error-correcting code, have following features.

Each m-bit information symbol or each m-bit string to be encoded is transformed into an n-bit symbol, where m/n is the code rate (n ≥ m) and

This transformation is a function of the last k information symbols, where k is the constraint length of the code.

Convolution code can be analyzed by

Circuit diagram

Trellis diagram

State diagram

Mathematically it can be represented mathematically by

Impulse response

D transform

Convolution codes are of two types

Recursive Codes

Non recursive codes

2.9. Turbo Codes

Introduced in 1993 by Burro, Gavieux and Thitimajshima, they name it as Turbo Codes. Turbo code provide near optimal performance almost approaching the Shannon limit. The basic working mechanism of Turbo codes is connecting two convolution codes and separating them by an interleaver. The major difference between turbo codes and serial concatenated codes is that in

Turbo Codes two identical Recursive Systematic Convolutional (RSC) codes are connected in parallel.

2.9.1. Turbo Encoding

A turbo encoder structure consists of two RSC encoders which are Encoder1 and Encoder2. And both encoders are separated by ainterleaver. The two encoders can operate on the same time simultaneously. This structure is known as parallel concatenated. A 1/3 turbo encoder diagram is shown

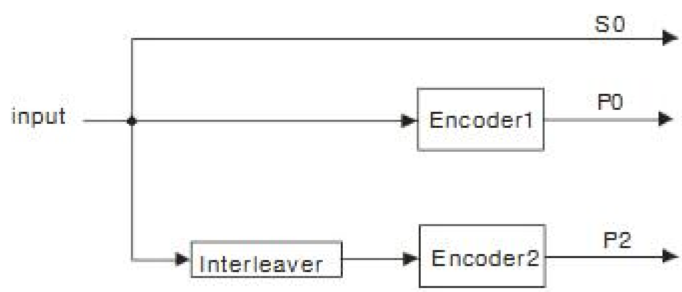


Figure 2.11 Turbo Encoder

The working mechanisms of Turbo Encoder is, the N bit data block is first encoded by Encoder1.The same data block is interleaved and then encoded by Encoder2. The first output S0 is equal to the input since the encoder is systematic. As shown from diagram the second output is the first parity bit P0.Encoder2 received interleaved input and generates the second parity bit P1.

2.9.2. MAP decoding algorithm

As discussed earlier the MAP algorithm checks every possible path through the convolutional decoder trellis, so that it seems very complex for application in the most systems. MAP decoding algorithm was not widely used before the discovery of turbo codes. The MAP algorithm is very efficient, it provides the estimated bit sequence, and also tells probabilities for each bit which has been recovered correctly. And the output can be used in the next iteration, and get more accurate values. The MAP algorithm is very complex according to large number of multiplications. P. Robertson, who proposed a simplified MAP algorithm, Log-MAP. In the Log-MAP algorithm all the calculation performs in logarithm domain. Turbo decoder calculates an accurate a-posteriori-probability for the received data block. Finally it will make a hard decision by guessing the largest APP for parity bits after alliterations finished.

2.10. DFT, FFT, IFFT

These are few thing are most commonly used in every communication system. Each of them is discussed in detail. The section will cover the structure and functions of the mentioned topics.

2.10.1. DFT

The discrete Fourier transform or DFT is a specific kind of discrete transform, which is used in Fourier analysis. It basically transforms the original function which is often in time domain to frequency domain representation, or in other word the DFT. But the basic requirement of DFT is that it requires an input function that should be discrete and its non-zero values have a limited and finite duration. Such inputs are generally created by sampling a continuous function satisfying nyquist criterion .The DFT block used in SC-FDMA only is its main difference with OFDMA. The basic two purposes of DFT block used in SC-FDMA are.

One is that the DFT block in the transmitter essentially transforms the time domain data block into frequency domain which are then mapped to the set of allocated subcarriers. Because the DFT block is always placed before IFFT, they theoretically cancel out and the resulting SC-FDMA modulated symbols are transmitted in the time domain. The other is to make frequency multiplexing or multiple accesses possible while maintaining the single carrier transmission. In other words, you can map each user's data symbols directly to the subcarriers OFDMA also do the same. So we can conclude the only difference between OFDMA and SC-FDMA in terms of functional blocks is that SC-FDMA has an additional DFT block but the addition of it makes the physical signal of SC-FDMA a time domain signal which reduces the peak power compared to OFDMA and it is also required in the case of uplink.

2.10.2. FFT/IFFT

A fast Fourier transform or FFT is a very efficient algorithm to compute the discrete Fourier transform or DFT and its inverse. The only major difference is that an FFT is much faster than DFT.

2.10.3. FFT/IFFT in OFDM/SCFDM systems

The block diagram of FFT/IFFT that is used in OFDM/SCFDM is shown, each of the block in the diagram perform a unique task.

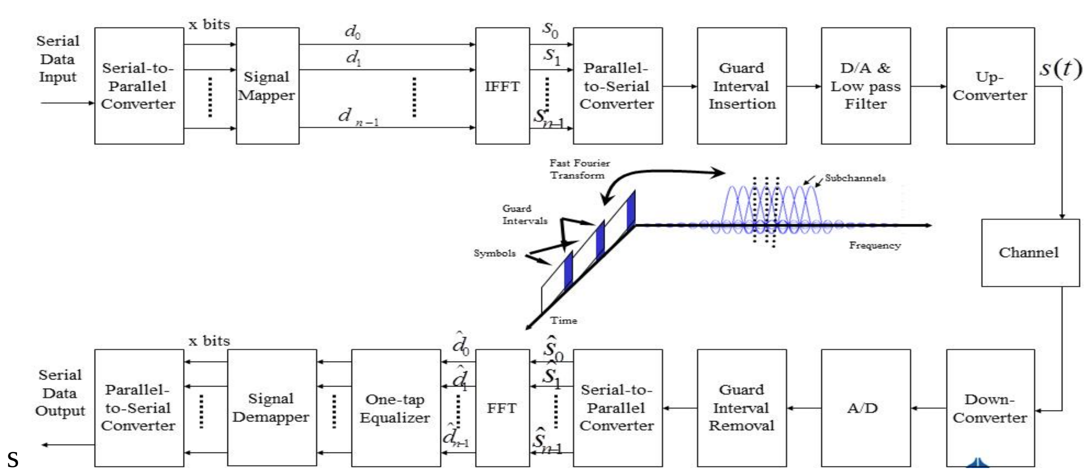


Figure 2.12: FFT/ IFFT in OFDM System

CHAPTER 3

LabVIEW

3.1. Introduction

“LabVIEW is basically a software development environment which is used to create a number of applications that has connection with real world of engineering and science”

LABVIEW is the programming language which is created by the National Instruments. In this programming language the code can be constructed and saved. As it is graphical programming language so the code are diagrammatical rather than text based, which is very easy to make and implement. So rather than conventional text based programming it is a new idea of graphical programming that is why this tool is very much appreciated by the programmer and scientists.

Virtual instruments or Vis are the programs of LABVIEW. There are basically two parts of these VIs one is called block diagram and the other is called front panel, the front panel is basically a user interface and easy to comprehend where as the block diagram shows the real code. LABVIEW also contain set of different tools acquiring, storing the data, analyzing it and then displaying the results.

The front panel of the program contains the indicators and controls:

Controls are: buttons, dials, knobs, meters and all similar input devices.

Indicators are: LEDs, graphs, and similar displaying tools.

Figure 3.1: LabVIEW logo

3.2. LABVIEW programming

LabVIEW is a programming language, which is graphical in nature. It used all around the world in research and academic project. It is computable with the national instrument equipments

3.2.1. Dataflow programming

LABVIEW uses data flow programming which is also referred as graphical programming language or simply G. the structure of the graphical block diagram determines the execution in which programmer with the help of wires can connect different function nodes. So as soon as the data become available these wires propagate the variables. This also allows multiple nodes, so the G programming is also referred as parallel programming. The hardware also support multitasking and multithreading.

3.2.2 Graphical programming

In the development cycle LABVIEW marks the creation of user interface. The programs of LABVIEW are called the virtual instruments. The virtual instruments have basically three parts:

The block diagram, front panel and connector panel. The connector panel is representing the front panel in some other VI also called the sub VI.

The front panel can be called as user interface. The front panel actually dictates the inputs and outputs for a described node through the connector panel. It basically provides the easy view of the whole programs.

The block diagram is used to represent the insight working of the program and the graphical and sequential working of program.

The graphical approach also provides the users to drag and drop the Vis into other programs.

3.3. LabVIEW fundamentals:

Few fundamentals of labVIEW are mention is under

The LabVIEW Environment:

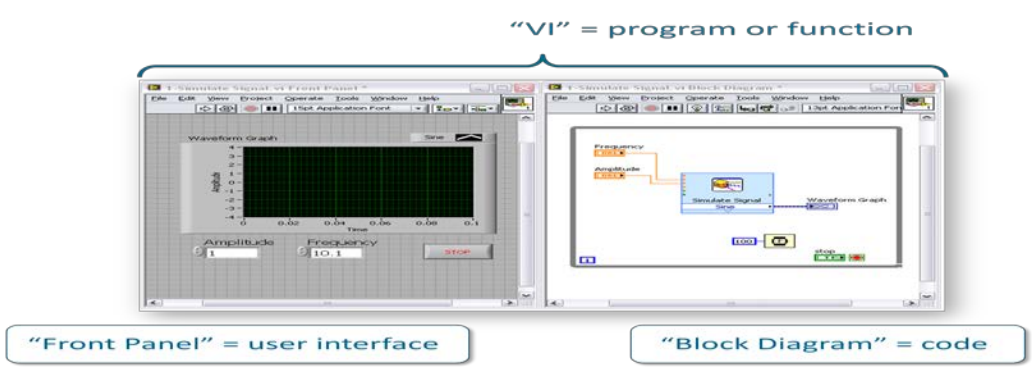


Figure 3.2 LabVIEW environment

Controls & Indicators:

Knobs/Dials

Graphs/Charts

Buttons

Digital Displays

Sliders

Thermometers

Customize and create your own

It can seen the below mention diagram that control and indicator consist of following part which are listed above.

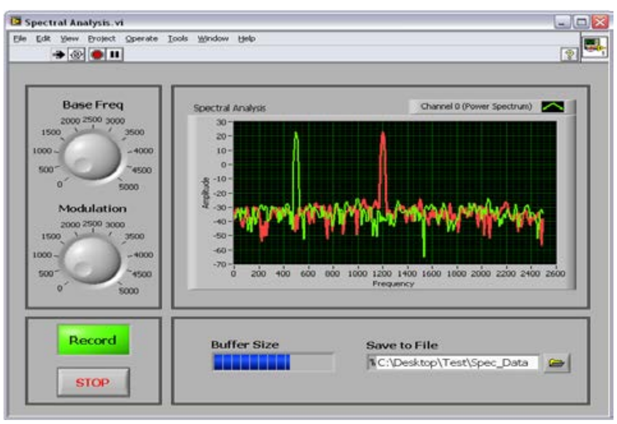


Figure 3.3 controls and indicators

Functions and Vis:

The Figure 5.4 shows display the how functions and VIs look like in this graphical programming language.

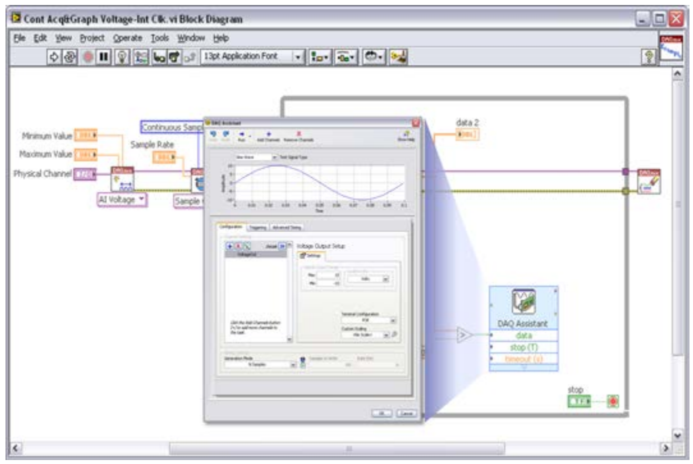


Figure 3.4 Functions and Vi

Dataflow Programming:

This Figure 5.5 the Data flow programming procedure in the labview.

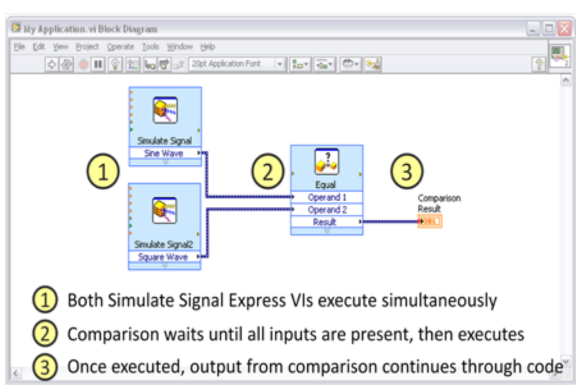


Figure 3.5 data flow programming

Transfer data between block diagram objects through wires

Wires are different colors, styles, and thicknesses, depending on their data types

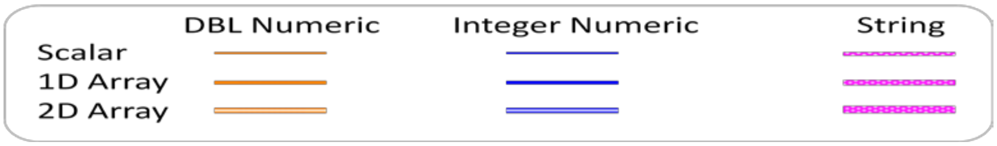


Figure 3.6 Wires of Different Data Types

Allow same piece of code to run multiple times

Exit conditions different for each

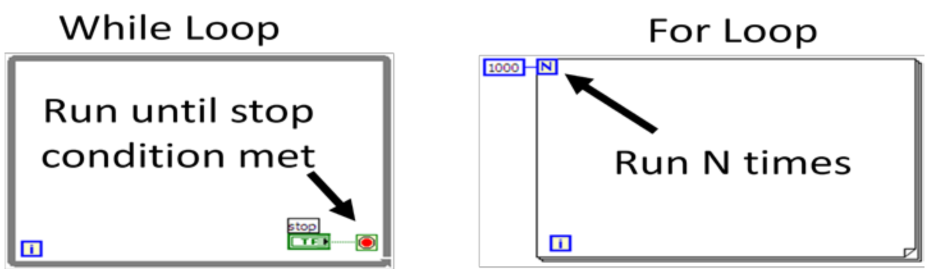


Figure 3.7 control structure

3.4. Benefits

Few benefit of using this programming language are listed below

3.4.1. Interfacing

The main advantage of LABVIEW over the other software like that is the support available by the National instruments.

There are two parts of interfacing, one is the drivers and the other thing is the abstraction layer.

Abstraction layer: it basically provides the interface between the hardware and the software part, so that the software may run smoothly on the hardware.

Drivers: they help in interfacing and saving the program as the program development under goes.

3.4.2. Code compilation

The main thing about the LABVIEW code is that the LABVIEW compiler produces a code for the CPU for all the platforms. The graphical program is then translated to the machine code by converting the syntax by the compiler. After the editing process the code is converted into machine executable code and can be saved whenever necessary. The source and the executable code can be merged to have a single machine code.

LABVIEW has a quality that it reduces the runtime and the compile time and it also provide an excellent interface to different operating systems, hardware systems and the graphical components. The machine executable code is portable and support different platforms.

3.4.3. Large libraries

LABVIEW support a large number of libraries such as signal generation, mathematics, signal conditioning, analysis etc. having a large no. of graphical interface elements. A large number of mathematical blocks and function such as integration filters and others are also available.

An additional feature of LABVIEW is that is also including a text based programming, it include a component called Math Script used for analysis mathematical and the signal processing. So LABVIEW can easily integrate itself with MATLAB.

3.4.5 Parallel programming

With the help of multithreading the programs of LABVIEW are preformed in parallel. This can be done using more than two parallel loops. It is indeed a great advantage in the industrial market as a number of processes should be run in parallel. So the efficiency of the whole work can be increased.

3.5. LabVIEW 2011

The latest of the LABVIEW software created by the National instrument, at the 25^{th} anniversary of the company. The company has added a number of features in providing a high efficiency throughput to the users. The software has been upgraded and the look is also been enhanced, LABVIEW 2011 has a number of additional toolkits providing solutions to the new technologies in the market.

3.6. LABVIEW TOOLKITS

The graphical programming language labview software comes with various toolkits, some of them developed by Labview research group and some are them are developed by private programmers

3.6.1. Modulation Toolkit

In addition to the build in capabilities of LABVIEW, the modulation toolkit provide extended tools and function for analysis, signal generation and software processing for the analogue and digital modulation formats. With the help of this toolkit, a number of research and design applications for communication systems. the application for the modulation toolkit include PAM, QAM, GMSK, FSK, MSK, PM, AM ,FM etc. they are included in WiMAX(802.16), RFID, satellite communication system, and Wifi etc.

At the RF frequency this modulation toolkit is implemented in NI RF PXI-5600 and NI RF PXI-5671 and for the lower frequency operations it works at 100MHz mixed signal test platform. It is implemented with digitizer, analogue wave form generation and digital I/O products.

3.6.2. Spectral Measurement Toolkit

Following are capabilities in the spectral toolkit:

Peak power, power spectrum, peak frequency, adjacent-channel power and the occupied bandwidth.

With help of spectral toolkit following functions can also be performed:

I-Q to IF conversion

Pass band (IF) to baseband (I-Q) conversion.

Generation/analysis of analog modulated signals.

This toolkit can be used in a number of NI hardware including:

Digitizers, PXI-5660 RF vector signal analyzer, and different other modular hardware

3.6.3 Simulation Interface Toolkit

This toolkit is basically used by the controls system, design and test engineers. It provides a simulation interface between the Math Works and the simulation software. With the help of this toolkit we can easily build LABVIEW application for control and design. So basically this toolkit provides a connection between real and imaginary worlds. With the help of this toolkit we take a model test and verify it.

3.6.4 VI Analyzer Toolkit

This toolkit is basically used to improve the quality and readability of the graphically developed code in the LABVIEW software. Following are the main functions provided by this toolkit:

Debugging

avoid improper coding

functionality

maintainability

coding styles

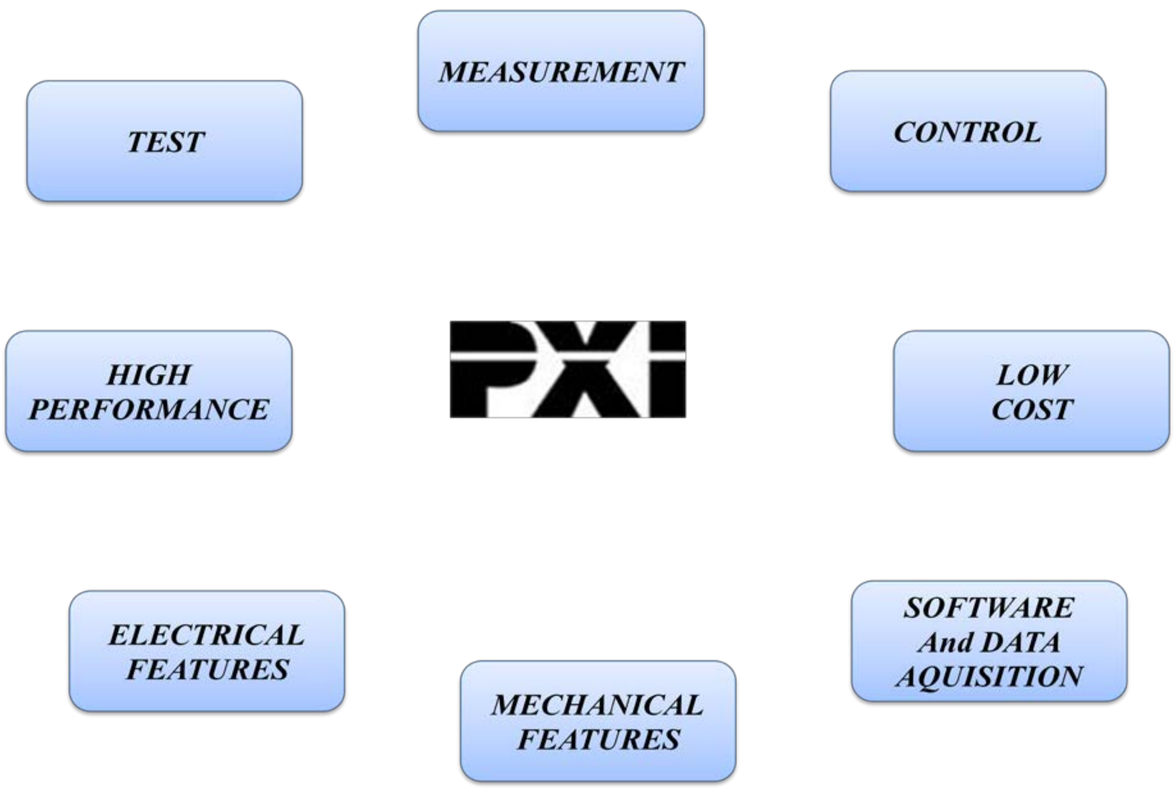
effective programming practices

Chapter 4

National Instrument's PXI-1045

4.1. Introduction

PXI: peripheral components interconnected extension for instrumentation. It is a Pc based platform providing solutions to the science and technology related applications.



The PXI is used in a number of applicationsfor example military, aerospace, machine monitoring, automotive, industerial test etc.

Features of PXI-1045:

- High-performance 18-slot PXI chassis

Accepts both 3U PXI and 3U Compact PCI modules

Software programmable trigger rout between bus segments

Low jitter (<5 ps) 10 MHz reference clock

External 10 MHz reference clock with BNC I/O connectors

Removable, high-performance power supply with universal AC input

Extended 0 to 55 °C operating range

Temperature controlled fan speed

Remote power-inhibit control and voltage monitoring

Front-panel LED that can indicate power supply failure

10 MHz REF IN and OUT BNC connectors for synchronizing multiple chassis using PXI_CLK10

Programmable PXI trigger routing between PXI bus segments

Carrying handle for portability

Tilt feet for bench-top applications

Rack mountable

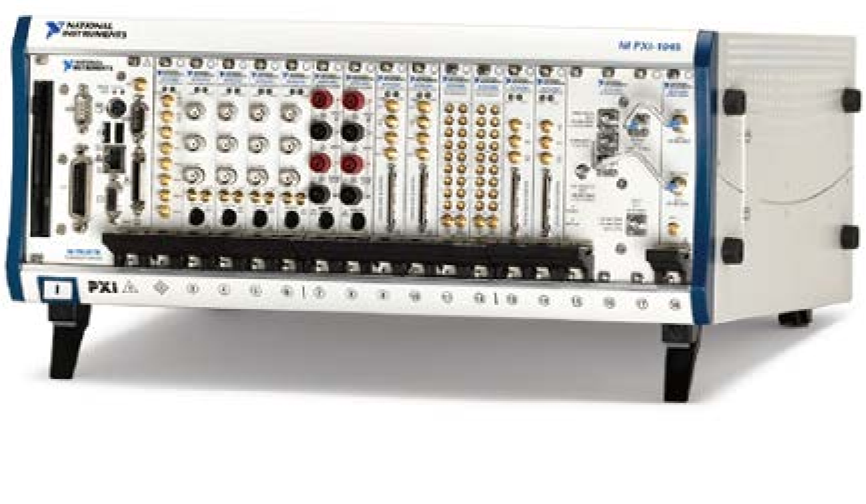
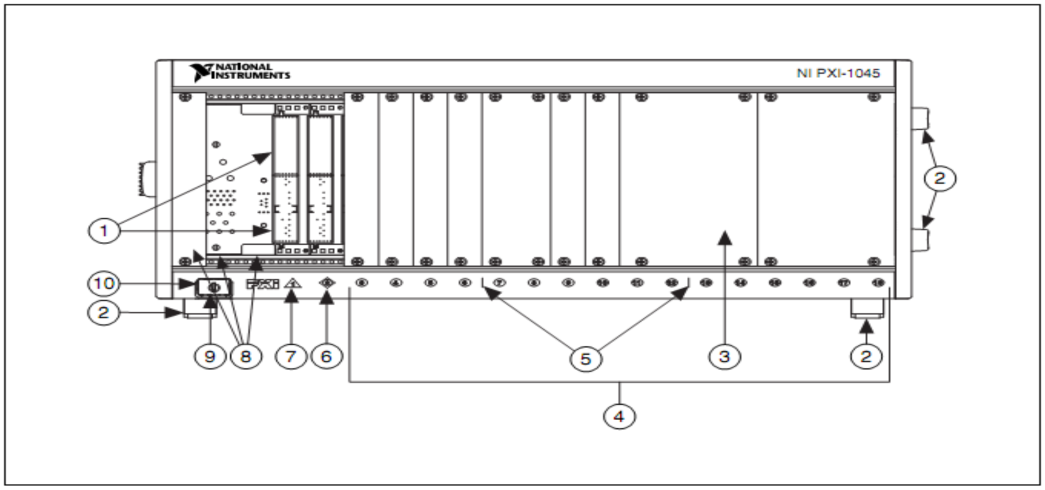


Figure 4.1 diagram of PXI-1045

Figure 4.2 description of PXI

4.2. Chassis description

The National Instruments PXI-1045 chassis is a high-power 18-slot chassis designed for a wide range of test and measurement applications. With its large slot capacity and modular structural design, the NI PXI-1045 is well suited for high-channel-count, multi-instrument bench-top or rack-mounted systems. The combination of integrated trigger buses and precise timing features provides the ideal platform for multiple-instrument synchronization and automated testing



1	Backplane Connectors (Located in slots 1–18)	6	Star Trigger/Peripheral Slot
2	Removable Feet	7	System Controller Slot
3	Filler Panel	8	Controller Expansion Slots
4	Generic Peripheral Slots	9	Power Switch LED
5	PXI Bus Segment Dividers	10	On/Off (Standby) Power Switch

Figure 4.3: complete description of PXI-1045

4.3. PXI controller

As shown in the above diagram the controller is inserted in the left most slots. All the base band processing is down by the controller. Controller is basically a min computer having all the function a computer have, it support the operating system mode.

Most PXI chassis contain a system controller slot in the leftmost slot of the chassis (slot 1). You can choose from a few options when determining the best system controller for an application, including remote controllers from a desktop, workstation, server, or laptop computer and high-performance embedded controllers with either a Microsoft OS (Windows 7/Vista/XP) or a real-time OS (LabVIEW Real-Time). The two types of controller options are laptop control of PXI and PC control of PXI.

Figure 4.4 PXI embedded controller

4.4. PXI modules

Modular instruments for analog and digital I/O ranging from high-resolution DC to 6 GHz RF

Data acquisition modules for multifunction analog, digital, and counter I/O

Switch modules featuring general-purpose relays, multiplexers, and matrices

Motion, vision, and analog and digital I/O modules for industrial applications

Synchronization modules for multichassis and advanced multi device synchronization

Bus interface modules for Gigabit Ethernet, GPIB, serial, IEEE 1394, CAN, VXI, and other buses

Following are the module used in the project:

4.4.1 NI PXI-5610 Up-converter

This component is used to up-convert the IF frequency to the RF frequency.

Following are the features of this device:

- 250 kHz to 2.7 GHz
- 20 MHz real-time bandwidth
- 130 dB adjustable gain
- High-stability OCXO time base

Figure 4.5 NI PXI-5610 up converter

4.4.2. NI PXI-5441 Arbitrary Waveform Generator

This module is used with the up-converter. The main features of this component:

Quadrature digital upconversion

FIR and CIC interpolation filters

Carrier frequencies up to 43 MHz with 355 nHz resolution

16-bit resolution,

400 MS/s effective sampling rate with DAC interpolation

32, 256, 512 MB of onboard memory

Multimodule synchronization with < 20 psrms skew

Continuous data streaming up to 100 MB/s

Figure 4.6 NI PXI-5441 Arbitrary Waveform Generator

4.4.3. NI PXI-5600 Down-converter

The NI RF-5600 is a high speed down-converter. The main features of this component:

- 9 kHz to 2.7 GHz
- 20 MHz real-time bandwidth
- High-stability timebase (10 MHz OCXO)
  - ±20 ppb frequency stability
  - ±50 ppb frequency accuracy
  - >80 dB spurious-free dynamic range
  - <-135 dBm/Hz average noise density
  - +30 dBm full-scale input range

Figure 4.7 NI PXI-5600 Downconverter

6.4.4. NI PXI-5620 Digitizer:

This component is used with the down-converter as a part of RF signal analyzer. The main features of this component:

1 kS/s to 64 MS/s sampling rate

10 kHz to 36 MHz bandwidth (-3 dB)

Outstanding distortion-free performance

Deep segmented memory

80 dB spurious-free dynamic range

14-bit resolution

Figure 4.8: NI PXI-5620 Digitizer

6.5. 10 MHz System Reference Clock

There are two BNC connectors on the rear of the PXI-1045 chassis designated 10 MHz REF. The connectors are labeled IN and OUT. You can use them for supplying the backplane with a 10 MHz reference clock or routing the backplane's PXI_CLK10 signal to another chassis.

6.6 PXI System Configuration with MAX:

A graphical interface used in LabVIEW, as brief discussion is given below

6.6.1 What is MAX?

Measurement & Automation Explorer (MAX), it is basically a graphical user interface, used to configure IVI. MAX usually provides the interfacing and integration of the software and hardware tools in the LABVIEW.

Basic PXI System Configuration:

Launch MAX.

In the Configuration tree, click on the Devices and Interfaces branch to expand it.

If the PXI system controller has not yet been configured, it will be labeled "PXI System (Unidentified)." Right-click on this entry to display the popup menu, then select the appropriate controller model from the Identify As submenu.

Click on the PXI System controller and the chassis (or multiple chassis, in a multi-chassis configuration) will be listed below it. Identify each chassis by right-clicking on its entry, then selecting the appropriate chassis model through the Identify As submenu. Further expanding the PXI System branch will show all of the devices in the system that can be recognized by NI-VISA. Once your controller and all of your chassis have been identified, the required pxisys.ini file will be complete.

Apply the chassis number labels included with your kit to each chassis in your PXI system, and write in the chassis number accordingly in the white space.

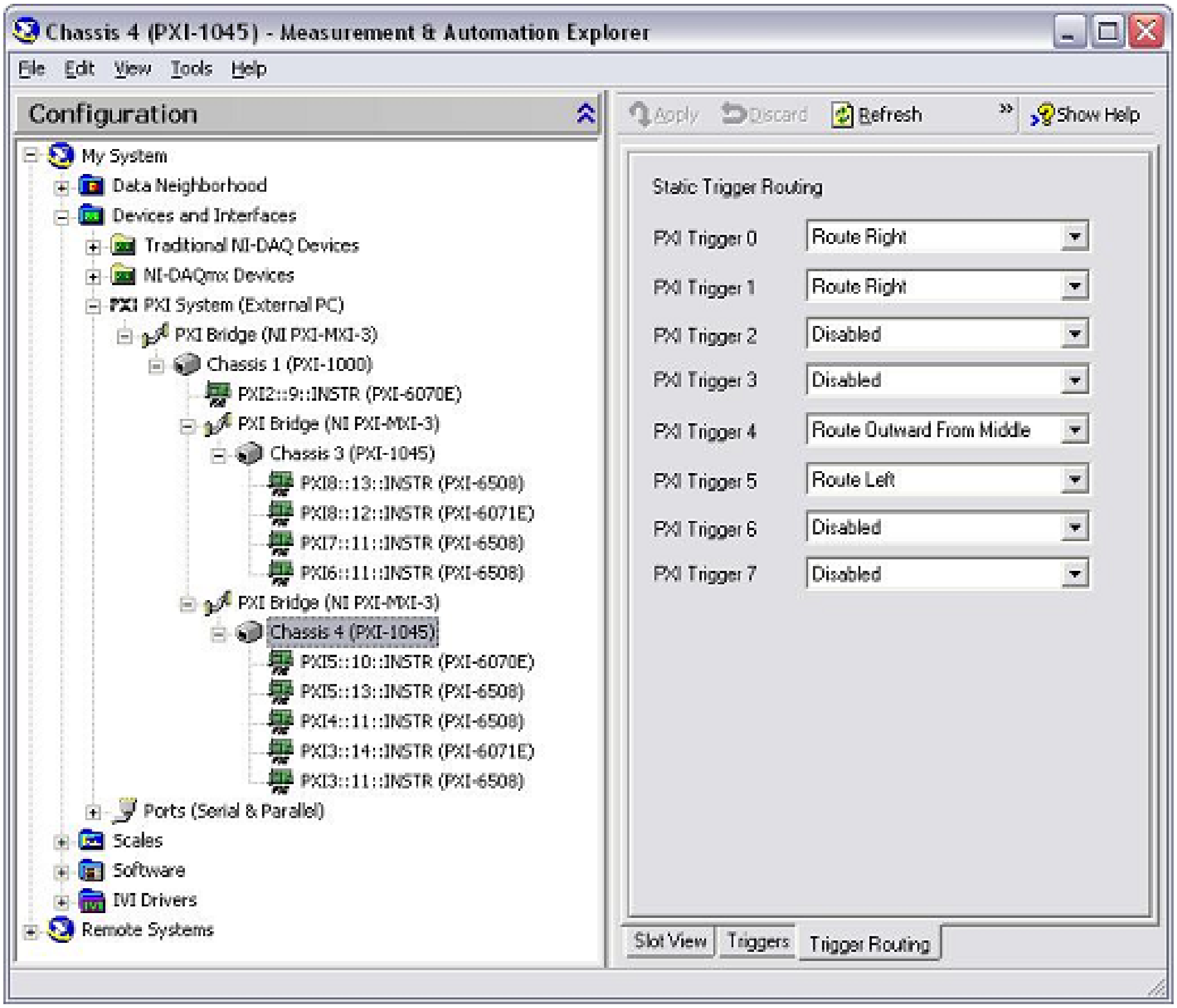


Figure 4.9 Snapshot of MAX

Chapter 5

Software and hardware Implementation

The first part of implementation is component coding. The components can be categorized into two major groups: The first group of components is part of the transmitter system and the second group is part of the receiver.

5.1. Transmitter Components

The transmitter system components include all what needs to be done to transmit the data. It includes converting data (text in our case) into bits, then channel coding the bits, then doing the modulation, then mapping the complex data on OFDM symbols and then transmitting the OFDM symbols. This procedure happens at two levels, software and hardware.

5.1.1. Software Level

In this section described the software implementation on PXI.

5.1.1.1. Text to Bits

The first step in the software level implementation is to transform the text into bits. This is done by transmittext.vi as shown.

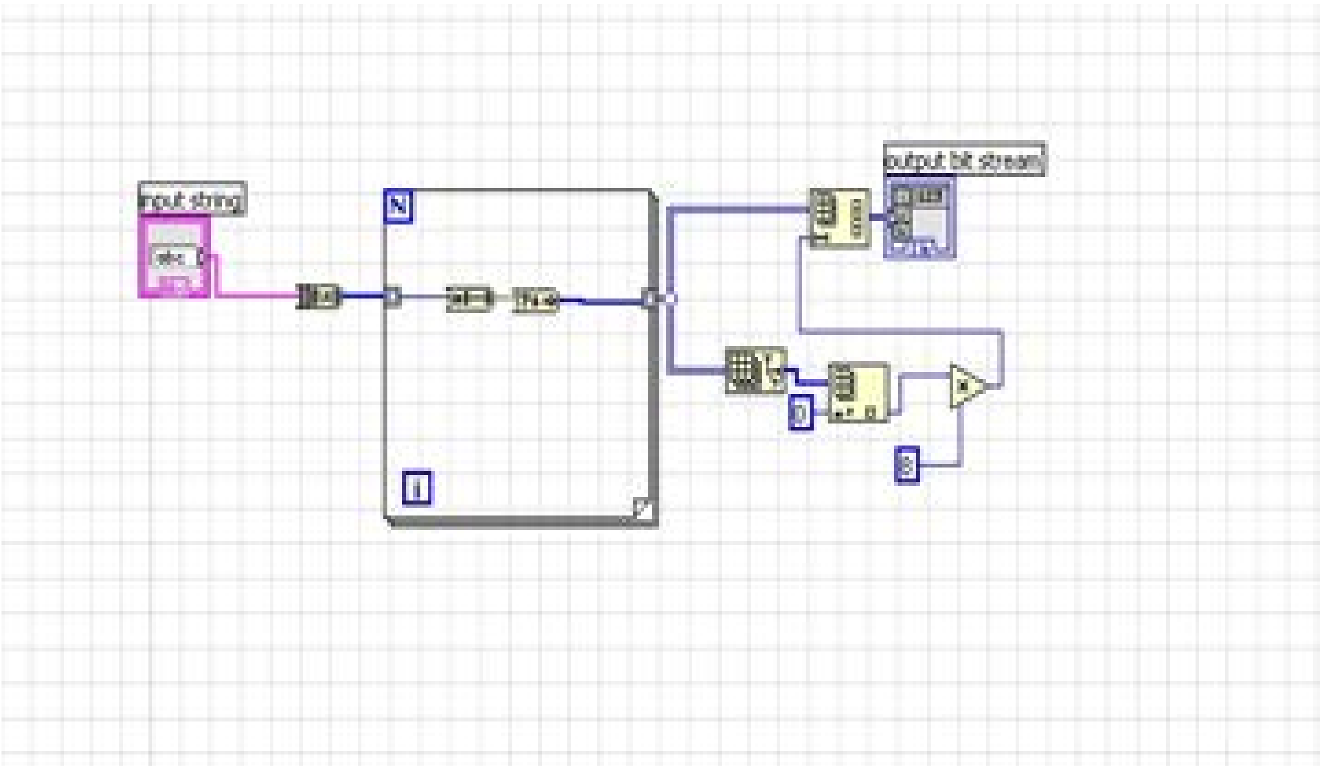


Figure 5.1: Text to Bits VI

5.1.1.2. Channel Coding and Interleaving

The technique used for channel coding in our code is turbo coding as it is used in the 3gpp standards. The turbo encoder used is rate 1/3 encoder. The type of interleaving used is Block interleaving. The turbo Codes are implemented in kk_project_TurboEncoder.vi

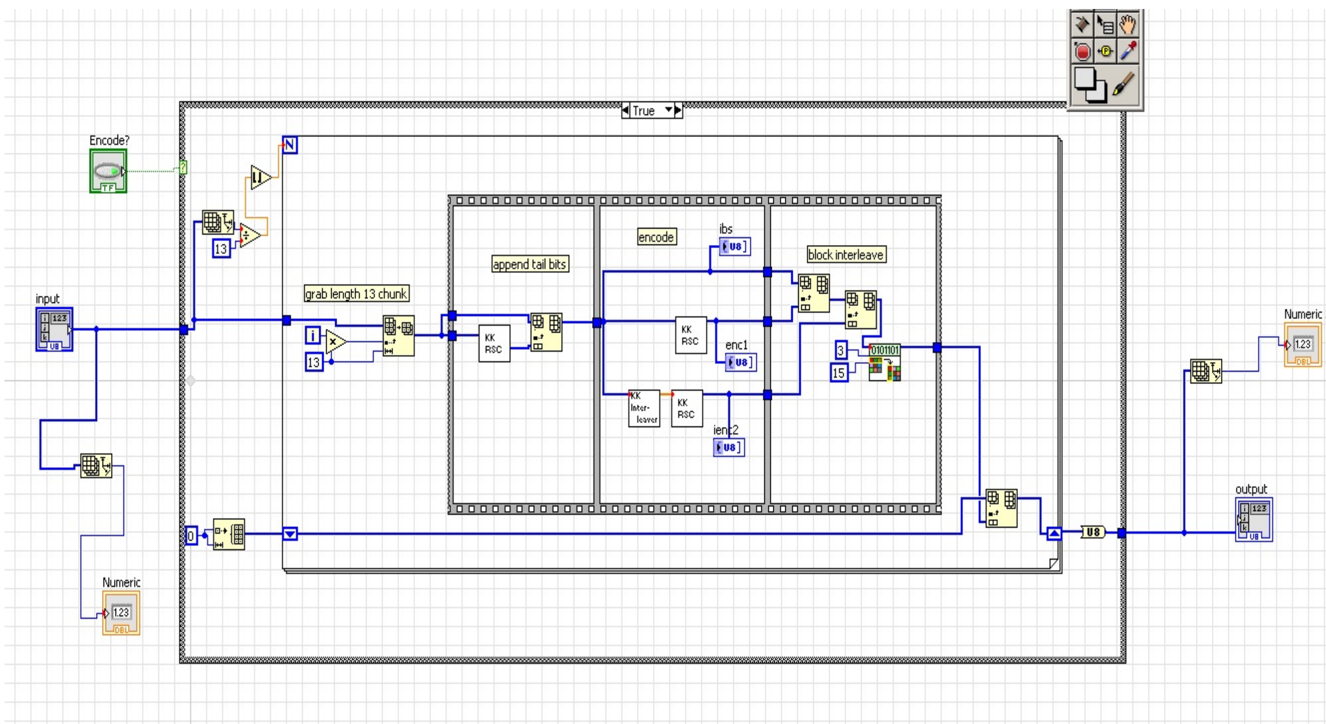


Figure 7.2: Channel Coding and Interleaving VI

5.1.1.3. QAM Mapping

At this stage, we expect to receive an array of coded and interleaved bits that need to be transformed into complex symbols. The type of modulations schemes that we have implemented are BPSK, 4-QAM, 16-QAM and 64-QAM. The modulation is implemented in QAM.vi

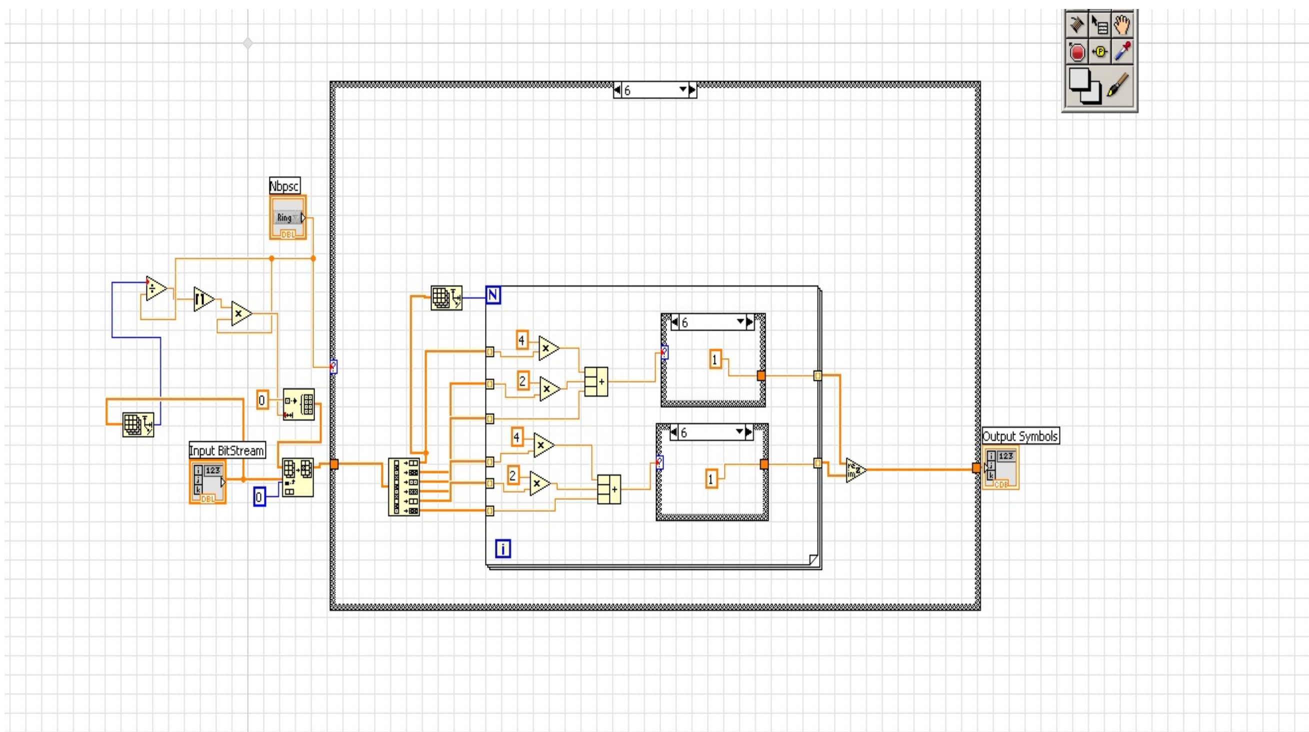


Figure 5.3: QAM Mapping VI

5.1.1.4. Pilot Insertion and Guard band Insertion

After the modulation we insert the pilots after a fixed number of symbols for channel estimation. However the number and location of pilots can be changed according to the need. Also the insertion of pilots depends upon the number of OFDM symbols that are used.

In this case we have tested our design on 256 symbols OFDM in which 192 are data symbols, 8 are pilots and 56 symbols are used as guard band. Again this specific configuration has been chosen by us but this can be changed as per the requirement.

The pilot insertion and guard band insertion are implemented in pilotinsertion.vi and guardbandinsertion.vi

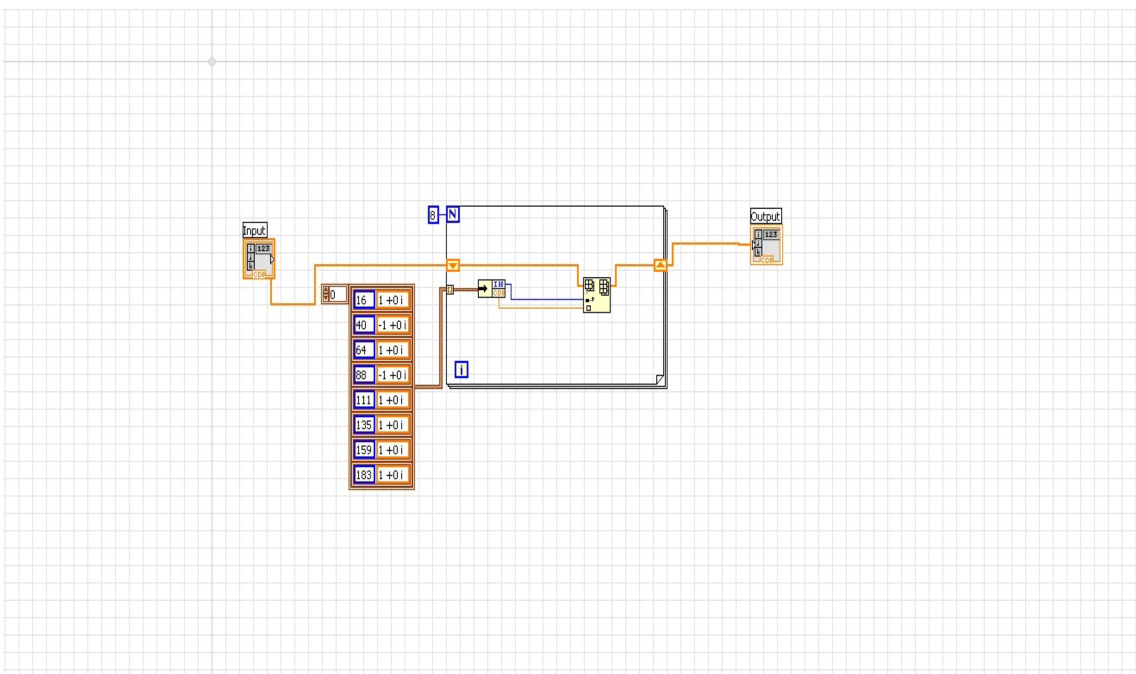


Figure 5.4: PILOT INSERTER

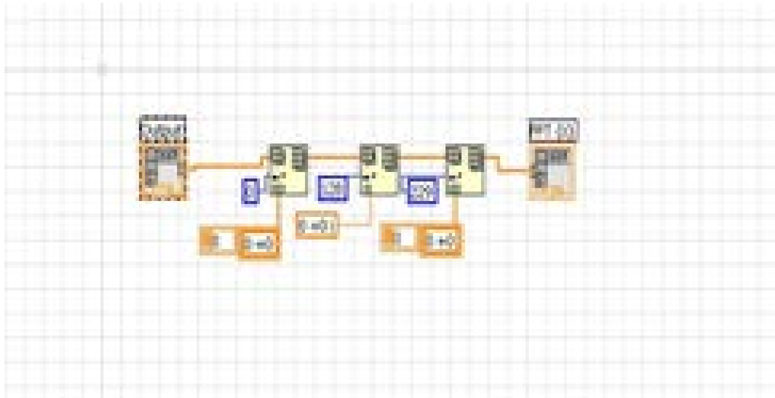


Figure 5.5: Guard band INSERTER

5.1.1.5. IFFT

Lab View implements a complex version of the IFFT. Referring back to the block diagram of the system in figure one may wonder where the S/P and P/S conversions took place; however, they are embedded in this component's functionality as taking 64 symbols at time resembles S/P conversion just as P/S conversion is achieved changing the array back to a one dimensional one after the IFFT block.

The OFDM supported in our code is flexible for example the OFDM can be of 64 symbols, 256 symbols, 512 symbols or as much as the requirement dictates. However one thing that has to be kept in mind is the resultant bandwidth of the signal in relation to the sampling rate of the arbitrary waveform generator. The relationship between IFFT and the sampling rate of the arbitrary waveform generator is

BW of the signal = (no of occupied subcarriers / no of empty subcarriers)* (sampling rate)

We generated a signal of 16 MHz with 256subcarrier OFDM. Since we only have sampling rate of 100 MS/s so we had to do zero padding to get the signal of desired bandwidth. Zero padding is done by splitting the OFDM data symbols into half (in our case split 256 symbols into two halves of 128 symbols each) and then inserting zeros between them. The OFDM is implemented in OFDM transmitter 16MHz.vi which is shown.

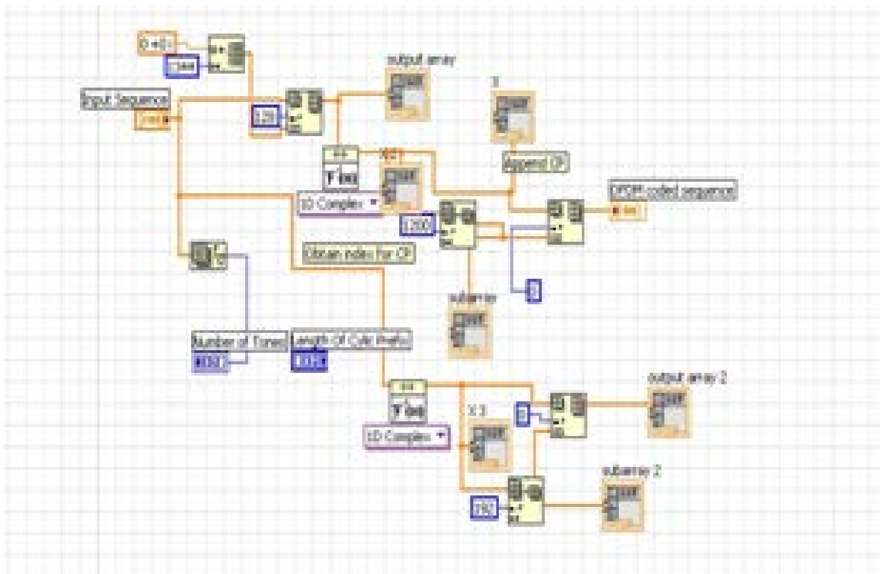


Figure 5.6: IFFT

5.1.1.6. Cyclic Prefix Addition

An OFDM signal is never completed without adding a cyclic prefix. This is implemented by taking the last symbols of every OFDM symbol to the beginning.

5.1.1.7. Inserting training symbols

We are also doing channel estimation by transmitting training symbols periodically. The number of training symbols to be transmitted can be controlled by the front panel. This symbol contains training data on all 256 tones.

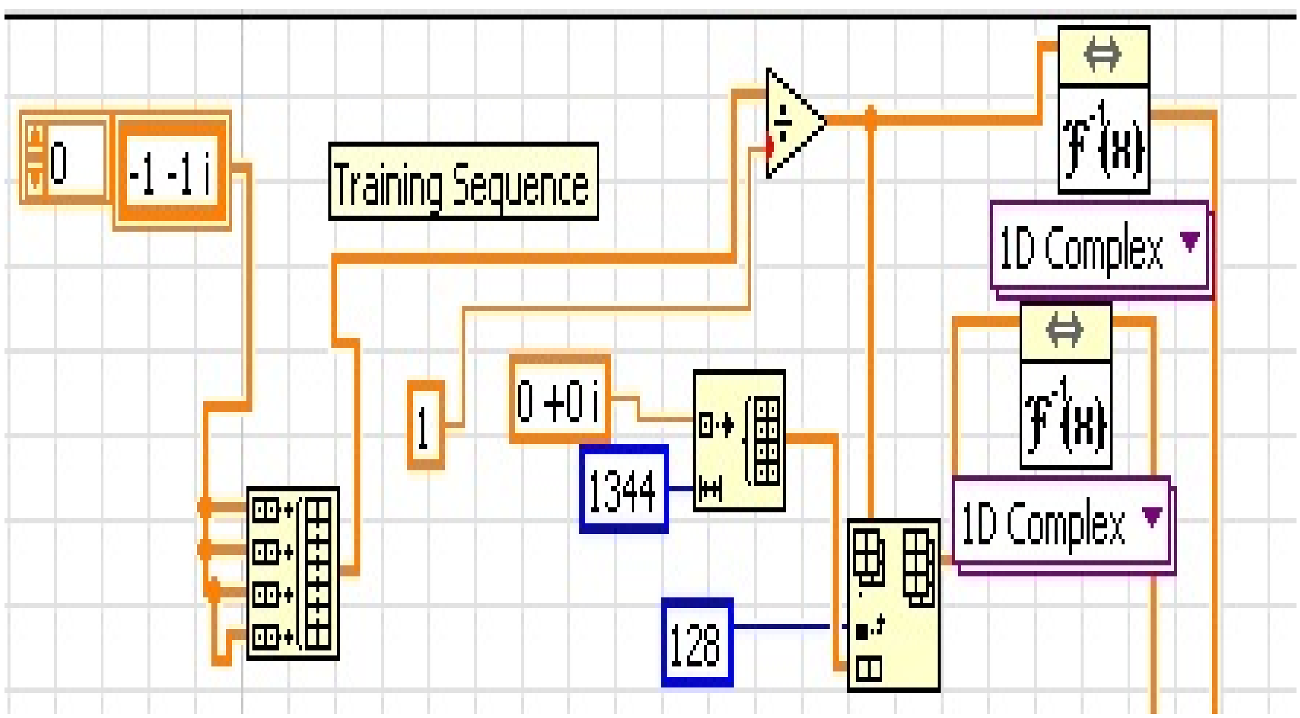


Figure 5.7: Inserting training symbols

5.1.2. Hardware Level

We use the NI RFSG library to up convert our signal to the required RF frequency which in our case is 1.9 GHz. The hardware is first initialized, then after the setting of clock source and RF frequency

The IQ data is transmitted. After the transmission is over the session is closed. This is implemented in transmitter.vi

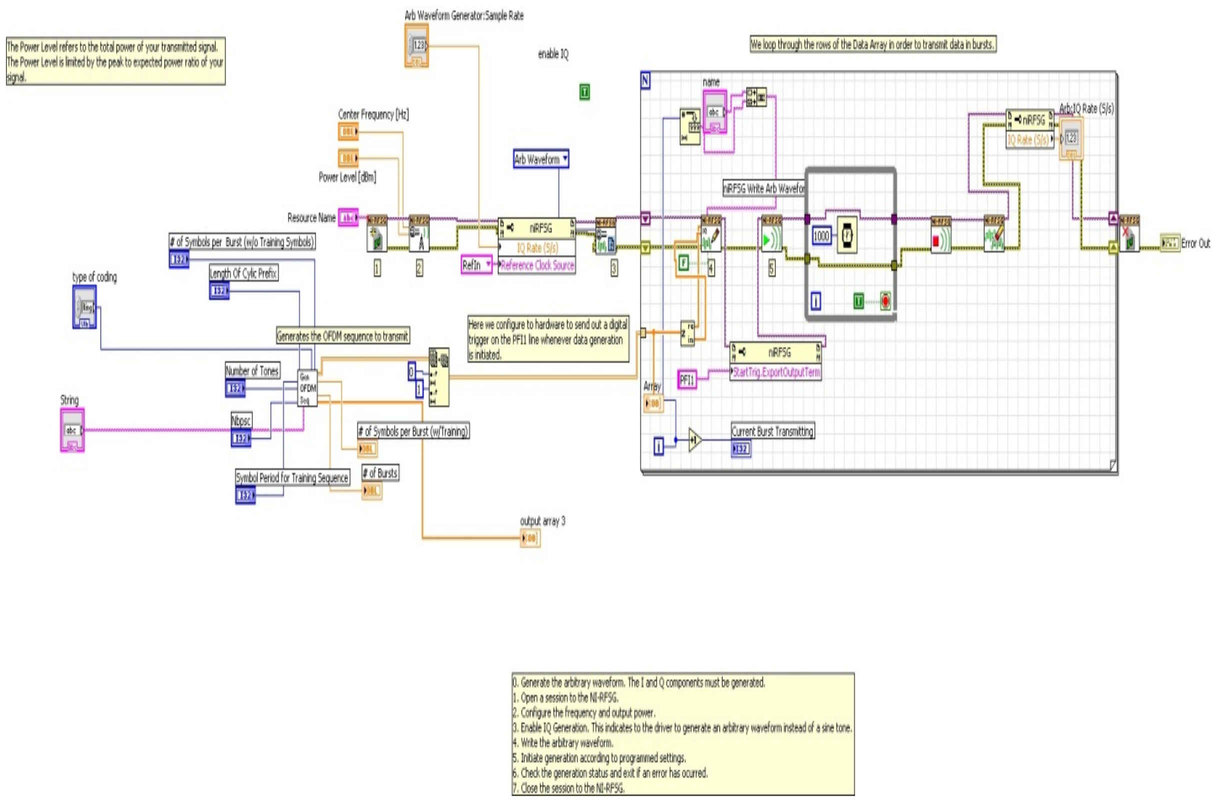


Figure 5.8: Transmitter Hardware Level

5.2. Receiver Components

Receiver components receive the data from the wireless channel and then transform it back into the bits which is then converted to text .This procedure also happens at two levels one is the hardware level and other is the software level

5.2.1. Software Level

The software implementation will be discussed with respect to our project requiem in this section

5.2.1.1. Ricean fading

In the design the RFSG and RFSA are on the same chassis. So the separation between antennas only gives the AWGN noise. To simulate the fading effects under different terrain profiles we use SUI-models which are defined by Stanford University the details of which have been described in earlier it can be either choose “no fading” from the front panel or choose “fading” and then the type of SUI model that has to be applied. This has been implemented in ricean_fading3.vi.

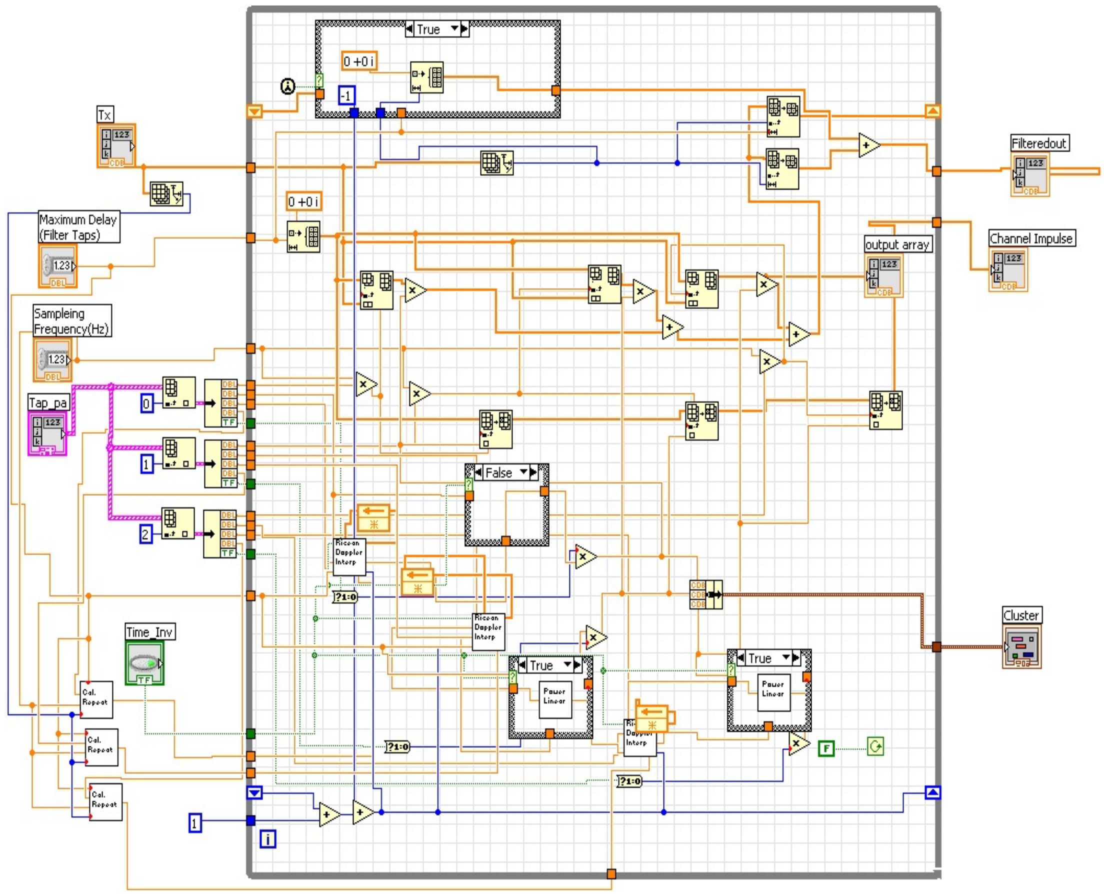


Figure 5.9: Ricean fading

5.2.2.2. Removal of Cyclic prefix

The next step in the receiver chain is to remove the cyclic prefix. The length of the cyclic prefix is against chosen according to the requirements. In this case it has been chosen the cyclic prefix length of 64.

5.2.2.3 FFT and Channel Estimation

After the removal of the cyclic prefix the next step is to take the FFT. Also the channel estimation is done using the periodic training sequence that was transmitted. This is implemented

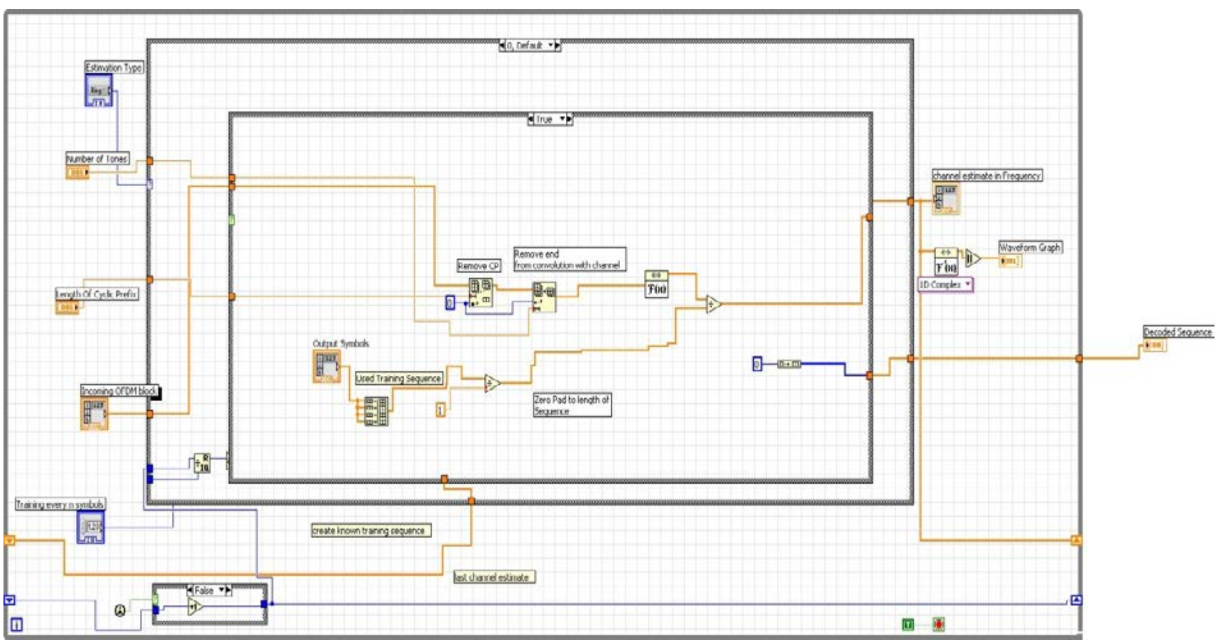


Figure 5.10: FFT and Channel Estimation

5.2.2.4. QAM De-mapping

After the FFT and the channel estimation we have to transform the complex QAM symbols back to bits. This is done using deQAM.vi

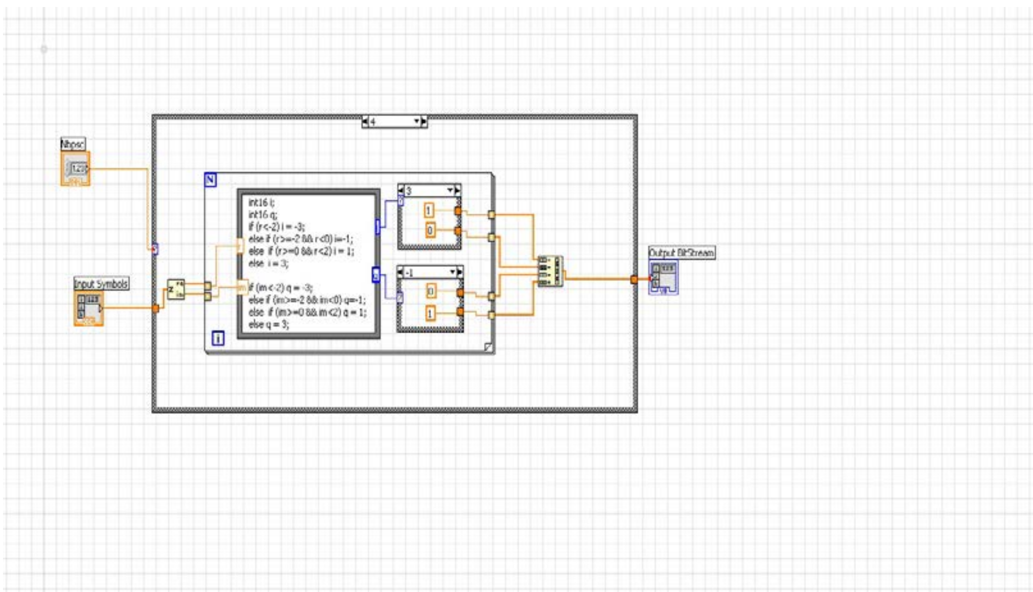


Figure 7.11: QAM De-mapping

5.2.2.5. Decoding and De-interleaving

Since the turbo coding at the transmitter end therefore at the receiver end we need to decode them using MAP decoder. Turbo Decoding works by using a set of maximum a posteriori probability (MAP) decoders. When the data is received it is de interleaved back into the three streams which were sent from the transmitter:

Original Data

Output from Convolutional Encoder 1.

Output from Convolutional Encoder 2.

The first MAP decoder takes as an input stream 1 and stream 2 and also the output from MAP decoder 2 (initialized to zeros for the first iteration). The second MAP decoder takes in an interleaved version of stream 2 (the same interleaver used to interleave the original data before it was sent to the Convolutional Encoder), stream 3, and the output from the first MAP Decoder. The two MAP Decoders then work together to converge on a solution: the most likely original bit sequence.

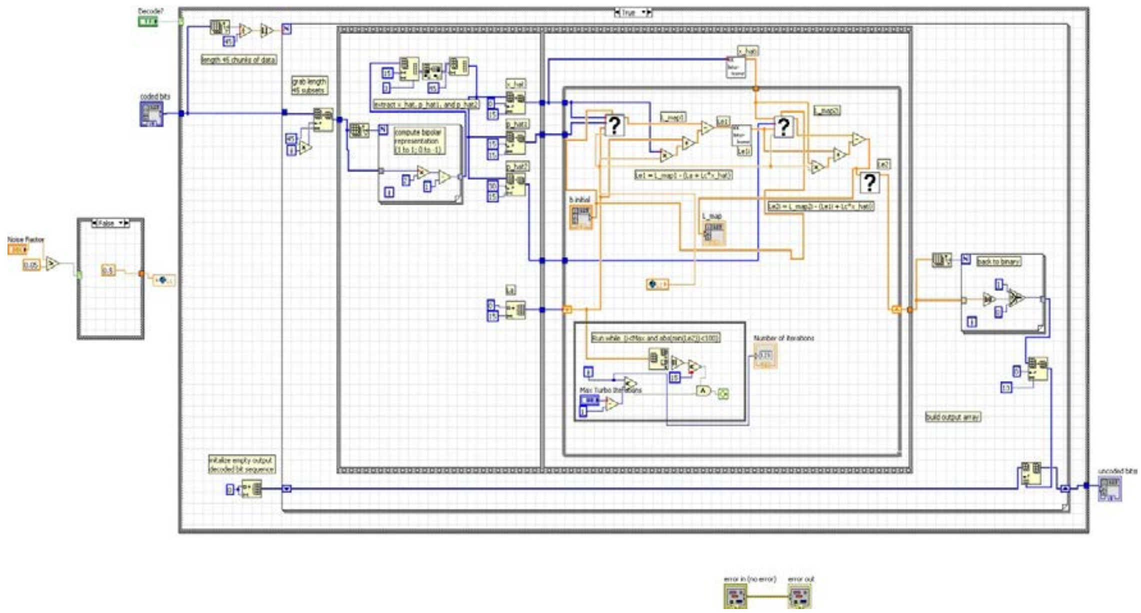


Figure5.12: Decoding and De-interleaving

5.2.2.6. Bits to Text

After the decoding of bits from the Turbo decoder. The bits are now ready to be transformed back into text.

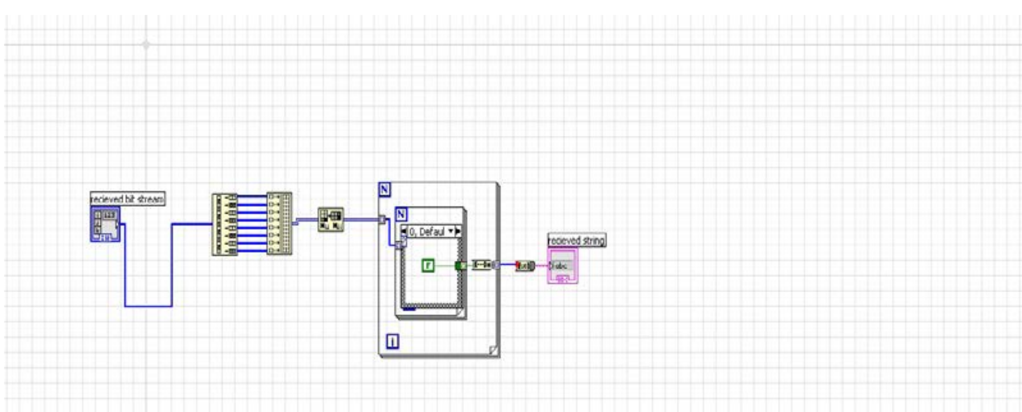


Figure 5.13: Bits to Text

5.2.2. Hardware Level

At the hardware level we are using ni tuner (which is the driver for down converter) driver and ni scope (which is the driver for the digitizer) driver to receive the signal from wireless channel. Collectively the down converter and the digitizer are known as RFSA. NI has a library of RFSA drivers but they are not compatible with our RFSA which is 5660. Our digitizer (5620) can sample at the rate of 64MS/s. So we sample the signal at the rate of 64MS/s and then we decimate it by four to receive the 16 MHz signal. Also the synchronization between the receiver and transmitter is done by sending a digital trigger on PFI 1 line from the transmitter to the receiver. Transmitter sends the trigger to the receiver to indicate that the transmission has begun. Also we have acquired some pre trigger samples to cater for small delay in the trigger. The number of pre trigger samples to acquire can be adjusted by hit and trial method. This is implemented in the main VI which is receiver.vi as

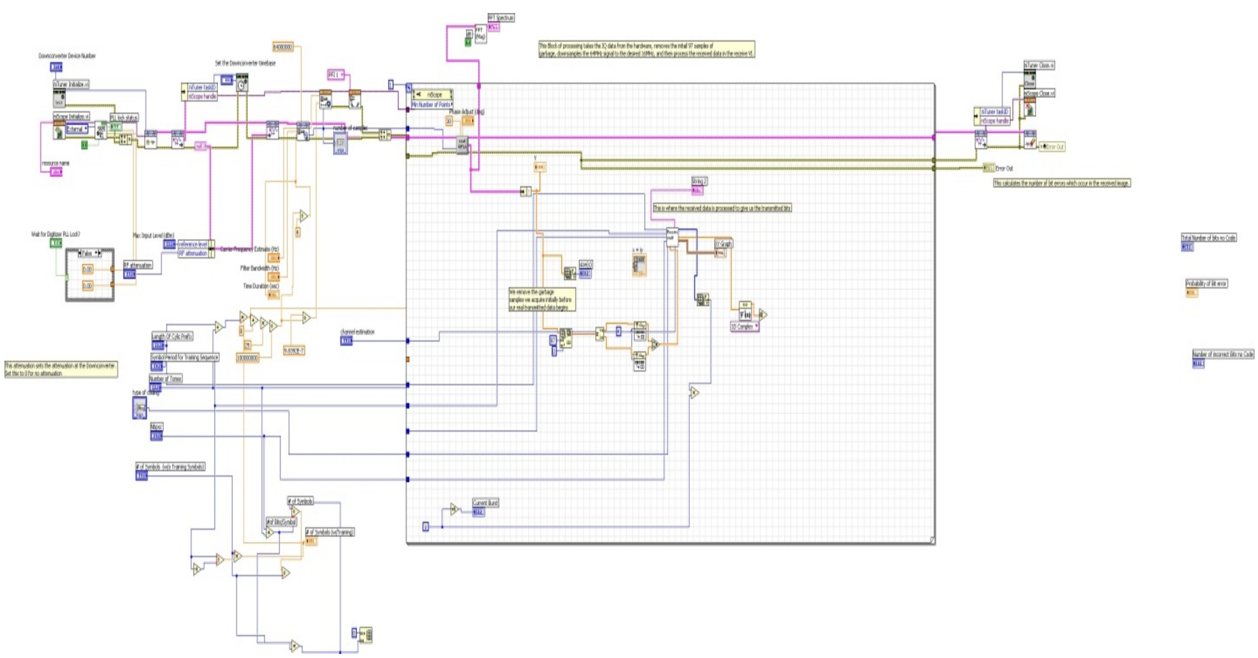


Figure 5.14: receiver Hardware Level

5.3. The End of work

The goal in the project as was defined in our proposal was to implement the architecture of LTE physical layer which was achieved by us. However, it could have gone ahead to make a real time system. But the limitation that we faced was of the digitizer. Our digitizer i.e. 5620 cannot do DDC (digital down conversion) for the signals above 1.25 MHz bandwidth and the least bandwidth defined in the LTE standards is 1.5 MHz so we had to downconvert the signals in the software which is computationally intensive and takes quite a few seconds. Therefore data could not be transmitted in real time. Rather we focused on implementing the architecture of LTE. However this limitation can be overcome in the future by using a newer digitizer which supports Digital down conversion.

CHAPTER 6

Results and Critical Evaluation

6.1. Results

The system has been tested under various conditions. The modulation schemes has been changed. We applied different fading profiles and analyzed our results. Below are some of the results which we obtained.

6.1.1. QPSK without fading

As can be seen from the figure below that QPSK without fading is easily decoded. The constellation diagram is fine and points are well separated from each other.

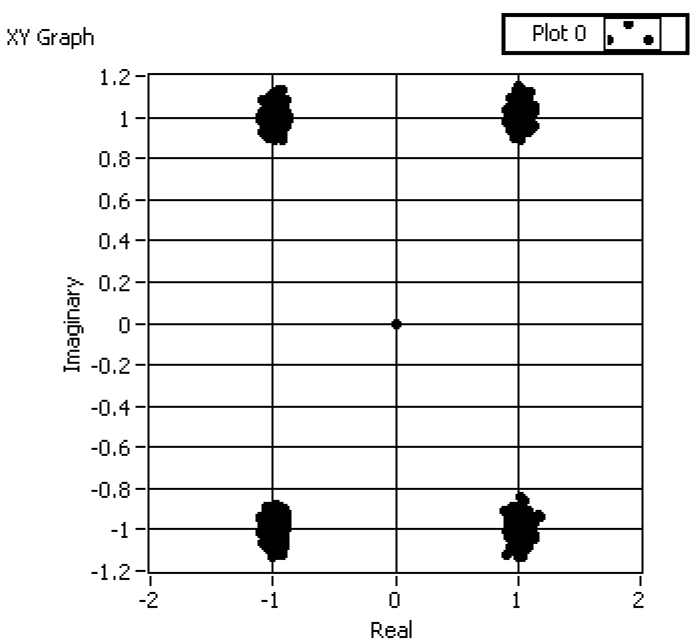


Figure 6.1: QPSK without fading

6.1.2. QPSK with fading

In the figure QPSK constellation diagram is shown when fading is applied. It can be clearly observed that the constellation points have dispersed considerably after the application of fading profile. The possible error in recovery of signal can be combated by using channel coding and better channel estimation algorithms.

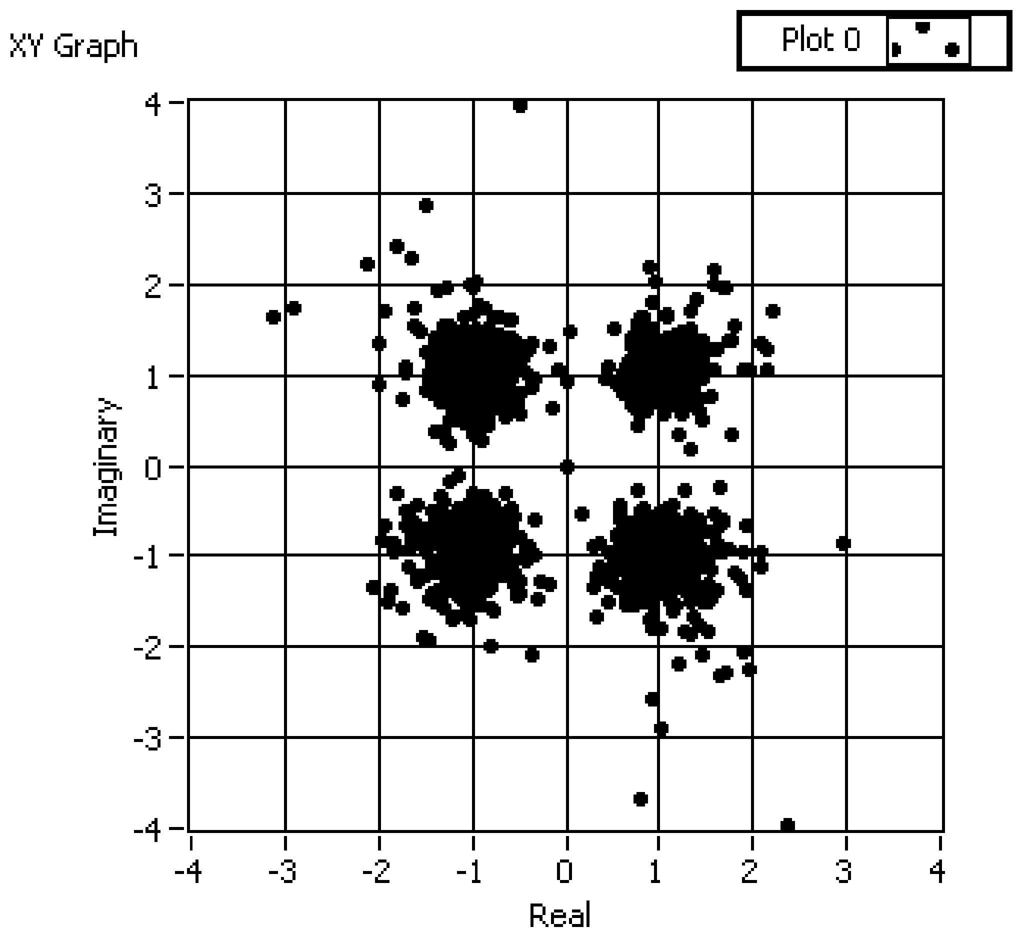


Figure 6.2: QPSK with fading

6.1.3. 16 QAM without fading

In the figure the constellation diagram of 16 QAM modulation scheme is shown when there is no fading .As it can be seen that the constellation points are distinguishable from each other hence the signal is decoded correctly.

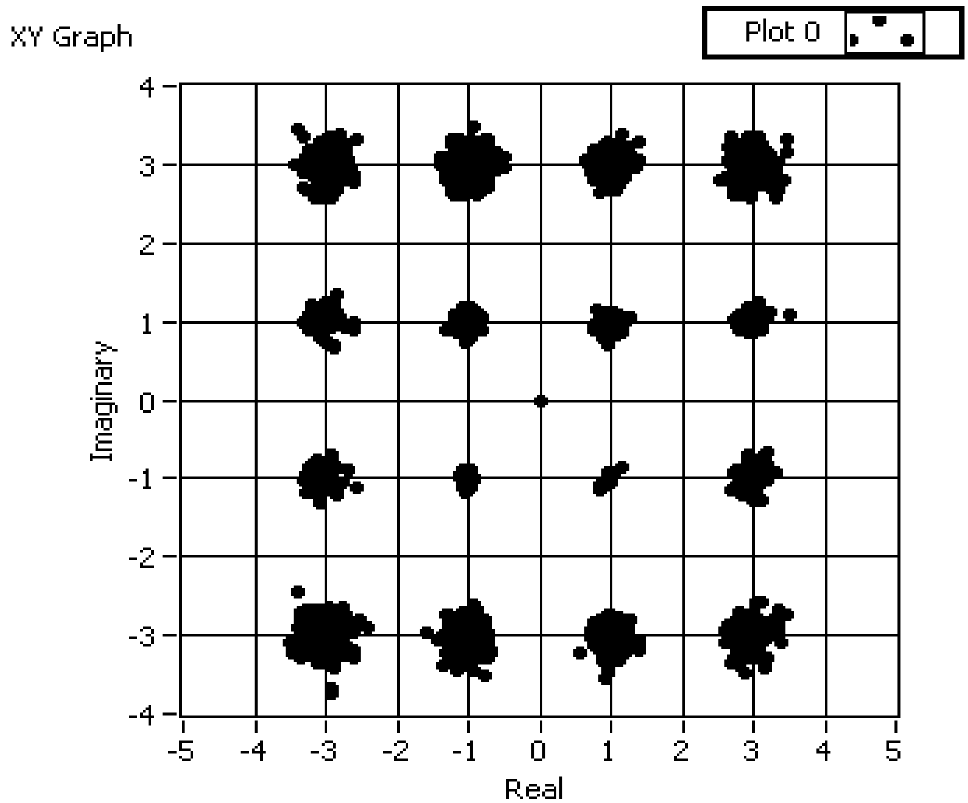


Figure 6.3: QAM without fading

6.1.4. 16 QAM with fading

the diagram which shows the constellation diagram of 16 QAM with fading; as the fading is applied constellation points drift from their position as compared to the previous constellation diagram.

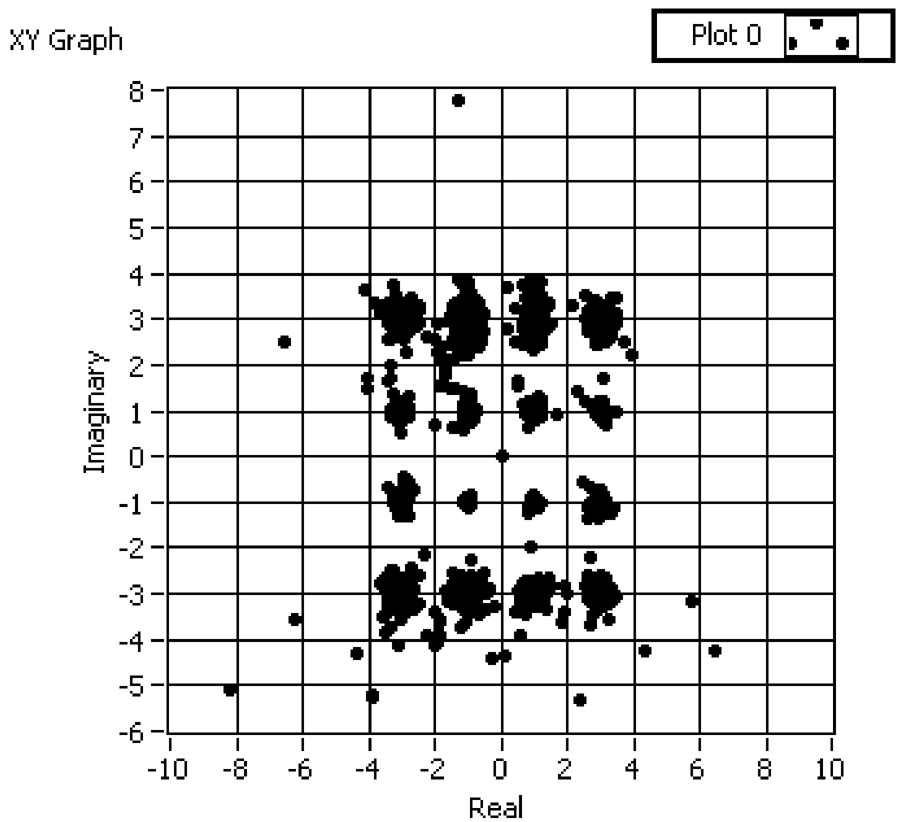


Figure 6.4: QAM with fading

6.1.5. 64 QAM without fading

Lastly it has been tested 64 QAM without fading. Since the antennas were not very powerful and by not using HPA(high power amplifier) at the transmitter or LNA(low noise amplifier) at the receiver so under 64 QAM modulation there is considerable error in the received signal but still the text can be decoded by using turbo codes. The diagram shows constellation of 64 QAM without fading

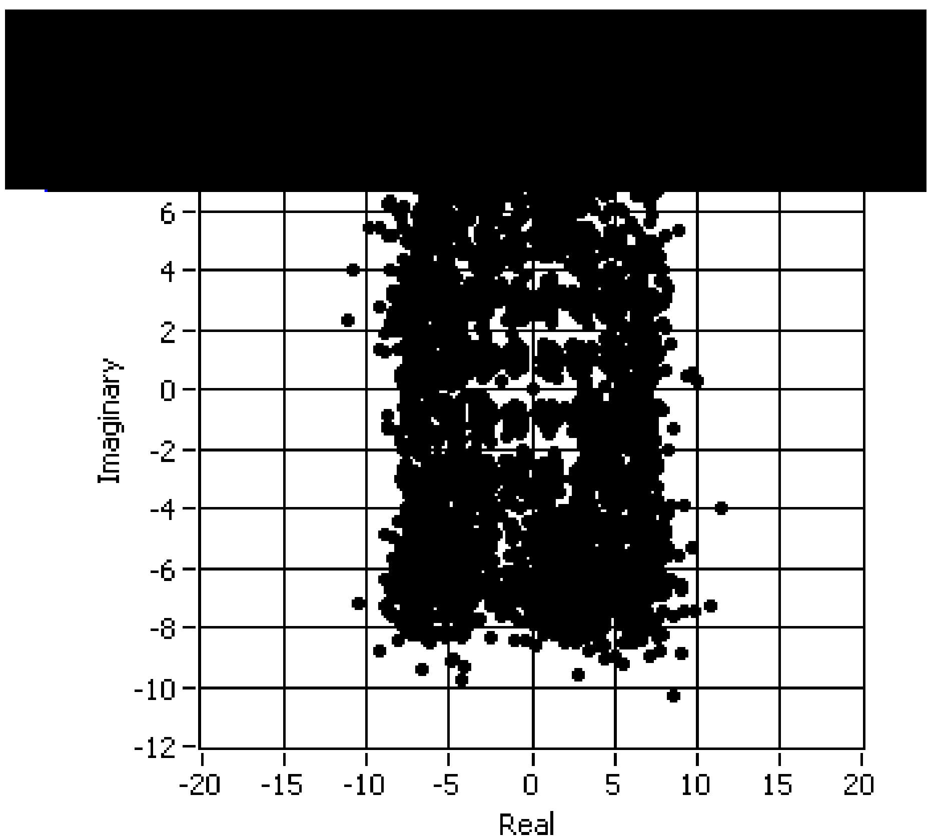


Figure 6.5: QAM without fading

6.1.6. OFDM waveform

In the figure the received baseband waveform of our OFDM signal is shown .It can be clearly observed that the OFDM signal occupies exactly 16 MHz of band.

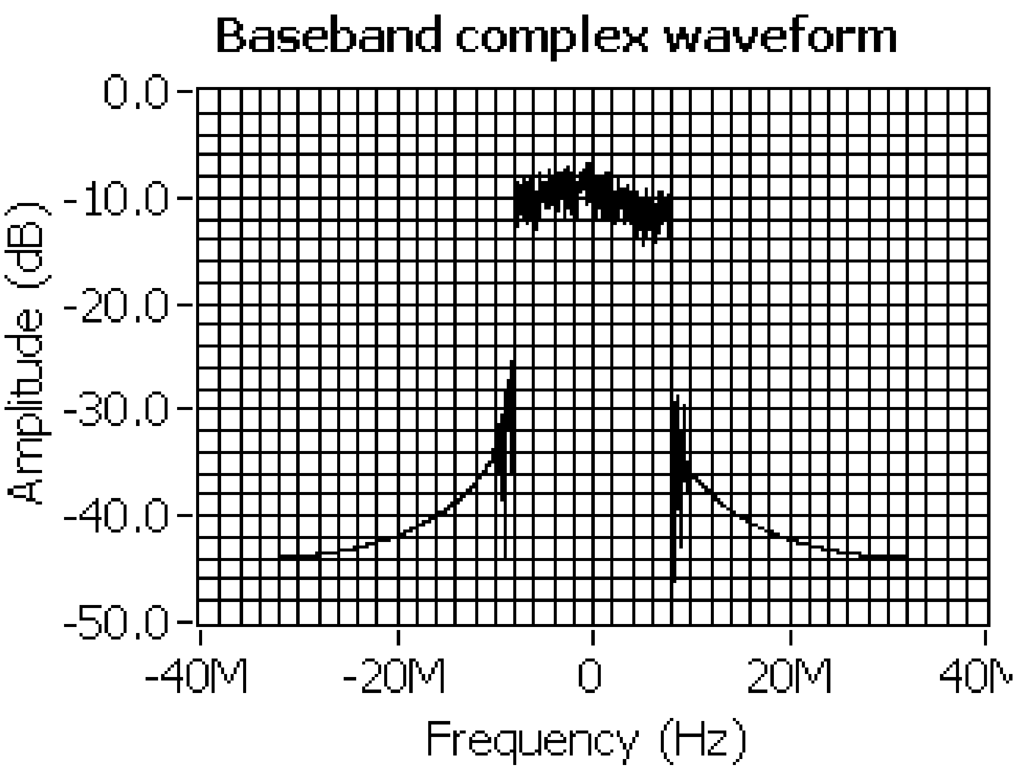


Figure 6.6: OFDM waveform

6.2. Critical Evaluation

As in any engineering project a systematic procedure has to be followed during the development of the project. After choosing the project we undertook a theoretical study of key digital communication concepts, modulation schemes, OFDM, Channel Coding and decoding, Channel estimation e.t.c. After building a strong theoretical base started working on the implementation of LTE physical layer design. Then chose the National Instruments PXI platform for the development of our code. To work on NI hardware we had to learn LabVIEW. Although there is lack of support of LabVIEW in Pakistan and there are very few people who are familiar with labVIEW we still managed to learn the Graphical language of LabVIEW. The resources made available by NI and their tutorials proved to be of great help.

Sometimes faced unforeseen problems like our downconverter was not working when we started working on our code and we had only one downconverter available in MCS. It took us quite a while to figure out the problem and it wasted quite a bit of our time But the faculty of Air University and NI representative Engr. Ahmad Bilal provided us a lot of help.

Team work was also a valuable experience during the project. Group leader coordinated effectively with all the members of the group and got the best out of every one. Working on a project requires good coordination between different members of the group. Also every group member has to be committed to the work and not delay the overall progress of the whole group.

From a technical point of view working on this FYP has greatly increased the knowledge in digital communications and LTE. We fully understood the key concepts about OFDM, Turbo Codes e.t.c . Also the opportunity to get familiar with state of the art National Instruments Hardware which is used worldwide in Industry and Research applications.

CHAPTER 7

Future Improvements

The project can be improved in following ways

Data can be transmitted and received in real time by using a digitizer which can support digital down conversion. However this would require purchase or availability of a new digitizer.

We have implemented SISO system. However future LTE systems are based on MIMO. To implement MIMO system additional set of RFSA or RFSG would be required.

Separate chasis can be used for transmitter and receiver. This would allow them to be placed far apart and then results can be analyzed. Also by using HPA (high power amplifier) at the transmitter and LNA (low noise amplifier) at the receiver the range of the system can be enhanced. This would again require availability of two chassis and two controllers.

Better OFDM synchronization algorithms can be used and tested.

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