LONGER TERM DYNAMICS OF BIT ERROR RATE USING UNIVERSAL SOFTWARE RADIO PERIPHERAL (USRP) SOFTWARE DEFINED RADIOS FOR INDOOR ENVIRONMENTS

A THESIS IN
Electrical Engineering

Presented to the Faculty of the University
Of Missouri-Kansas City in partial fulfillment of the
Requirements for the Degree

MASTER OF SCIENCE

BY

ANIRUDH SRINIVAS

Bachelors, Jawaharlal Nehru Technological University, 2014
Master of Science, University of Missouri- Kansas City, 2017

Kansas City, Missouri
2017

L LONGER TERM DYNAMICS OF BIT ERROR RATE USING UNIVERSAL SOFTWARE RADIO PERIPHERAL (USRP) SOFTWARE DEFINED RADIOS FOR INDOOR ENVIRONMENTS

Anirudh Srinivas, Candidate for the Master of Science Degree.

University of Missouri-Kansas City, 2017

ABSTRACT

In a wireless channel, we encounter several problems like multipath fading, interference, reduced spectrum efficiency which makes the system less reliable. In our thesis, we made an analysis of performance of different modulation schemes using Software Defined Radios. Software Defined Radios provides inexpensive approach for engineering problems and paves way for its use in academics and research. We implemented our work using two Universal Software Radio Peripheral kits which are tested at different environments.

The main advantage of using a Software Defined Radio over the traditional radios is that they can be reconfigured on the go. Plethora of experiments can be performed on a single device unlike the traditional device. Owing to its user-friendly nature SDR is being used by many hobby researchers and academicians.

Our primary goal is to perform an analysis on the usage of SDR with different modulation schemes and to compare the results of Bit Error Rate Vs Packets Received for each of the modulation scheme in the indoor environment. For this research, we used GNU radio as a simulation tool along with the USRP hardware.

APPROVAL PAGE

The faculty listed below, appointed by the Dean of the School of Computing and Engineering, have examined a thesis titled "Longer Term Dynamics of Bit Error Rates using Universal Software Radio Peripheral (USRP) Software Defined Radios for Indoor Environments," presented by Anirudh Srinivas, candidate for the Master of Science degree, and certify that in their opinion, it is worthy of acceptance.

Supervisory Committee

Cory Beard, Committee Chair

Associate Professor, School of Computing and Engineering.

Ghulam M. Chaudhry,

Professor & CSEE Department Chair.

Ahmed M. Hassan,

Assistant Professor, School of Computing and Engineering.

TABLE OF CONTENTS

ILLUSTRATIONS

Figure Page

LIST OF TABLES

Figure Page

ACKNOWLEDGEMENTS

I would like to thanks Professor. Cory Beard for his immense faith in me and our work. This work would have not been possible without his valuable suggestions and guidance. With his optimistic approach, he made us learn new things which helped us not only in our research work but also in finding our jobs. Without Dr. Beard's support, we could not have come this far. His perspective towards making students learn make him a unique teacher and I can always proudly say in my life that I worked for Dr. Beard. I also thank Aklilu Gebremichail who introduced us to the GNU Radio. I thank Mustafa Tekinay, Todd Gardner and Rahul Paropkari for always giving their time to make our work a distinguished one. Last but not the least this acknowledgement will be incomplete without thanking my partner Jaya Chandra, who helped me in times of need.

This acknowledgement will be incomplete if I forget to thank my family and friends who helped me a lot when I was struggling. Thanks for being there.

To my family and friends,

CHAPTER 1

INTRODUCTION

1.1 Overview

In the recent times the world has witnessed phenomenal changes in the wireless technology. Software Defined models are penetrating the world owing to their advantages over hardware based traditional devices. The emergence of Software Defined Radio can be termed as a huge leap in the wireless industry. Software Defined Radio (SDR) brings flexibility, cost efficiency and ease of working to the users. These distinguished features made SDR a widespread commodity in the present-day market.

The users can use SDR and customize the software depending on their needs and requirements. Instead of building extra circuitry for different uses of radio signals, in SDR the user can customize the script (code) and use it on the go. By reusing the hardware for different applications, it is possible to reduce the time to market and development cost.

SDR works on the concept of making radio functions hardware independent. Complex wireless and DSP functions like modulation, demodulation, filtering etc. can be actualized in software disposing the need of hardware.

SDR provides a great advantage to the academic field by providing equipment at least cost and helps the students to gain hands on experience working with the equipment. Apart from the cost it provides a great flexibility in working on different schemes. We used USRP as hardware and used GNU Radio as our software implementation for the radios. A combination of USRP and GNU Radio help us to realize SDR. Various signal processing functions are implemented using C++. The signal processing blocks are implemented in C++ and the main functions are written in Python language. Simplified Wrapper and Interface Generator works as a glue between C++ and

Python. C++ classes are converted into python compatible classes using SWIG. The GNU Radio framework can tie these two languages together. On a comparative scale, C++ provides a compact code for signal processing while Python provides flexibility and ease of programming.

In the process of our thesis work, various modulation schemes are used to transmit the desired signal at different rates. Modulation comes as a blessing in many ways, in providing higher data security and better quality communications and also with many more advantages.

In this thesis, we investigate which modulation scheme is effective in different environments, i.e., the received signal is checked and analyzed for the bit error rates and the readings obtained are taken onto a graph using MATLAB.

1.2 Motivation

We were fascinated when we studied about communication systems and how real world communication happens. This keen interest and enthusiasm made us work with the radios which are very user friendly which means it does not need many man days to spend for its understanding.

1.3 Methodology

Working with the SDR and USRP require good knowledge in signal processing and wireless communications. We had the USRP 1 available to us so we started to work on it for our research.

1.4 Major Concerns

After deciding to work on GNU Radio and USRP we had a question on what operating system will be suitable for handling these two together. We found that implementation of GNU Radio in windows is not taken off and Windows is not GNU Radio friendly. So, we chose to work on Linux platform (Ubuntu) which is very user friendly and supports GNU Radio without any major problems.

1.5 Objective

The main objective of our thesis project is to evaluate the performance of modulation schemes like BPSK, QPSK and GMSK using received Bit Error Rates as key performance indicators. We conducted our experiments at different environments like lab, hallway and outside environments. We have chosen to use USRP and GNU radio, which are widely used software defined radios hardware and software platforms. Firstly, we sent data from the transmitter to the receiver using the USRP.

The data is nothing but a string of letters 'hhh' that are transmitted over the air and checked at the receiver. Secondly we made necessary changes to the existing Python code so that we can get the Bit Error Rates displayed at the output receiver. Finally, we plotted the data that is received at the receiver using MATLAB and generated the plots for various experiments.

Our approach is as follows: We used the benchmarking tool of GNU radio to carry out our experiment. Benchmarking gives us the flexibility to choose which modulation scheme to use and gives us an opportunity to change other parameters like operating frequency, gain (TX and RX) and symbols per second. As already discussed we conducted this experiments at different environments depicting the characteristics of indoor and outdoor channel propagation models.

There is also an alternate method for benchmarking. We can use the GNU Radio Companion to build blocks and make it work through the constructed blocks. We choose the benchmarking as it is time saving and pretty much easier to interpret to new users. The problem with using GRC (GNU Radio Companion) is that if proper care is not taken in building the blocks, a lot of errors may arise and it takes time to recognize the errors and correct them.

1.6 Related Work

When we started working on the Software Defined Radios, we started to look for some work which was done previously so that they might help us in our course of work. As seen earlier our work was analyzing the peak burst error rates for different modulation schemes in the indoor environment. We used the benchmarking technique where we can edit the parameters like: operating frequency, transmitter and receiver gain and samples per symbol. The closest work which we found out was a thesis work where they discussed on how data is sent to the receiver. Let's discuss in detail on this work that was carried out.

- **Implementation of Wireless Communications over GNU Radio [6]:**

This work is a thesis report submitted to the University of North Texas by Simon M. Njoki. They used the benchmarking technique and their work was mainly concentrated on only the data transfer and its reception. Normally when the packet is sent to the receiver and if it is received correctly, it is indicated by showing "ok=True" or "ok = False" if the data is corrupted.

```
ok = True  pktno = 149 n_rcvd = 150 n_right = 150
ok = True  pktno = 150 n_rcvd = 151 n_right = 151
ok = True  pktno = 151 n_rcvd = 152 n_right = 152
ok = True  pktno = 152 n_rcvd = 153 n_right = 153
ok = True  pktno = 153 n_rcvd = 154 n_right = 154
ok = True  pktno = 154 n_rcvd = 155 n_right = 155
ok = True  pktno = 155 n_rcvd = 156 n_right = 156
ok = True  pktno = 156 n_rcvd = 157 n_right = 157
ok = True  pktno = 157 n_rcvd = 158 n_right = 158
ok = True  pktno = 158 n_rcvd = 159 n_right = 159
ok = True  pktno = 159 n_rcvd = 160 n_right = 160
ok = True  pktno = 160 n_rcvd = 161 n_right = 161
ok = True  pktno = 161 n_rcvd = 162 n_right = 162
ok = True  pktno = 162 n_rcvd = 163 n_right = 163
ok = False pktno = 163 n_rcvd = 164 n_right = 161
ok = False pktno = 164 n_rcvd = 165 n_right = 159
ok = False pktno = 165 n_rcvd = 166 n_right = 157
ok = False pktno = 166 n_rcvd = 167 n_right = 155
ok = False pktno = 167 n_rcvd = 168 n_right = 153
ok = False pktno = 168 n_rcvd = 169 n_right = 152
ok = False pktno = 169 n_rcvd = 170 n_right = 150
ok = False pktno = 170 n_rcvd = 171 n_right = 147
ok = False pktno = 171 n_rcvd = 172 n_right = 145
```

Figure 1: Receiver Terminal Window

As we can see their research was limited to checking the received data if it is corrupted or not. This is the closest match for our research work. There are a few journals and research papers which we studied in the course of improving our knowledge on SDR's. Now we are going to discuss on the research works which we studied in the course of our preparation. These works also use USRP and GNU Radio for implementing their desired results.

- **Analysis of FEC in digital signal transmission with USRP over SD-RANs [7]:**

In this research, Forward Error Correction was experimentally studied in software defined radio access networks by means of transceivers based on USRP. A system separated by a 2 meter wireless link was tested and attained an improvement in the performance of 4 dB for BPSK and QPSK modulation formats and also 5 dB for 8-PSK when adding a Reed Solomon code for reducing the errors.

Code	Bits corrected	Effective data [%]	Processing time [ms]
RS(127, 123)	2	96.85	0.596
RS(255, 253)	1	99.21	1.13
RS(511, 505)	3	98.82	2.27
RS(1023, 1017)	3	99.41	4.27

Figure 2: Results obtained

So as we observe the bits which are corrected and which reed solomon code was used was discussed in the paper along with a few graphs that discuss about the SNR vs BER.

- **SDR-based transceiver of Digital Communication Systems using USRP and GNU Radio [8]:**

In this research the digital communication system is realised using USRP and GNU radio. GNU Radio companion is used for this research which uses process blocks called flowgraphs which are connected togethor for attaining a certain output. The processing blocks used in this research are encode/decoder, source/sink and modulator/demodulator. An analysis of SNR vs BER for different modulation schemes of BPSK, QPSK, 16 QAM and 64 QAM were analysed. Flow graphs for the modulators are built in GNU Radio Companion and thus the results were obtained. On a whole this research discusses more on the behaviour of different modulation schemes under the same signal to noise ratio which is commonly taught in the daily literature.

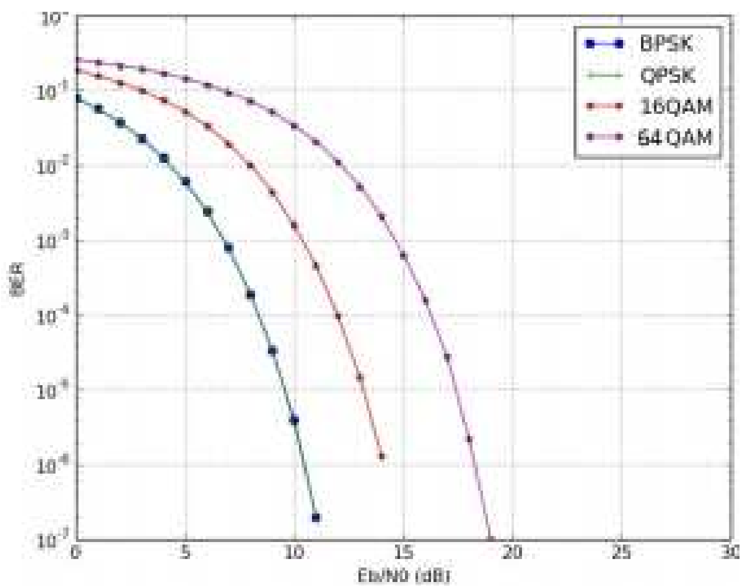

Figure 3: SNR vs BER

- **Development of Radio Telescope Receiver Based on GNU Radio and USRP [9]:**

This research focusses on the development of radio telescope receiver based on GNU radio and Universal Software Radio Peripheral. Here the design of the radio telescope receiver is developed on GNU Radio and implemented using the hardware interface USRP. By using the SDR the operating frequency selection can be carried out freely and easily. In this work the SDR used for developing the radio telescope receiver is based on GNU Radio and the implementation of it is done using USRP. An existing telescope receiver can only be used for a fixed frequency; hence the other frequency receiver needs to be carried out with different observations.

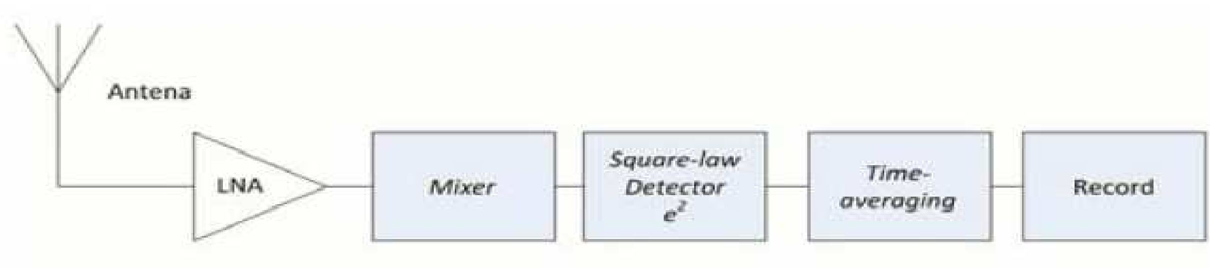

Figure 4: Block Diagram of a Radio Telescope Receiver

The tests are carried out by sending two sinusoid signals corrupted by noise. A series of results were plotted for the average output power at certain frequencies. The results depict that the implemented radio telescope receiver which is applied for continuous observation can clearly detect signals at frequencies of 322 MHz and 406 MHz in which those frequencies are usually used in radio telescope.

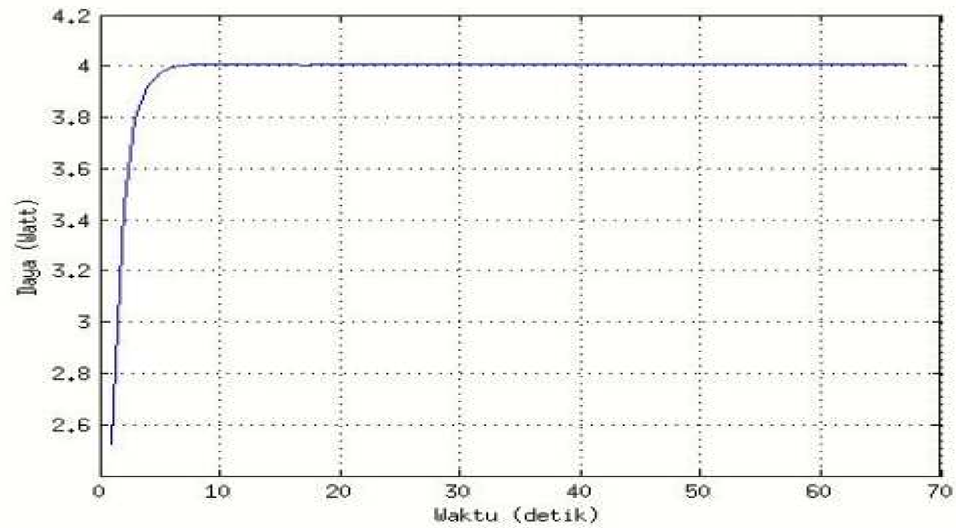

Figure 5: Results for Continuous Observation

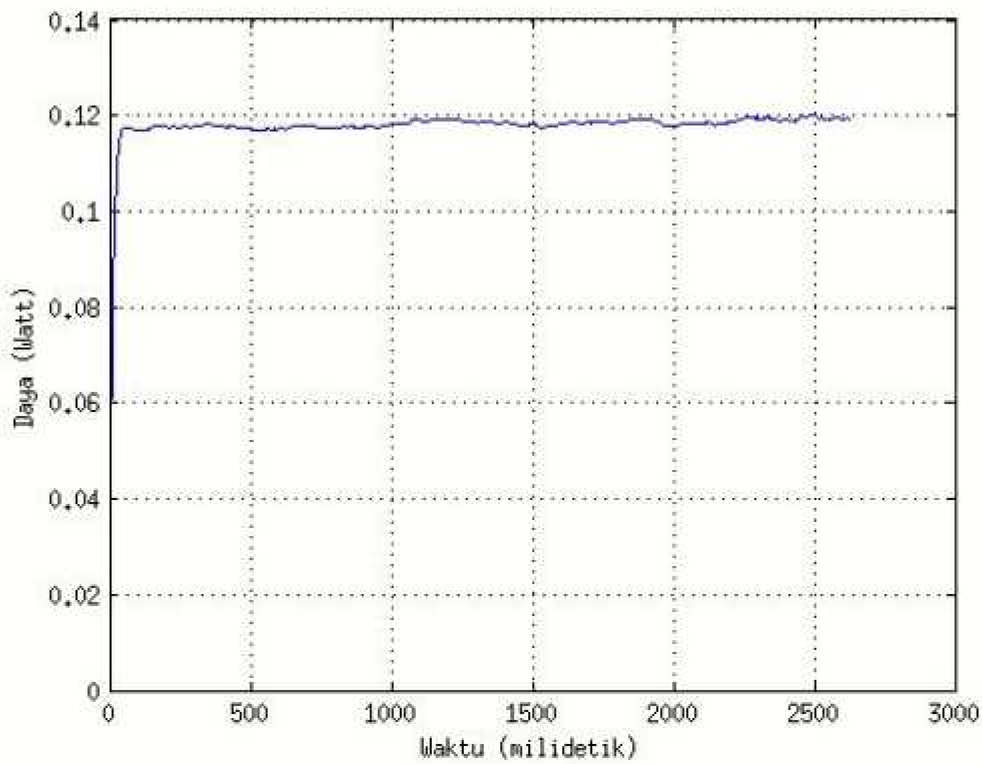

Figure 6: Average Power Output at 322 MHz

- **Experimental Emergency Communication Systems Using USRP and GNU Radio [10]:**

This research solely focus on how to establish a temporary emergency communication system (ECS). A USRP platform with GNU Radio is employed for experimental purpose with basic voice communications and exchange of short message services. A pre-installed app in the victim's smartphone gives valuable information about his identity, location or physical condition.

The aim of this research is to add light on GSM-based BS deployment in disaster area and discuss their effects on emergency communications and relief operations. With the recent development in SDR, it can substitute the back-end hardware with real-time software applications. The development of USRP and GNU Radio drives an effective SDR solution called Open Base Transceiver Station (OpenBTS). With an emulation of GSM architecture over USRP radio boards, OpenBTS has been successfully implemented to provide voice connectivity and messaging in rural areas at low costs. Several topics on the impact of disaster to emergency communication system was explained and are divided into 3 phases: namely Preparation Phase, Action Phase and Recovery Phase.

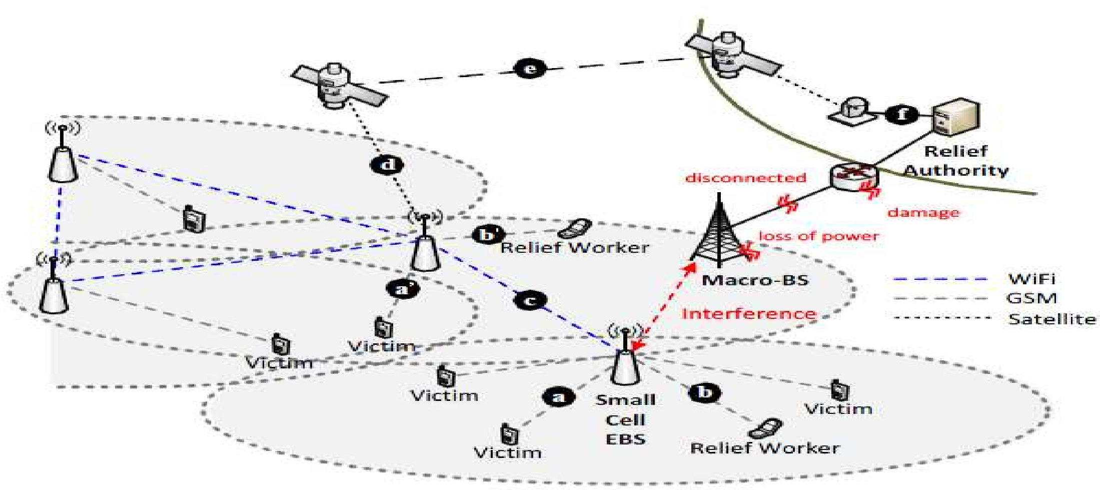

Figure 7: Network Architecture of ECS

The proposed ECS adopts mesh topology, integrates the GSM,WiFi technologies and provides various kinds of communications between participants. Participants could just use the App and thus be beneficial in life saving.

CHAPTER 2

SOFTWARE DEFINED RADIO

2.1 Software Defined Radio Architecture

A software defined radio is a real-time system. Actions are performed by the radio operator and the data is produced by active elements present in the SDR like Analog to Digital Convertor which acts as inputs to the system. The outputs are the graphical and digital depictions of the radio signals.

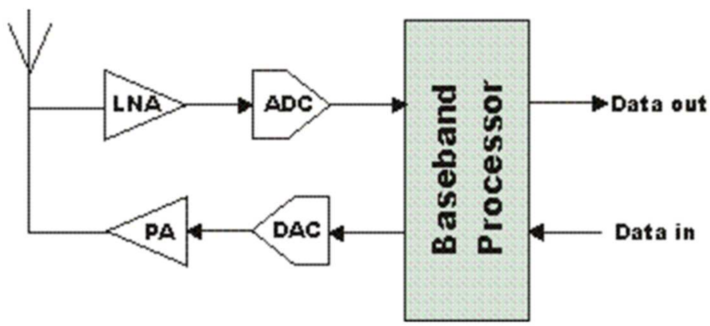

Figure 8: Block Diagram of an ideal SDR

The above shown block diagram is a depiction of basic software defined radio and we are going to see in detail about the basic working of SDR.

RF Amplification: The amplifier is used to increase the level of the RF signal to the required power to be transmitted. On the receiver side signals from the antennas need to be amplified before going further into the receiver. If the antenna signals are directly converted to digital signals, quantization noise becomes an issue.

Digital Conversion: Signals are converted from digital to analogue formats.

Baseband Processor: This is the center of the Software Defined Radio. It digitally converts the incoming or outgoing signals in frequency. These elements are known as Digital Up Convertors which are used for converting the outgoing signal from baseband frequency to the required output frequency for conversion from digital to analog. On the receiver side, Digital Down Convertor is used to bring the signal down in frequency. The signal also needs to be demodulated, filtered and original data extracted for further process.

In the above description, we have seen the general description and working of how a basic SDR works. Now we dive into the step-by-step process that takes place when a signal gets transported from the transmitter to the receiver.

2.2 Detailed description of Radio Transmission

The following figure outlines the steps involved in radio transmission.

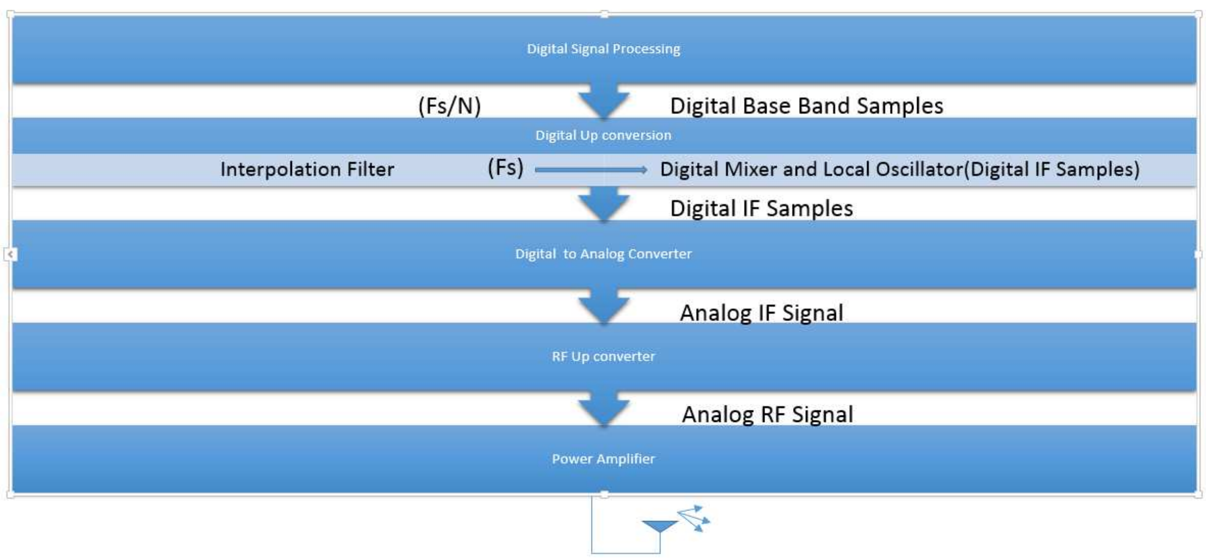

Figure 9: Block Diagram of a Radio Transmitter

2.2.1 Digital Signal Processing (DSP)

The input to the transmit side of an SDR is a digital baseband signal generated by the sampling stage. The input can be of any form like audio, video, data, etc.

2.2.2 Digital Up Converter

For a signal to get transmitted to the destination, a transition from the baseband frequency to an intermediate frequency is needed and a DUC serves this purpose.

A DUC has three important sections:

- Interpolation filter
- Digital Mixer
- Digital Local Oscillator

The digital mixer and local oscillator translate the baseband samples to the IF frequency. The local oscillator decides the frequency to which the baseband samples are to converted. A mixer generates one output sample for two input samples provided. The output from the mixer must be equal to the D/A sample frequency f_s. Therefore, the sample rates of both the inputs should be f_s. The local oscillator already has a sampling rate of f_s. Interpolation filter is used: as the input baseband frequency is very low when compared to the sampling frequency.

The interpolation filter increases the baseband signal frequency by a factor of N known to be the Interpolation Factor.

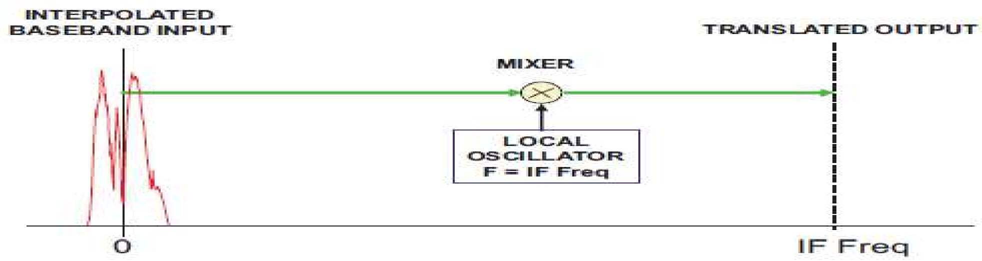

Figure 10: Digital Up Converter Process

2.2.3 D – A converter

The Digital to Analog converter converts the digital IF samples to an analog IF signal.

2.2.4 RF Up Converter

This converts the analog IF signal to the RF frequencies.

2.3 Detailed Description of Radio Reception

The following figure shows how the data after getting transmitted from the transmitter is received at the receiver.

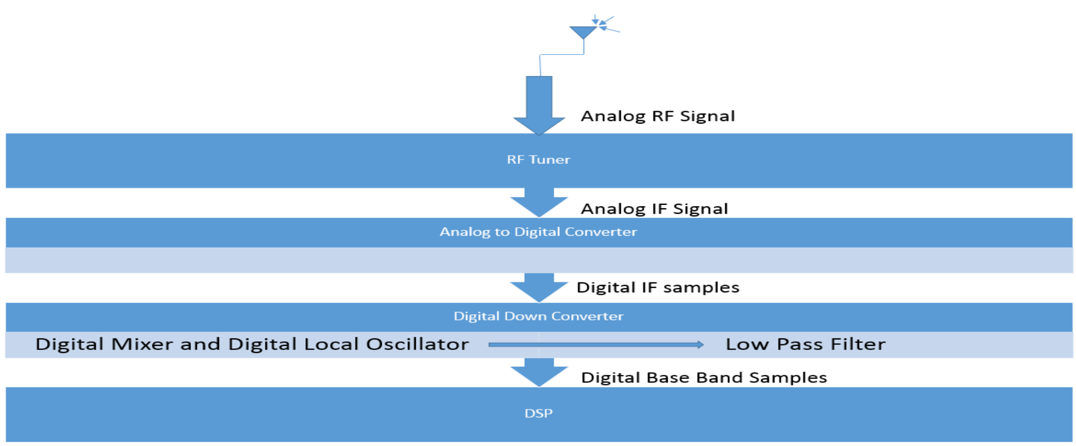

Figure 11: Block Diagram of Radio Receiver

2.3.1 RF Tuner

The RF tuner has a mixer, amplifier and oscillator. The signal is amplified and fed as inputs to the mixer. The mixer gets another input from local oscillator whose signal frequency can be determined by tuning the radio. The mixer converts the signal to an Intermediate Frequency (IF).

2.3.2 A to D Converter

Once an analog IF signal is obtained it is sent to the ADC to convert the analog signals to digital signals.

2.3.3 Digital Down Converter

An SDR consists of a DDC which is typically an FPGA IP which is considered to play a key role in processing of the signal.

A DDC has 3 sections:

- A Digital Mixer
- A Digital Local Oscillator
- An FIR Low Pass Filter

A DDC performs the following functions:

- Frequency translation with tuning control local oscillator
- Low pass filter with bandwidth controlled by a decimation setting

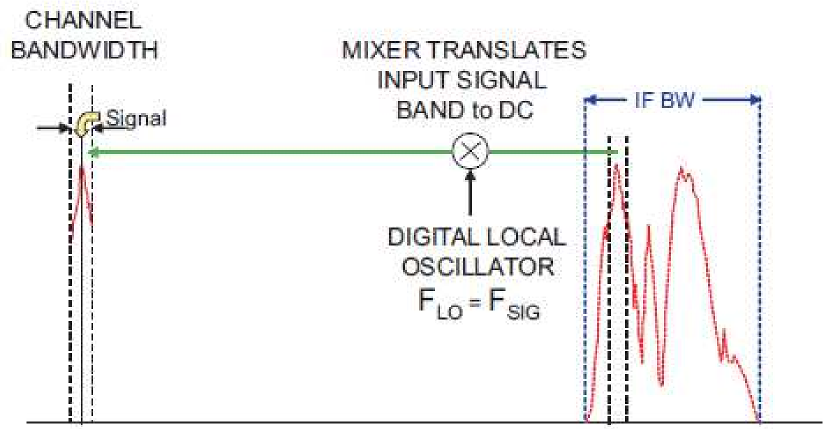

Figure 12: DDC Block Diagram

2.3.4 Digital Signal Processing

The digital baseband signals are then fed to a DSP block where decoding, demodulation and other processing takes place. We used the following components in our research work:

1.) Antennas: To transmit and receive radio signals on the desired frequencies.

2.) Daughter Boards: They serve as digital baseband and IF section of the communication system.

3.) Personal Computer with GNU Radio: The signals are processed on a PC and then fed through a USB connection.

2.4 Advantages of SDR

- Reducing the cost of hardware which is a major problem.
- Software can be reused across radio products reducing development costs dramatically.
- New features and capabilities can be added to existing infrastructure without spending huge amounts on the infrastructure.
- Reconfigurable to suite customer requirements.

- The ability to transmit and receive various modulation methods on a common hardware makes it a winner.
- The chance of new experimentation.

2.5 Disadvantages of SDR

- There are technology limits on achievable RF performances.
- The choice of architecture depends on available technology.
- Software reliability may define overall radio reliability.
- Documentation can be scarcely available for hardware radios.

2.6 GNU Radio

GNU Radio is open source development toolkit providing signal processing blocks to implement software-defined radios. It can be used with readily available low cost external hardware to create software-defined radios

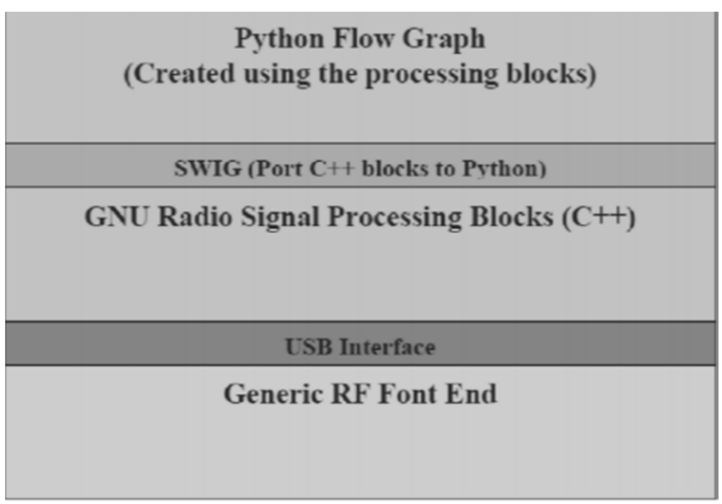

Figure 13: GNU Radio Block Diagram

All the signal processing is done by the GNU Radio. One can use it to write applications to receive data out of digital streams, to push data into digital streams, which is then transmitted using hardware. GNU Radio has filters, channel codes, synchronization elements, equalizers, demodulators, decoders and many elements. We call these elements as blocks in GNU jargon.

Usually, complex baseband samples are the input data type for transmitters. The users can design their own blocks using C++ and install these blocks to the library after generating Python code by SWIG.

2.7 USRP

The Universal Software Radio Peripheral is the hardware set up for the SDR which is composed of programmable field gate array, Analog to Digital Convertor, Digital to Analog Convertor and a USB. It is designed to interface analog signal to software. It takes an analog signal and interfaces it with the SDR libraries such as GNU Radio, SIMULINK with MATLAB, LabView and UHD.

USRP basically is a motherboard with FPGA as well as a USB controller. It has daughter boards with transmitter and receiver. The daughterboard contains transformers with impedance match. Altera FPGA outputs streams of data into a Cypress FZ 2 microcontroller. The microcontroller accesses the interface between the FPGA and USB 2.0 so that we can transfer data into the PC. In addition to two analog signal inputs or outputs for basic transmitter and receiver boards we also have access to various auxiliary digitizers as part of a mixed signal front end.

2.7.1 Applications of USRP

- RFID Reader
- Cellular GSM base station
- GPS Receiver
- FM Radio Transmitter
- FM Radio Receiver
- Amateur Radio
- Synthetic Aperture Radar
- Digital television (ATSC) decoder
- Mobile WiMax receiver with USRP N 2*0
- APC025 compatible transmitter/receiver and decoder
- Digital Broadcasting (DAB/DAB+/DMB) transmitter

The following figure shows the picture of the USRP board in casing. To be simple, this is how the USRP looks from the inside.

Figure 14: Inside view of a USRP in a case

2.7.2 Block Diagram of USRP

The following diagram depicts the systematic representation of the block diagram of a USRP. Each USRP module can be configured to TX or RX operation mode. We can see below the block diagram of a USRP showing its basic components like transmit and receive daughter boards and the A to D convertors.

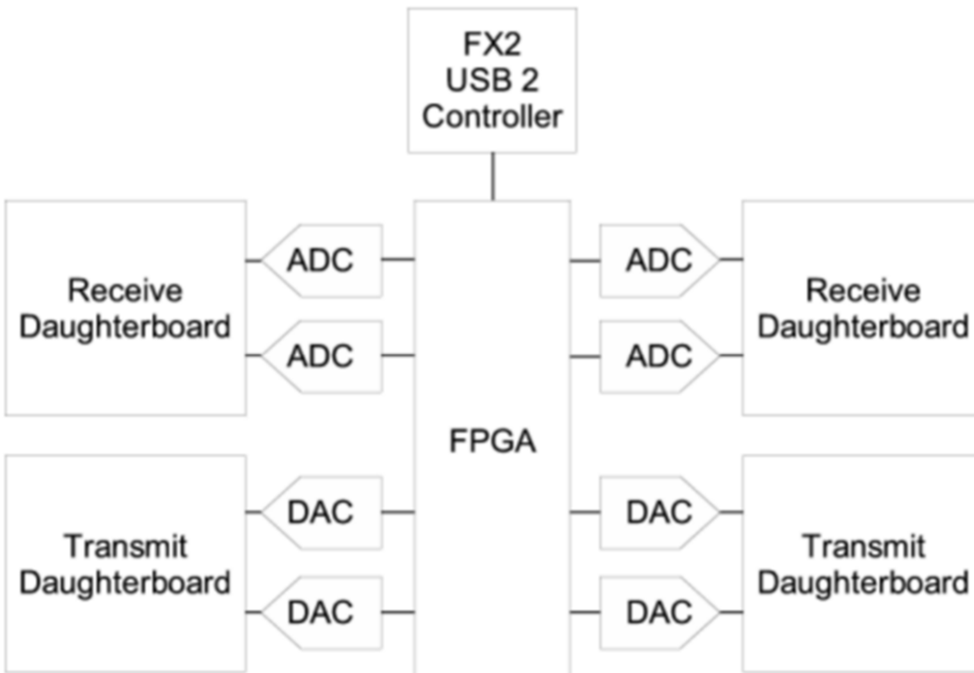

Figure 15: Block Diagram of a USRP

2.7.3 USRP Daughter Boards

Ettus Research offers many daughter boards with distinguishable features. The daughter boards are easily installed and available for any projects. We used the USRP 1 which comes with the RX 900 daughter boards. A USRP device has 2 daughter boards – 2 each for a transmitter and a receiver.

Daughter boards make it possible to use the USRP in different frequency spectrums. This is because there are physical RF components needed to receive different frequency spectrum. Each daughter board slot has access to 2 of the 4-high speed AD/DA converters. It is possible to use transceiver daughter boards to enable USRP to send and receive data simultaneously.

2.7.4 Analog to Digital Convertors

The ADC converts analog signal to digital. It consists of 4 - 64 MS/s 12-bit A to D convertors. It could digitize a bandwidth of 32 MHz. The only problem is, it is not possible to receive signal with bandwidth larger than 32 MHz. Therefore, the 32 MHz is calculated based on the Nyquist Rate.

2.7.5 Digital to Analog Convertors

DAC converts the digitized signal to analog form. On the TX side there are 4 high speed 14-bit D-A convertors. The DAC clock frequency is 128 million samples per second and Nyquist rate is 64 MHz.

2.7.6 Auxiliary Digital I/O Ports

The USRP motherboard has 32 bits each for the transmitter and the receiver consisting of high speed 64-bit digital I/O ports. These are connected to the connectors of daughterboard interfaces (RXA, TXA, RXB, TXB).

Several operations like automatic receive and transmit mode, synthesizer lock detection, power supply control etc. are performed using these pins.

2.7.7 FPGA

The Field Programming Gate Array is one of the most important parts in the USRP system. It performs high bandwidth math, and reduces the data rate that it transmits over USB 2.0. The FPGA connects to a USB 2 interface chip, the Cypress FX2. The FPGA circuitry and USB microcontroller is programmable over the USB2 bus.

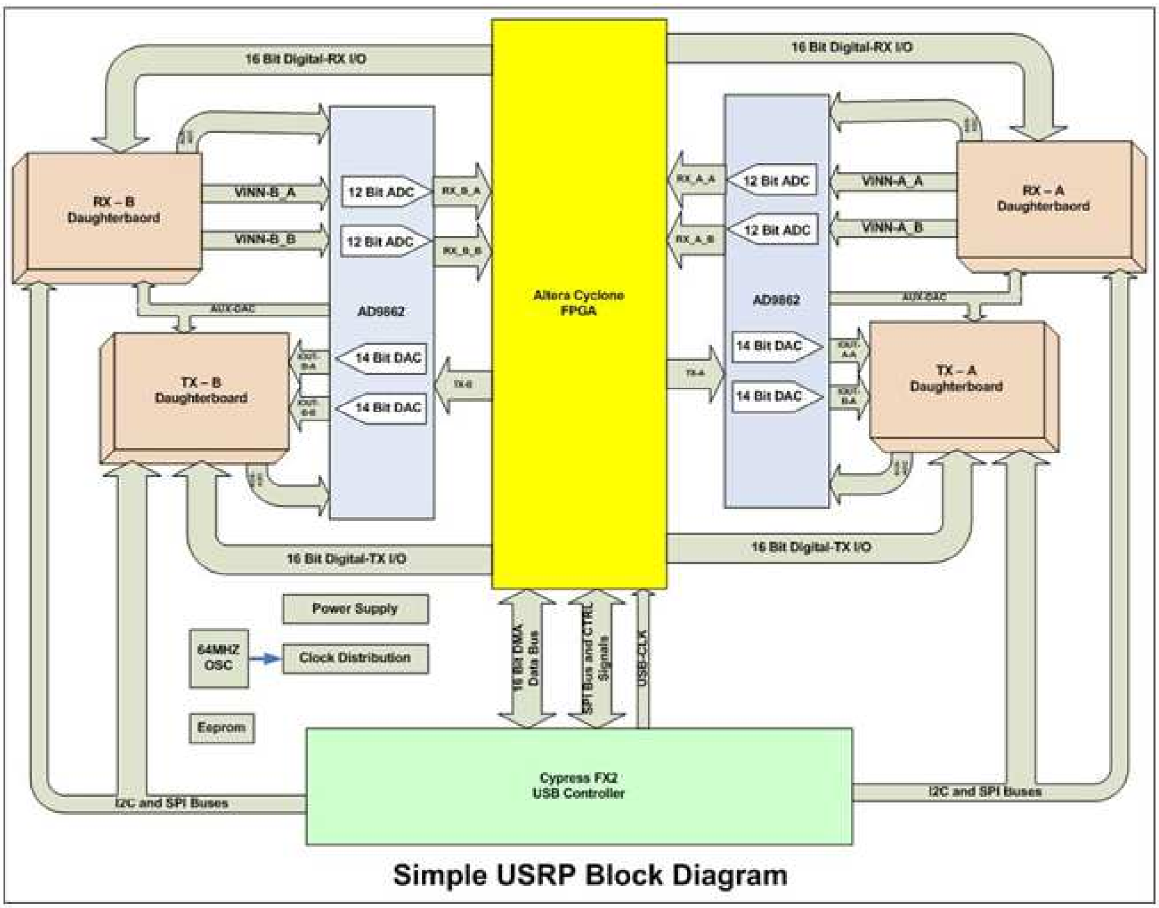

Figure 16: USRP Functionality Block Diagram [ref for diagram]

2.7.8 Digital Down Convertors (DDC)

The Digital Down convertors (DDC) are implemented with 4 stage Cascaded Integrator Comb (CIC) filters. These filters are high performance filters using adders and delays. The standard FPGA configuration implements 2 complete digital down convertors. There is a configuration with 4 DDCs but without half band filters, which allows 1,2 or 4 separate RX channels.

In the 4 DDC execution, the RX way has 4 ADCs and 4 DDCs. Every DDC has two sources of information coming from I and Q. Each of the 4 ADCs can be directed to either of I or the Q contribution of any of the 4 DDCs. This considers having numerous channels chosen out of the same ADC test stream.

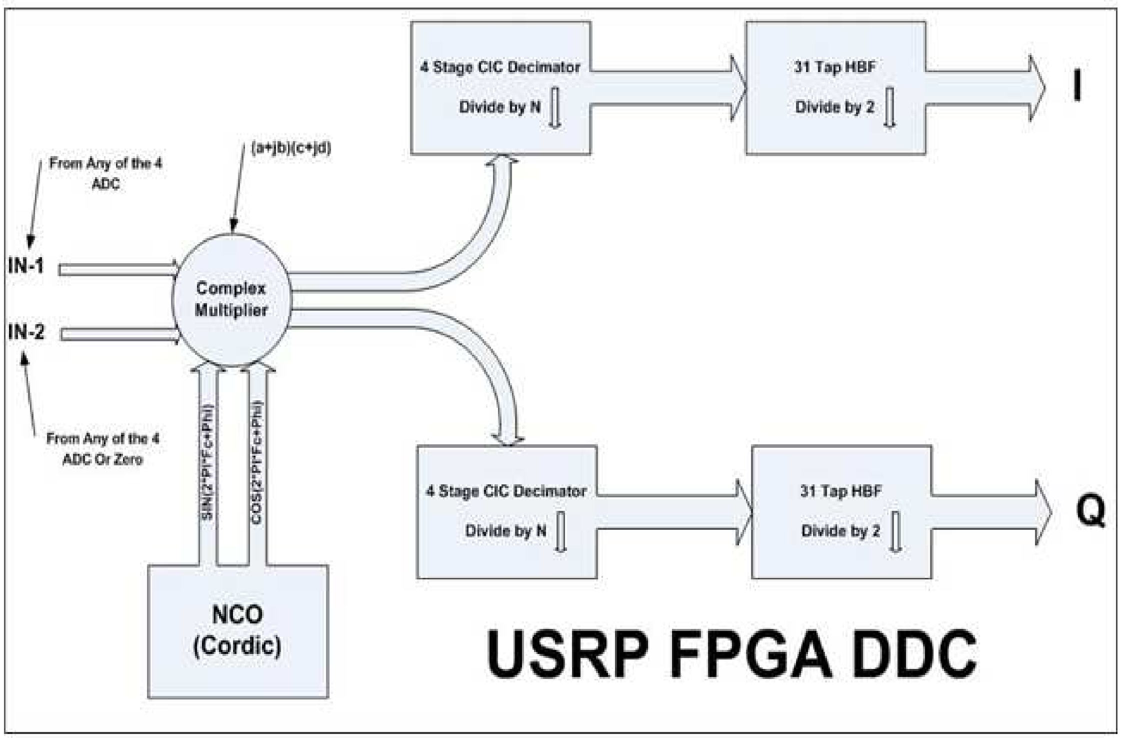

Figure 17: FPGA Digital Down Convertor Block Diagram

As the name suggests, the DDC down converts the signal from the IF band to the base band. Then the data rate is decimated so that it can be adjusted by the USB 2.0 and is sensible for the PC's processing ability. The complex IF signal is duplicated by a consistent recurrence exponential signal. The subsequent signal is focused at 0. At this point we annihilate the signal with a variable of N.

The decimator can be dealt with as a low pass filter taken after by a down sampler. Suppose the decimation factor is *N*. If we look at the digital spectrum, the low pass filter chooses out the band [-Fs/N, Fs/N], and afterward the down sampler de-spreads the spectrum from [-Fs,Fs] to [-Fs/N,Fs/N]. Therefore, we narrowed the bandwidth of the digital signal by a factor of N.

2.7.9 Digital Up Convertors

The DUC is needed on the transmitter side so that the frequency of the baseband can be increased and sent over the air. The DUCs are present in AD9862 CODEC chips and not in the FPGA.CIC interpolators are the only transmit signal processing blocks in the FPGA. The interpolator outputs can be routed to any of the 4 CODEC outputs.

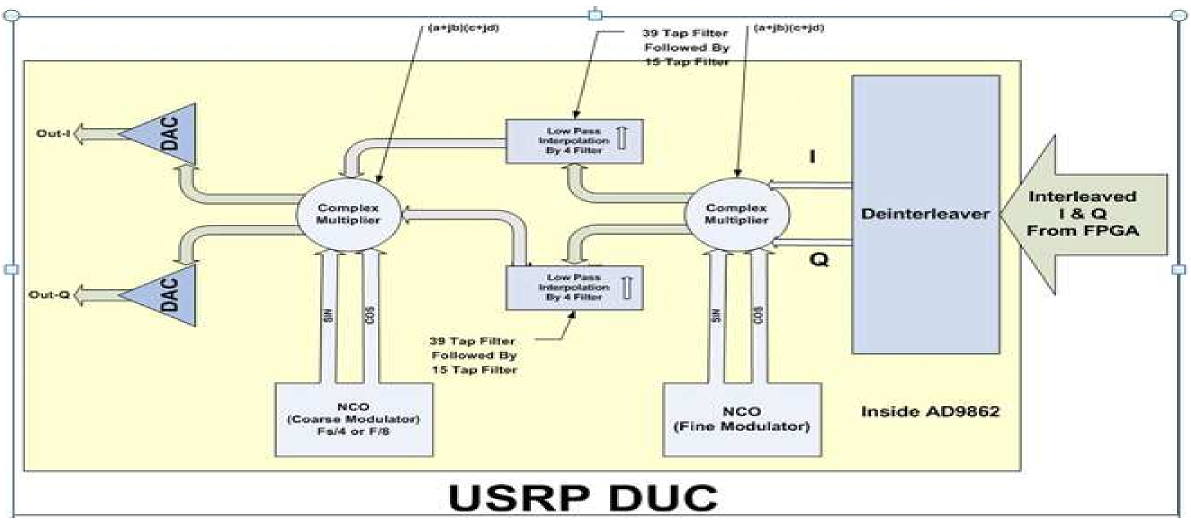

Figure 18: Block Diagram of DUC [ref for diagram]

2.7.10 Power

The USRP is powered by a 6V 4A AC/DC power converter. This converter is capable of 90-260V AC, 50/60 Hz operations. The USRP itself needs 5 V of supply and 6 V of supply is required for the daughter boards. It draws 1.6 A withi2 daughter boards fixed on it.

2.7.11 Universal Serial Bus 2.0 Controller

USB is used to connect the USRP to the computer. USRP connects the computer via a high-speed USB 2 interface only. The data throughput is 32 MB/s. The USB connection has impact on the performance of the system

2.7.12 USRP Version 1 and Version 2

The following shows the pictures of USRP 1 and USRP 2.

Figure 19: USRP 1

Figure 20: USRP 2

We are going to check their specifications and compare accordingly.

Table 1: Specifications of USRP 1 and USRP 2

Interface	USRP1	USRP2
ADC	12 bit ,64 MS/second	14 bit,100MS/second
DAC	14 bit,128 MS/second	16 bit,400 MS/second
Power	6V,3A	6V,3A
RF Band width	8 MHz at 16 bits	25 MHz at 16 bits
FPGA	Altera EP1C12	Xilinx Spartan 3 2000
Daughterboard Capacity	2 TX,2RX	1TX,1 RX
SRAM	None	1 M byte
Cost	$700	$1500

The laboratory had previously purchased the USRP 1. It was a suitable radio for our research, which is very capable and efficient in terms of cost.

2.7.13 USRP 1

The USRP 1 provides entry level RF processing capability. It is designed to provide software defined radio capability for users at low-costs. The architecture includes an Altera Cyclone FPGA, 128 MS/s dual DAC, 64 MS/s dual ADC, and USB 2.0. A modular design allows the USRP 1 to operate from DC to 6 GHz. The USRP platform can support two complete RF daughter boards. The USRP hardware driver is the official driver for all Ettus Research products and supports quick advancement in a comprehensive environment. The USRP hardware driver supports Mac OSX, Linux and windows.

2.7.14 RFX 900 daughter board

Figure 21: RFX 900 Daughter Board

The RFX 900 is a high-performance transceiver which is specifically designed for operation in the 900 MHz band. With a typical power output of 200 mW, and noise figure of 8 dB. It is used in areas like paging, cellular, two-way radio and the 902-928 MHz ISM unlicensed band.

2.7.15 VERT 900 Vertical Antenna

This is an omnidirectional antenna and has a 3 dBi Gain.

Figure 22: VERT900 Antenna

2.7.16 SMA-Bulkhead Cable

Fig 23: SMA-Cable

A 0.2M long SMA-M to SMA-F bulk head cable connects daughter board and the antenna.

2.7.17 Features of USRP 1

- Use with GNU Radio
- Modular Architecture: DC-6 GHz

- Connectivity for two complete TX/RX chains
- Two dual 64 MS/s,12-bit ADC's
- Two dual 128 MS/s, 14-bit DAC's
- DDC/DUC with 1 mHz resolution
- USB 2.0 interface to host
- Auxiliary digital to analog I/o
- 25 ppm TCXO frequency reference

We used the USRP by connecting it to a computer with GNU Radio installed in addition to USRPs.

CHAPTER 3

INSTALLATION OF GNU RADIO

3.1 Selection of Operating System

When we chose to work with the GNU Radio, the next big question was the Operating system to work on. We did extensive research on different operating systems and their support for GNU Radio. We checked with the present day operating systems and researched on their usability for GNU Radio. Installing GNU radio on Windows was not recommended as there were issues for users who worked on Windows. The most flexible operating system to work with GNU Radio is Linux. So we installed Linux in our already present Windows laptops and were ready to carry out our research.

3.2 Installation Overview:

Installing GNU Radio on any recent Ubuntu system is easy and requires the following steps:

We recommend to install GNU radio via the gnuradio package from the distribution's standard repositories. The following command was used for installing GNU radio from binaries:

$ apt-get install gnuradio

It is important to use a recent version, at least on the latest minor, e.g if the most current version is 3.7.2, installing a 3.7.0 is okay, but 3.6.5 is too old.

A Word-like file called the build-gnuradio that has all the modules and libraries that are required for the GNU Radio to be installed. So as discussed earlier the Linux distribution "Ubuntu" has binaries available through their packaging system. These are termed as "Linux standard distro packages". The following overview gives more insight into the installation of GNU radio.

3.3 Commands for installation

As the build-gnuradio will be downloaded in the downloads folder run the following commands:

- Cd downloads/
- Downloads ls (You will notice the gnuradio files appearing in the command prompt)
- Downloads$ chmod a+x build-gnuradio (this command assigns executive privilege to user, group and others. Basically, anybody can execute this file.)
- Downloads$ ls
- Downloads$. /build-gnuradio
- Continue with y(yes) for a few questions asked next. Then there goes the installation for all the libraries. The below picture shows the process when the libraries are being installed into the laptop.

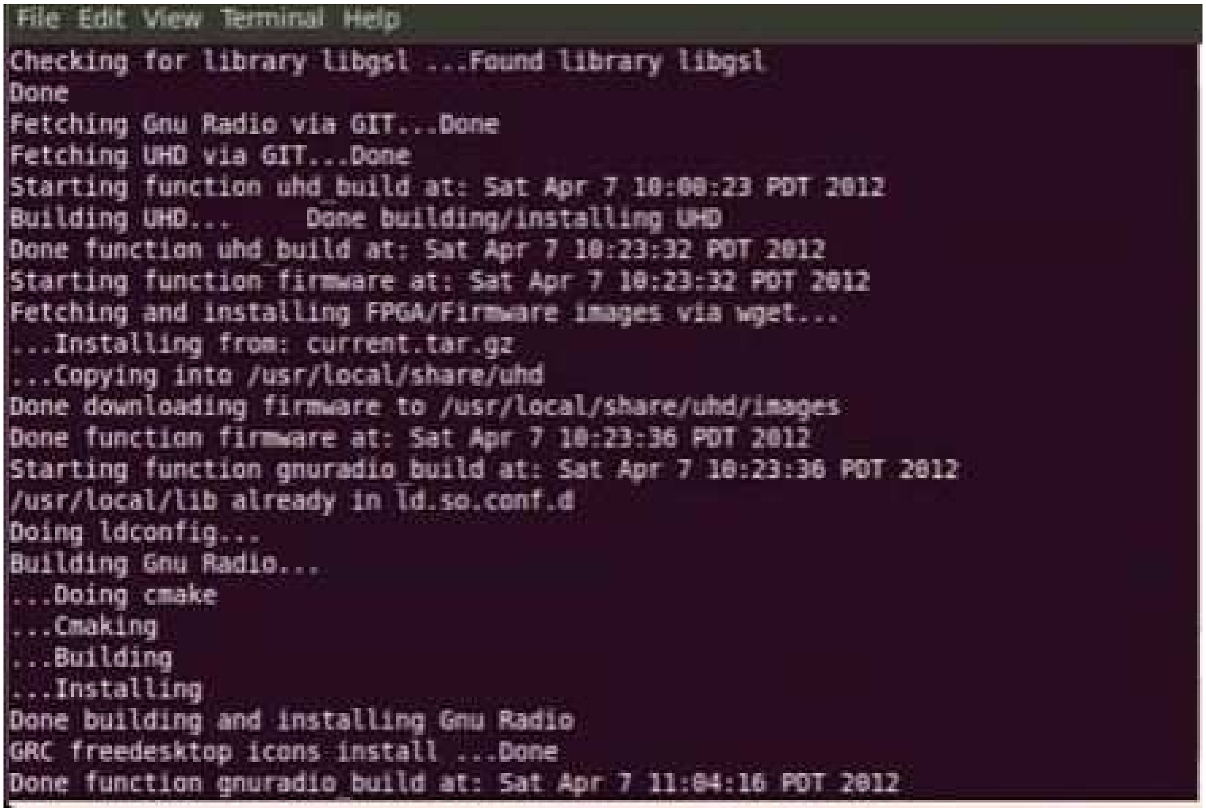

Figure 24: Figure Showing the Completion of Installation

CHAPTER 4

MODULATION SCHEMES

Modulation is that term that is used very frequently during this research. So, modulation can be defined as a process of varying one or more properties of a periodic waveform, called the carrier signal.

4.1 Need for Modulation:

Before diving deep into the concepts of modulation and types of modulation it is advisable to know some basic terminology of modulation techniques. In modulation process, two signals are used, namely the modulating signal and the carrier signal. A carrier wave has a constant frequency, like a sine wave. It doesn't carry much information that we can relate to. To include any other data, another wave needs to be imposed, called an input signal, on the top of the carrier wave. This process of imposing one signal on the other to send the data is called modulation. The modulating signal is the information signal while the carrier is a high frequency sinusoidal signal.

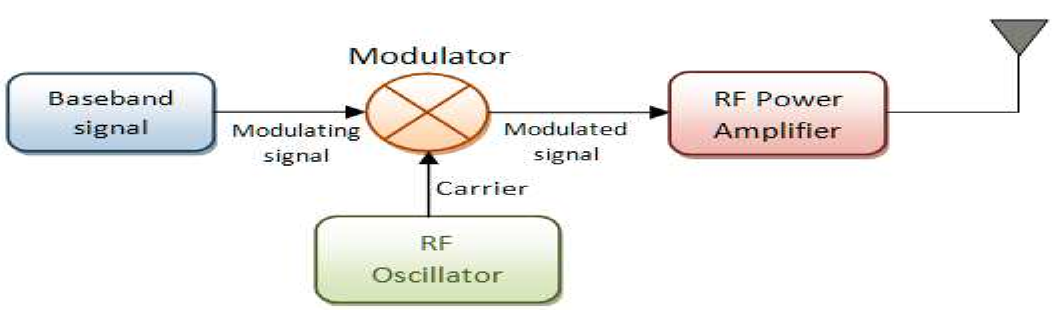

Figure 25: Block Diagram of Modulation

So, you may get a doubt and ask: when the baseband signal can be transmitted directly why we need modulation? The answer is that the baseband transmission has many limitations which can be overcome using modulation. Modulation gives strength to the signal so that it can reach the receiver without getting dropped midway. So, an un-modulated signal has low frequency range hence the signal cannot travel longer distances because of lower energies. Secondly since the antenna length is inversely proportional to frequency, a lower frequency signal will increase the antenna length beyond imagination. In modulation, the characteristics such as amplitude, frequency or phase of a higher frequency (carrier) signal is changed in accordance with the instantaneous value of the base band signal which can be transmitted to a larger distance. The reverse process is done at the receiver to recover back the original signal.

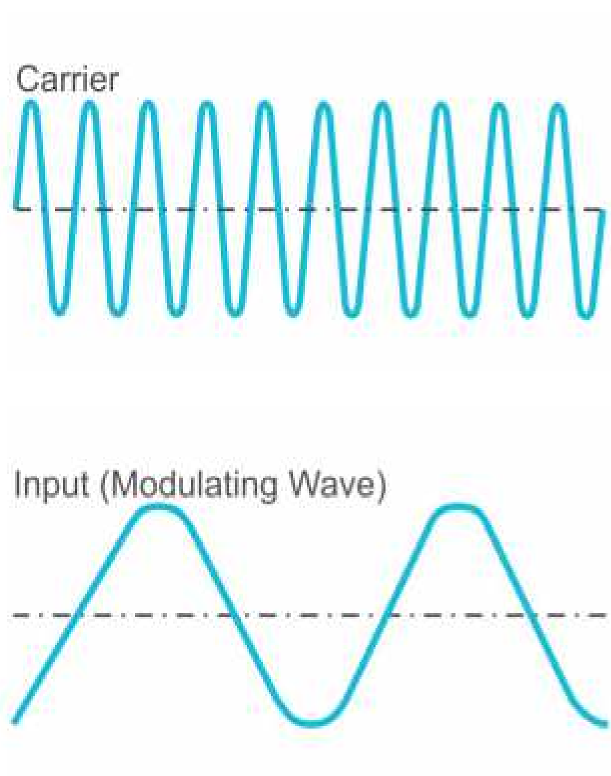

Figure 26: Carrier and Modulating Signal

As we learned why modulation is necessary in wireless communications lets wrap up by discussing on the advantages of modulation in the coming section.

4.1.1 Advantages of Modulation

- Reduction in the height of Antenna
- Avoids mixing of signals
- Increase range of communication
- Multiplexing
- Improves quality of reception

4.2 Types of Modulation

There are two types of fundamental modulation schemes in which they can be divided into: Analog and Digital modulation schemes. The aim of analog modulation is to transfer an analog baseband signal over an analog bandpass channel at a different frequency. The aim of digital modulation is to transfer a digital bit stream over an analog bandpass channel.

4.2.1 Analog Modulation Methods

Any wave has three basic properties: Amplitude: height of the wave, Frequency- several waves passing through in each second and phase – where the phase is at any given moment.

Common analog modulation techniques are Amplitude Modulation, frequency modulation and phase modulation. Amplitude modulation is a technique where the amplitude of the carrier wave if varied in proportion to the waveform being transmitted. Frequency modulation is the encoding of information in a carrier wave by varying the instantaneous frequency of the wave. Phase modulation is a modulation pattern that encodes information as variations in the instantaneous phase of a carrier wave. There are different strategies for modulating the carrier wave as discussed above. The following three figures show the pictorial representation of the above discussed modulation schemes.

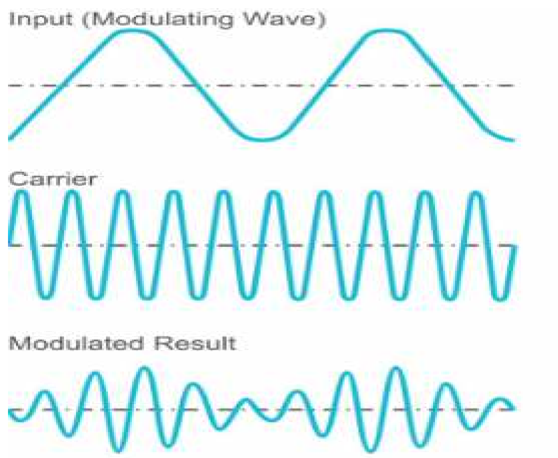

Figure 27: Amplitude Modulation

The change in carrier's amplitude corresponding to the input signal: This is called Amplitude modulation.

Frequency of an input signal can also be changed. If the input signal is added to the pure carrier wave it will thereby change the frequency of the carrier wave. Users can use changes of frequency to carry information

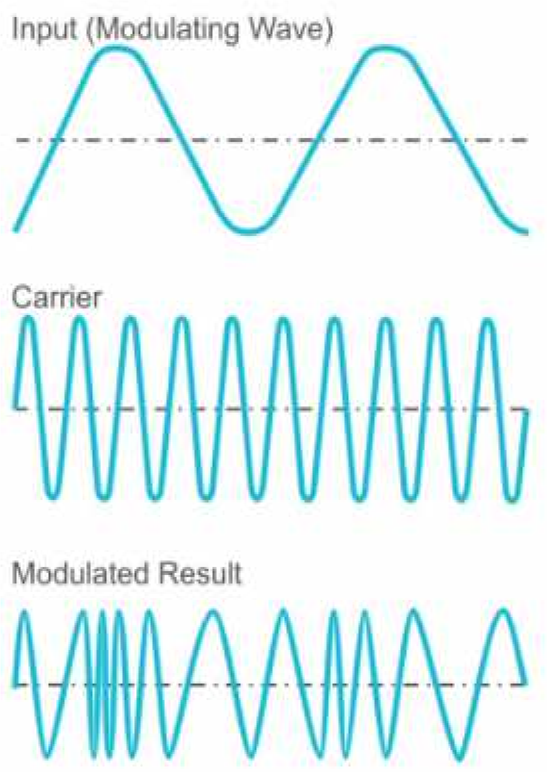

Figure 28: Frequency Modulation

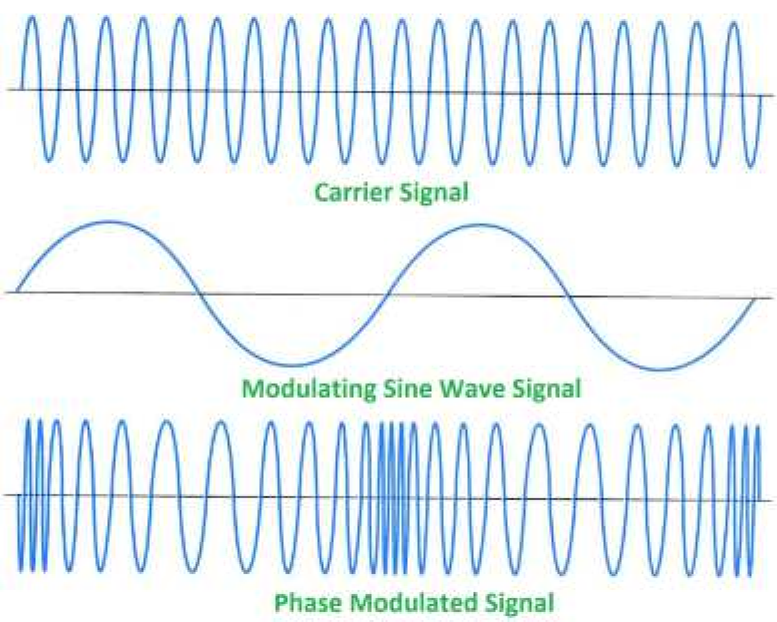

Figure 29: Phase Modulation

4.2.2 Digital Modulation Methods

The most common digital modulation methods are: Amplitude Shift Keying, Frequency shift keying and Phase Shift Keying. Amplitude shift Keying is a form of amplitude modulation that represents digital data as variations in the amplitude of a carrier wave. If the signal value is 1 then the carrier signal will be transmitted; otherwise a signal value of 0 will be transmitted. Frequency shift keying is a frequency modulation scheme in which digital information is transmitted through discrete frequency changes of a carrier signal. This technology is used for communication systems such as amateur radio; emergency broadcasts and caller ID. Phase-shift keying is a digital modulation scheme that conveys data by changing the phase of a reference signal.

4.3 Advantages of Digital Modulation over Analog Modulation

In the recent times, digital modulation is being used all over when compared to the old-traditional analog modulation. Let us enumerate the points which prove the worth of digital over analog:

- Digital system tends to be less susceptible to crosstalk, non-linarites, and noise compared to analog systems.
- Digital transmission provides cheapest possible interface to digital switching systems.
- Large scale integration technology favor digital processing techniques over analog.
- Digital modulation can easily detect and correct noise. Whereas analog modulation has little complexity.
- Digital modulated signal can traverse a long distance compared to analog.

Owing to the widespread and effective functioning of digital modulation over analog modulation we preferred to work with the Phase shift keying which offers much more advantages than its counterparts.

4.4 Phase Shift Keying

Our work is completely based on Phase Shift keying digital modulation and one might wonder why we used phase shift keying when we had many other digital modulation techniques like Amplitude Shift keying, Frequency Shift keying and Quadrature Amplitude Modulation. Let’s have a look on why PSK is chosen over others:

- Phase shift keying enable data to be carried on a radio communication signal in a more efficient manner than Frequency shift keying or any other modulation schemes.
- One more reason to modulate only phase is to maximize the efficiency of RF power amplifier in the transmitter.
- SNR is great for PSK, which allows communication under adverse conditions such as fading, noise and interference.
- Phase Shift Keying is more resilient to AWGN than amplitude shift keying. So we can get away with transmitting les power for same Bit error rate.
- Phase Shift Keying has a smaller bandwidth footprint than Frequency shift keying at same capacity and bit error rate.
- In PSK information is stored in phase variations of the transmitted signal and in FSK information is stored in frequency variations. Noise can effect frequency but not the phase easily. So PSK is better in combatting noise.
- BPSK is antipodal and BFSK is orthogonal signal. Thus, BPSK has a 3 db over BFSK. Additionally, FSK is detected incoherently.

As we have seen the numerous advantages of PSK over other digital modulation scheme lets go ahead and learn about the basic modulation schemes of PSK: Binary Phase Shift Keying, Quadrature Phase Shift Keying, Guassian Mean Shift Keying.

4.5 Binary Phase Shift Keying:

BPSK is the simplest form of PSK sometimes referred as phase reversal keying or 2PSK. It uses two phases which are separated by 180 degrees. This modulation is the most robust of all the PSK's since it takes the highest level of noise distortion to make the demodulator reach the incorrect decision. The only limitation with this scheme is it can only be able to modulate at 1 bit/symbol, so it is unsuitable for high data rate applications.

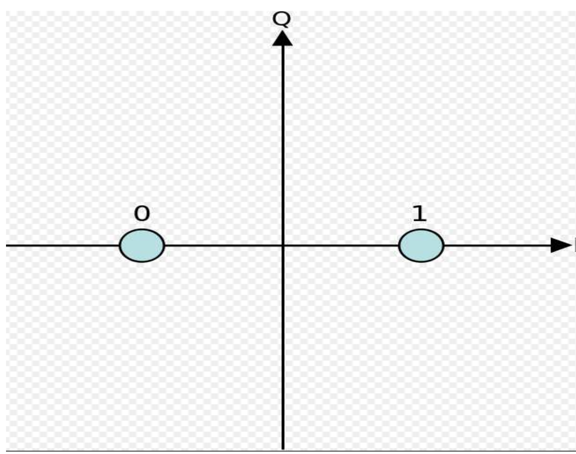

Figure 30: Constellation Diagram

4.6 Quadrature Phase Shift Keying:

In QPSK, the data bits to be modulated are grouped into symbols, each containing two bits, and each symbol can take on one of the four possible values: 00,01,10 or 11. The phases are each 90 degrees apart, and these phases are usually selected such that the signal constellation matches the configuration as shown in the below figure.

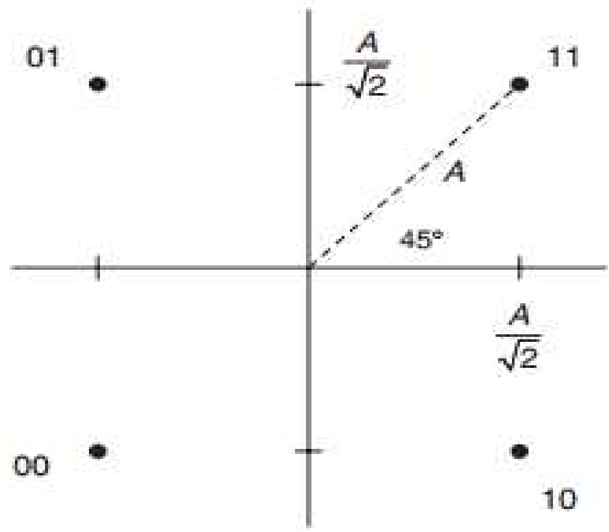

Figure 31: QPSK Constellation Diagram

Practical QPSK modulators are often implemented using structures similar to the one shown in the below figure. This structure uses the trignometric identity :

I cos $\omega_c t$ + Q sin $\omega_c t$ = R cos ($\omega_c t + \theta$); where R = square root ($I^2 + Q^2$). When I and Q take on the values of $\pm A\sqrt{2}$ in all possible combinations, the phase of the resulting output signal takes on the values of 45,135, 225 and 315 degrees. The modulate signal is given by:

$$x(t) = I(t) + j\,Q(t)$$

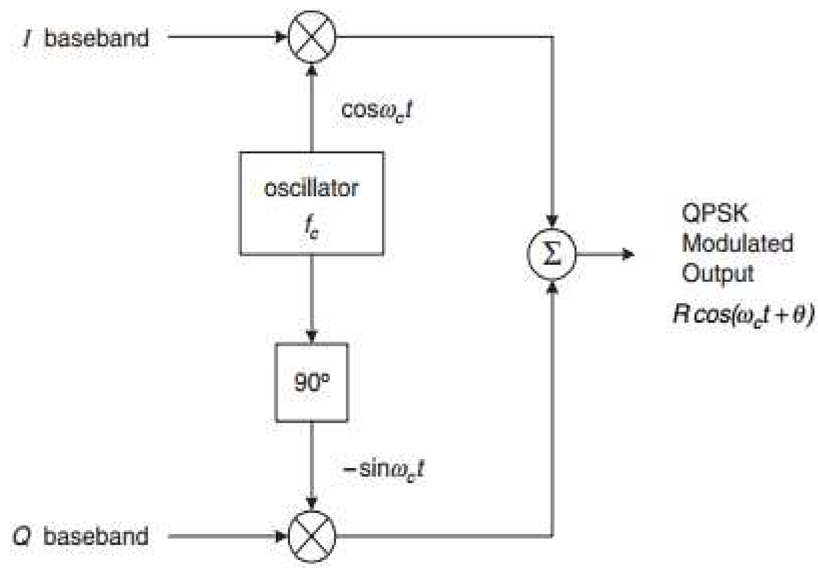

Figure 32: QPSK Modulator Block Diagram

4.7 Guassian Minimum Shift Keying

GMSK is a form of modulation used in a variety of digital radio communications systems. One of its advangtage is it uses the spectrum effeciently. One of the problems with other forns of phase shift keying is that sidebands extended outwards from the main carrier causing interference to other radio communications systems using nearby channels. As a efficient method, GMSK modulation has been used in a number of radio communications applications. Possibly the most widely used in the GSM cellular technology which is used worldwide and has well over 3 billion subcribers.

GMSK is based on MSK, which is itself a form of continous-phase frequency-shift keying. One of the problems with the standard forms of PSK is that sidebands extend out from the carrier.To overcome this, MSK and its deivative GMSK can be used. MSK and also GMSK are called as continous phase frequency shift keying. Here there are no phase discontinuties because the frequency changes occur at the zero crossing points. This arises as a result of the modulation index is always equal to 0.5.

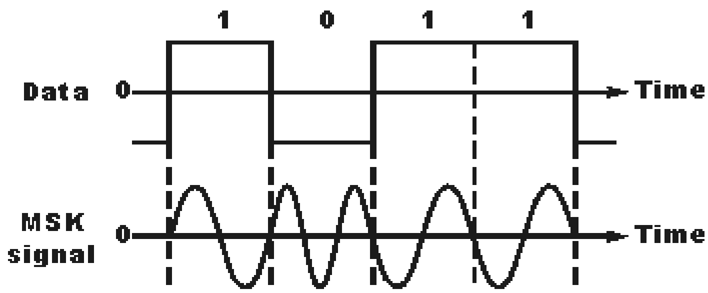

Figure 33: Signal using MSK Modulation

CHAPTER 5

WORKING ENVIRONMENTS AND RESULTS

We decided to work with the radios in three different environments: indoor (lab environment), corridor, and outdoor (quadrangle) set up. My work (we are 2 people who worked) is related to the tests carried out in the indoor laboratory. Let us discuss on the indoor environment:

5.1 Test Setup

Two USRP radios and two laptops were used to run the experiments. The PC1 with USRP A acts as the transmitter while PC2 with USRP B acts as the receiver. The daughter boards used for these experiments are RFX 900 which can cover frequencies from 750 MHz to 1050 MHz. The antenna used was a vertical antenna (VERT 900). It allows the operation of frequencies ranging from 824 MHz to 960 MHz and 1710 MHz to 1900 MHz (dual band) with a gain of 3 dBi. As discussed before, for the software part the reconfigurable Python codes benchmark_tx.py and benchmark_rx.py were used, located in the path /gnuradio/gr-digital/examples/narrowband. Considerable changes are made to the GNU Radio Python code for our requirement so that we could have our desired BER calculated and displayed in the window console. Data with a string of the character 't' was sent from the transmitter to the receiver, so the receiver could compare the received results with these known characters. For all the scenarios, from the transmitter we sent 2000 packets of the same data, each packet comprising of 11,960 bits. The following figures show the commands to open and run the benchmark code for both transmitter and receiver in the terminal window, then a sample output is shown.

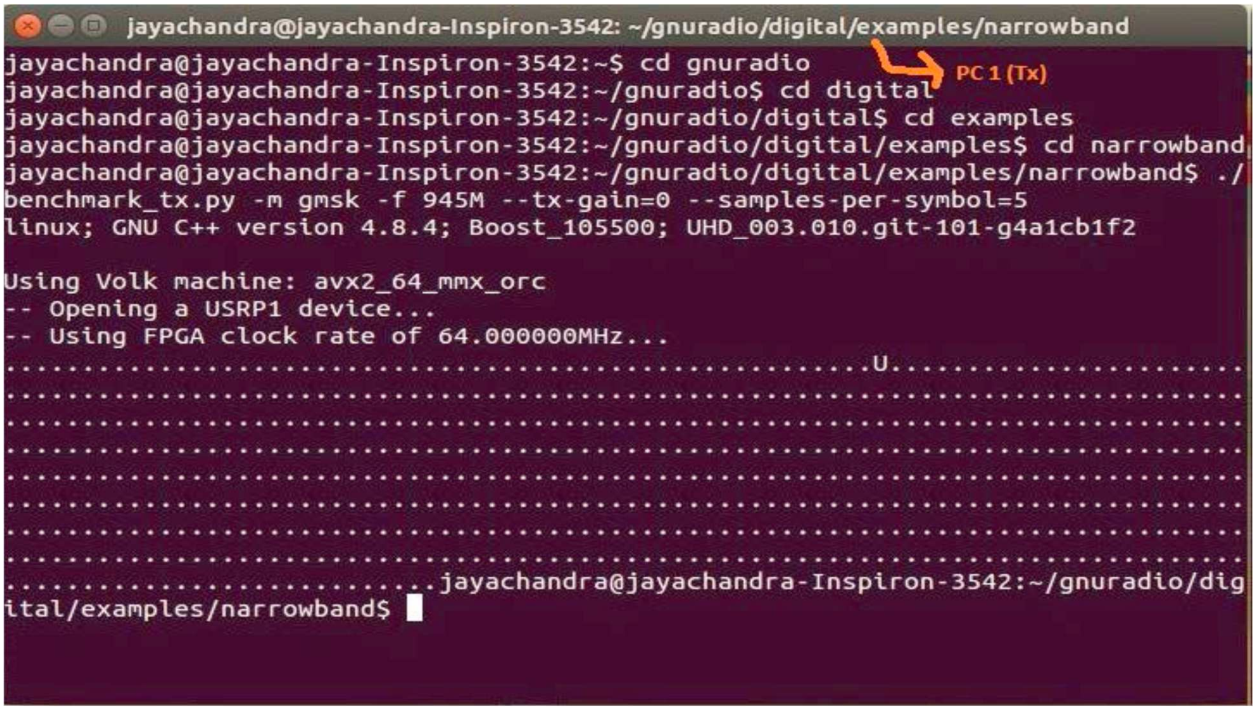

Figure 34: Transmitter Terminal Window while sending

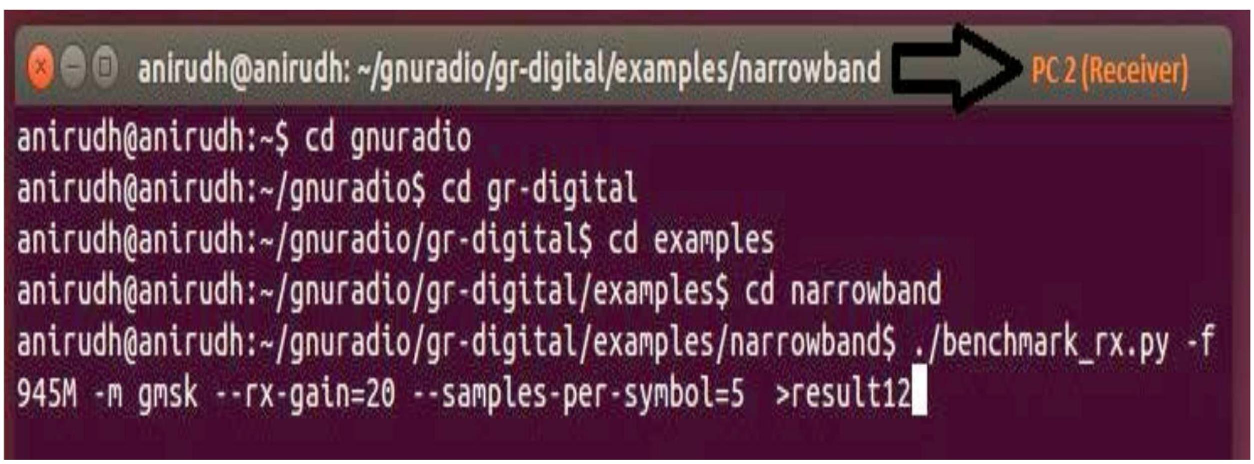

Figure 35: Receiver Terminal Window Setting Before Data Is Sent

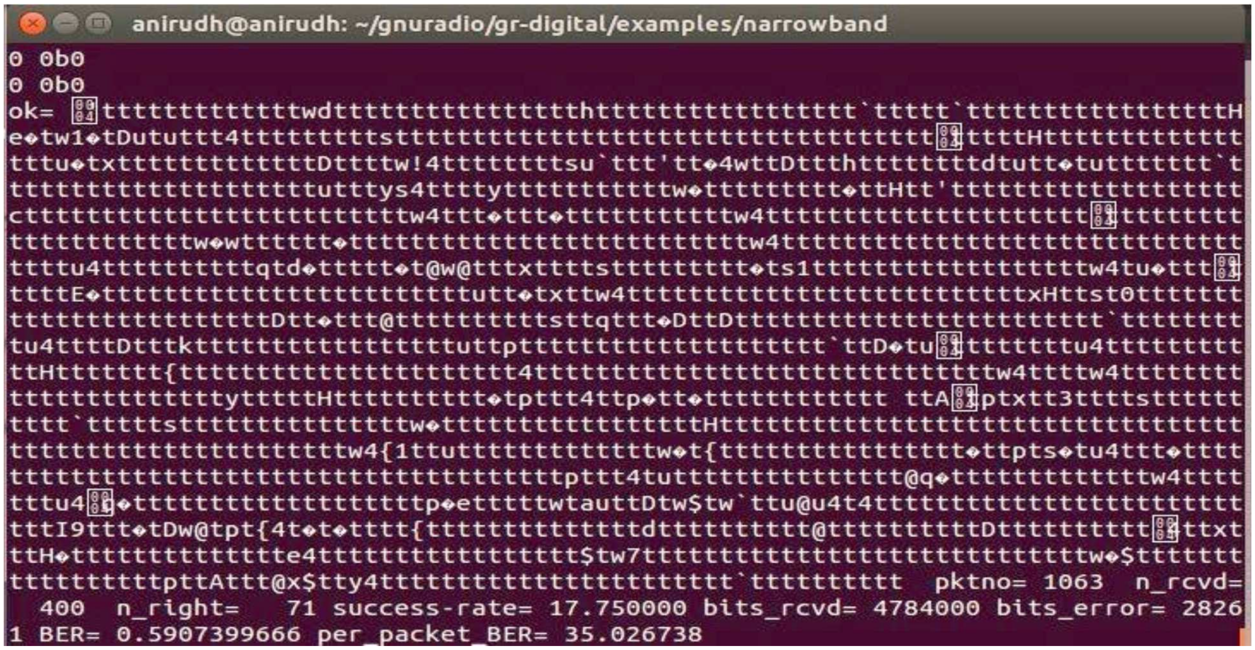

Figure 36: Receiver Window When the Data Is Being Sent

So, as we saw how the console window looks at both the transmitter and receiver now let us see how the entire set up was put in the lab in the following figure.

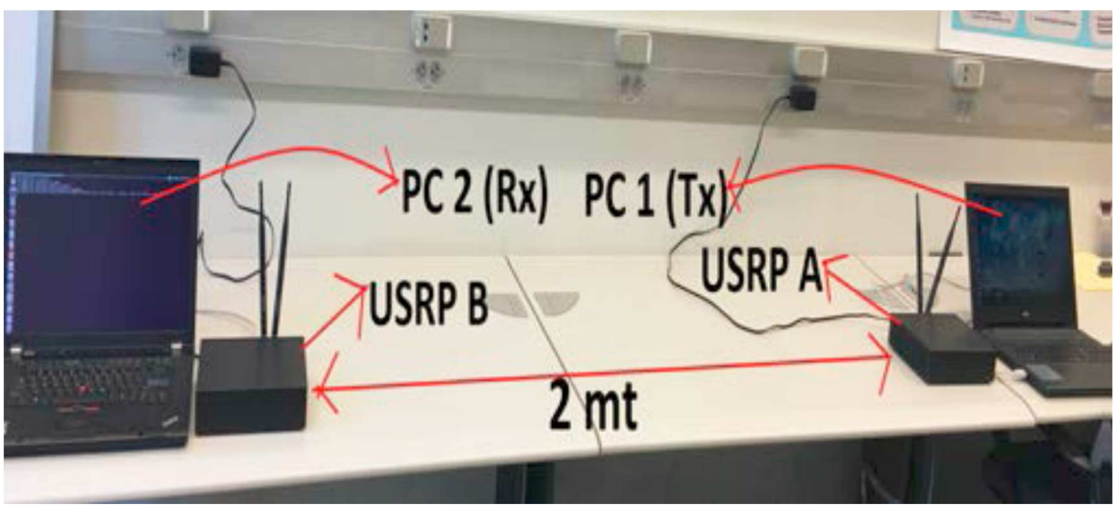

Figure 37: Experiment Set Up In the Lab

Benchmarking is the process used to send the data which is present in the GNU Radio. The benchmarking has two codes each for the transmitting side and the receiving side. The code is set to default parameters (modulation, number of bits, tx-gain, rx-gain etc.). We made a few additions to the code and changed it on the receiver side (benchmark_rx.py) such that we get the Bit Error Rate for each packet which was sent. Let's discuss the parameters which we used in the benchmarking setup that suited our work by discussing the two benchmarking codes that we used.

Benchmark_tx.py: This generates packets of size you specify and sends them across the air using the USRP. We can select the modulation to use with the -m <modulation> command line argument.

Benchmark_rx.py: This prints a summary of each packet received and keeps a running total number of packets received, and how many of them are error free. There are two levels of error reporting that takes place. If the access code (PN Code) and header of a packet were properly detected, then you will get an output line. If the CRC32 of the payload is correct you get "ok = True", else "ok = false"

5.2 Parameters

- Operating Frequency: The frequency which we used for the radios for the data transfer is 945 MHz. It is denoted by -f. After some experimentation, this frequency was found to be used most effectively by the USRP 1, daughter board, and antenna.
- Modulation type: Which modulation is being used can be changed by varying the -m modulation type i.e. for example if we want to send the data using BPSK we use -m bpsk.
- TX-Gain: The transmitter gain is one of the important parameters in the whole process of data communications. This gain describes how well the antenna converts input power

into radio waves headed in a specific direction. It is specified by -tx-gain. We have taken the tx-gain as 5 dB in all our cases by default.

- RX-Gain: The receiver gain also plays a key role in the accurate reception of data. The gain describes how well the antenna converts radio waves arriving from specified direction into electrical power. We worked with different gains of 5, 10, 15 dB.

5.3 Experiments

As we discussed earlier we worked on three modulation schemes which are Binary Phase Shift Keying, Quadrature Phase Shift Keying, Gaussian Minimum Shift Keying. The parameters which we have taken into consideration and altered is the Rx-gain. We chose the Tx-gain to be 0 and Rx gain to be 5, 10, 15 in different test cases. We chose a stable Tx-gain because the distance at which we placed the radios is near and it does not require more strength for the transmitter to scatter the data to the receiver. Interestingly we chose variable Rx-gain so that we can differentiate the receiver capability for different gains and its behavior with all the interference and delay effects.

5.3.1 BPSK Results

Let's discuss on the results that we obtained for the BPSK for different receiver gains i.e. 5, 10, 15. The Tx-gain is maintained at 0 dB. The samples per symbol is set to 5 samples. Now let's see the case where Rx-gain is set to 5.

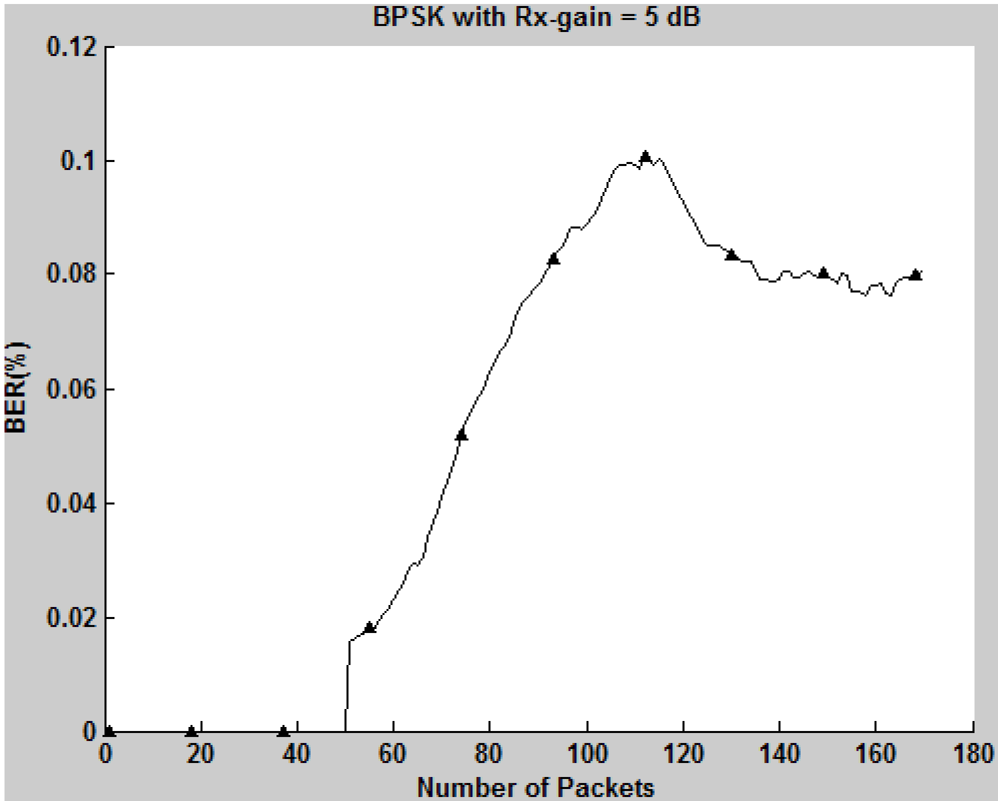

Figure 38: Plot when Rx-gain is 5

As we can observe the number of packets received are much less to what that was expected. We have set 2000 packets to go to the receiver but there were only 170 that made it to the receiver. We might owe to the fact that when the USRP was on for the first time there might be the initial device performance that made the most of the packets lost in the space. The averaged BER (%) for this is 0.05057 which is low (good), but compared to the fact that only a few packets that made to the destination.

Rx-gain : 10

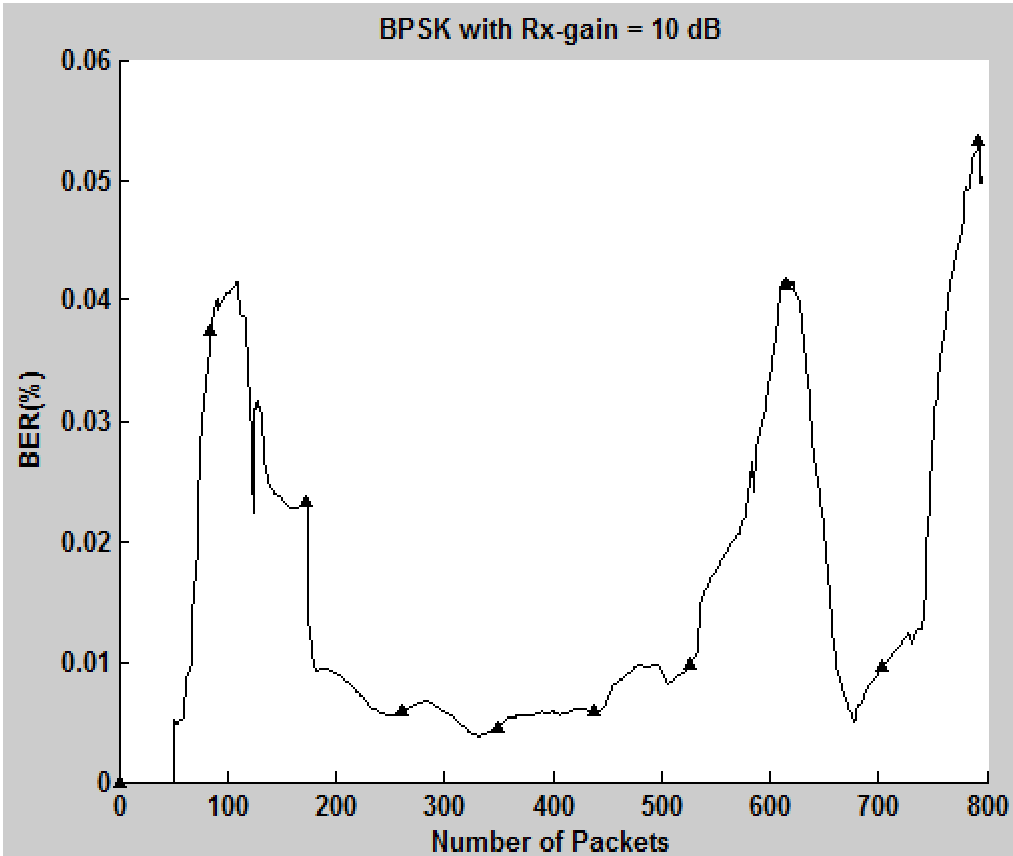

Figure 39: Rx-gain: 10

As we can see the number of packets got tremendously increased with the last experiment. There are around 797 packets that are received without any error at the receiver. With the greater gain, we tend to get more packets as observed. The averaged BER (%) for this case is 0.01526.

Rx-Gain: 15

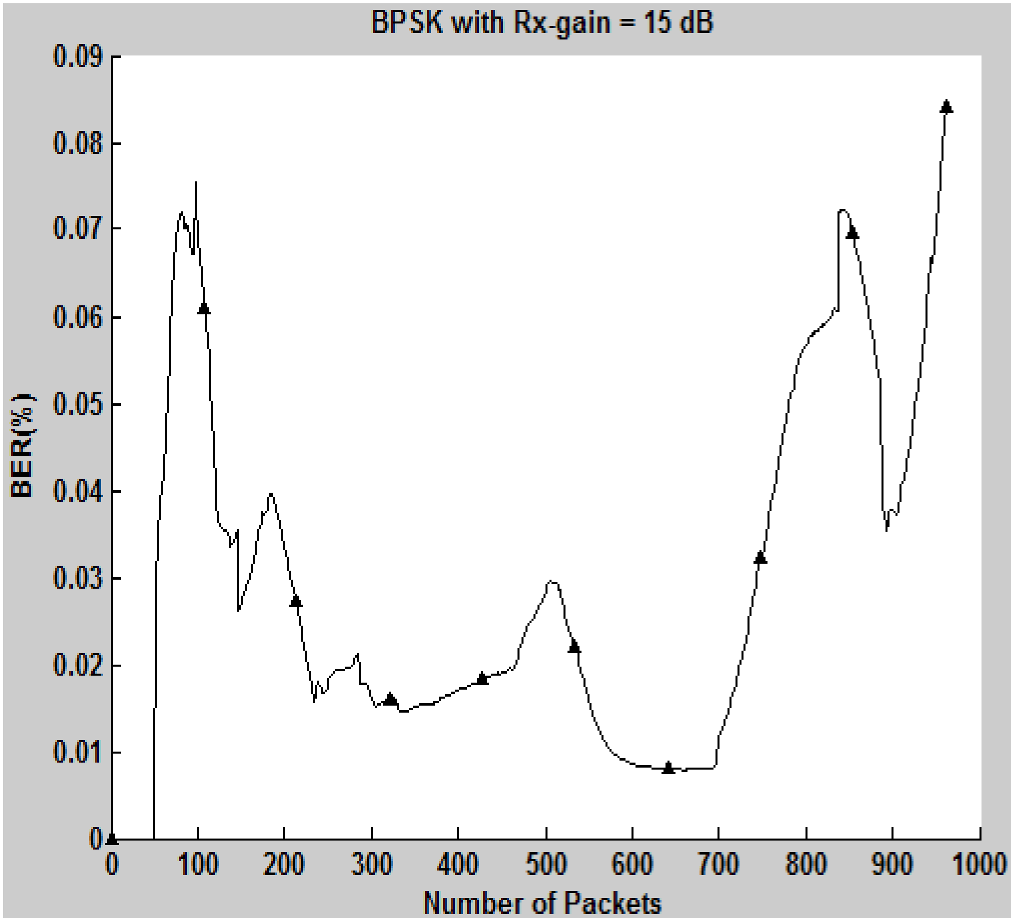

Figure 40: Plot with Rx-gain 15

So now the receiver has more power of receiving the packets rather than the previous case. We can see the increase in the number of packets that reached the destination. In this case, we got 961 packets that reached the destination. The averaged BER is 0.02891 which is a bit higher than the previous case but the packets sent in this case are five times that of the gain with 5.

5.3.2 QPSK Results

As in the previous case results are carried out for different Rx-gains of 5, 10 and 15 while all other parameters are left the same. Let's check out the behavior of QPSK under the same lab conditions.

QPSK Rx-gain:5

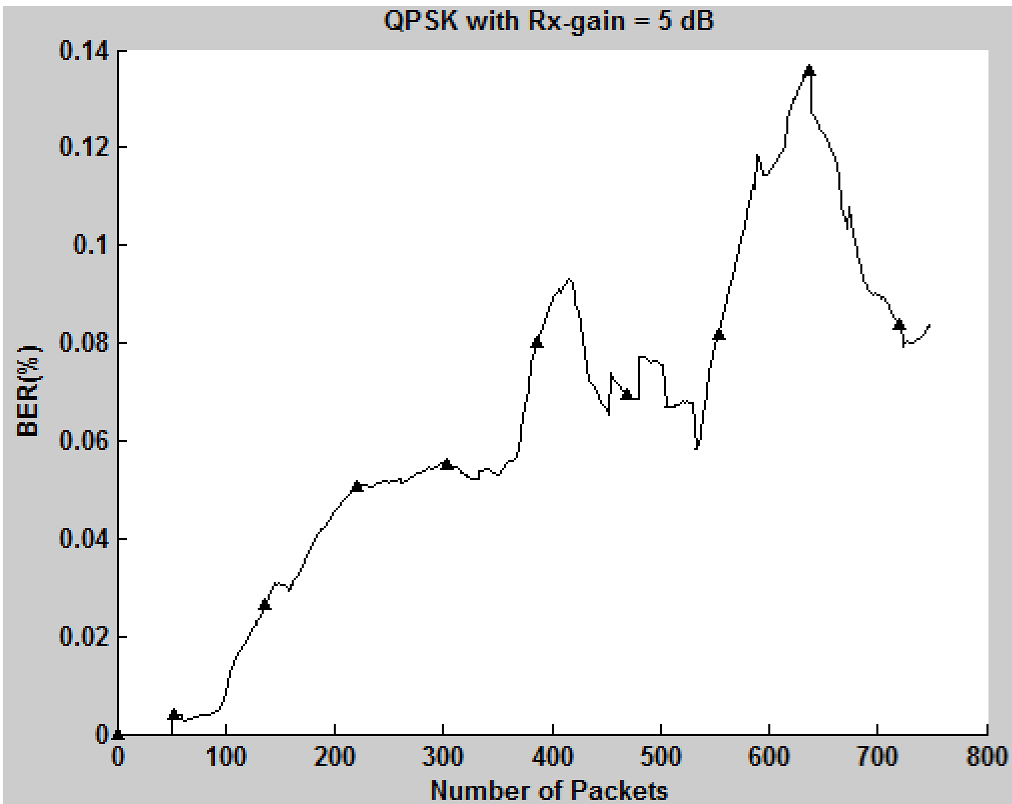

Figure 41: QPSK with Rx-gain of 5

So in this case of QPSK, we can see the number of packets sent are 750 which is much more better than its counterpart (BPSK) for the same settings. This is due to the fact that QPSK is a stronger modulation scheme and in this model each symbol is encoded with two bits and it effeciently uses the bandwidth. Though theoritically the BER formula is same for these two modulation schemes , as we are conducting these experiments in the lab environment which is vulnerable to multipath fading and electromagnetic interference. We can make a confirmation that the number of packets are much more greater than that of the BPSK cases. The average BER is 0.07652.

Rx-gain: 10

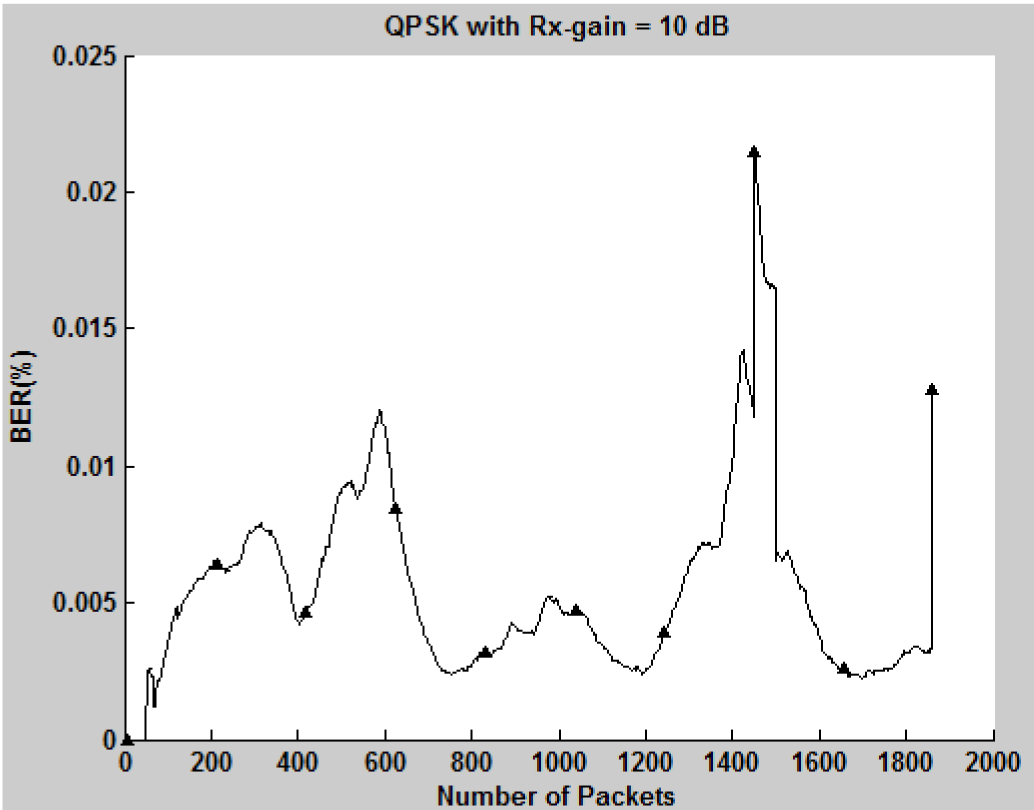

Figure 42: QPSK with Rx-gain 10

In this case, there are 1860 packets that are sent which is a good indicator of working with an increased receiver gain value. The averaged BER for this is 0.005414which is quite impressive for this setting.

Rx-gain:15

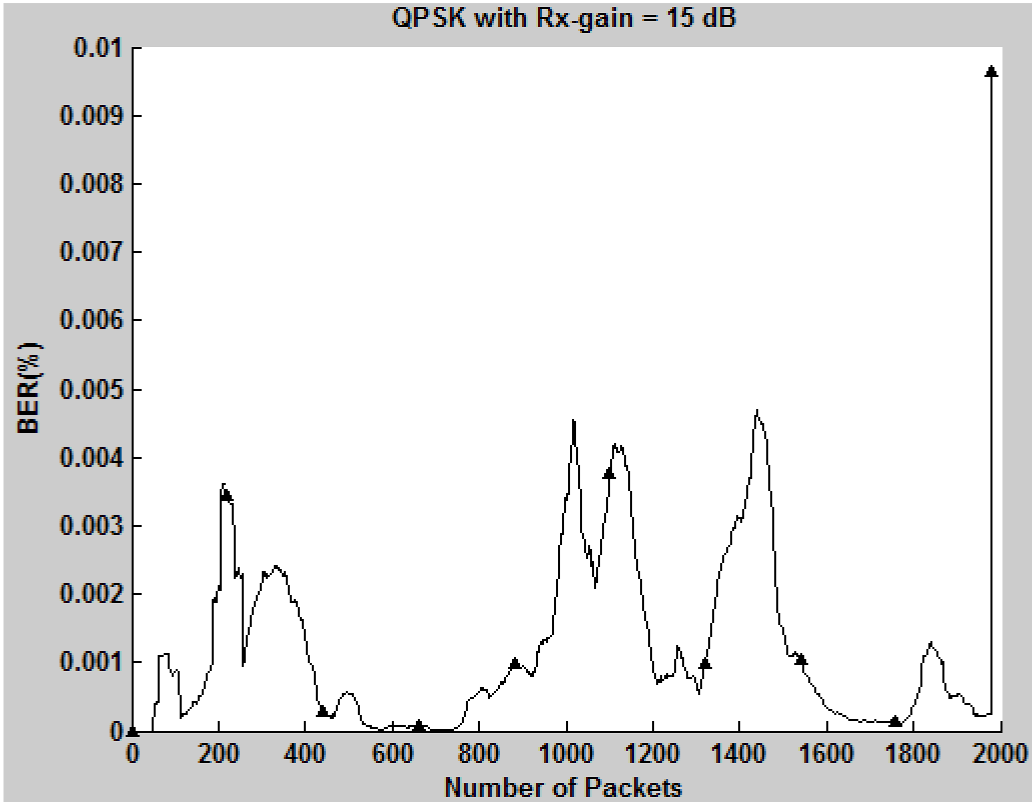

Figure 43: QPSK with gain 15

In this case, we got 1980 packets reaching the destination which is approximately 90% of the transmitted data. The averaged BER is 0.001192 which is the best of all. The BER is low and the number of packets sent are the highest. This case is a true winner and we can say with a good receiver gain the receiver can reciprocate the data as much as it can from the data sent.

5.3.3 GMSK Results

As in the previous case results are carried out for different Rx-gains of 5, 10 and 15 while all other parameters are left the same. Let's check out the behavior of GMSK under the same lab conditions.

Rx-Gain: 5

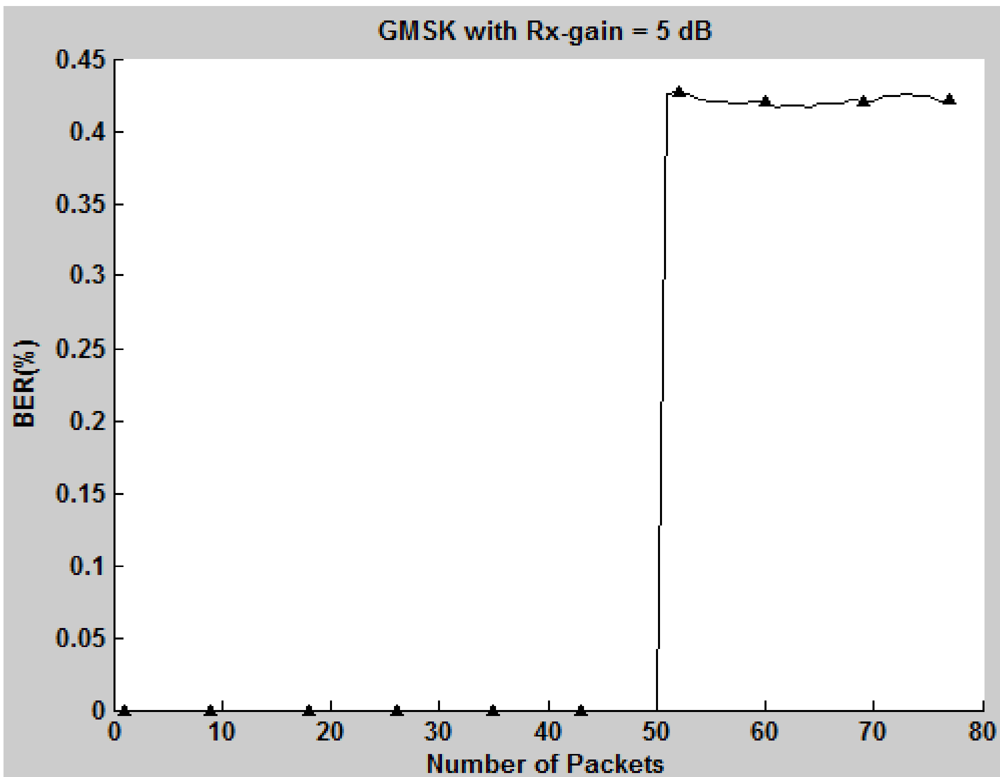

Figure 44: QPSK with gain 5

The GMSK modulation with a rx-gain of 5 has an averaged BER of 0.1476 with only 77 packets reaching the destination.

Rx-gain: 10

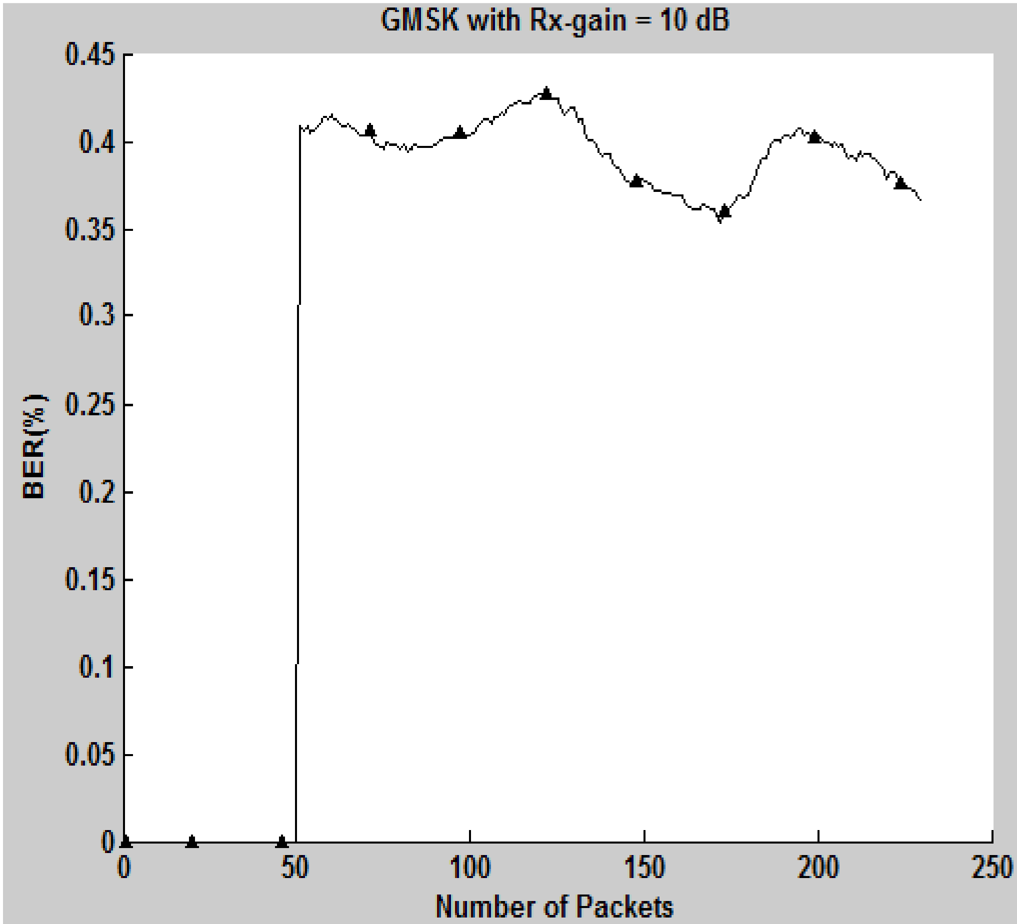

Figure 45: GMSK with Rx-gain: 10

In the above result where the rx-gain is 10 db, the number of packets that reached the destination are 230 with the averaged BER being 0.3088.

Rx-gain: 15

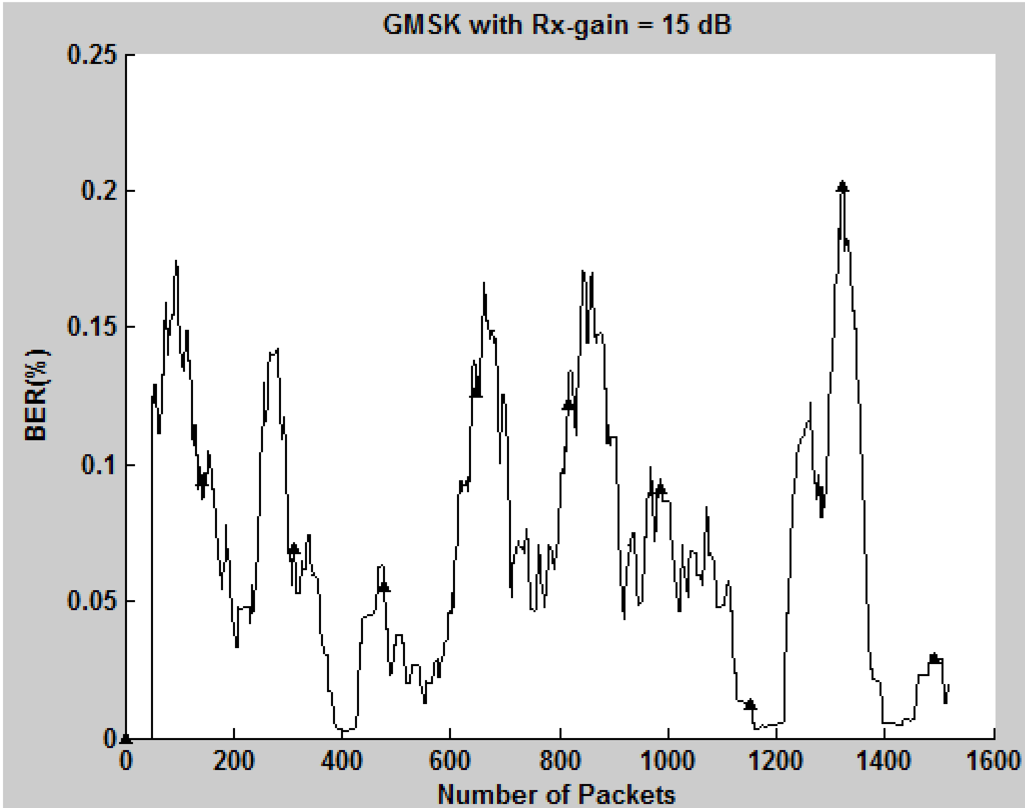

Figure 46: GMSK with Rx-gain 15

In the above case there was a tremondous increase in the number of packets that reached the receiver. It was 1517 packets.

5.4 Results Analysis

The above 9 results which we obtained clearly show the importance of the receiver gain in the data reception. Let's evaluate which modulation scheme performed better by taking into consideration the number of packets received and the corresponding BER.

Table 2: Comparison between modulation schemes

Rx-gain	BPSK Packets, BER	QPSK Packets, BER	GMSK Packets, BER
5	170,0.05057	750,0.07652	77, 0.1476
10	797,0.01526	1860,0.005414	230, 0.3088
15	961,0.02891	1980,0.001192	1517, 0.0839

So, the BER rate acts as one of the valuable QOS parameters in the wireless industry and the researchers who work on a wireless model try to achieve smaller BER. In our experiments, we observed QPSK worked the best among the three and achieved the least BER and sent the highest number of packets.

We analyzed the modulation schemes and compared which scheme works well under the lab conditions. Now there is a need for us to know why and how the plots are generated which is quite opposite to the literature where mostly you find the results which are linear. Let's talk on this in the next section.

5.5 Factors effecting data transmission

- **Noise**

In a wireless channel, apart from the signals from our communication system (SDR in our case) there are many other noise signals and many effects that cause many problems and make the system less reliable.

Noise is a disturbance generated by an external source that affects an electrical circuit. The disturbance may degrade the performance of the device and if the severity is high it might also cause the device to stop working. In case of data path, these effects can range from an increase in error rate to a total loss of the data. It can affect mobile phones, FM radios and televisions. Both manmade and natural sources like automobile ignitions, mobile phones radiations and thunderstorms can be causes for this interference.

- **Radio Signal Path Loss**

Radio Signal Path loss is an important phenomenon in the design of any radio communications system. It determines many elements of the system like the transmitter power, the antenna gain, height at which the antenna is and general location. Thus, it is necessary to understand the reasons for radio path loss. The signal path loss can be often determined mathematically and these calculations are often undertaken when preparing coverage or system design activities.

- **Free Space Path Loss:**

One of the common phenomenon in wireless data transfer where there is a loss in signal strength of an electromagnetic wave that world result from a line of sight path through free space is the Free Space Path Loss phenomenon. The free space loss occurs as the signal travels through space without any other effects attenuating the signal it will still diminish as it spreads out. This can be thought of as the radio communications signal spreading out as an ever-increasing sphere. As the signal must cover a wider area, conservation of energy tells us that the energy in any area will reduce as the area covered becomes larger.

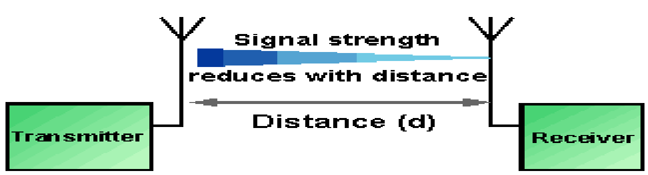

Figure 47: Free Space Path Loss

Free Space Path Loss = $(4*pi*d*f/c)^2$

Where d is the distance between the transmitter and the receiver (meters).

C is the speed of light (c).

F is the signal frequency (Hertz).

Free Space Path Loss formula in decibels = 20 log d + 20 log f + 32.44 $-G_t$-G_r.

G_t is the transmitter gain.

G_r is the receiver gain.

The Free Space Path Loss in db for our work environment is:

20 log 2 + 20 log 945 * 10^6 + 32.44 – 5 -0 = 32.96 dB.

Other Explanations for Results

There are many other possible explanations for the results that were seen in Section 5.3. For sure we have seen that BER and long term BER effects are dependent on the choice of modulation and RX-gain.

These could be issues such as motion of surrounding objects, time-of-day, USRP hardware, choice of which device was transmitter or receiver, etc. We conducted several measurement studies to investigate explanations but were not able to find consistent results. We did not see a clear answer as to whether a certain issue for sure affected or did not affect these long term BER effects.

5.6 Conclusion

In our work, it is challenging to find out the reasons behind the behavior of the radios, as the work was carried in real-world environment and not in a simulation controlled environment. We wanted to stress on the real-world data transfer between two radios under the general every day environment. So, we did not create any pre-simulated noise by which we can estimate what the receiver end error rate could be.

The results which received are not very common that is being used in daily literature. We wanted to know how the real data transfer occurs in day to day scenarios. In a nutshell, our research is focused on the compliance of the USRP with the GNU Radio. We focused on the analysis of Bit Error Rates for different modulation schemes. Thus, we showed a way of analysis that can be carried out with USRP without involving any huge costs.

5.7 Future Work

The present-day research with the SDR paves way for so many new ways of research for students who try to gain hands on experience. Not only in academics, SDR is also used for military and commercial purposes. In times of conflict, military communications significantly depend on precision, clarity, adaptability and speed. Lack of any of these aspects may result in dire consequences. Thus, SDR's have grown to have a significant influence on defense mechanisms as the device not only provides standard two-way communication, but also offers secure wireless nodes and provides very low latency point to point wireless links.

Our main aim was to make the radios transmit the data in real-world environment without introducing any noise signals from our side, rather the data traverses the surroundings and reaches the destination. The receiver uses the Cyclic Redundancy Check method of error detection. We can make the radios not only detect errors but also correct the errors and retrieve the original data. So, Forward Error Correction can be used by changing the source code in the GNU libraries and once the code is successfully changed without any bugs we can have the receiver radio detect and subsequently correct errors.

Figure 48: Anechoic Chamber

Though our research is on making the radios work for the indoor environments there is an environment where you can test any of the wireless communication system without the fear of having a signal loss or possible signal interference. It is called the “anechoic chamber”. It is a non-reflective and non-echoic chamber which is designed to completely absorb reflections of sound and electromagnetic waves. They are also designed to be isolated from the waves from entering from the surroundings. Anechoic chambers range from small compartments to the size of household microwave ovens to ones as large as aircraft hangars. The size of the chambers depends on the frequency ranges and the size of the objects being tested. In case of initial testing of the radios which require precise results such that to estimate its performance, this kind of environment can be used first and after the estimation, noise channel can be introduced.

BIBLIOGRAPHY

[1] R.H. Hosking, Software Defined Radio Handbook, New Jersey: Pentek.

[2] GNU Radio, "GNU Radio Companion – usage tips". [Online]. Available: http://gnuradio.org/redmine/projects/gnuradio/wiki/GNURadioCompanion

[3] Ettus Research, "Universal Software Radio Peripheral," [Online]. Available: http://www.ettus.com

[4] Electro Magnetic Interference, Wikipedia, [Online]. Available: https://en.wikipedia.org/wiki/Electromagnetic_interference

[5] A. Khandakar, A. Mohamed, A. El Sherif "Study and analysis of basic modulation scheme in wireless environment using USRP 2 and Matlab (Simulink)", in *2013 International Conference on Wireless Networks (ICWN),* Qatar*,* 2014. [Online]. Available: http://weblidi.info.unlp.edu.ar/WorldComp2013-Mirror/p2013/ICW2505.pdf

[6] S.M. Njoki, "Implementation of wireless communication on GNU Radio," M.S. thesis, Department of Electrical Engineering,University of North Texas, Denton, May 2012. [Online]. Available: https://digital.library.unt.edu/ark:/67531/metadc115130/

[7] M. N. Tipán, R. I. Zapata, G. V. Arévalo and I. N. Cano, "Analysis of FEC in digital data signal transmission with USRP over SD-RANs," *2016 8th IEEE Latin-American Conference on Communications (LATINCOM)*, Medellin, 2016, pp. 1-4. doi: 10.1109/LATINCOM.2016.7811571

[8] J. Muslimin, A. L. Asnawi, A. F. Ismail and A. Z. Jusoh, "SDR-Based Transceiver of Digital Communication System Using USRP and GNU Radio," *2016 International Conference on Computer and Communication Engineering (ICCCE)*, Kuala Lumpur, 2016, pp. 449-453. doi: 10.1109/ICCCE.2016.100

[9] B. I. Supriyatno, T. Hidayat, A. B. Susksmono and A. Munir, "Development of radio telescope receiver based on GNU radio and USRP," *2015 1st International Conference on Wireless and Telematics (ICWT)*, Manado, 2015, pp. 1-4. doi: 10.1109/ICWT.2015.7449244

[10] S-M. Cheng, W-R. Huang, R-G. Cheng, C-H.Gan, "Experimental emergency communication systems using USRP and GNU radio platform," *2015 11th International Conference on Heterogeneous Networking for Quality, Reliability, Security and Robustness (QSHINE)*, Taipei, 2015, pp. 75-79.

VITA

With an aim in working closely to the present day wireless technology, the author started his research work. At present, he works with AT&T: one of the biggest telecom service provider in the United States as a LTE/VOLTE Engineer. His present duties and responsibilities help me in reaching my goal of being a pioneer in the wireless industry. His research work on wireless communication systems helped him to excel in his job.

The author wants to continue his work in this industry and work on his MBA simultaneously such that it gives him a great edge and an easy scope for moving to higher positions within the firm.