SOFTWARE DEFINED RADIO IMPLEMENTATION OF IMPROVED OFDM SYSTEM

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Submitted By

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DECLARATION

I, Inderbir Singh, hereby declare that the work that is being presented in the dissertation entitled as **"Software Defined Radio Implementation of Improved OFDM System"** is an authentic record of my research carried out as requirement for the award of degree of Master of Engineering (Electronics and Communication Engineering) at Thapar University (Deemed University), Patiala, under the supervision of **Dr. Hemdutt Joshi**, "Electronics and Communication Engineering Department".

The matter being presented in the dissertation has not been submitted in any other University Institute for the award of any degree.

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ABSTRACT

As the technologies grow quickly and the devices and computers become cost-effective and powerful, tracks of research seam to allow a group of new researchers the chance to use and perform experiments on the technologies that were only available to a few people. This is the scenario for wireless communications system technologies. The practical research was very costly in terms of money and time because it was necessary requirement to make prototype circuit boards for testing purpose of a possible model.

Now-a-days, computers are being used for the signal processing tasks which were previously done by dedicated devices. Inexpensive computers which we use in our day-to-day lives at home are capable of doing the important computation that these dedicated devices are performing. Software Defined Radio (SDR) is similar to this kind of stuff.

The transformation of the signal processing over some dedicated device into software run by a common PC opens up great potentials at very reasonable price. With the help of the SDR, we can now examine and modify every value of the given communication system.

By doing research on this topic, command on both wireless communication systems and SDR can be gained. With this objective in my mind, I tried to implement the wireless communication system. Because of the enormous advantages of OFDM (Orthogonal Frequency Division Multiplexing), it was selected for implementation. Due to multiple disadvantages of normal OFDM, different techniques can be employed to overcome their effect and the most effective technique can be obtained.

Table of Contents

LIST OF ACRONYMS

OFDM	Orthogonal Frequency Division Multiplexing
SDR	Software Defined Radio
USRP	Universal Software Radio Peripheral
SLM	Selective Mapping
PTS	Partial Transmit Sequence
LTE	Long Term Evaluation
ICI	Inter-carrier interference
ISI	Inter-symbol interference
FFT	Fast Fourier Transform
USB	Universal Serial Bus
BER	Bit Error Rate
SNR	Signal to Noise Ratio
GUI	Graphic User Interface
MIMO	Multiple-input Multiple-output
PAPR	Peak to Average Power Ratio
IFFT	Inverse Fast Fourier Transform

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

Nowadays, wireless communication standards are increasing rapidly, thus necessitating the design of smaller and more sophisticated technologies that support a wide range of standards. A flexible and cost effective solution can be found in highly reconfigurable Software Defined Radio (SDR) platforms. These designs do not only cope with the challenging task of multimodal standard processing but are also easy adaptable to future technologies like LTE [1]. This makes these platforms of high interest not only for academic world but also for upcoming industrial solutions.

Demand for broadband access is increasing at a quick rate, and at the same time, is not limited to areas that already have an existing high quality infrastructure. For instance, developing countries and rural areas may not have the existing telecom infrastructure or the existing connections, typically over copper, to meet the requirements of Digital Subscriber Line (DSL) technology. Furthermore, it is expected that users will require more bandwidth on the move. While current technologies can meet this demand, the useful range is limited. This limitation opens up opportunities for technologies such as Orthogonal Frequency Division Multiplexing. The main aim of all new wireless communications techniques is to get maximum throughput in the given bandwidth with minimum amount of errors. Orthogonal Frequency Division Multiplexing (OFDM) is a very often used modulation approach. One high speed serial data stream is divided into more parallel ones which can be slower. These slower data streams serve as input data source for parallel modulators. The modulator output is summed and the superposition of the modulated signals is transmitted. The realization of modulation is performed in the frequency domain and the principal of the Fourier transform is utilized. This modulation approach is utilized very often these days. We can find it in Wi-Fi systems, in the system for terrestrial Digital Video Broadcasting, LTE and others.

1.1 OFDM

OFDM is the acronym for Orthogonal Frequency Division Multiplexing. OFDM is the method of encoding the given digital data on multiple carrier frequencies. Therefore, it is also known as digital multi- carrier modulation scheme. In this system, the data is carried by closely spaced orthogonal sub- carriers.

OFDM is based on the basic principle of splitting of a high rate stream of data into streams of lower rate that are to be transmitted over a number of sub-carriers simultaneously. Now, with the increase in symbol duration for parallel subcarriers having lower rate, the amount of dispersion caused in the time domain is decreased. Inter symbol interference is effectively removed by including guard time in all OFDM symbols [2]

OFDM carrier is formed by all the sub-carriers. A range of frequencies are assigned to every sub-carrier. These frequency slots are used to transmit the given data which will be transmitted in phase of the signal.

1.1.1 Advantages and disadvantages of OFDM

Table 1.1: Advantages and disadvantages of OFDM

S. No.	Advantages	Disadvantages
1	Efficient way to transmit at very high data rates over multipath fading channels.	More sensitive to frequency offset.
2.	For slow channels, loading is easier than single carrier	OFDM has large PAPR which results in reducing the power efficiency or the RF amplifier.
3.	OFDM is robust against narrow band interference, as it will affect only portion of subcarrier and may overcome it by using coding.	Sensitive to Doppler shift.
4.	Eliminates ISI and IFI through use of a cyclic prefix.	The OFDM signal has a noise like amplitude with a very large dynamic range, therefore it requires RF power amplifiers with a high peak to average power ratio.
5.	OFDM is computationally efficient by using FFT techniques to implement the modulation and demodulation functions.	

1.1.2 Applications of OFDM

It is the latest technology which has found its place in the list of the most important wireless communications standards in this new generation of technology called 4G.

WiMAX uses OFDM as a method for multiplexing in its physical layer. LTE uses it for downlink purpose, which is a function of transmission from base station to terminal, and a pre-coded version of OFDM called Single Carrier FDMA (SC-FDMA) [1]. OFDM is used even in the technologies, like ADSL, digital radio (Digital Audio Broadcasting (DAB)), terrestrial digital TV (Digital Video Broadcasting - Terrestrial (DVB-T)) and terrestrial mobile TV (Digital Video Broadcasting - Handheld (DVB-H)).

OFDM techniques are employed in

- American National Standards Institute's (ANSI)
- Asymmetric Digital Subscriber Line (ADSL),
- High-bit-rate Digital Subscriber Line (HDSL), and
- Very-high-speed Digital Subscriber Line (VDSL) standards as well as in the European Telecommunication Standard Institute's (ETSI) [1]

1.1.3 Important issues and Challenges of OFDM

1.1.3.1 Orthogonality

The effectiveness of OFDM technique depends upon the orthogonality among its sub-carriers to gain a good spectral performance. For multiple carrier data transmission systems, the designated frequencies must be orthogonal to each other. If the sub-carrier frequencies are orthogonal to each other, it leads to the reduction in the crosstalk interference among sub-carriers and thus results in more spectrum utilization. [3].

All OFDM sub-carriers are assigned a range of frequencies. All these frequencies in combined manner form the frequency spectrum which is further used as the OFDM carrier. The data bits will be divided among the sub-carriers by using serial to parallel convertor. For every single sub-carrier, it is separately modulated using phase shift keying modulation (PSK) or quadrature amplitude modulation (QAM) (in most cases). Then, the OFDM carrier is generated with the help of all the modulated sub-carriers by employing

Inverse Fourier Transform Module (IFFT). The IFFT module to generate a single broadband complex signal by calculating the time domain signal with all the sub-carriers which is consisted of the data belonging to each of the sub-carrier: the OFDM carrier signal. This signal is further used for the modulation a Radio Frequency (RF) carrier.

1.1.3.2 Peak to Average Power Ratio Problem

A number of independently modulated subcarriers are consisted in an OFDM signal, which may reveal a high instantaneous signal peak w.r.t. the average signal level, which give rise to large peak-to-average power ratio (PAPR).

Mathematically, PAPR [4] may be given as-

$$PAPR = \frac{Maximum\ power\ of\ a\ sample\ in\ a\ given\ OFDM\ transmit\ symbol}{\text{the average power of that OFDM symbol}} \tag{1.1}$$

The effects of increased PAPR are:

1. The complexity of the analog-to-digital converters (ADC) and digital-to-analog converters (ADC) is increased.
2. The efficiency of the RF power amplifier is reduced.

1.1.3.3 Delay spread and cyclic prefix

Multiple copies of the transmitted signal are received due to the multipath propagation in wireless communication system. This effect gives as a result in the receiver a number of signals with different amounts of delay respect the first multipath signal, which usually corresponds with the line of sight path. The difference of time between the first of the multipath components and the last component is called delay spread. The consequence of delay spread is especially present in urban environments, in which the number of multipath components is higher than in rural environments, but also in environments where sender or receiver are moving at high speeds [5].

The basic problems caused by the delay spread are:

1. Echoes that do not arrive at same time may come in a different phase with respect to the main signal and can cause a little distortion in the main component.
2. Effect caused by the delayed echoes in the next transmitted symbol. This is known as inter-symbol interference (ISI).

Figure 1.1 shows the effect that multipath echoes can cause on a transmitted signal. To eliminate ISI completely a guard time is introduced for each OFDM signal as shown in figure 1.2. However, the problem of **ICI (Inter-Carrier Interference)** would arise. ICI is the cross talk between different subcarriers which means they are no longer orthogonal. To eliminate ICI, OFDM symbols are cyclically extended in the guard time as shown in figure 1.3. This ensures that delayed replicas of the OFDM symbol always have an integer number of cycles within the FFT interval which is called as CP.

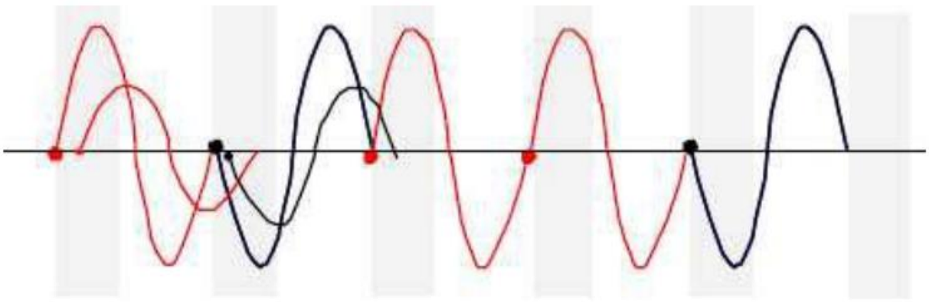


Figure 1.1: Signal in the presence of ISI[5]

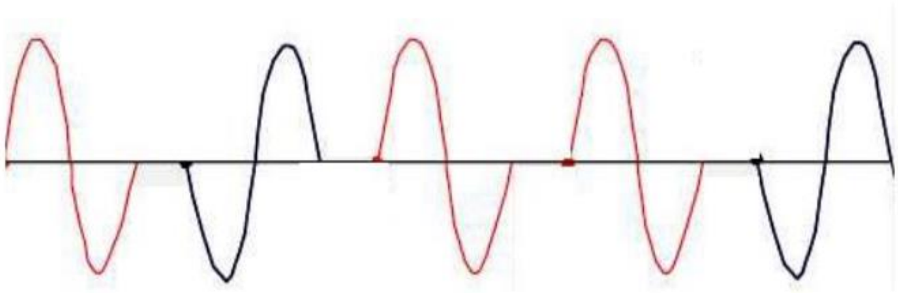


Figure 1.2: Signal in the presence of GT [5]

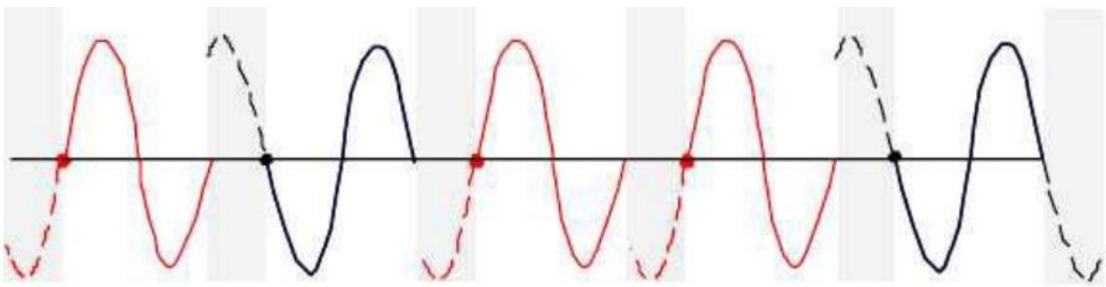


Figure 1.3: The result of adding a cyclic prefix to the signal [5]

1.2. Parameters under consideration

Signal to Noise Ratio

In analog communication or digital communication systems, the signal to noise ratio is a measure of improvement. It is the ratio of the signal strength to the background noise. It is usually measured in decibels. Mathematically, the formula can be given as

$$SNR = 20\log\left(\frac{P_s}{P_n}\right) \tag{1.2}$$

Where, $P_s = Signal\ Power.$

And $P_n = \ the\ noise\ power\ spectral\ density.$

Signal to noise ratio is generally represented as E_b/N_o. The signal to noise ratio or E_b/N_o are more related to the radio link or the wireless communication channel. The term noise power spectral density may be defined as the noise power contained in a 1 Hz bandwidth.

Bit Error Rate

BER is defined as the ratio of the total number of bits in error to the total number of bits transmitted. In other words, it is the rate at which the error occurs during the transmission [6]. So, we can translate the definition of BER into a simple formula:

$$Bit\ Error\ Rate = \frac{number\ of\ errors}{total\ numbers\ of\ bits\ transmitted} \tag{1.3}$$

The BER will be very small in a case when the medium or cannel of transmission is good and SNR is high. It is always necessary to check the performance of the system. Because, we cannot compromise with the quality. BER is an ideal tool to check the end-to-end performance of the whole system which includes the channel of transmission as well as transmitter and receiver. So, rather than testing the electronics components and devices and hoping that the outcome will be satisfactory, we use BER as the measure of actual performance of the whole system. Bit error rate can also be find in terms of probability of error. POE is directly related to the E_b/N_o which is a form of SNR.

1.3 Software Defined Radio

1.3.1 Definition

SDR is an idea which has been in focus since the early nineties. The main purpose of Software Defined Radio was to create a device which should be capable of working with many radios operating at different parameters. Moreover, it can adjust to any range and any modulation scheme by using a powerful software along with programmable hardware.

An alternative definition for SDR is to merge hardware and software technologies to make the system flexible for wireless communication [7] [8]. Software Defined Radio provide an effective and inexpensive solution for building multi-mode, multi-range and multi-functional wireless devices that can be improved by means of software advancements. By using SDR enabled devices, the same piece of “hardware" can be modified to perform different functions at different times. SDR performs noteworthy amount of signal processing in a common PC. In SDR, signal handled in digital domain instead in analog domain as in the conventional radio. The analog signal can be converted to the digital domain with the help of Analog to Digital Converter. Fig.1.4 shows the concept of Software Defined Radio. This figure shows that the ADC process is taking place after the Front End (FE) circuit. The A/D converter will convert the signal to digital form and pass it to the baseband processor for more processes; detection, channel coding, source coding and etc.

Software defined radio is a tool which helps the latest wireless and mobile communications industry in many ways. The term (SDR) was introduced by Joseph Mitola from MITRE Corporation in 1991[7]. His first paper on SDR was published in 1992 at IEEE National Tele systems Conference. Though the concept was first proposed in 1991, software-defined radios have their origins in the defense sector since the late 1970’s in both the U.S. and Europe.

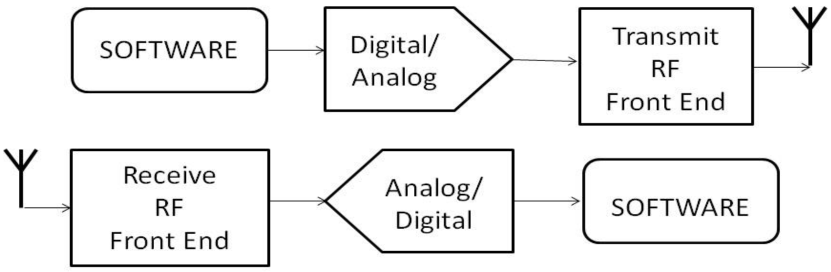


Figure 1.4: SDR sender and receiver module diagram[5]

1.3.2. History of SDR

The term software radio was first introduced by the company E-Systems, now Raytheon in the newsletter in the year 1984. It was referred as prototype digital baseband receiver equipped with an array of processors that performed adaptive filtering for interference cancelation and demodulation of broadband signals [9].

Then in the year 1991, DARPA's SPEAKeasy was the first military program in which the physical layer components of the radio were implemented in the software. The objectives of the software radio according to the requirement of U.S. Air Force were as given below

- support ten different military radio protocols.
- operate anywhere between 2 MHz and 2 GHz
- incorporate new protocols and modulations
- future-proofing the radio hardware.

In 1992, Joseph Mitola published a paper titled, "Software Radio: Survey, Critical Analysis and Future Directions" about software radio at IEEE National Telesystems Conference. This was the first research paper on SDR. Therefore, Joseph Mitola referred to by many as the godfather of software radio.

After that, the first industry association dedicated to SDR was founded in 1996 as "The Modular Multifunction Information Transfer System (MMITS) Forum." In 1998 it became the SDR Forum, and then in 2010, the Wireless Innovation Forum. The forum consisted of people and organizations from government, industry and academia, all driven by the goal of advancing SDR-related technologies.

In 1997, the Joint Tactical Radio System was created by the U.S. Department of Defense to increase interoperability and waveform portability. In the year 1998, Nutaq (then Lyrtech) teamed up with MathWorks to create the first development environment that could generate executables directly from a Simulink model for a Texas Instruments DSP and a Xilinx FPGA and thus the first automated code was generated for embedded SDR.

1.3.3 Need of SDR

The design of a "standard" radio receiver is shown in the block diagram below. This diagram illustrates the value of software programming and implementation. All of the functionality shown in the purple blocks can be accomplished via software running on digital signal processors or via imbedded software programs running on microprocessors, instead of all the functionality being done solely by inflexible and fixed hardware. Even much of the human-to-machine interface, HMI, is accomplished in software once the analog-to-digital conversion (or vice versa) is made. This was the foundation of the concept of software radio – most of the functionality is performed by software. Hence, the term "software radio" was coined by Dr. Joe Mitola in 1992[7][10].

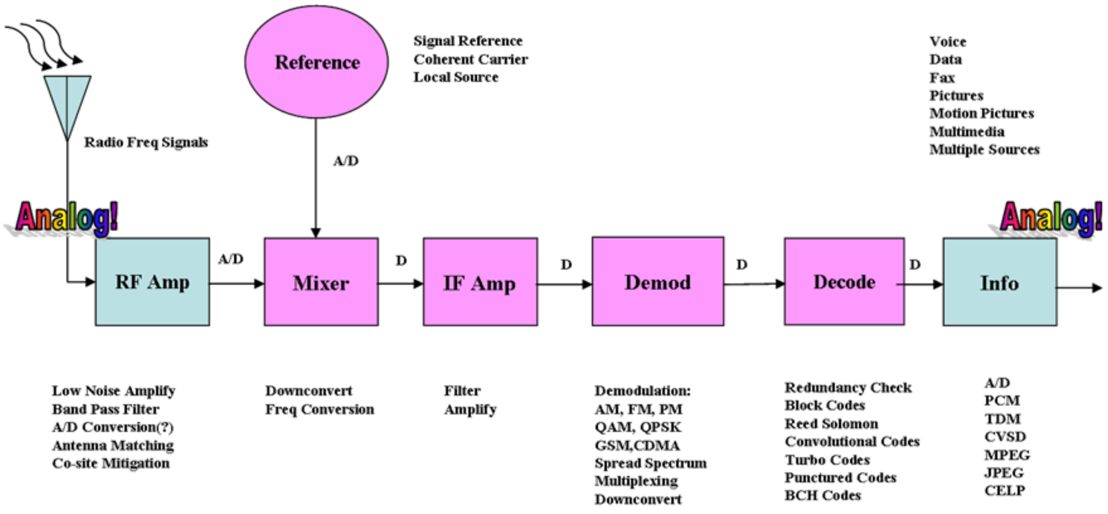


Figure 1.5: Design of standard Radio Receiver [11]

1.3.4 Basic principle of Software Defined Radio

The basic principle of SDR is to reduce the hardware required for signal processing work and its transformation into software which should be performed through a general - purpose computer. The signal should be produced in digital form and operated as much as possible within the PC (the functions performed like modulation, filtering, passing through FFT blocks and even amplification), until the signal is set to be sent. The data in the form of digital samples is then transformed to analog signal by the hardware block. In the last stage, this transformed signal is given to the antenna for transmission.

The idea of SDR is different to the traditional radios which have been used until now. Traditional radio depends on dedicated hardware for all its functions and every single hardware part has a fixed function. Whereas in case of SDR, the single processor will perform all the signal processing functions and the software will be the one responsible of ordering the function that will be computed [11]. The absence of dedicated hardware has important advantage relative to traditional radios in a way that all parameters which the radio system uses can be configured by the software used. This makes the research and development of new systems a lot easier, cheaper and faster. We can test all types of variations and configurations by using the prototype of software radio.

1.3.5 Challenges of SDR implementation

In our application the aim is to implement a communications system based on OFDM, which is a kind of wide band application. A number of challenges are prohibiting the use of SDR to a limited number of applications [12].

- Power consumption of a SDR device
  - It has been observed that powerful computers are required to run an application. The power consumption of SDR devices is not same as the power needed by the hardware radios.
- Larger Size of Hardware Needed
  - the size of hardware required for the processing of the signal is much larger than the traditional radio’s dedicated hardware.

Due to the above stated reasons, the system of having a portable device based on SDR has not developed so much which can be used as many different radios, and the use of SDR has been limited to research or applications in the base station, instead of the mobile terminal, where the power needs are not of much consideration.

1.3.6 Classification of Software Radio

Different tiers of Software Radio as defined by the SDR Forum are as following which describe its evolving capabilities in terms of flexibility [13].

- Tier 0: The **Hardware Radio**

The radio is implemented using only the hardware components and it cannot be modified except through the physical intervention.

- Tier 1: **Software Controlled Radio (SCR)**

Control functions of an SCR are only implemented in software - thus only a small number of functions are changeable using software. This extends usually to power levels, inter-connects etc. But the functions like modulation types and/or frequency bands etc. cannot be changed using software.

- Tier 2: **Software Defined Radio (SDR)**

In SDRs, a variety of functions like modulation techniques, wideband or narrow-band operation, communications security functions (such as hopping), and waveform requirements of current and evolving standards over a broad frequency range can be controlled by software. The frequency bands used may still be varied at the front-end with the help of a switch in the antenna system.

- Tier 3: **Ideal Software Radio (ISR)**

ISRs provide great improvement over an SDR by eradicating the analog amplification or heterodyne mixing prior to digital-analog conversion. Programmability extends to the entire system with analog conversion only at the antenna, speaker and microphones.

- Tier 4: **Ultimate Software Radio (USR)**

USR accepts fully programmable traffic and control information and supports a wide range of frequencies, applications software & air-interfaces. USR can switch from one air interface format to other in few milliseconds, use GPS for tracking purpose, store money using smartcard technology, or provide video so that the user can watch a local broadcast station or receive a satellite transmission.

1.4 Universal Software Radio Peripheral

USRP was first designed and used by Matt Ettus [14], to which radio front end, DAC and ADC were combined via Universal Serial Bus 2.0 (USB 2.0). USRP had been designed to make the SDR reconfigurable and adjustable according to the given conditions. USRP block diagram is shown in figure

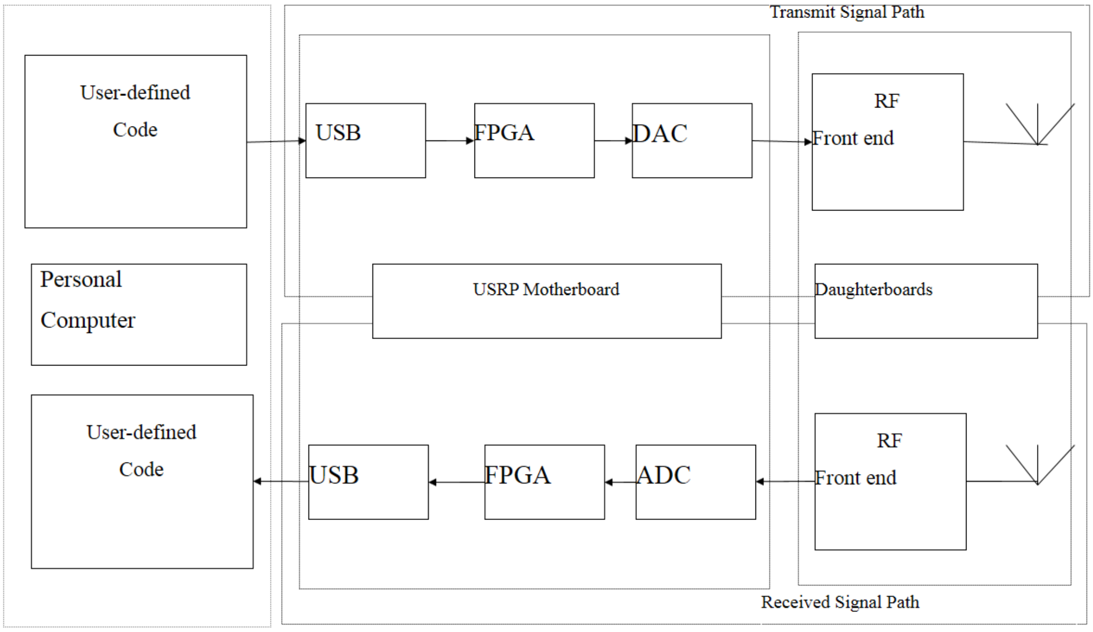


Figure 1.6: USRP block diagram

The USRP which is used for the research purpose is provided by national instruments.NI USRP 2920 hardware was used to build the communication system to implement the OFDM system. The front panel of NI USRP 2920 is shown in the following figure

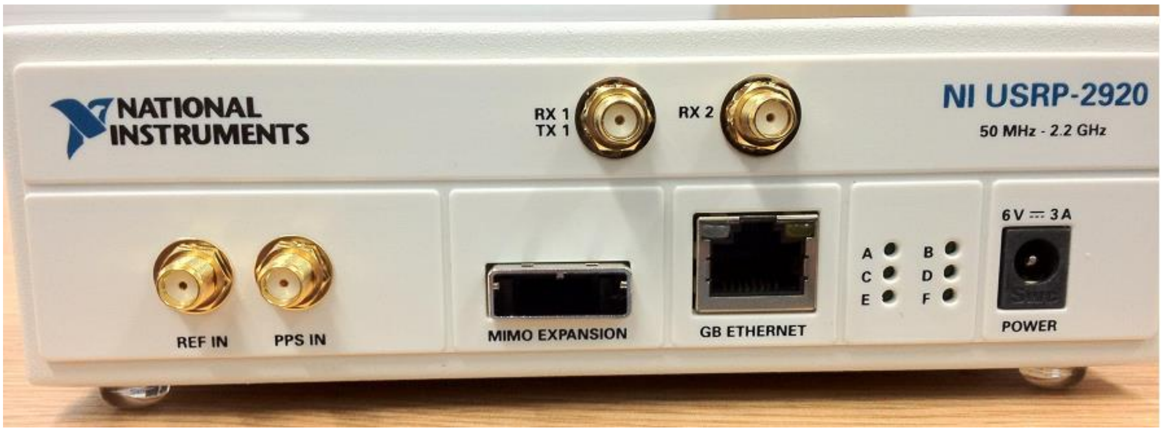


Figure 1.7: Front Panel of NI-USRP

NI USRP forms the transceiver's RF front end and whole signal processing is done using LabVIEW on personal computer available in the lab. Gigabit Ethernet cable was used to connect the USRP and PC with the help of which PC is capable of controlling the USRP [15].

1.5 STRUCTURE OF THESIS

The thesis is organized as follows: -

Chapter 1 gives the introduction to all the topics related to the research work which has been done during the thesis. There are some very important aspects related to the OFDM system such as ICI, PAPR and Orthogonality which have been introduced in the first chapter. Some limelight has been thrown on the topics of SNR and BER. Then, an introduction to the topics of SDR and USRP is given.

Chapter 2 provides the Literature review. In this chapter, various literature work done by some dedicated researchers is discussed. In the end of chapter 2, Some Gaps in the study and thesis objectives have been discussed.

Chapter 3 provides the detailed study of OFDM, its techniques. Various PAPR reduction techniques such as SLM, PTS, Hybrid, Clipping and filtering have also been discussed in detail in this chapter. Some of the techniques results in increased BER. But, where the main concern is power efficiency PAPR may be drastically reduced.

Chapter 4 provides a deep study of the hardware and software used for the thesis is done. Specifications, features of USRP have been discussed. With the help of figures, the connections of USRP to the PC are shown. Also, the configuration steps of USRP and LabVIEW have been discussed. The whole experimental set up of USRP and PC has been demonstrated in this chapter.

In the chapter 5, Results have been included. Different values of PAPR and BER have been indicated for different techniques. The efficiency of these techniques have been discussed in this chapter. Some results based on the image transmission with the help of USRP are also included in this chapter.

Chapter 6 includes the concluding remarks. Future scope points have been provided in the chapter.

In the end, References have been included from which different facts, figures, values or ideas have been taken.

CHAPTER 2

LITERATURE REVIEW

In order to start the thesis, the first step is to study the research papers that have been published till now by other researchers. By studying the research papers, we can have an idea of what work has been done. Papers related to this work are selected and studied. Researched papers are described below:

First of all, in the year 1992, J. Mitola published a paper titled, "Software Radios: Survey, Critical Evaluation and Future Directions" [7] in which he stated Software radio as a set of Digital Signal Processing (DSP) primitives, a meta level system for combining the primitives into communications systems functions (transmitter, channel model, receiver etc.) and a set of target processors on which the software radio is hosted for real-time communication. The paper also compared the enabling hardware technologies to software radio requirements. The proposed applications of Software Radio were speech/music, modems, packet radio, telemetry and High Definition Television.

In the year 2007, S. Venkatachalam and *et al.* presented a paper, "Implementation of Orthogonal Frequency Division Multiplexing (OFDM) Using Software Definable Radio (SDR) Platform" [8], in which the basic concepts of SDR architecture and OFDM were discussed and the various sections that are needed to reduce ISI were analyzed. The OFDM system was carried out in digital domain. It was also proposed that OFDM system could be easily implemented in SDR. The research paper left the implementation of the receiver section of OFDM and GSM speech coder in SDR platform. But, voice coder, convolution coder and OFDM modulation had been implemented in SDR platform.

In October 2009, Brian Kelley in his conference paper titled "Software Defined Radio for Broadband OFDM Protocols" [12] proposed different challenges for new generations of software defined radio. The main challenges stated were maintaining flexibility while simultaneously supporting computationally efficient broadband communication algorithms and ease of programming. He focused principally on OFDM transceiver styles due to their bandwidth scalability and their popularity in many next generation wireless air interfaces.

The system level framework was optimized around a hybrid software-hardware entity which was defined as a microcomputer object (MCO). The system was designed for both flexibility and extensibility. The bane of the optimization problems for broadband SDR discussed was that we are always resource limited. Therefore, extensibility concepts, virtual abstraction, and acceleration hardware are important architectural features. The new simulation models in Matlab that lead toward the concept of the virtual system sample were also discussed.

Further in December 2009, Arief Marwanto *et al.* presented a paper in the international conference titled, "Experimental Study of OFDM Implementation Utilizing GNU Radio and USRP - SDR" [16], in which they explored the viability of using GNU Radio; an open source SDR implementation and the Universal Software Radio Peripheral (USRP); an SDR hardware platform, to transmit and receive the OFDM radio signal with QPSK and BPSK modulation. Quality of Service (QoS) in terms of Packet Received Ratio (PRR) on the data transmitted was investigated and analyzed.

The experiment resulted in the statement that OFDM with BPSK modulation gives a better performance of communication compared to the OFDM with QPSK in terms of PRR. Also the relation between the performance of PRR and FFT length was discussed from [17]. The greater the length, the less the error and hence, a better PRR was observed.

In the year 2010, Hen-Geul Yeh and Paul Ingerson presented a paper "Software-Defined Radio for OFDM Transceivers" [18] in which they proposed a software-defined radio (SDR) system with reconfigurable architecture for wireless communications. For example-adaptable orthogonal frequency division multiplexing (OFDM) transceiver for standards, such as IEEE 802.11 was studied. SDR system using OFDM transceiver was demonstrated by a software reconfigurable OFDM system using a programmable fixed-point DSP. Both the interoperability and adaptability among BPSK and QPSK operational modes of the OFDM systems were discussed.

In the year 2010, John E. Kleider *et al.* [19] focussed on the disadvantages of using Co-located MIMO radios were discussed such as, inability to provide sufficient antenna spacing for soldier communication frequencies, increased radio size form factors, more complex RF and modem signal processing and higher digital hardware power requirements. But, multiple antenna systems give better performance than the single antenna systems. This paper proposes the new idea of using low-cost and simple single-antenna radios in "distributed groups" to make MIMO virtual arrays which are created by transmitter and receiver antennas.

In the year 2011, Rajiv Saxena *et al.* [20] published a paper in which they proposed a new hybrid technique of reducing PAPR. This new hybrid technique was based on the combination of the clipping as well as pre-coding technique. The reason of using clipping technique being simplicity and lower complexity for simulation. Whereas, the precoding technique was used due to the better reduction in PAPR as well as improvement in the BER performance.

Also, a new method based on pulse shape named MBH was proposed for the generation of pre-coding matrix. Then, the performance of MBH was compared with the $SQRC$ pulse shape. Different BER plots were drawn so as to illustrate the performance of the proposed method.

In the year 2011, Gilberto Berardinelli *et al*, presented a paper titled, "An SDR architecture for OFDM transmission over USRP2 boards" [21] in which they discussed that USRPs were emerging as one of the most promising hardware solution for building a Software Defined Radio (SDR) platform. The implementation of a coded Orthogonal Frequency Division Multiplexing (OFDM) transceiver running over USRP2 BOARDS was accomplished. The baseband processing and the radio-frequency settings were designed for coping with a local area scenario as well as with the physical capabilities of the USRP2 boards.

In 2011, R.Gandhiraj *et al.* [22]introduced a new toolkit named GNU radio companion (GRC) so that the practical implementation can be made easy. As, GNU radio is open source software platform, so users can even build there ow applications according to the requirements. More than 150 blocks are consisted in the entire interface of GRC. GRC provides a graphical user interface to the user so that any hardware functions like mixers, oscillators, etc., can be implemented as a block and can be executed. Python codes are used to define the functionality of these blocks and xml codes are used to create the GUI. Different communication experiments had been illustrated with the help of GRC such as signal generation, signal processing, analog and digital modulation/demodulation schemes. So, the paper was more focused on the practical knowledge of the communication systems.

In the year 2012, Ali El Moussati *et al.*, presented a paper titled, "HARDWARE IMPLEMENTATION FOR TURBO CODE-OFDM USING SOFTWARE DEFINED RADIO" [23] in which they presented the design and implementation of wireless Turbo Code OFDM (TC-OFDM) on the Small Form Factor (SFF) Software defined Radio (SDR) Platform, provided by Lyrtech and Texas Instrument (TI). The performance analysis of the TC-OFDM system was evaluated by simulations in different channels including AWGN and multipath Rayleigh fading channel. The presented research paper also stated that Turbo codes eliminate the residual inter symbol interference (ISI) and inter channel interference (ICI) and therefore reduce the length of the required Cyclic prefix in an OFDM system. So, this decreases the overhead associated with the Cyclic Prefix.

Again in the year 2012, Marek TICHY and Karel ULOVEC presented a paper titled, "OFDM System Implementation Using a USRP Unit for Testing Purposes" [24] in which they focused on the testing and verification of the Practical OFDM System. Some of the important tasks like equalization, synchronization, signal processing and demodulation were accomplished by the coding done on matlab. The simulink module was used to control the SDR functionality.

The system was also checked under the static multipath-propagation. The two path channel was selected in which the second path was delayed by 0.667 μs and 3dB attenuated. So, by utilizing the software defined radio, the system was capable of processing the OFDM system using Matlab and Simulink software. However, the synchronization algorithm failed for SNR lower than 0 dB.

In the year 2012, Anton Blad *et al.* [25] proposed the spectrum sensing in OFDM systems so as to solve the problem of carrier frequency offset (CFO). They also proposed some modifications in the state of art detectors to handle that problem. Those detectors were implemented using USRP and the GNU radio. The whole system was verified over a actual medium. Different SNR estimations were used in this paper. The conclusion was that the average detector had plus points in some cases. However, they had left some realistic situations, such as interference from adjacent frequency bands or other subordinate users.

In the year 2012, M.A. Mohamed *et al.* presented a paper titled, "Implementation of the OFDM Physical Layer Using FPGA" [26] in which the detailed simulation of the OFDM system was performed using MATLAB-2011 program to study the effect of various design parameters on the system performance. OFDM transceiver was implemented using FPGA Spartan 3A kit. All modules were designed using VHDL programming language.

In February 2012, Elizabeth A. Thompson *et al.* [27] published a paper in which they proposed the GPS signal reception with the help of USRP- SDR platform. A non-real-time Global Positioning System SDR system was implemented and tested with the help of USRP platform. In this whole process, front end was employed to receive and down-convert the GPS signal to the intermediate frequency. Linux desktop computer, power supply, signal generator, spectrum analyzer along with USRP by Ettus research were used for the implementation of the whole system. The system was slower because of the direct coding done in Matlab.

In September 2012, Arun Gangwar *et al.* published a paper titled "An Overview: Peak to Average Power Ratio in OFDM system & its Effect" [4] in which he stated some of the obstacles which come in the way of Effective OFDM system such as PAPR, sensitive to frequency errors (Transmitter & Receiver offset), Intercarrier Interference (ICI) between the subcarriers. He concluded that the high peak-to average ratio is the main obstacle which causes non-linearity at the receiving end. He also named some techniques which could be used to reduce the PAPR according to the requirement such as

1. Signal Scrambling Techniques and
2. Signal Distortion Techniques

In 2013, Irfan Ali [6] introduces the method of BER simulation with the help of Matlab. According to the paper, radio link systems as well as fiber optic were the two systems for which BER is applicable. Due to the tremendous data visualization abilities and easy coding language, Matlab is the most ideal tool for simulation of digital communication systems. Then, various factors which affect the BER performance were discussed such as bandwidth, throughput, interference and the modulation scheme used. The received data bits were compared with the transmitted data bits so as to draw the BER versus SNR plot.

In April 2013, AN. KA. VITA and M.MADHU BABU presented a paper titled, "Implementation of OFDM Transmitter and Receiver for FPGA Based Applications" [28] in which they implemented ofdm transmitter and receiver with fully digital techniques. VHDL was used for RTL description and FPGA synthesis tools was be used for performance analysis of the proposed core. The VHDL implementation allows the design to be extended for either FPGA or ASIC implementation, which suits more for the Software Defined Radio (SDR) design methodology.

They had used Xilinx ISE for the synthesis and Xilinx's Chip scope tool for verifying the results on Spartan 3E FPGA. The supposed design can be applied to real-time signal processing system, which completes the main computing modules in the OFDM for multi services.

In the year 2013, Hazrat Ali, Xianwei Zhou and Khalid Iqbal presented a research paper titled, "FPGA Architecture for OFDM Software Defined Radio with an optimized Direct Digital Frequency Synthesizer" [29] in which they proposed a system that uses digital signal processing (DSP) for coding, decoding, modulating, and demodulating data. The paper presented the framework for hardware implementation of SDR using Orthogonal Frequency Division Multiplexing (OFDM). The framework comprises of VLSI mapping of algorithms, Orthogonal Frequency Division Multiplexing (OFDM), Quadrature Phase Shift Keying (QPSK), Fast Fourier Transform (FFT) Algorithms and most importantly, the algorithm for Direct Digital Frequency Synthesis (DDFS). This paper also presented an area and speed optimized architecture for Direct Digital Frequency Synthesis, one of the backbones for SDR.

Again in July 2013, Nasreen Mev and Brig. R.M. Khaire presented a paper titled, "Implementation of OFDM transmitter and Receiver Using FPGA" [30]. The main objective of this paper was to carry out an efficient implementation of the OFDM system (i.e. transmitter and receiver) using "Field Programmable Gate Array (FPGA)" and find the result by simulating all the blocks used in proposed project by using QuartusII & Modelsim simulation tool.

In September 2013, R. Gandhiraj *et al.* [31] proposed that GNU Radio based USRP hardware implementation can be used as the test bed for many advanced protocol implementations in real time before going for any hardware mass production. The GNU Radio platform can also be used in Virtual Lab implementation, Deep space imaging, Ionosphere study, Aviation mapping application and Weather Satellite data reception. The work also assisted to convert any theoretical study into physically realizable one.

In November 2013, Ozgur Ozdemir *et al.* [32] presented a paper in which they proposed packet based OFDM Systems by using experimental testbed and RF- front ends. At receiver side I-Q imbalance estimation and compensation algorithm is implemented. The effect of carrier frequency offset(CFO) is also discussed in this paper. EVM is also defined in this paper. By implementing IQ imbalance compensation, a significant amount of improvement is obtained.

In november 2013, Miloš Janjic *et al.* [33] presented a paper in which they inserted the results of practical implementation of OFDM system based secondary cognitive link which was realized using USRP N210 kit platforms. Some of the new algorithms to solve the transmission issues were introduced such as frequency offset compensation, time synchronization and channel estimation. An image was transmitted in real environment by solving a lot of issues that do not come under software simulation. Coginitive feature was also used for changing transmission parameters. As all the processing was done over matlab, so the speed for the transmission and reception was very slow.

In the year 2014, Todd E. Schmuland and Mohsin M. Jamali presented a paper titled, "Generation of Fixed-point VHDL MIMO-OFDM QR Pre-processor for Spherical Detectors" [34] in which they proposed an automatic VHDL generator for a modified fixed-point interpolation QR decomposition algorithm for Spherical Detector (SD) based Multiple-Input Multiple Output (MIMO) Orthogonal Frequency Division Multiplexing (OFDM) systems.

A modified algorithm was proposed which moves the bulk of complex domain calculations to the real domain, by leveraging Givens rotations requiring only additions, multiplications, and inverse square root operations. An efficient inverse square root algorithm was presented along with fixed-point analysis of a typical MIMO-OFDM system in various noisy wireless channels.

In 2014, C Anjana *et al.* [35] presented a paper in ICICT in which they proposed a method for the reduction of error rate. This method used the channel estimation and synchronization techniques with the help of GNU radio. The BER plot of OFDM system was observed with and without channel estimation. There was an improvement in the plot which used channel estimation and synchronization.

In the year 2014, A.S.Chavan *et al.* presented a paper in international journal named, "FPGA Based Implementation of Baseband OFDM Transceiver Using VHDL" [36] in which they presented the design and an implementation of OFDM transceiver on FPGA.

The system was designed using VHDL, synthesized using high level synthesis tool and targeted on Xilinx Spartan 3e device. The proposed design utilizes the Intellectual Property (IP) cores provided by Xilinx for floating point multiplication, addition subtraction and division. DIT radix-2 butterfly approach was used to calculate IFFT and FFT.

Then again in the April 2014, Pratibha Mane *et al.* presented a paper titled, "Implementation of 802.11n OFDM Transmitter and Receiver Using FPGA" [37] in which they proposed a method of designing and simulating the combination of OFDM with MIMO. This new method resulted in less BER. According to this paper, the 802.11n standard is predicted to be capable of supporting data rates up to 600Mbps by deploying the latest communication method such as MIMO. The implementation of MIMO-OFDM was done using Xilinx spartan6 FPGA board.

In July 2014, Zainab S. Hadi and Buthaina M. Omran [38] proposed a new hybrid PAPR reduction technique which may be caused due to superposition of different subcarriers. This new hybrid technique was based on the repeated clipping and frequency domain filtering with SQRT companding over LTE channel. The effectiveness and efficiency of this new hybrid technique had been emphasized in this paper.

This new hybrid technique provides at least 5 dB improvement than the individual PAPR reduction schemes. PAPR could be further reduced by decreasing the clipping ratio and oversampling. But with this, BER may become high.

GAPS IN STUDY

Based on the literature review on SDR and OFDM system, following gaps were identified:

- ➢ The SDR implementation of conventional OFDM systems has been accomplished. But, there is a scope of implementing the Improved OFDM system on hardware.
- ➢ One of the major challenges of OFDM system is the high PAPR of transmitted signal. A lot of techniques have been given in literature to reduce the PAPR such as signal scrambling techniques and signal distortion techniques. However, only analytical and simulation results have been provided. Hence, there is a scope of work in the hardware implementations of these methods of PAPR reduction.
- ➢ Second major issue in OFDM systems is large ICI. Some methods have been derived to reduce the ICI such as frequency domain equalization, self-cancellation scheme, time domain windowing and by using IMBH (Improved Modified Bartlett-Hanning window family) pulse shape [19]. But again, all these techniques have been theoretically proved and analytically studied, very little amount of work has been done for the implementation of these techniques.
- ➢ Third major issue in OFDM systems is synchronization which includes both timing offset and frequency offset estimation and correction. Similar to above problem, only theoretical derivations have been proved. A few practical implementations have been done.

PROPOSED OBJECTIVES

From the literature survey done, some gaps were found in the literature. From the careful observations of gaps, following objectives were proposed for the thesis work.

- To experimentally implement the "IMPROVED OFDM SYSTEM" on Software Defined Radio so as to prove the analytical studies and simulations done for improved OFDM system in which the problems like High PAPR and Synchronization issues have been resolved.
- To enhance the knowledge about actual SDR systems, the state of art along with the possibilities they can offer.

CHAPTER 3

OFDM SYSTEM MODEL

The need of broadband wireless system is growing exponentially. Broadband wireless systems require the environment with higher mobility, data transmission rate and higher carrier frequency. This type of channel can be modelled by fast time varying frequency selective channel. Multi carrier techniques such as MC-CDMA and OFDM are more suited for these types of channels.

3.1. SYSTEM MODEL OF OFDM

The main principle of OFDM technique is to divide the whole stream of available data with higher rate into multiple data streams with lower rate. Then, these lower rate streams are transmitted in parallel using multiple subcarriers which are orthogonal (independent) to each other. So, the time duration of the symbol increases and the time dispersion due to multipath delay spread reduces. Therefore, many wireless communication standards have adopted OFDM as major modulation or data transmission technique [39].

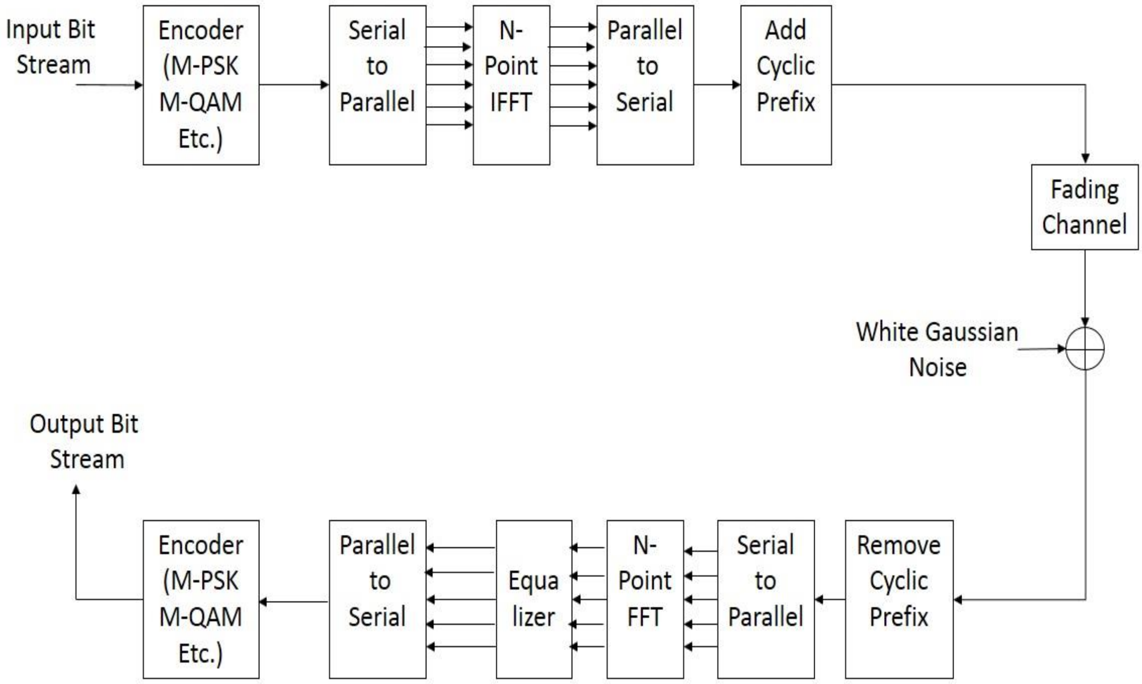


Figure 3.1: OFDM system block diagram

If the input data which is to be transmitted has the symbol rate of $1/T$, then the interval of the OFDM symbol becomes NT. Further, we can insert guard band between adjacent frequency bands so as to reduce the ISI (inter-symbol interference). The following figure shows N- subcarriers OFDM system. Figure 3.1 shows the transmitter, receiver and the channel of the OFDM system.

3.1.1. OFDM SIGNAL GENERATION

The input to the system is a block of $log_2(m)$ bits. An M-ary encoder maps this block of data into a symbol constellation point d_k. Then, these blocks are transferred to serial to parallel convertor. We can use any type of modulation scheme at the data encoding part. May it be BPSK, QPSK, QAM or any other scheme. These parallel data symbols are further modulated by several sub-carriers. We cannot choose any sub-carrier or frequency band, they should be orthogonal to each other and must satisfy the following condition:

$$\frac{1}{T_u}\int_0^{T_u} e^{j2\pi f_k t} e^{j2\pi f_m t} dt = \begin{cases} 1, k = m \\ 0, k \neq m \end{cases} \tag{3.1}$$

$where, f_k = \frac{k}{T_u}$, for $k = 0,1,2,3, \ldots . N-1$. It is the sub-carrier frequency of the k^{th} sub-carrier.

And $\frac{1}{T_u}$ is the required minimum spacing among the sub-carriers.

The OFDM baseband signal transmitted during i^{th} block can be represented as

$$S_i(t) = \sum_{k=0}^{N-1} d_{i,k} e^{j2\pi f_k t}, \qquad 0 \leq t \leq T_u \tag{3.2}$$

Where T_u = symbol's useful duration.

$d_{i,k}$ = complex data symbol of i^{th} block

N = Total number of subcarriers

Assumption: Complex data symbols are uncorrelated. The condition for uncorrelated symbols is given by:

$$E\left[d_{i,k} d_{i,m}^{*}\right] = \begin{cases} 1, & for\, k = m \\ 0, & for\, k \neq m \end{cases} \tag{3.3}$$

Where $d_{i,m}^{*}$ = complex conjugate of $d_{i,m}$.

The OFDM baseband signal $s(t)$ can be written in the discrete form as:

$$S_i[n] = \sum_{k=0}^{N-1} d_{i,k} e^{\frac{j2\pi nk}{N}} \tag{3.4}$$

From the above equation, it is clear that the transmitted signal is the IDFT of $d_{i,k}$ and thus, it can be easily obtained with the help of IFFT. Reverse engineering can be done at the receiver part of the system. We can use FFT block at the receiver.

3.1.2. GUARD BAND INSERTION

To reduce the effect of Inter symbol interference, we need to insert guard-band between adjacent OFDM symbols. ISI is caused because of the presence of delay spread in a multipath channel. But sometimes with the insertion of guard band where no signal is present, an immediate change of waveform occurs in which components of higher spectrum are consisted. This further results in ICI which can be avoid with the help of cyclic prefix.

3.1.3. CYCLIC PREFIX INSERTION

Peled and Ruiz introduced this scheme in 1980 in which they recommended a cyclic extension (CE) which is more often known as cyclic prefix. This scheme becomes the solution to maintain the orthogonality in the case of multi-path fading channel. This leads to conversion of a linear convolution channel to a channel which performs cyclic convolution which ensures orthogonality among different frequency channels. Thus, this scheme eliminates ISI completely as long as cyclic extension is larger than the impulse response of the channel. This leads to the decrease in the data rates. But, the zero inter-carrier interference recompenses for this reduction.

In this scheme, OFDM symbol is extended cyclically in the guard time. Because of CO insertion, the time duration of the transmitted signal becomes $T_s = T_g + T_u$ and it can be expressed as:

$$\widetilde{s_i}(t) = \sum_{k=0}^{N-1} d_{i,k} e^{j2\pi f_k t}, \quad -T_g \le t \le T_u \tag{3.5}$$

Where $\widetilde{s_i}(t) = s_i(t + T_u)$ for $-T_g \le t \le 0$.

The length of cyclic prefix (CP) or guard interval plays crucial role in OFDM system's performance. If the maximum delay of the channel with multipath characteristics is longer than the length of CP, the previous symbol's tail part affects the upcoming symbol's head part. This, leads to increase in ISI. On other hand, with the increase in CP or guard interval, the overhead of the system also increases.

3.1.4. CHANNEL MODEL

OFDM system is often used for wireless communication. Hence, multipath-fading channel is generally preferred. The impulse response $h(\tau, t)$ for this type of channel is given as:

$$h(\tau, t) = \sum_{l=0}^{L-1} h_l(t)\delta(t - \tau_l) \tag{3.6}$$

where, $h(\tau, t)$ is l^{th} path's complex amplitude.

And τ_l = l^{th} path's propagation delay

3.1.5. RECEIVER MODEL

After passing through the channel, the i^{th} received signal $r_i(t)$ may be expressed as

$$r_i(t) = \sum_{l=0}^{L-1} h_l(t)\, \widetilde{s_i}(t - \tau_l) + w(t) \tag{3.7}$$

Where $w(t)$ = Additive white Gaussian noise (AWGN). The two sided PSD of this AWGN noise is $N_o/2$.

We can recover the OFDM signal correctly in the following three conditions

- Timing and frequency offsets are not present.
- These offsets are estimated correctly
- Length of CP $>$ maximum delay spread.

The received signal is given to the FFT block after the removal of cyclic prefix. The output of the FFT block can be written as:

$$\hat{d}_{i,k} = H_k d_{i,k} + w_k, \quad for\ 0 \leq k \leq N - 1 \tag{3.8}$$

Where H_k represents the k^{th} sub-channel and can be defined as

$$H_k = \sum_{l=0}^{L-1} H_l(t) e^{j2\pi k T_l / N} \tag{3.9}$$

3.2. PEAK TO AVERAGE POWER RATIO

One of the foremost problems of the OFDM system is its high PAPR. PAPR is a result of large range of sub-carriers. A number of subcarriers which are modulated independently are when added up coherently, leads to a large value of PAPR. Summing up of N number of signal which are in same phase produce a peak power which is N times that of average power. Most RF communication systems use high power amplifier (HPA) at transmitter side to get enough transmit power. So as to ensure the linear amplification, HPA is forced to have very large back-off by high PAPR. This leads to the decrease in the efficiency of the amplifier. And if an amplifier works with nonlinear characteristics, unwanted distortion will be caused such as in-band distortion and out-band radiation. This results in the low BER performance.

So, we can sum up two main disadvantages of high PAPR

I. Complexity increases in ADC and DAC convertor.
II. Efficiency of RF amplifier reduces.

If we do not use the PAPR reduction methods, some part of signal will be clipped which makes the receiver prone to more errors. Therefore, PAPR reduction is very important research topic for OFDM systems.

3.2.1. DEFINITION

In case of continuous time OFDM signal, we can define PAPR as the ratio of maximum instantaneous power of the signal to its average power.

Mathematically, PAPR can be defined as-

$$PAPR[s(t)] = \frac{\max\left[|s(t)|^2\right]}{P_{av}}, \quad for\ 0 \le t \le NT \tag{3.10}$$

Where, P_{av}= average power of $s(t)$.

For a discrete time OFDM signal, we can compute PAPR from the L time over-sampled OFDM signals as-

$$PAPR\left[s[n]\right] = \frac{\max\left[\left|s[n]\right|^2\right]}{E\left[\left|s[n]\right|^2\right]}, \quad for\ 0 \le t \le NL-1 \tag{3.11}$$

Where, $E[.]$ represents the expectation of $\left[\left|s[n]\right|^2\right]$.

Rather than using the power as measurement factor, the above said characteristics can also be defined in terms of the magnitudes of the signal [38]. This measurement factor is known as crest factor (CF) and is given as

$$CF = \sqrt{PAPR} \tag{3.12}$$

Reduction of the peak power of the signal is the prime goal of the PAPR reduction schemes. Because we often deal with the discrete time systems, many PAPR schemes are designed to deal with the amplitudes of different samples of the signal.

3.2.2. PAPR Reduction Techniques

The following PAPR reduction schemes are often used while designing the OFDM system:

- Clipping and Filtering,
- Selective Mapping(SLM)
- Partial Transmit Sequence (PTS)
- Hybrid methods

Every scheme has some merits and demerits. There is often a trade-off between reduction in PAPR and other factors like computational complexity, bandwidth, average power and most importantly BER performance.

The main requirements of the PAPR reduction scheme are:

- Out-of-band radiation and in-band distortion must be small with a large reduction in PAPR value.
- Average power should be low. A large linear operation region is required in HPA due to high value of average power due to which BER performance degrades.
- Required additional power must be low. If the PAPR reduction scheme requires more power, then the BER performance degrades.

- The PAPR reduction scheme should not change the orthogonality among several sub-carriers.
- Implementation should be simple because a complex design will be difficult to implement. Also with this, the transmission delay rises which results in reduced data rate.
- BER performance should not be degraded. The main purpose of PAPR scheme is to achieve better performance than the original OFDM system.

3.2.2.1. CLIPPING AND FILTERING TECHNIQUE

Clipping and filtering scheme is a type of signal distortion techniques. Clipping method restricts the maximum amplitude to pre-specified level. The implementation complexity of this method is lower. But, it has the given below limitations:

- The in-band signal distortion is caused which degrades BER performance.
- out-of-band radiation also occurs which leads to the interference in the adjacent channels. This out-of-band radiation may be reduced with the help of filtering technique. But, it may also affect the desired high frequency components of the current channel when we perform clipping at the Nyquist sampling rate.
- After filtering procedure, the signal may exceed the clipping level indicated for the clipping action. So, the filtering scheme may decrease out-of-band radiation but the peak in the signal may regrow above the prescribed level which again becomes a disadvantage.

To avoid the problem of overall peak regrowth, we can use a repeated clipping and filtering scheme so as to achieve a desirable PAPR value. But with this, the computational complexity will get increased.

The operation of the repeated clipping and filtering scheme can be understood by the block diagram given in the figure. First of all, the input data samples are taken at the input. Let, the input signal be denoted a. Then, the samples at the input will be denoted as

$$a_0, a_1, \dots \dots \dots \dots \dots \dots .. a_{N-1} \tag{3.13}$$

Where, $N =$ the total number of samples.

Now, this input signal is oversampled by a given variable I by padding $N(I-1)$ zeroes in the centre of the vector. This signal is then converted to the time domain signal by using Inverse FFT. After inverse IFFT, the signal is clipped in the present state.

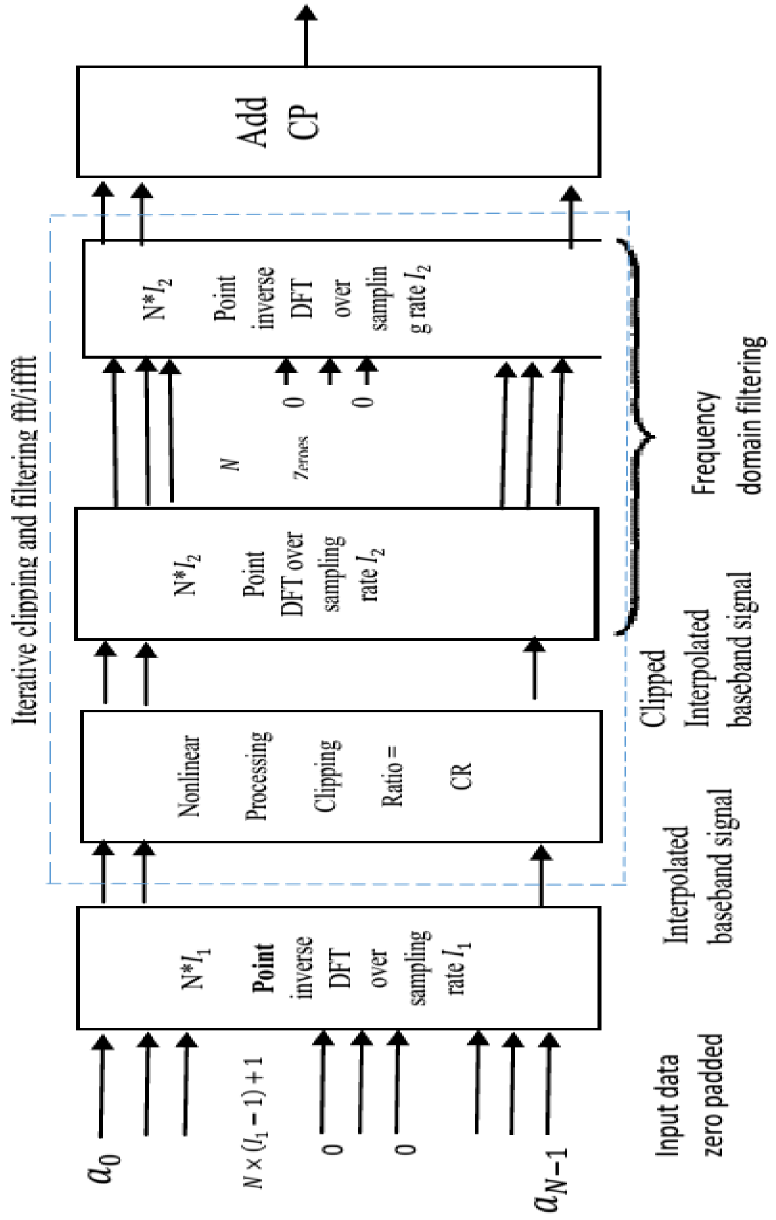


Figure 3.2: Repeated Clipping and Filtering technique

We can define the clipping ratio as the ratio between the clipping level and the average power of the unclipped signal. The clipping process in then followed by filtering in frequency domain filtering so as to decrease out-of-band power. After this, the signal is transformed back into the frequency domain signal with the help of FFT. Then after passing the signal again through the IFFT block, the signal is passed through the serial to parallel converter, DAC and amplification. The effect of the filtering technique must be as low as on the in-band frequency domain signals and as much high as possible on the out-of-band signal components.

3.2.2.2. SELECTIVE MAPPING (SLM)

The probabilistic schemes are focused on mixing of each OFDM symbol with several scrambling sequences with the help of some error correcting codes. The main idea of these coding methods for reducing PAPR is to diminish the occurrence of the co-phase signals. In the last, the sequence with the smallest value of PAPR is selected. These methods do not create any out-band radiation or any distortion. But due to the reduction in code rate, the bandwidth efficiency also decreases. The complexity of these methods is also very high as it takes time and complex design to find the best suited code. There are two main examples of probabilistic techniques- SLM and PTS.

In SLM scheme, every single data input sequence is multiplied by all the phase sequences to produce an alternative input symbol sequences. Then, these data sequences are fed to IFFT block. At, the output of IFFT block, one sequence with the lowest PAPR is chosen for transmission. The following figure shows the block diagram for SLM scheme.

The input data sequence is divided into a data block Y of length N. Then these data blocks are multiplied with the phase sequences given by

$$W^{(u)} = \left[w_{u,0} + w_{u,1} + \ldots\ldots w_{u,0}\right]^T \tag{3.14}$$

Where, $u = 1,2, \ldots\ldots\ldots, U$

The above process is done to rotate the phase of the signal U times. And the new signal becomes,

$$Y^{(u)} = \left[y_{u,0} + y_{u,1} + \ldots\ldots y_{u,0}\right]^T \tag{3.15}$$

After passing through the whole procedure of SLM scheme, the resulting OFDM signal becomes:

$$y^{y}(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} Y_n w_{u,n} e^{j2\pi f_n t} \tag{3.16}$$

for $0 \leq t \leq NT$ and $u = 0,1, \ldots\ldots.. U - 1$

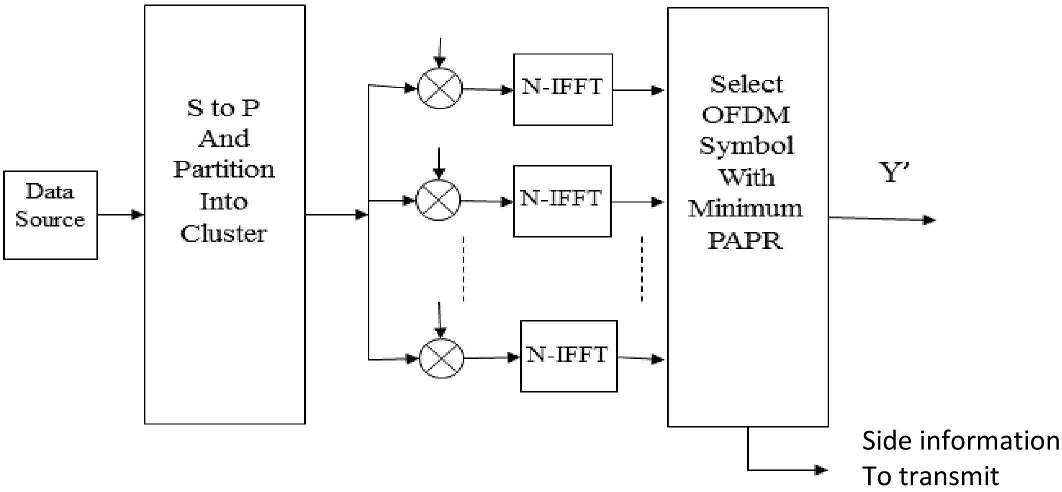


Figure 3.3: Selective Mapping technique of PAPR reduction

One of these data blocks will be selected which will have the smallest value of PAPR. This block will be along with the phase factor $w_{u,n}$which satisfies the condition. The major limitation of this scheme is that it is computationally very complex and the bandwidth efficiency is also very low.

3.2.2.3. PARTIAL TRANSMIT SEQUENCE

In this PAPR reduction scheme, the frequency-domain data of the original sequence is grouped into several disjoint sub-blocks. These blocks are then weighted by a number of phase sequences to generate a set of contenders. Finally, the contender which has the lowest value of PAPR is selected for the transmission.

The block diagram of the PTS method is shown below:

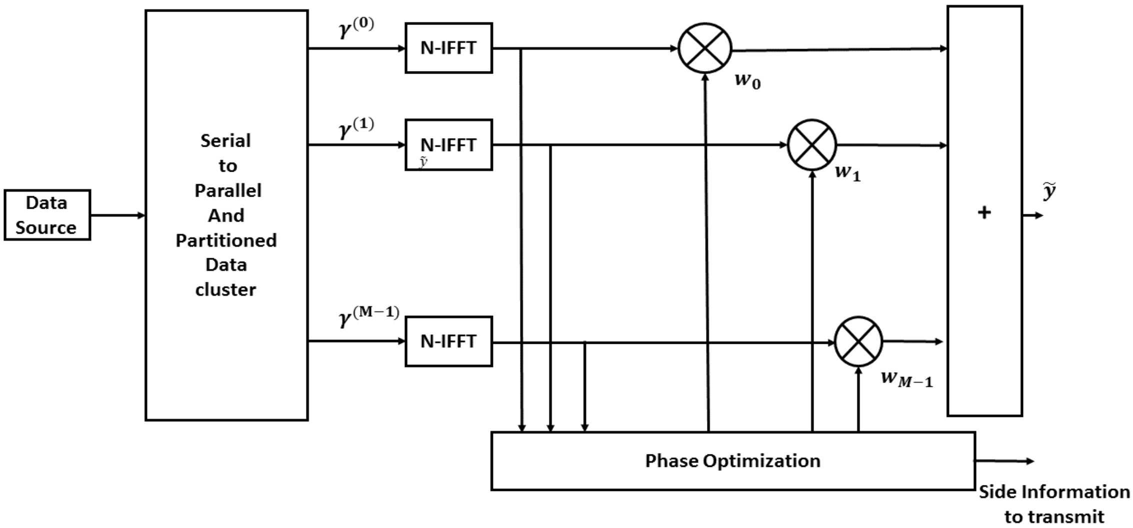


Figure 3.4: PTS technique of PAPR reduction

3.2.2.4. HYBRID METHODS

The procedure for these methods is formed by combining two or more than two schemes. We can combine the SLM scheme with the pre-coding scheme or with the clipping scheme. This often leads to the reduction in PAPR value while maintaining the satisfactory response in the bit error rate sense. Various examples have also been specified in the literature review regarding this hybrid scheme. The proposed method in [38] was composed of three steps which can be easily understood by the given block diagram-

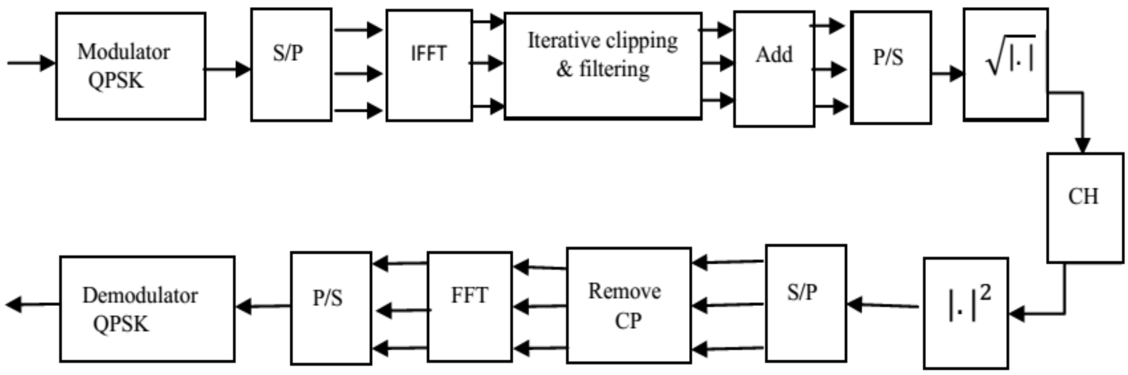


Figure 3.5: Hybrid Technique block diagram

CHAPTER 4

OFDM SYSTEM IMPLEMENTATION USING SOFTWARE DEFINED RADIO.

There were different methods by which we could implement the system model. Either we could

- **a)** directly write a code in HDL for our system model,
- **b)** use Simulink library,
- **c)** use Xilinx's system generator to convert a Matlab code to VHDL code,
- **d)** Use Labview and the USRP kit which is provided by National Instruments Ltd.

These ideas could be implemented with the help of some sort of software and hardware. As the Labview and USRP was available in the research lab, so I decided to use this approach. For this approach the following hardware and Software tools were required:

4.1. System Specifications

4.1.1. Software Specifications:

1. Processor: Intel (R) Core (TM) i3, CPU 1.80 GHz
2. RAM: 4 GHz
3. System type: 64- bit operating system
4. MATLAB version: 8.3.0.532(R2014a)
5. Labview version 14.0 (64- bit)
6. Driver for NI-USRP 2920 (version 1.4)

4.1.2. Hardware Specifications:

1. National Instruments USRP N-2920
2. Agilent Technology's E4401B spectrum analyzer
3. Scientech technologies Digital Storage Oscilloscope

4.1.2.1. Detailed Specifications of Hardware Used [40]

1. NI- USRP 2920 Kit (Features and specifications)

   The features of NI-USRP 2920 are discussed below

I. Transmitter

- a. Frequency range 50 MHz to 2.2 GHz
- b. Frequency step <1 kHz
- c. Maximum Output Power (Pout)
  - 50 MHz to 1.2 GHz 50 mW to 100 mW (17 dBm to 20 dBm)
  - 1.2 GHz to 2.2 GHz 30 mW to 70 mW (15 dBm to 18 dBm)
- d. Gain range 10 dB to 31 dB
- e. Gain step 1.0 dB
- f. Frequency accuracy 2.5 ppm
- g. Maximum real-time instantaneous bandwidth
  - 16-bit sample width 20 MHz
  - 8-bit sample width 40 MHz
- h. Maximum I/Q sampling rate
  - 16-bit sample width 25 MS/s
  - 8-bit sample width 50 MS/s
- i. DAC 2 channels, 400 MS/s, 16 bit
- j. DAC SFDR 80 dB

II. Receiver

- a. Frequency range 50 MHz to 2.2 GHz
- b. Frequency step <1 kHz
- c. Gain range 0 dB to 31.5 dB
- d. Gain step 0.5 dB
- e. Maximum input power (Pin) 0 dBm
- f. Noise figure 5 dB to 7 dB
- g. Frequency accuracy 2.5 ppm
- h. Maximum real-time instantaneous bandwidth
  - 16-bit sample width 20 MHz
  - 8-bit sample width 40 MHz
- i. Maximum I/Q sampling rate
  - 16-bit sample width 25 MS/s
  - 8-bit sample width 50 MS/s
- j. ADC 2 channels, 100 MS/s, 14 bit
- k. ADC SFDR 88 Db

4.1.3. Connectors of NI USRP-2920

The front end connectors of the USRP-2920 kit are discussed in the following table.

Table 4.1: Connectors of NI USRP-2920

S. No.	CONNECTOR	USE
1.	RX1 TX1	RF signal input and output terminal. RX1 TX1 is an SMA (f) connector with an impedance of 50 Ω and is a single-ended input or output channel.
2.	RX2	RF signal input terminal. RX2 is an SMA (f) connector with an impedance of 50 Ω and is a single-ended input channel.
3.	REF IN	Input terminal for an external reference signal for the local oscillator (LO). REF IN is an SMA (f) connector with an impedance of 50 Ω and is a single-ended reference input. It takes a 10 MHz signal having a minimum input power of 0 dBm (.632 V) and a maximum input power of 15 dBm (3.56 V) for a square wave or sine wave.
4.	PPS IN	Pulse per second (PPS) timing reference input terminal. PPS IN is an SMA (f) connector with an impedance of 50 Ω and is a single-ended input. It takes 0 V to 3.3 V TTL and 0 V to 5 V TTL signals.
5.	MIMO EXPANSION	The multiple input multiple output (MIMO) EXPANSION interface port connects two USRP devices using a compatible MIMO cable.
6.	GB ETHERNET	The gigabit Ethernet port accepts an RJ-45 connector (Category 5, Category 5e, or Category 6).
7.	POWER	The power input takes a 6 Volt, 3 Ampere external DC power connector.

4.1.4. NI USRP-2920 Module LEDs

The module LEDs are listed in the following table

Table 4.2: NI USRP-2920 Module LEDs

LED	INDICATION
A	Indicates the transmit status of the NI USRP-2920 module: OFF—The module is not transmitting data. GREEN—The module is transmitting data.
B	Indicates the status of the physical MIMO cable link: OFF—The modules are not connected using the MIMO cable. GREEN—The modules are connected using the MIMO cable.
C	Indicates the receive status of the NI USRP-2920 module: OFF—The module is not receiving data. GREEN—The module is receiving data.
D	Indicates the firmware status of the NI USRP-2920 module: OFF—The firmware is not loaded. GREEN—The firmware is loaded.
E	Indicates the reference lock status of the local oscillator (LO) on the NI USRP-2920 module: OFF—There is no reference signal, or the LO is not locked to a reference signal. BLINKING—The LO is not locked to a reference signal. GREEN—The LO is locked to a reference signal.
F	Indicates the power status of the NI USRP-2920 module: OFF—The module is powered off. GREEN—The module is powered on.

4.1.5. NI USRP-2920 Front Panel

The front panel of the USRP kit for the demonstration is shown in the following figure. The use of all the ports available is also shown in the diagram itself

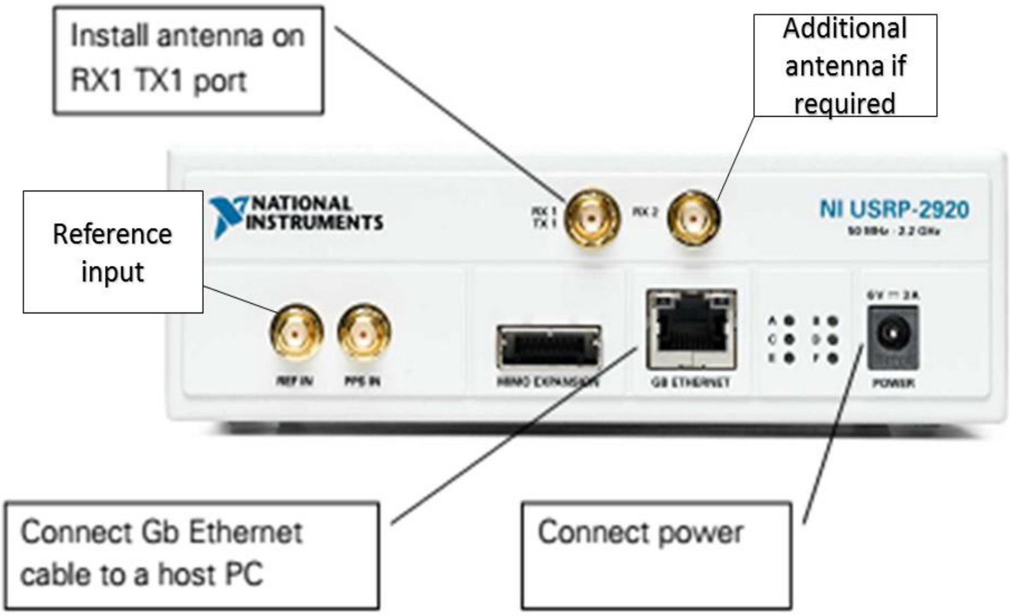


Figure 4.1: Detailed view of Front Panel of NI USRP-2920 [40]

4.2. SYSTEM IMPLEMENTATION

For the OFDM system implementation with the help of Labview and NI-USRP 2920, there were again two options available. Either we could use the different communication or signal processing blocks that are available to us. We could also design these blocks as per our requirement. OFDM system implementation was experimented in Labview by using these blocks. Or we could make use of the Matlab software. As all the previous communication system's coding was done in Matlab and most of the codes had been simulated in the literature, so I decided to use the second one approach. In this approach the matlab code is called by Labview and rest of the function is performed by Labview in collaboration with the NI-USRP kit.

4.2.1. NI-USRP 2920 Block diagram

The block diagram of NI-USRP 2920 kit is shown in the figure 4.2. The NI USRP kit connects to the PC to serve as a software-defined radio. For the purpose of transmission, baseband I/Q signal samples are generated by the computer and given to the USRP-2920 kit at the rate of 20 MS/s over Gigabit Ethernet. These are represented with 32-bits (16-bits for the in-phase and 16 for the quadrature phase components).

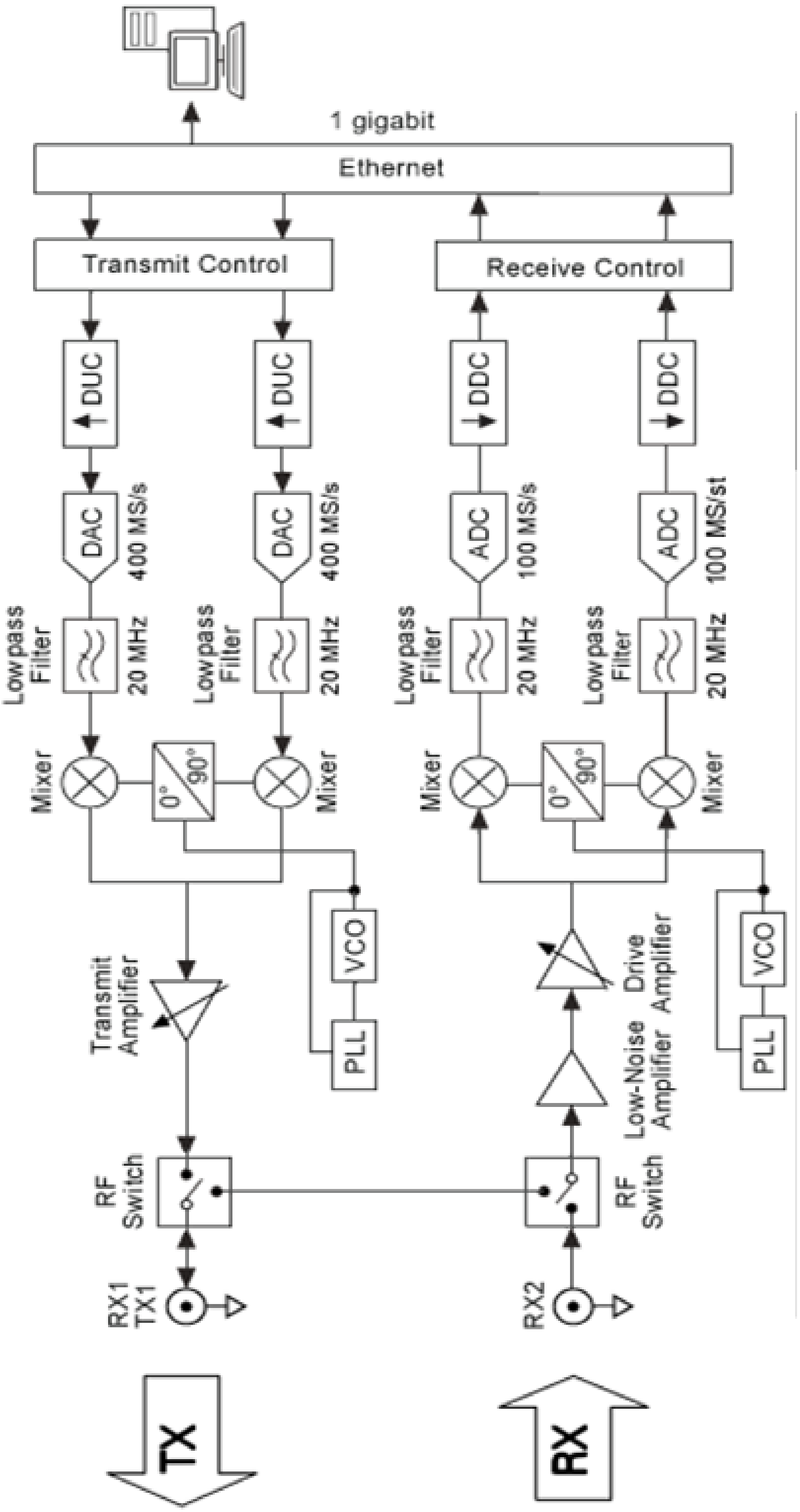


Figure 4.2: Detailed block diagram of NI-USRP 2920

The USRP mixes the incoming signal with 400 MS/s with the help of a digital up-convertor (DUC) and then transforms the signal from digital form to analog with a dual-channel, 16-bit DAC. The resulting signal in analog form is then mixed up with some specified carrier frequency.

4.2.2. INTERFACING OF THE HOST PC WITH THE KIT

Before installing the software for the functioning of USRP, we need to install Matlab and LabVIEW. The latest version of LabVIEW available in the market is LabVIEW 2014 which was released for the users in August 2014. After installing the LabVIEW software, follow the following steps

- NI USRP Software Suite DVD should be inserted into the PC and installed.
- There are some optional products which if required may be installed such as LabVIEW Modulation Toolkit, LabVIEW Digital Filter Design Toolkit and LabVIEW Math script RT module.
- Keep the host PC powered on.
- The power cable should be connected to the USRP kit as shown in the following figure.

Figure 4.3: Power connections to the USRP kit

- Now, attach the cable or antenna to the terminals of the NI USRP-2920 front panel according to the requirement.

➢ Connect the device directly to your computer with the included Ethernet cable as shown in the following figure

Figure 4.4: Ethernet cable and antenna connections to the USRP kit

➢ Insert the Ethernet cable in the available slot on the host PC. The whole procedure must be followed as shown in the following figure

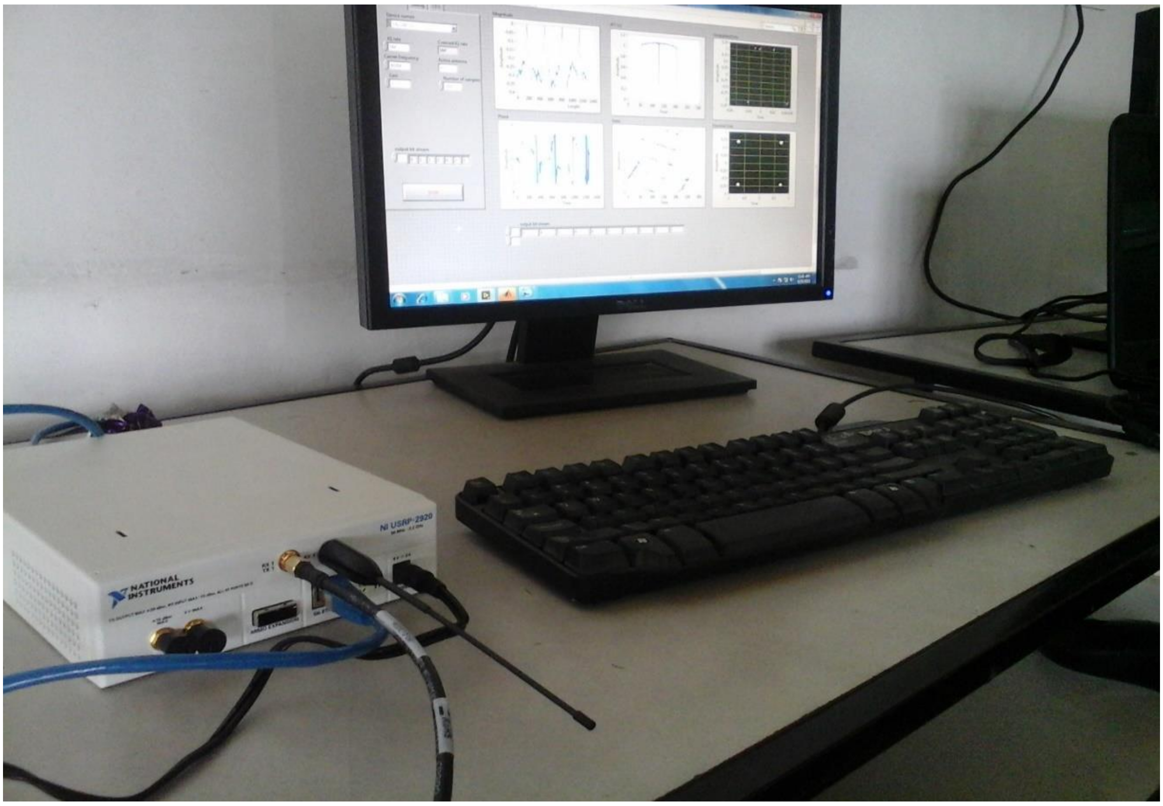


Figure 4.5: Connections of the NI-USRP kit to the host PC

- After ensuring that all the connections, are correct, setting up up the network takes some time to start the communication with the USRP device.
- The IP addresses for the computer and each connected USRP device must be unique.
- To confirm the network connection, we have to open the NI-USRP Configuration Utility. The following window will be displayed

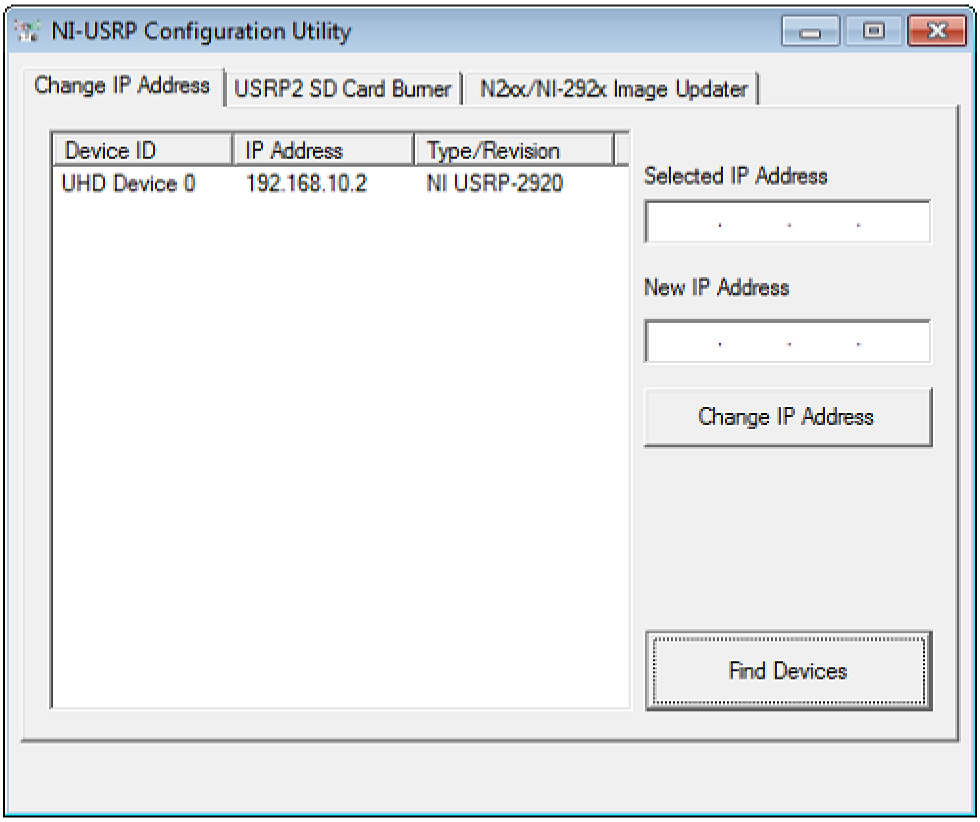


Figure 4.6: Verifying the device in NI-USRP Configuration Utility

- On this window, go to the Change IP Address tab of the utility. Your device should appear in the selected IP address available on the left side of the tab,
- If the device name is not present in the list, check all the connections and power supply again, then click the "find devices" button to scan for USRP devices.
- We can also change the IP address of the device by selecting the device from the list. The IP address of the device which we select is displayed in the Selected IP Address textbox.
- We can enter the new IP address which for the device in the New IP Address textbox as shown in the following figure:

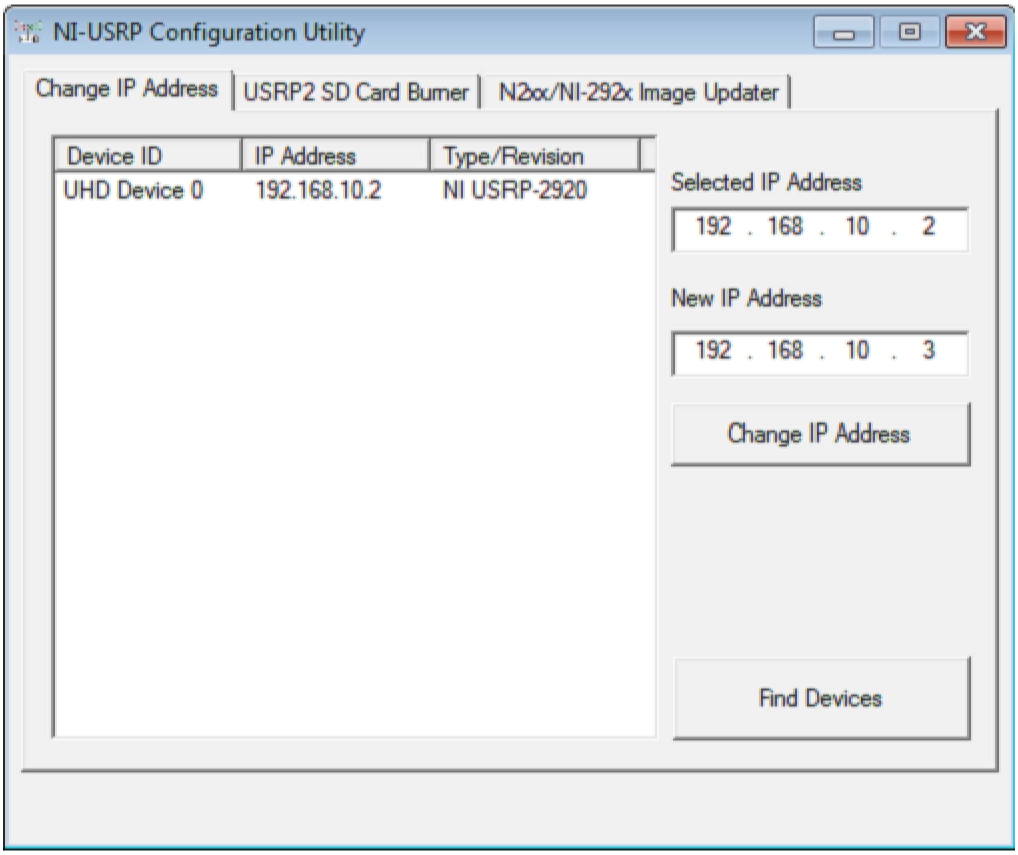


Figure 4.7: Changing the device IP of the device

- After this step, we were ready to use the software so as to design and implement the system model.

4.2.3. SYSTEM IMPLEMENTATION ON USRP

To implement the system on the software defined radio, we needed an interface between the hardware and the computer. The system model was designed in LabVIEW with the help of Matlab latest version and the USRP driver software was installed for the interfacing with the hardware.

After all the steps, open LabVIEW software. Now after clicking “Launch LabVIEW”, two windows will open. One being the block diagram and other front panel as shown in the following figure.

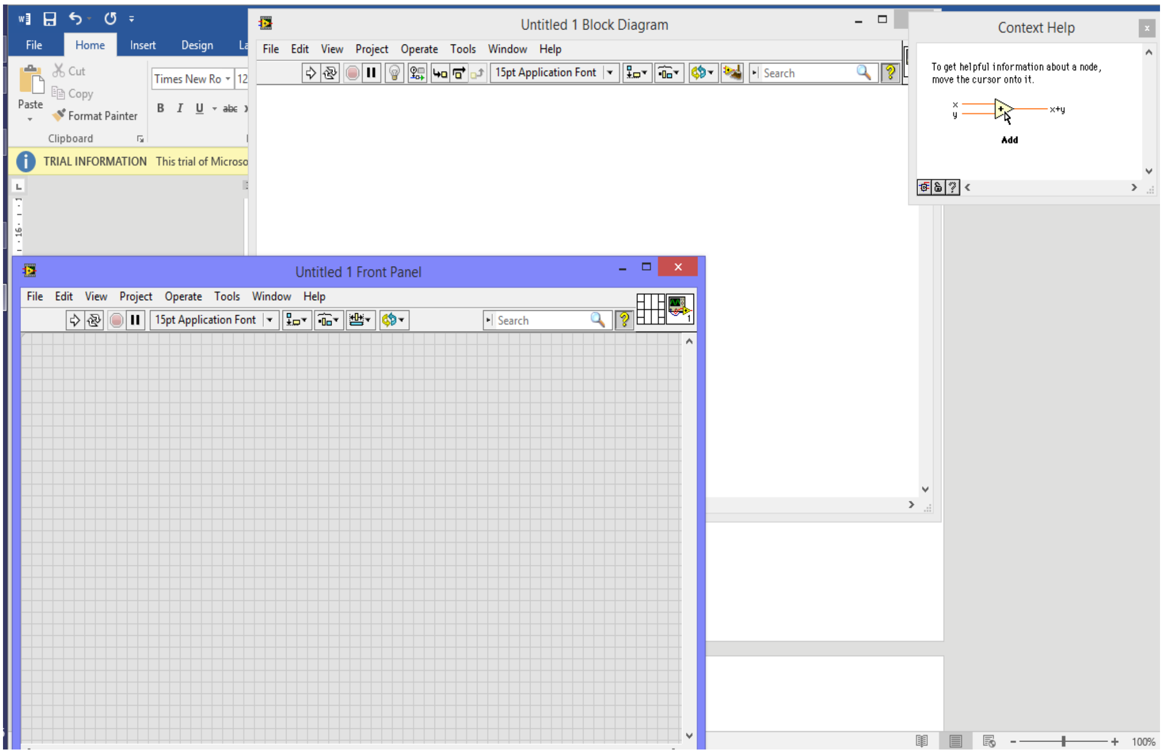


Figure 4.8: Block diagram and Front panel of LabVIEW

In this software, we can design the system either by using the blocks in the block diagram window (as shown in figure 4.9), with the help of Mathscript or by using the Matlab software coding.

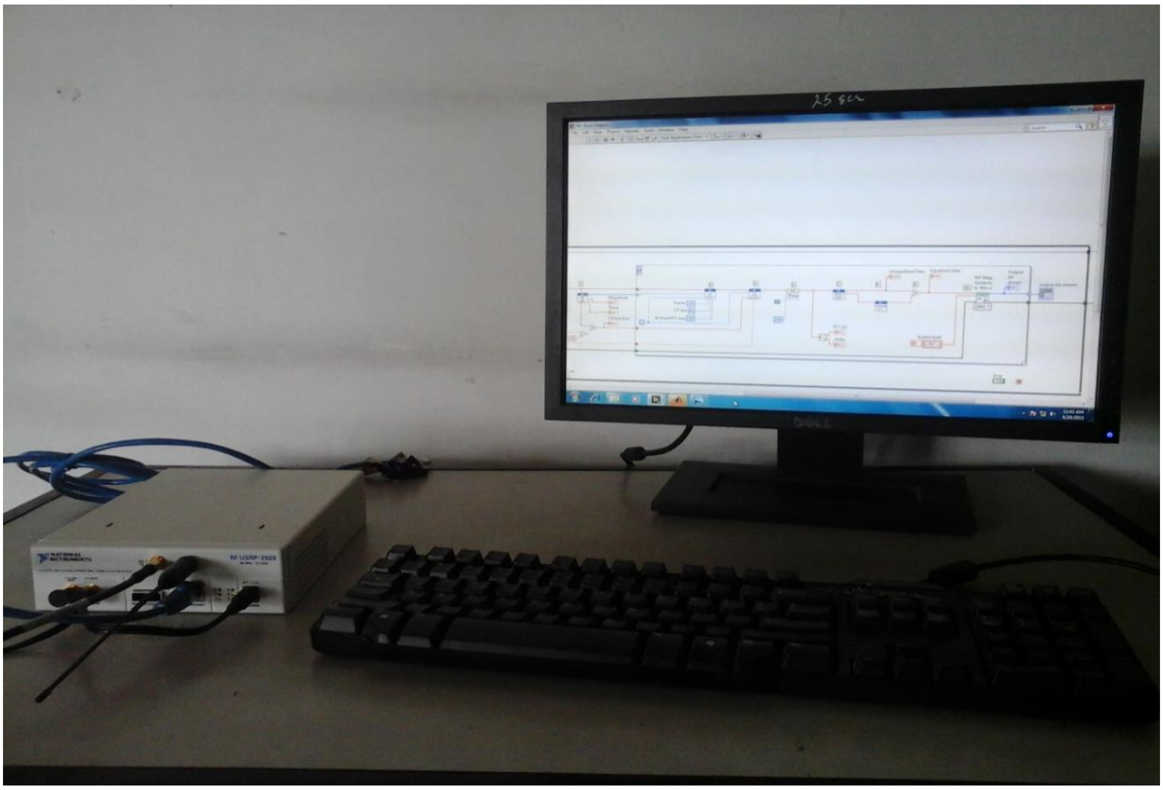


Figure 4.9: Designing the system with blocks in LabVIEW

After designing the system, we can check and run the code either one time or continuously for real time data. Whereas in the second case, the matlab simulated code may be altered according to the requirement of the Labview simulation.

The simulated system model was tested with simple AWGN channel. Then, the improved OFDM system was simulated by reducing the PAPR factor**.**

After the simulation on Labview, I inserted the blocks of USRP in the Labview block diagram, so that they could be used to transmit the signals from transmitter to the receiver through a physical channel.

CHAPTER 5

RESULTS AND DISCUSSIONS

This chapter presents the results obtained by simulating and implementing the OFDM system.

In the initial steps, the OFDM system was designed with the help of different blocks. Some of these blocks were available for the use. Whereas, other were designed according to the need of the system. And some of them were generated by creating different Virtual instrument in the Labview. The whole system was designed along with the transmitter and receiver. The block diagram of the transmitter is shown in the following figure:

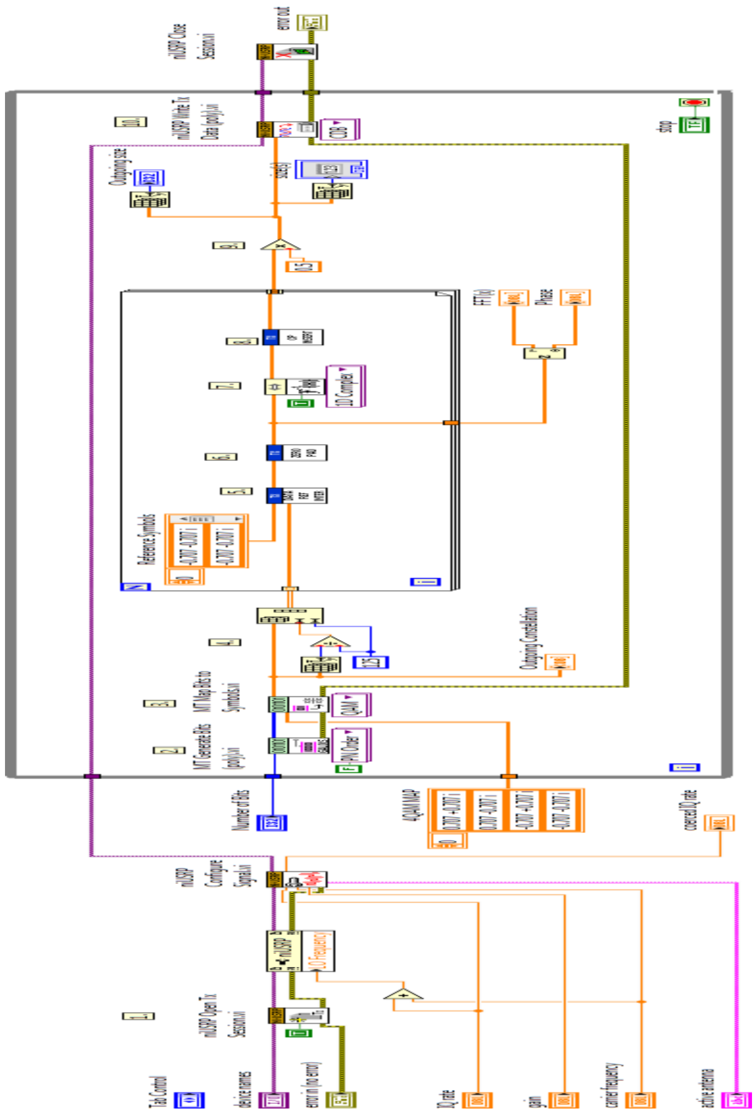


Figure 5.1: OFDM transmitter design with USRP using blocks

The front panel of the transmitter is shown in the following figure. The constellation diagram of the QPSK is shown in the figure. Along with which the FFT of the signal and phase are shown.

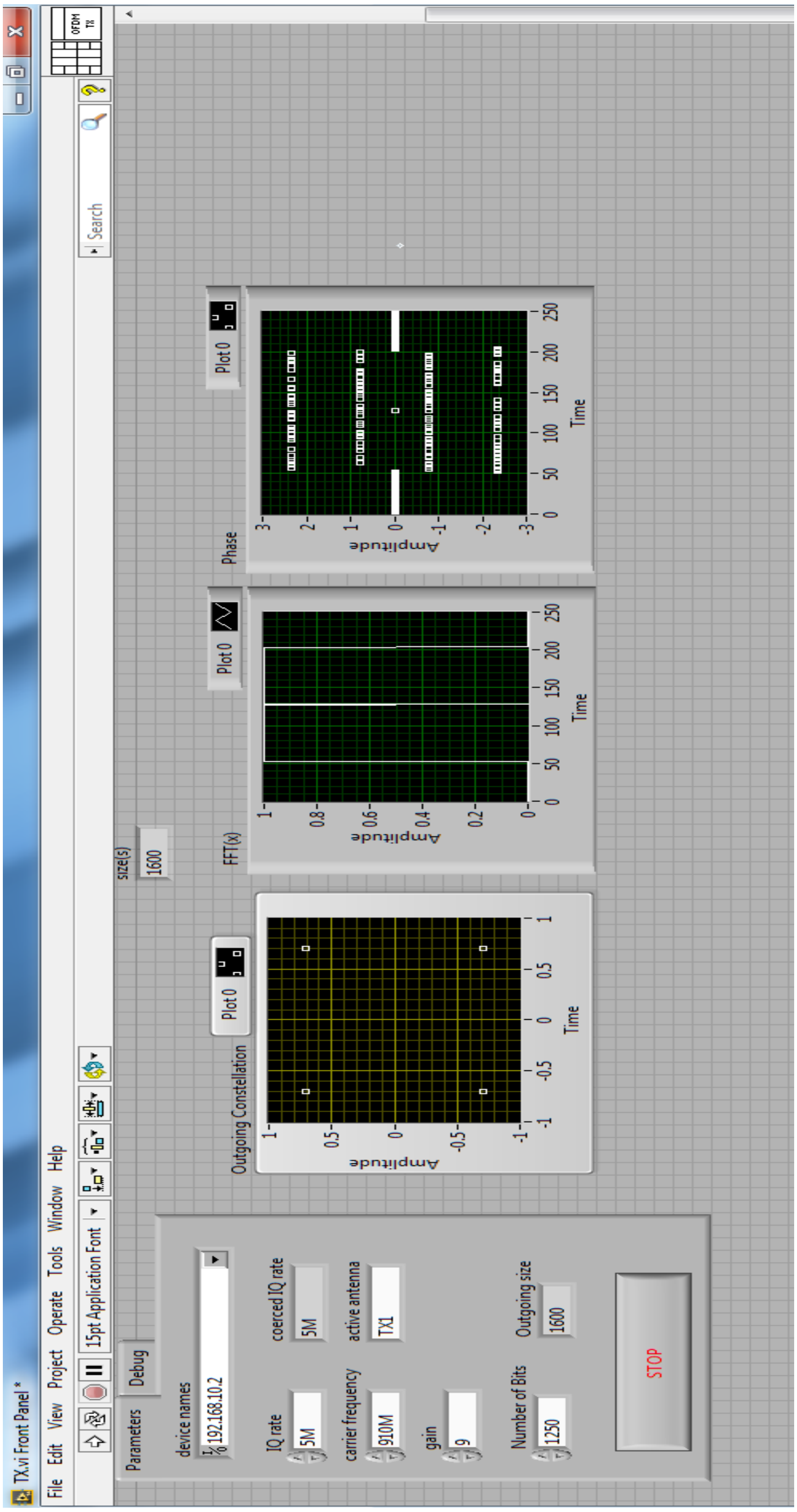


Figure 5.2: Front panel of OFDM transmitter with USRP

Similarily, the block diagram for the receiver could be drawn:

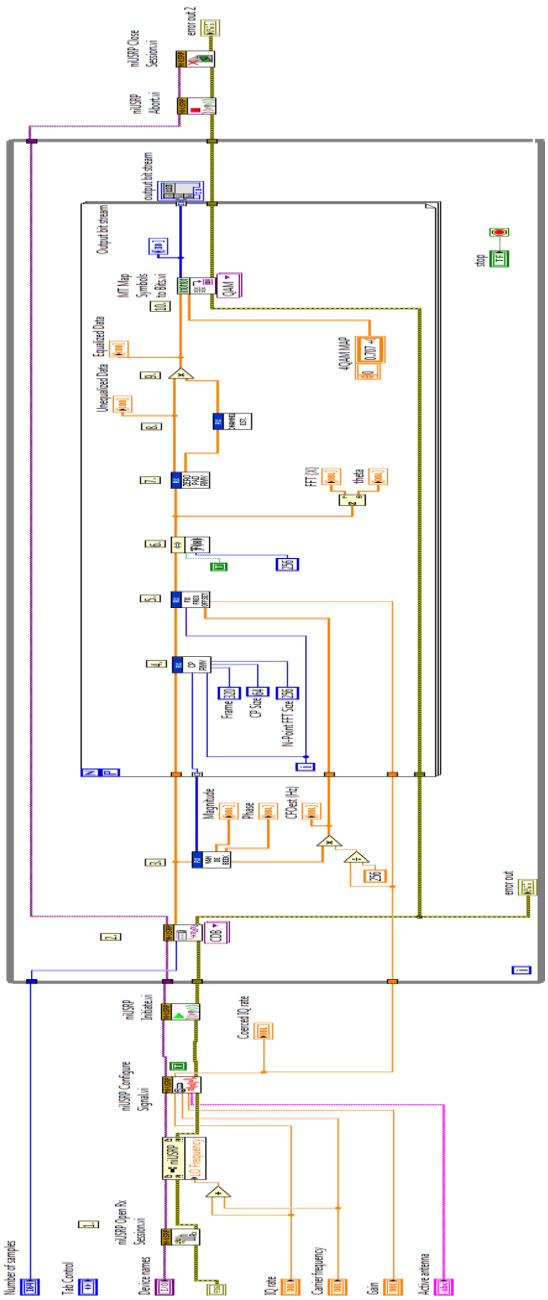


Figure 5.3: OFDM receiver design with USRP using blocks

After this, the resulted figure of receiver front panel was observed. The improvement was observed after the channel equalization block. This figure also shows phase and constellation diagram. But along with that, the constellation of un-equalized data is also available in the front panel.

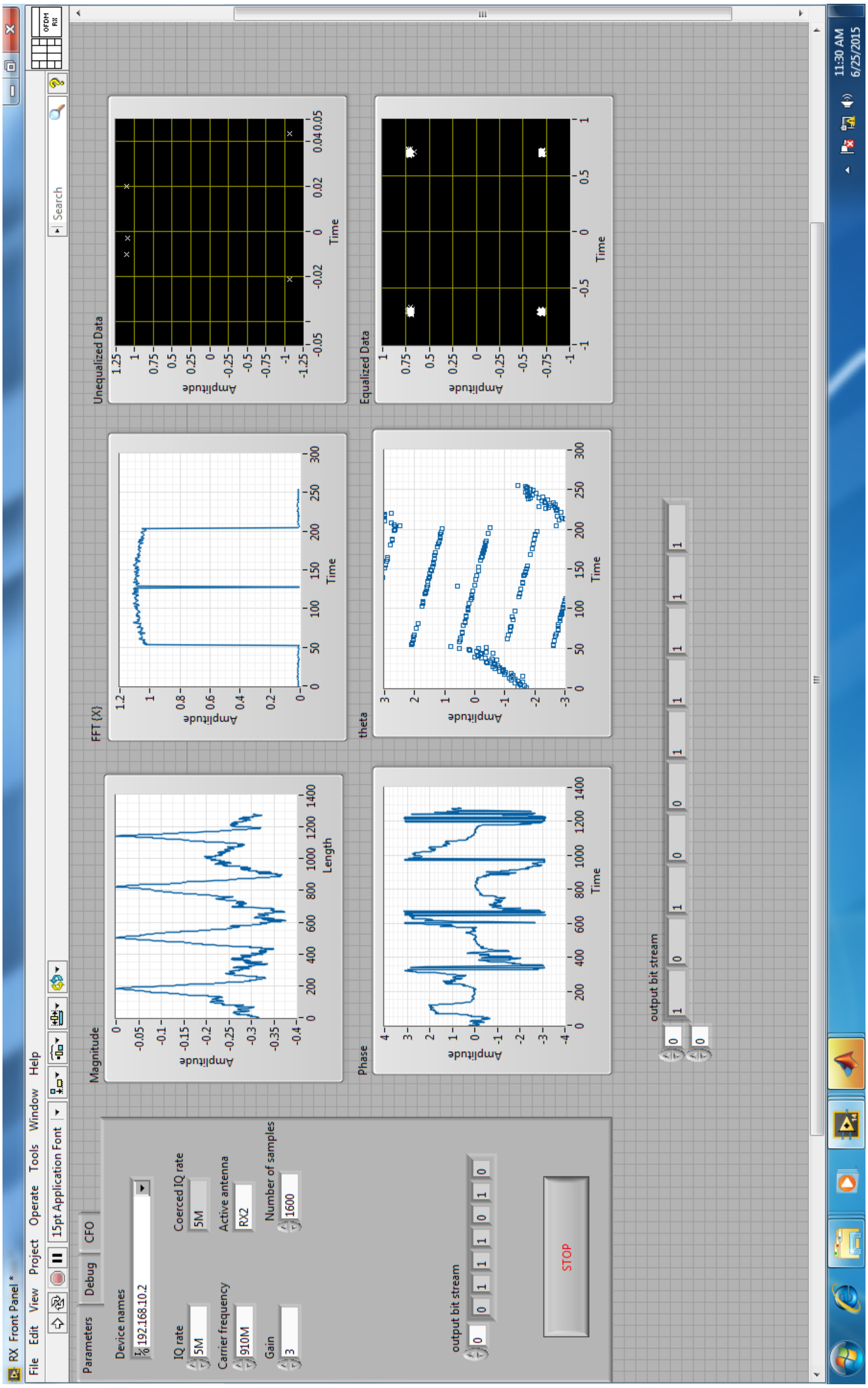


Figure 5.4: Front panel of OFDM receiver with USRP

After the successful implementation of the OFDM system on LabVIEW with the help of different blocks, it was the time to design and implement the system with the help of Matlab functioning. So first of all the OFDM system was designed and implemented.

Then, the system was designed with the SLM PAPR reduction technique. The simulation results along with the block diagram are shown in figures 5.5 and 5.6. In the figure 5.5, the steps are denoted with numbers. In the first step, the OFDM signal is generated which is given to the channel in step 2. Then, the signal is passed through channel in the 3rd step, the signal is received and demodulated and the value of BER is calculated.

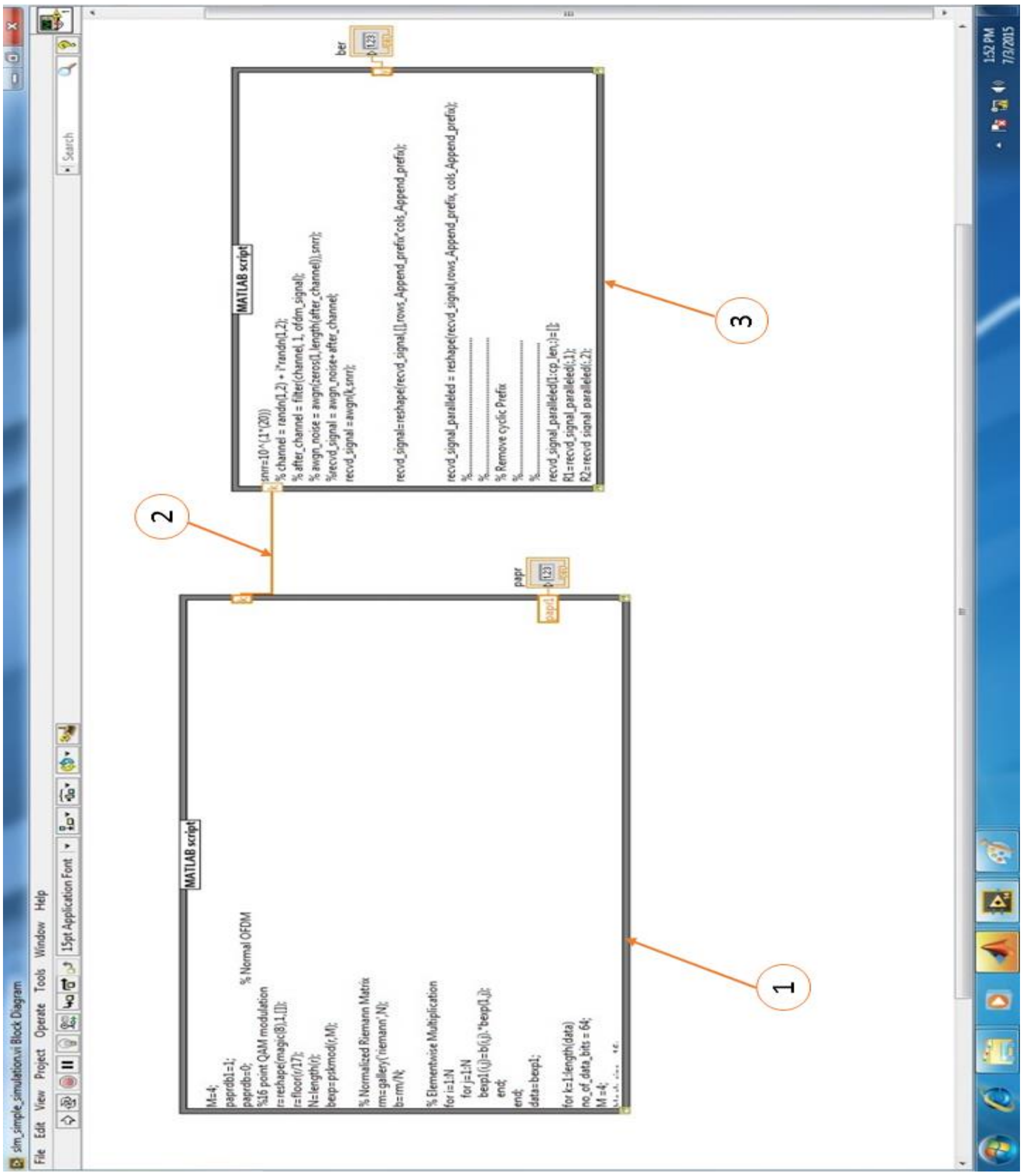


Figure 5.5: Block diagram of SLM technique simulation on LabVIEW using Matlab

The system was verified by taking static input for all of the cases. Because random data is effective in case of a very large number of bits or symbols, therefore I have used 8×8 magic matrix in some cases. Whereas, in other case, I have used the coloured image as input. The 8×8 magic matrix has fixed values as shown in the following table:

Table 5.1: Static input data of 8×8 magic matrix

64	2	3	61	60	6	7	57
9	55	54	12	13	51	50	16
17	47	46	20	21	43	42	24
40	26	27	37	36	30	31	33
32	34	35	29	28	38	39	25
41	23	22	44	45	19	18	48
49	15	14	52	53	11	10	56
8	58	59	5	4	62	63	1

These 64 data values were firstly converted to the QPSK data and then modulated for OFDM system. The front panel for SLM based simulated system is shown below:

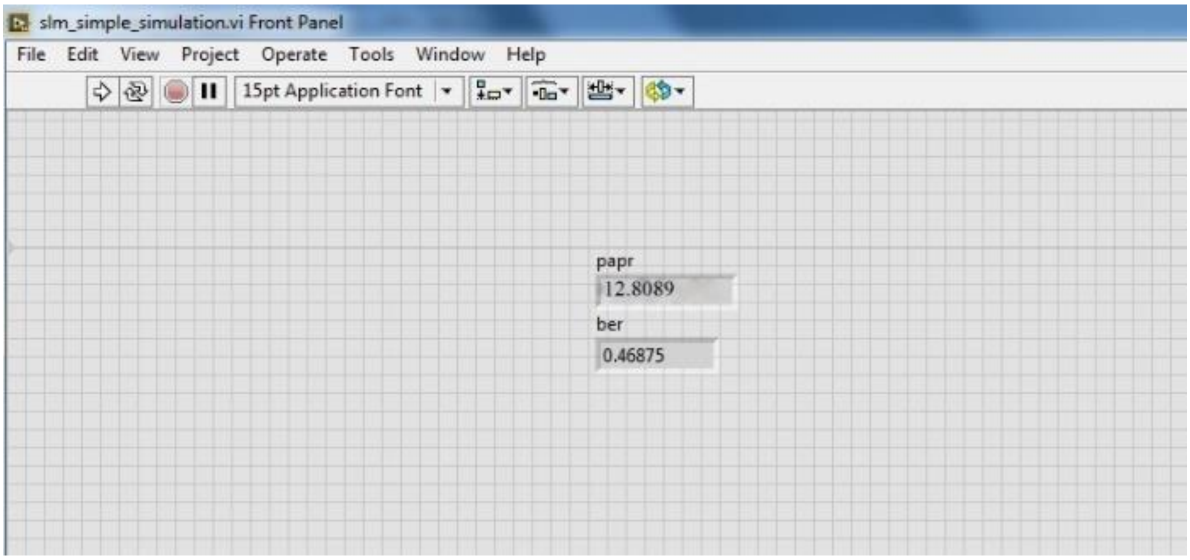


Figure 5.6: Front panel of SLM technique simulation on LabVIEW using Matlab

Then the system was implemented with the SLM technique of PAPR reduction on the NI-USRP 2920 as shown in the figure 5.7. In this figure, the OFDM signal is generated in 1st step. Then, the signal is given to the USRP transmitter section from where it is transmitted to the physical channel. The transmitted signal is then received through the USRP receiver section as shown in 3rd step. In the last step, the signal is demodulated with the help of the Matlab code.

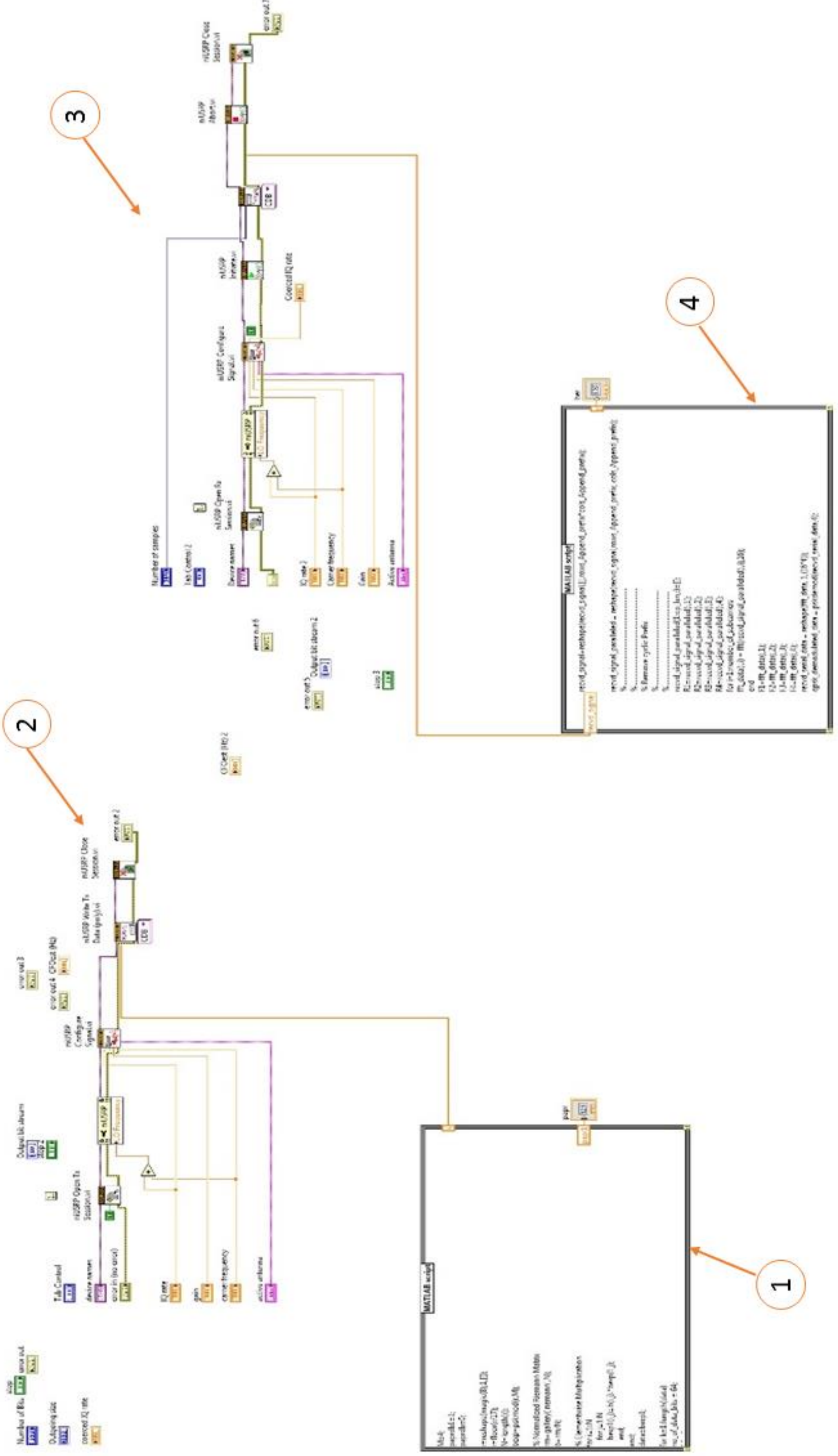


Figure 5.7: Block diagram of SLM technique implementation on LabVIEW using Matlab

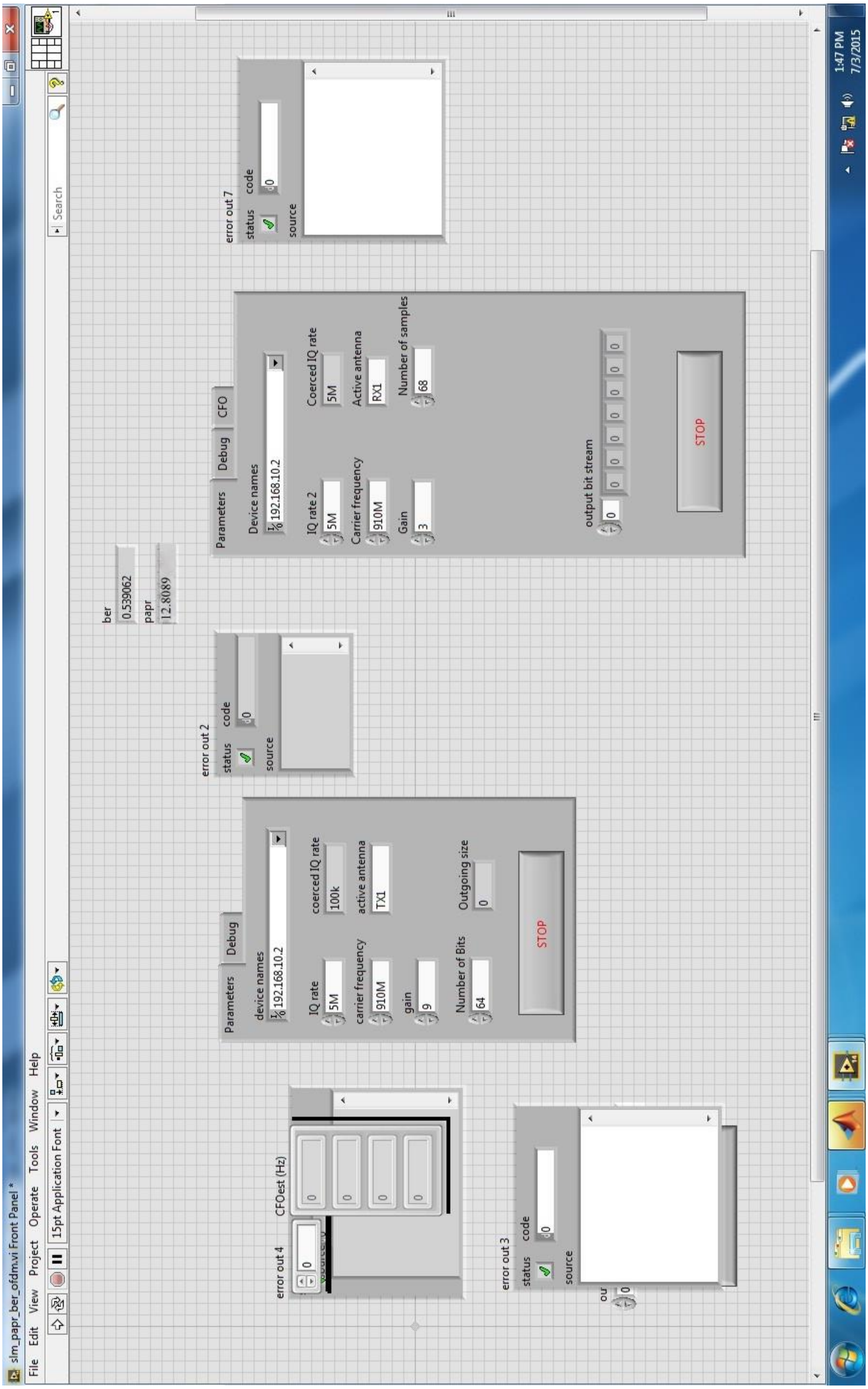


Figure 5.8: Front panel of SLM technique implementation on LabVIEW using Matlab

Then, the system was designed with the Clipping and filtering scheme of PAPR reduction technique. The simulation results along with the block diagram are shown in the figures 5.9 and 5.10. Figure 5.9 explains the steps of OFDM signal generation, transmission and reception with the help of step numbers 1,2 and 3. In the last the BER value is stored in the variable Real2.

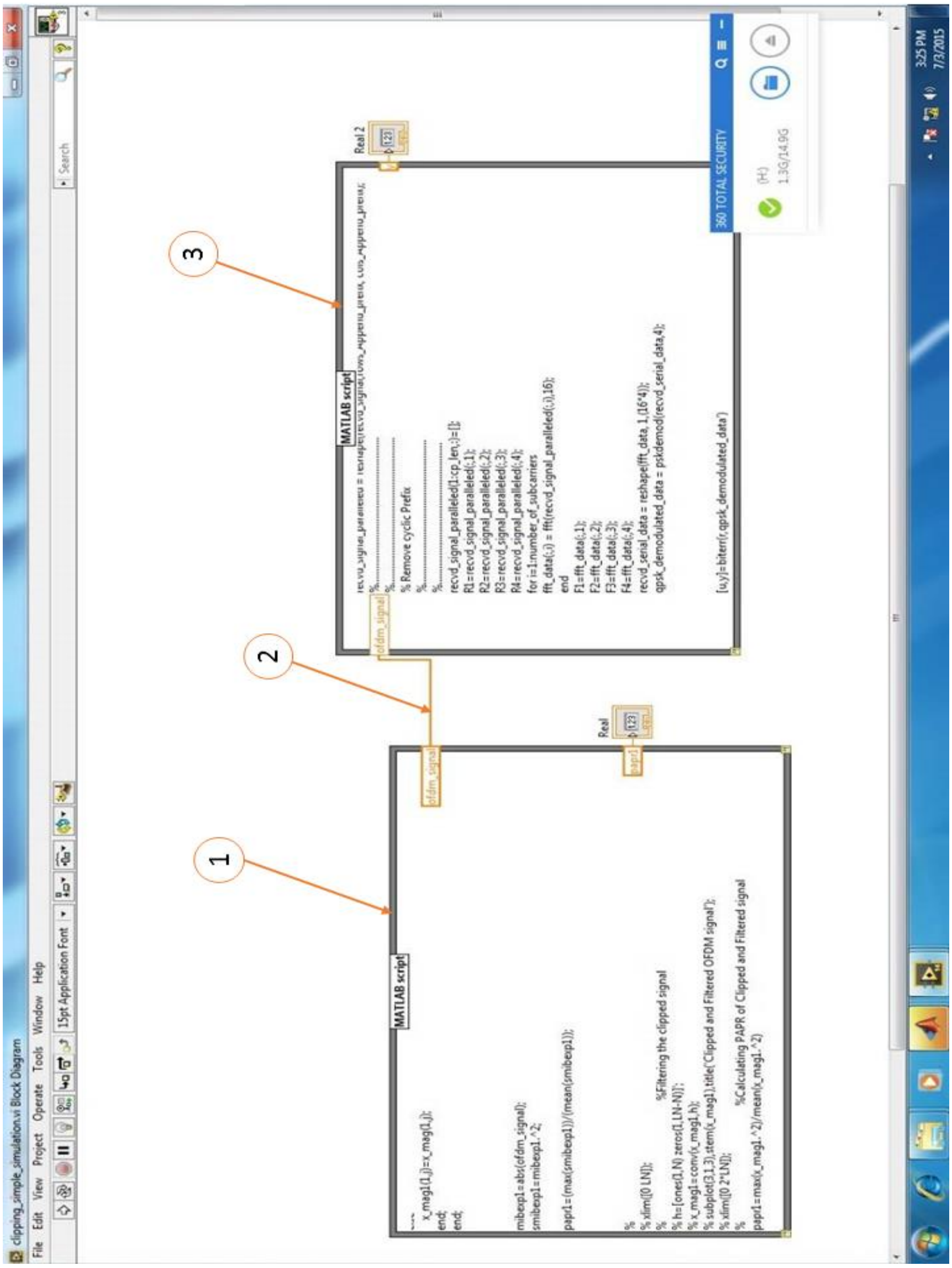


Figure 5.9: Block diagram of Clipping and filtering technique simulation on LabVIEW using Matlab

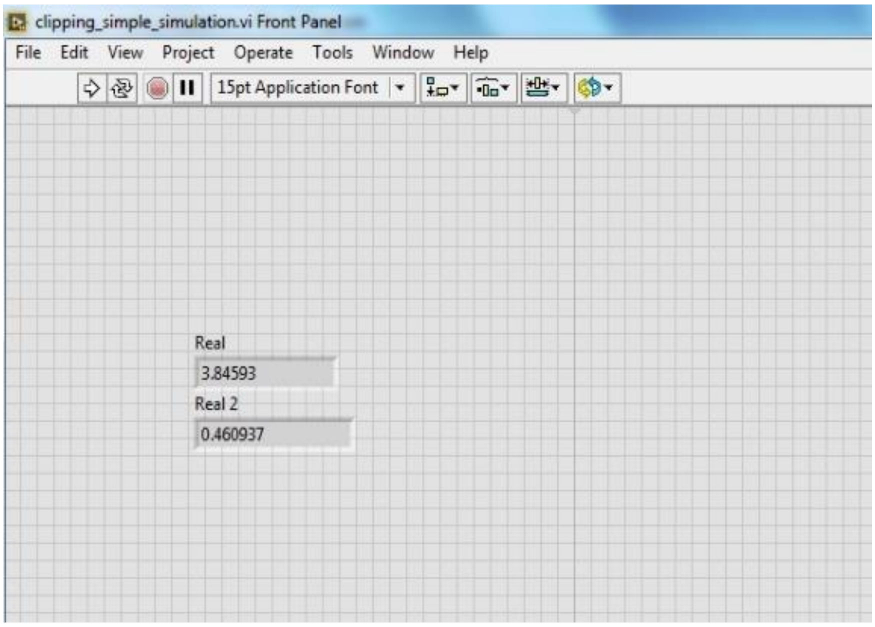


Figure 5.10: Front panel of Clipping and filtering technique simulation on LabVIEW using Matlab

Similarly, the above simulated system was implemented on the NI-USRP 2920 kit and the results were observed as shown below:

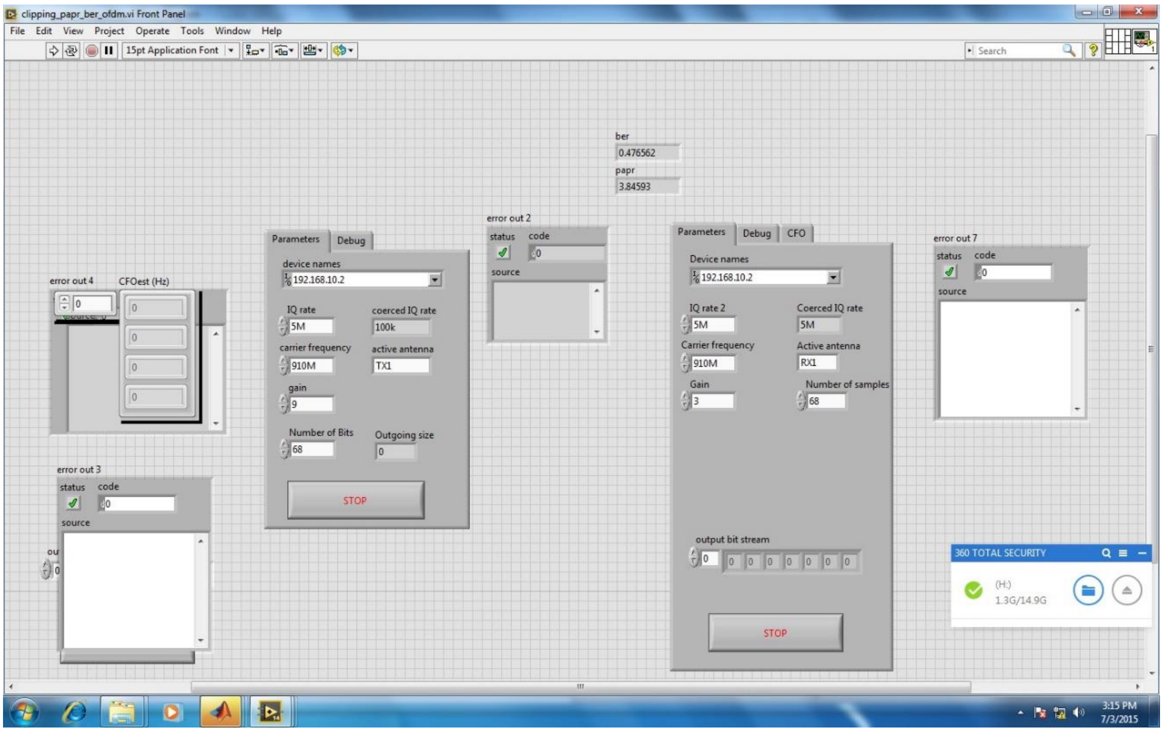


Figure 5.11: Front panel of Clipping and filtering technique implementation on LabVIEW using Matlab

In the block diagram of clipping and filtering (figure 5.12), 4 steps are followed. In the 1st step, the OFDM signal is generated with the help of Matlab code which is transmitted with the help of USRP transmitter section in the 2nd step. Then, the signal is received through USRP receiver section (step 3) which is then demodulated in 4th step

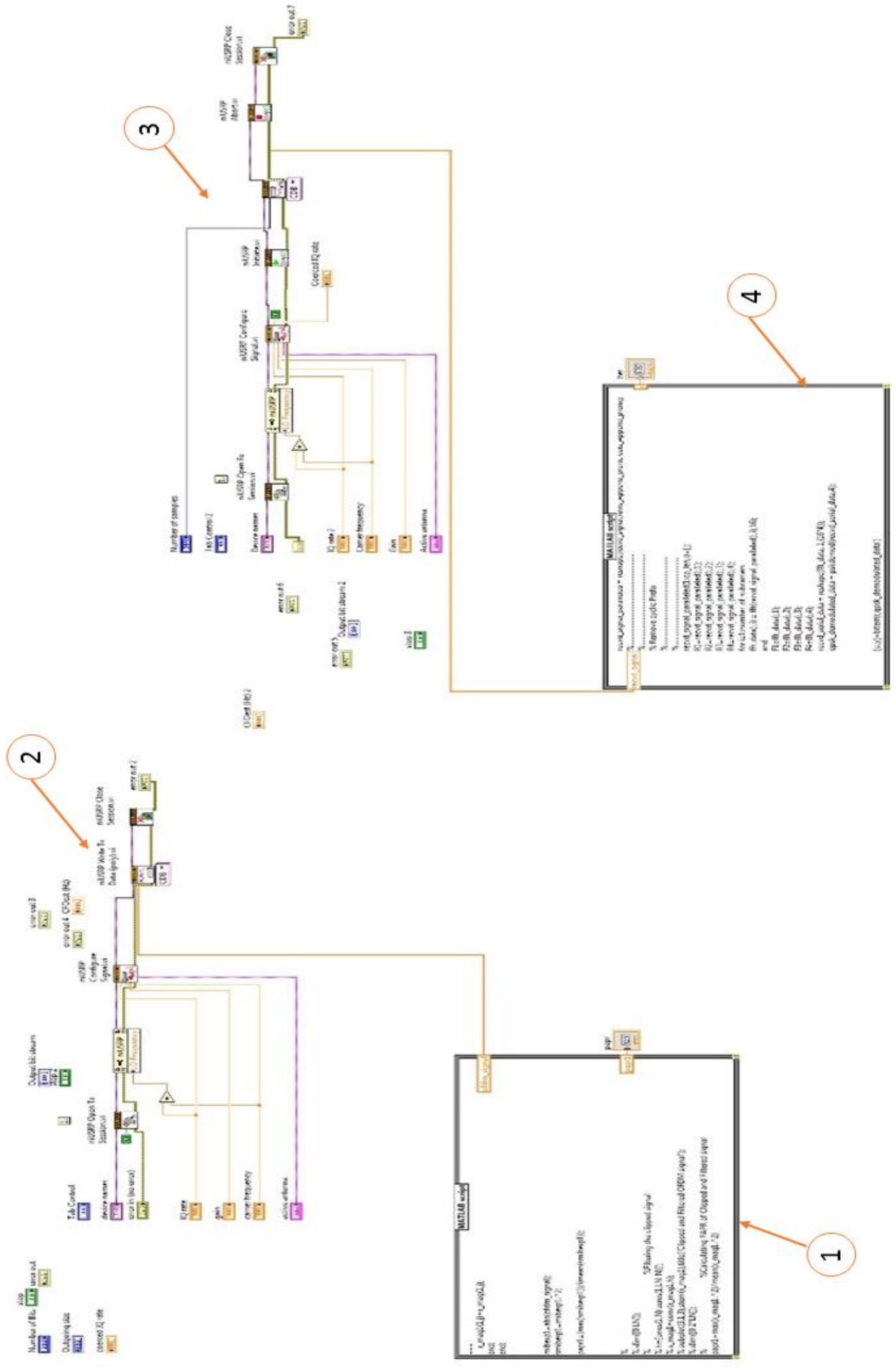


Figure 5.12: Block diagram of Clipping and filtering technique implementation on LabVIEW using Matlab

The values of PAPR and BER taken from different observations are specified in the following table:

Table 5.2: Comparison of different PAPR reduction techniques

Technique Used	PAPR	BER
Simple OFDM	16.2114	0.5156
SLM simulated	12.8089	0.4687
Clipping and Filtering simulated	3.84593	0.4609
Combined Technique	3.84593	0.4609
SLM implemented	12.8089	0.53
Clipping and Filtering implemented	3.84593	0.4765

When all these steps were performed successfully and all the observed values were noted down, the OFDM system implementation was verified by transmitting a coloured image. The transmitted image is shown in the figure 5.13.

Figure5.13: Image transmitted

The block diagram for the above stated system implementation along with the front panel is shown in the figure 5.14 and 5.15 respectively. In the block diagram (figure 5.14), the whole system implementation can be explained with the help of 5 steps/blocks. In the 1st step the image was converted into the useful data (for QPSK modulator input having 4 symbols) and the OFDM signal was generated which was then transmitted with the help of USRP transmitter section. The transmitted data was received with the help of USRP receiver section composed of different blocks. The received signal was demodulated in step 4 and the data was used to generate the image. In step 5, BER was calculated by considering the transmitted and demodulated data.

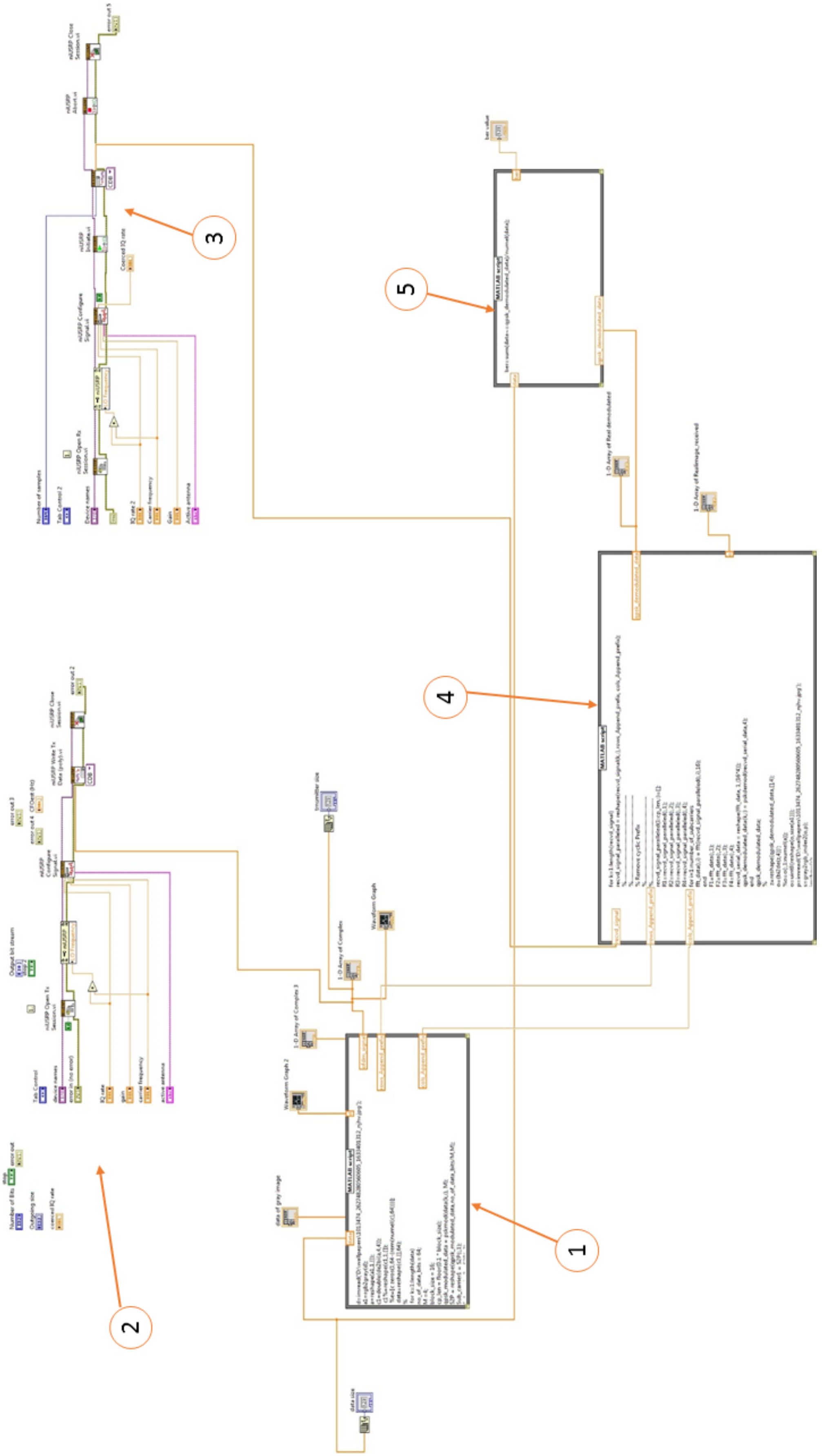


Figure 5.14: Block diagram of OFDM transmitter for transmitting image using USRP

It is clear from the front panel (figure 5.15) that total of 137700 samples were transmitted through the transmitter of the USRP to the receiver. The BER recorded is also specified in the figure.

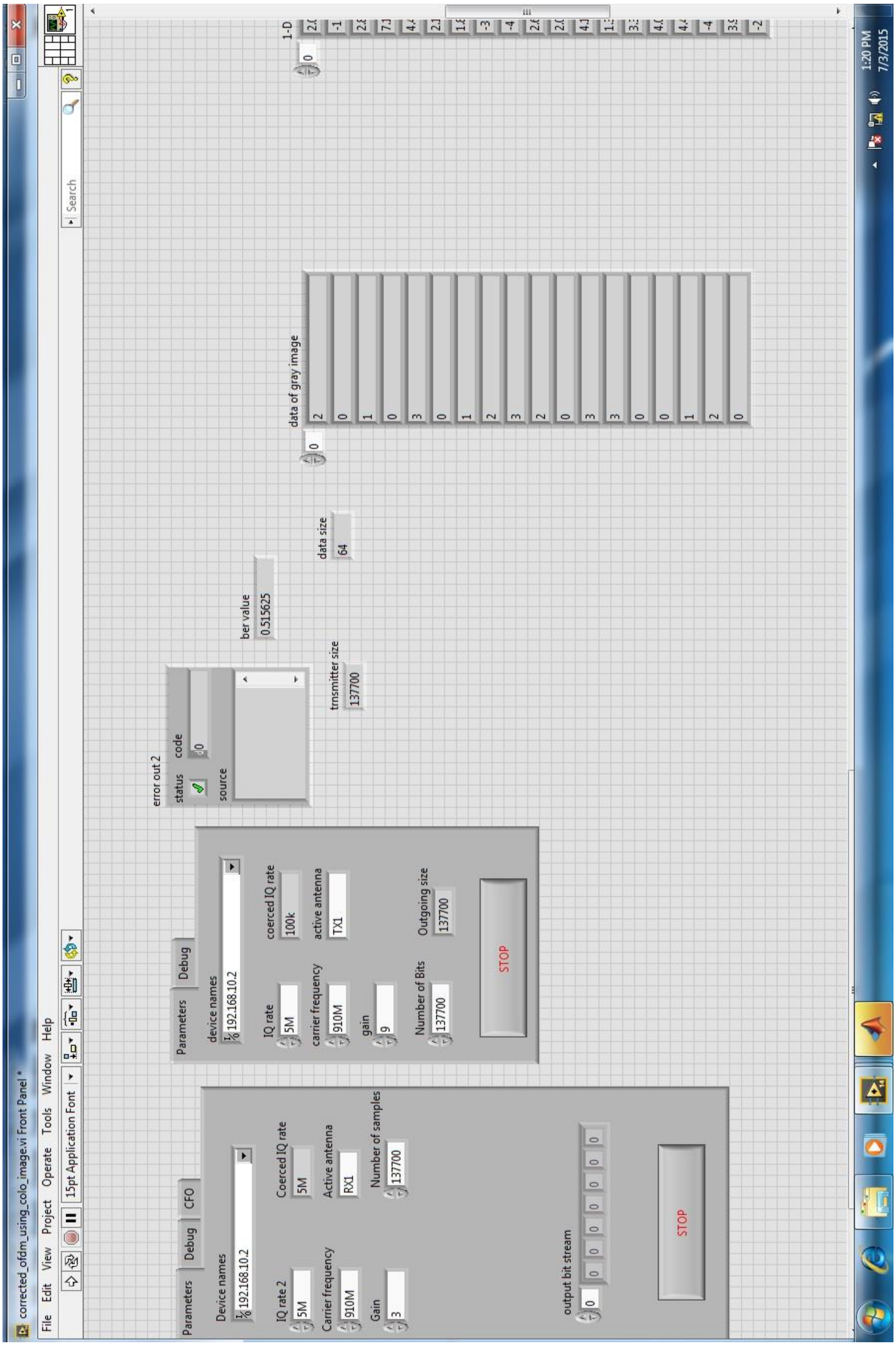
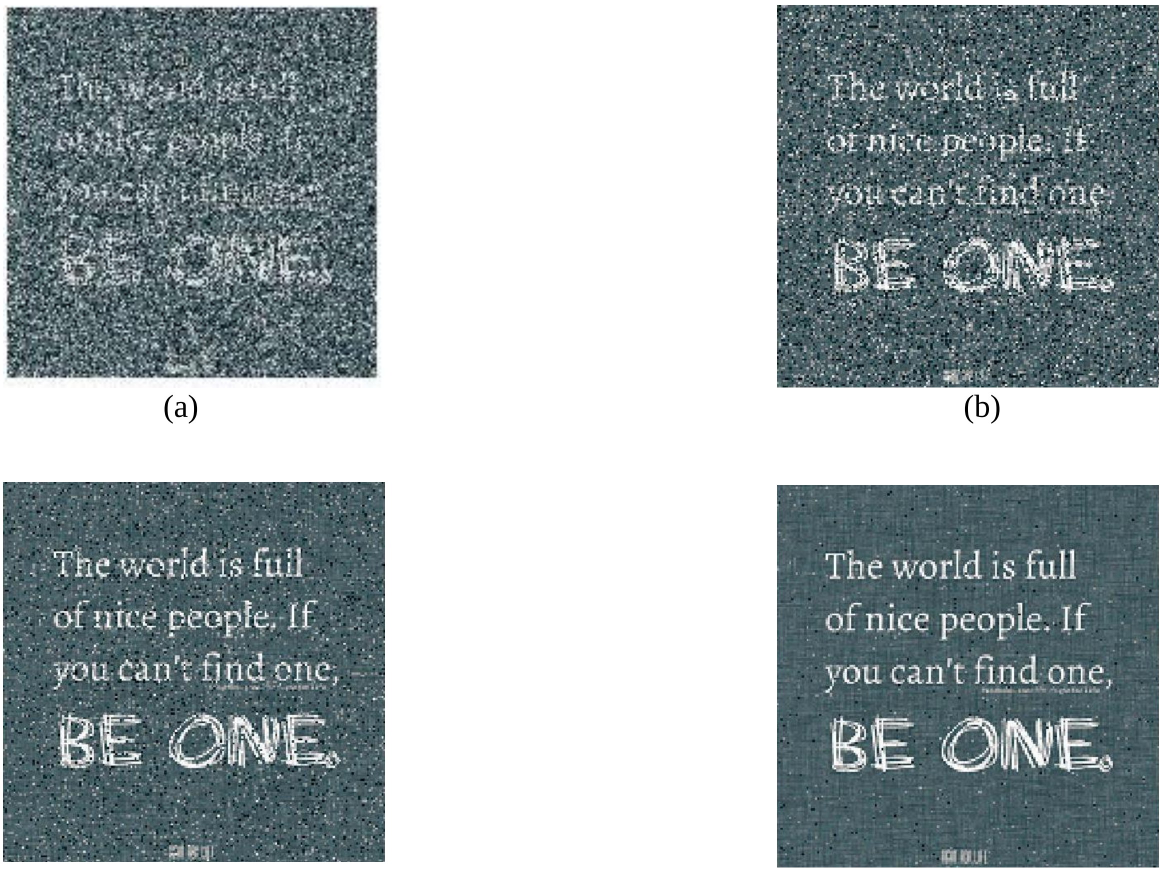


Figure 5.15: Front panel of OFDM transmitter for transmitting image using USRP

The first BER value was taken as a record. The images shown in figure 5.16 were obtained after the successful reception and demodulation of data. The following images were received by transmitting the data at different power levels by varying the 'gain' variable as shown in the front panel.



(a) (b) (c) (d)

Figure5.16: Images received at different gain values

CHAPTER 6

CONCLUDING REMARKS AND FUTURE SCOPE

This dissertation set out to examine the role that PAPR reduction techniques play in improving the efficiency of the system. In this final chapter, the research contributions of this thesis will be concluded. We will also discuss different directions for the future research work.

CONCLUSION

Irrespective of so many advantages of the OFDM system, there exist some major drawbacks which must be solved for getting all the advantages. Hence, for overall improvement in the system performance, it is required to handle all these issues one by one. This thesis presented a brief review of major problems of OFDM system with their existing solutions. The main focus was to provide a solution to the high PAPR problem in implementation of the OFDM system.

From the results given in the previous chapter and the simulations and implementations performed, it can be concluded that this method of OFDM implementation on SDR is quite easy with the help of LabVIEW and the latest Matlab version available.

The OFDM system with reduced values of PAPR was implemented. For the comparison, static data had been taken as the input. Magic matrix was used to define the input to the system. From, the results obtained we can say that clipping and filtering scheme of PAPR reduction behaves much better than any other tested scheme in both the aspects of PAPR and BER.

We have accomplished the implementation of image transmission in OFDM with some level of noise. The image was first converted to the data with different RGB values and then these data samples were used as input to the system.

FUTURE SCOPE

Both the areas like PAPR and BER can still be improved by implementing the system with the help of hybrid techniques that have either been simulated or are yet in the initial stages of research.

Along with PAPR, other issues like large ICI and synchronization can be resolved in the hardware implementation. We have accomplished the implementation of image transmission in OFDM with some level of noise. Further research can be done so as to reduce the level of noise in the actual transmission of image or some data.

The BER value is large to some extent. The level of noise is controlled by varying power level. But, further advances can be done to provide power which is adaptive (according to the BER level required) in nature so that a more efficient and reliable transmission is possible.

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