FM TRANSMITTER USING HACKRF ONE

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I certify that in my opinion the thesis submitted by Abdelaziz Omran AL DAWI entitled "FM TRANSMITTER USING HACKRF ONE" is fully adequate in scope and in quality as a thesis for the degree of Master of Science.

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"I declare that all the information within this thesis has been gathered and presented in accordance with academic regulations and ethical principles and I have according to the requirements of these regulations and principles cited all those which do not originate in this work as well."

Abdelaziz Omran AL DAWI

ABSTRACT

M. Sc. Thesis

FM TRANSMITTER USING HACKRF ONE

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FM transmitter is low power FM radio transmitter, which broadcasts signal from a portable audio device like MP3 player to the standard FM radio. Most of the devices plug into the headphone jack as well as then transmit into radio frequency. HackRF is a software defined radio peripheral and capable of transmitting as well as reception of radio signals from the range between 1 MHz to 6 MHz. It is designed to enable test as well as growth of modern as well as next generation radio technologies. HackRF One is one of the open source platforms based on hardware, which can be utilized as USB peripheral as well as programmed for the stand-alone operation. Hence, it is required to develop research on the topic. Literature reviews from several articles are described in the present research. In addition, SDR and GNU Radio, modulation as well as demodulation of the signals are discussed along with software defined radio and its applications. Implementation of the communication protocols utilizing SDR as well as background of the topic is discussed in the research. Appropriate

methodology is followed in order to conduct the research in proper way that results correct result for the research.

Key Word : Frequency modulation, HACKRF ONE, SDR, RTL-SDR.
Science Code : 905.1.067

ÖZET

Yüksek Lisans Tezi

FM TRANSMITTER USING HACKRF ONE

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FM vericisi, MP3 çalar gibi taşınabilir bir ses cihazından standart FM radyoya sinyal gönderen düşük güçlü FM radyo vericisidir. Cihazların çoğu, kulaklık jakına takılır ve radyo frekansına aktarılır. HackRF, yazılım tanımlı bir radyo cihazı olup, 1 MHz ila 6 MHz. aralığındaki radyo sinyallerini alıp gönderebilme yeteneğine sahip bir cihazdır. Yeni nesil radyo teknolojilerinin ve testin yanı sıra gelişmeyi sağlamak için de tasarlanmıştır. HackRF One, donanım temelli açık kaynaklı platformlardan biridir ve USB periferik olarak kullanılabilir veya tek başına çalıştırma için programlanabilir. Bu nedenle, konuyla ilgili araştırma ve geliştirme çalışmalarının yapılması gerekmektedir. Bu çalışmada, konuyla ilgili literatürdeki bazı makaleler incelenmiştir kaynaklı literatür taramaları bu araştırmada tanımlanmıştır. Bununla birlikte, SDR ve GNU Radyosu kullanılarak sinyallerin modülasyonunun yanı sıra demodülasyonu yazılım tanımlı radyo ve uygulamaları ile birlikte tartışılmaktadır. Araştırmada SDR'yi kullanan iletişim protokolleriyle birlikte uygulamaya özel kullanımları da sunulmuştur.

Ayrıca, bu çalışmada, araştırmanın teorik alt yapısı tartışılmıştır. Araştırmada doğru sonuçlar elde etmek için uygun method izlenmiştir.

Anahtar Kelimeler : Frequency modulation, HACKRF ONE, SDR, RTL-SDR.
Bilim Kodu : 905.1.067

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ABBREVITIONS

ADC	: Analog Digital Converter
AM	: Analog Modulation
ASIC	: Application Specific Integrated Circuits
ASK	: Amplitude-Shift Keying
BER	: Bit Error Ratio
BFSK	: Binary Frequency Shift Keying
CORBA	: Common Object Request Broker Architecture
CPFSK	: Continuous-Phase Frequency Shift Keying
DAC	: Digital Analog Converter
DDC	: Digital Down Converter
DM	: Delta Modulation
DPWM	: Digital Pulse Width Modulator
DSP	: Digital Signal Processors
DSP	: Digital Signal Processing
DUC	: Digital Up Converter
FIR	: Finite Impulse Response
FM	: Frequency Modulation
FPGA	: Field Programmable Gate Array
FSK	: Frequency Sift Keying
GFSK	: Gaussian Frequency Shift Keying
GPP	: General Purpose Processors
GRC	: GNU Radio Companion
IF	: Intermediate Frequency
ISM Bands	: Industrial, Scientific, and Medical radio band
PPG	: Photo-Plethysmo-Gram
PRMS	: Percentile Root Mean Square Error

PSK : Phase-Shift Keying

PWM : Pulse Width Modulator

RF : Radio Frequency

RX : Receiver

SWIG : Simplified Wrapper and Interface Generator

TX : Transmitter

USRP : Universal Software Radio Peripheral

VHDL : VHSIC Hardware Description Language

CHAPTER 1

INTRODUCTION

1.1. INTRODUCTION

The term ‘radio’ as a device capable of transmitting and receiving signals within the radio frequency range of the electromagnetic spectrum. The transmission of signals in this particular spectrum essentially facilitates information transfer: thus, in today’s world, radio is considered as one of the most essential components of all communication devices including cellular mobile phone televisions, automated car door opening systems and transport vehicles. However, the fact that traditional hardware-based radio system have several limitations, the most significant ones being the utter lack of cross functionality and the mandated physical intervention required for the bringing about any changes in the configuration of the systems. Needless to say, the utilization of such traditional radio communication system incurs high production costs, besides being associated with a very flexibility terms of supporting multiple ranges of radio waveform [1-2].

A software defined radio, widely known as SDR, can be defined as that particular radio communication system that utilizes software based signaling modules instead of the hardware modules included in traditional radio signaling systems [3]. Software based radio systems usually take advantage of the hardware components included in embedded systems and personal computers for the transmission and receival of radio signals [4]. the concept of software define radio system is indeed not new to the domain of radio communication, however the practical implementation a utilization of the same has gained a huge momentum in the very recent past, owing to the progress achieved in the domain of digital electronics and IC technologies.

Researchers Humphries and Malocha [5]. have made detailed discussions on the core functional components of any software defined radio system: according to them, a very basic SDR system might include a personal computing device that has a sound card installed in it, or any other functional analog to digital converter system. However, in either of the cases, the presence of a RF front end is essential. The authors are of the opinion that the general-purpose processors associated with such devices are capable of handling the signal processing activities to a large extent, thus replacing the "special purpose hardware units" (basically the electronic components) included in any traditional radio system. Therefore, the entire setup, being armed with signal processors and software supporting analog to digital conversion of RF signals, is capable of receiving and transmitting a wide range of radio signals or protocols, often termed as radio waveforms.

The academic research study being proposed in this report would be aimed at the practical implementation of a software-based radio system with the utilization of open source software modules readily available in the market. During the course of the study, effort would be directed towards the identification of the software modules that can be installed on Linux based operating system for transmitting and receiving radio signals. Upon the identification of thee appropriate module, the installation and tuning of the same would be conducted, attempts would be made to demonstrate the operations of the same in a practical manner.

1.2. RESEARCH AIM

In current time, software-based radio systems are being utilized in large scale for facilitating secured communication in between defense organizations [6]. Besides this, software-based radio transmissions are also effectively utilized by mobile connectivity service providers, primarily due to the fact that such software-based communication systems are inexpensive besides being effective. Thus, it can be concluded that software-based radio or SDR systems are finally under limelight and would in the very near future result in the abolition of hardware radio communication systems [7].

Such being the circumstances, this research study would be primarily aimed at the identifying the steps required for installing open source SDR modules in Linux based personal computing devices. The outputs of the SDR modules would also be analyzed and interpreted using RTL-SDR.

1.3. RESEARCH OBJECTIVES

According to Kothari, Kumar and Uusitalo [8]. framing the research objective is one of the most rudimentary steps of conducting any research study, as the same facilitates the process of penetrating deeper into the research domain.

Therefore, the following research objectives have been outlined on the basis of the discussion made in section 1.2 of the report:

a. To identify the open source software radio toolkits that can be utilized for the practical implementation of software-based radio system.
b. To select one from the above-mentioned toolkits and install the same on Linux based operating systems.
c. To demonstrate the process of installing the radio software module in a step by step manner and describe the manner in which the FM signals are obtained and processed in the said module [8].

1.4. RESEARCH QUESTIONS

Pedler [9]. has commented that the development of ‘research questions’ is an essential element associated with any academic research study. Researchers Gozalvez, Sepulcre, and Bauza [10]. second this opinion by stating that the setting up research questions helps in the identification of those areas of the research domain which needs to be emphasized on. Thus, in order to identify the primary areas of interest (with respect to this particular study), the following questions have been identified:

a. What is software defined radio?
b. Which readily available software radio toolkits are commonly utilized for the practical implementation of software-based radio system?
c. What are the basic steps of installing the radio software module in a Linux based system, and how are FM signals obtained and processed within the said module? [9-10].

1.5. BACKGROUND OF THE TOPIC

The immense growth in the field of digital electronics in the past decade has brought about a revolution in the manner in which human beings nowadays communicate with each other [11]. In fact, author Prabaswara [12]. state that the exponential growth of all medium communication, including data, voice and video communication, control and command communication, emergency response communication and broadcast messages have been feasible solely due to development of efficient and cost effective digital signal transmitters and processors. The ease of availability of the radio signaling elements and their cost affectivity has now become crucial for all organizations conducting business in the domain of communication and as stated by Ralston and Hargrave [13]. software defined radio system has emerged as the sole technology capable of meeting the expectations of the users [12-13].

According to Rondeau, Shea, and Goergen [14].the software defined radio system technology incorporates in itself the flexibility, power, reliability and cost- efficiency required to support the communication needs of the present time besides taking the existing communication technologies to the next league. The authors have also commented that the mobile communication service providers are, at this point f time, directing all their efforts in making the wide spectrum benefits of SDR available to the their customers [15].

Software defined radio systems can be defined as set of software and hardware technologies in which most of the functional elements of the radio are implemented on a firmware processing element [5]. Along with these modules, SDR systems also consist of FPGAs or field programmable gate arrays, digital signal processors or DSPs, SoCs or programmable System on Chip, GPPs or general-purpose processors and other application specific programmable processors [5]. Kumar and Noghanian [16]. have commented that it is the collaborative function of all these elements that discards the use of hardware components for the transmission and capture of radio frequencies [17].

In 2011, the Mobile Experts LLC was commissioned by the he Wireless Innovation Forum, with the aim of evaluating the extent of SDR technologies adaptation in various sections of the market [18]. The Mobile Experts LLC conducted a survey, the result of which indicated that business organizations are expressing their interests in his technology not because of its innovative nature but because of the fact that the use of this technology has proved to be useful in enhancing the efficiencies of radio systems (as utilized in these markets) [19]. The findings of this survey are being outlined in the following section:

a. As much as 93 percent of all organizations operating in the domain of mobile communication infrastructure development utilize SDR based technologies for transmitting and receiving radio frequency signals. The numbers of SDR technology based mobile base stations are likely to increase in the future so as to support the growing demand of mobile data communications.
b. In 2011 alone, the number of SD radios that were shipped so as to be installed at mobile terminal applications crossed 1 billion
c. Almost all of the tactical radio communication devices utilized by military and defense organizations operating across different sections of the globe utilize the software-defined radio technologies. On the other hand, almost90 percent of all public safety radio equipments available in the market utilize radio-based technologies for transmitting information [20].

Researcher Sruthi [21]. have made an outline of the several benefits of adopting and utilizing software defines radio systems: in the following section, some such advantages would be highlighted along with the identities of the user groups that reap the benefits.

Some organizations that manufacture radio equipment and/ or operate as System Integrators avail the following benefits through the use of SDR-

a. The very same architecture can be utilized for developing new devices: thus, the time required for launching new products in the market reduces drastically [20].
b. The software modules utilized in developing the radio devices remain unaltered, thus reducing the time and cost of development.
c. SDR technologies are essentially implemented over firmware, so as to make all future updates available to the users. Thus, elimination of all bugs and/ or other issues present in the software modules become easier in case of SDR (through firmware upgrades), which in turn enhances the level of services made available to the customers [21].

On the other hand, the use of software defined radio systems makes available several benefits to those organizations that act as service providers. According to Szlachetko and Lewandowski [23]. the major benefit available to these service providers is they are able to make their networks almost future-proof. This is possible as in case of software define radio technologies, addition of new features or module can be conducted simply by releasing an updated version of the firmware. On the other hand, the software defined radio platform can be utilized for providing services across several markets: thus, allowing the organization to make huge savings in terms of operational expenditures and logistical support.

The advantages of software defined radio systems, as available to the users, have been outlined by researchers Truong and Yu [24]. Some of these benefits include the following:

a. Ease of communication: The use of software defined radio systems allow users to receive and transmit radio signals from any place they are located at thus making the task of communicating with others much easier.

b. Reduced cost of usage: Researchers have highlighted the fact that the cost of using SDR systems is significantly lower than that of using traditional hardware based radio system, primarily because of the fact that such radio communication devices do not require any application specific device for the receival and transmission of radio frequency waves [22]. Thus, reduction in the cost of usage is yet another benefit that users can avail from these devices.

1.6. RATIONALE OF THE STUDY

Researchers are of the opinion that the anticipated opportunities and benefits available from SDR technologies have no only accelerated the utilization of the same in the wireless communication industry, but have also started influencing the value chain of the industry [23]. The value chain essentially consists of product based service providers and service based service providers and 'value' is added to the chain at each and every stage of the same, thus resulting in the development of SDR based technologies that finally meet the communication requirement of the users.

On the other hand, according to yet another school of researchers, SDR technologies have the capability of acting as the key technology in several other configurable radio technologies, like that of cognitive radio, intelligent radio, adaptive radio, and so on and so forth [24]. The author states that although the use of the SDR technology is not mandatory for operating these technologies, the utilization of the same would indeed facilitate the process of adding more flexibility to the configurable radio devices, thus allowing them to reach their true potential.

In the light of the discussions made in the sections above, it can be concluded that the software defined radio technology is playing a very significant role in meeting the communication demands of this era and has the capabilities of taking the same to newer heights. Thus, the proposed study is indeed relevant at this point of time, as it would allow the practical implementation of a configurable radio that works on any personal computer device. It is being expected that the successful achievement of the project objectives would pave the way for optimization of the functionalities of such radio devices.

1.7. PURPOSE OF THE STUDY

It has already been discussed in section 1.2 of the report that the primary aim of the study is to install any open source software defined radio module on a personal computer supporting Linux based operating system. Thus, it can be said that the most important purpose that would be solved through these activities would essentially be conducting a study of the various SDR based modules that are currently available across the market. The step by step installation of the same would result in gathering knowledge regarding the functional operations of each of the elements, besides allowing a detailed knowledge of the mechanism in which a SDR module receives processes and transmits signals in the radio frequency range.

1.8. STRUCTURE OF THE STUDY

The primary objective of documenting this report is to provide the audience a detailed review of the various aspects of the research study being conducted. The report would therefore be subdivided into a number of sections, each highlighting a specific domain of the study. The structure of the report is being outlined in the section below:

Chapter 1: Introduction

This particular chapter has been utilized to provide an overview of the research work to be conducted, besides outlining the aims, objectives and the purpose of the study. It is worth mentioning that the research questions have also been defined in this chapter of the report.

Chapter 2: Literature Review

In this chapter of the report, detailed discussion would be conducted on the finding and results of the academic studies that have been conducted in the same research domain in the past. Attempts would also be made to identify any gap in the previously conducted studies, such that same can be addressed to through this work.

Chapter 3: Theoretical Background

The third chapter of the report would provide an insight into the background theories of the selected research domain, which would indeed help the target audience in understanding the research techniques and the outputs in a clear way.

Chapter 4: Research Methodology

The tools and techniques utilized for conducting this study would be detailed in this section of the report.

Chapter 5: Summary

The concluding section of the report would be utilized to present the findings of the study, along with an analysis of the same. Besides this, the limitations of the research work and any future scope of study would also be included in this section.

CHAPTER 2

LITERATURE REVIEW

2.1. INTRODUCTION

Researcher Ranjit [25]. is of the opinion that reviewing the existing literary articles and contemporary academic pieces is one of the foremost activities that need to be conducted at the very onset of any research study. Ramirez [26]. second their opinion while stating that an efficiently conducted literature review facilitates the process of gaining detailed knowledge of the research domain, thus facilitating a deeper penetration into the same [26].

Taking a cue from the above-mentioned statements, a review of several scholarly and academic research papers was conducted before proceeding with the study in consideration. The following sections of the report would be utilized for summarizing the information available from these articles, such that a conceptual framework of the research work can be derived from the same.

It is worth mentioning that the discussion on the existing research works would also allow us to identify any gap in the same, which in turn would help us to direct our efforts in addressing the limitations/ shortcomings of the previously conducted work (through this study).

2.2. LITERATURE REVIEW

2.2.1. SDR And GNU Radio

The very first literary article, which was reviewed during the initial stages of this study, was primarily aimed at providing the audience with an overview of the process required for setting up a software defined radio. Authors Gandhiraj, Ram and Soman [7]. are of the opinion that the primary objective behind developing the graphical user interface based GRC (that is, the GNU radio companion) is to provide “practical exposure” to various concepts of digital communication theory, including the concept of generating signals, operating them, signal modulation and demodulation schemes (for both analog and digital signals), multiplexing and much more, with the help of GNU radio The authors have also stated that the primary and only reason behind utilizing the GNU platform in their research study was that the GNU radio is available free of cost and thus can be utilized by the common mass easily for developing software defined radios. Besides this, the GNU platform also allows the users to modify the source codes to meet their specific requirements. Von Ehr, Neuson and E. Dunne [22]. made a very similar attempt of providing a detailed description of the SDR technologies. The authors have made an in depth discussion regarding the characteristic features of the most commonly utilized SDR systems, besides making a comparative study of the capabilities and costs of these systems. The authors have also highlighted the mechanism using which these systems can be configured on personal computer devices and be customized for meeting user specific requirements [26].

2.2.2. Modulation And Demodulation Of Signals Using SDR

On the other hand, researchers Marpanaji [27]. had made an attempt of implementing the Differential Quadri phase Shift Keying modulation on the SDR platform and have discussed the findings of the experiment in the article titled “Experimental Study of DQPSK Modulation on SDR Platform”. The authors provide a detailed description of the software defined radio architecture and the characteristics of the same, before proceeding with a description of the Differential Quadri phase Shift Keying modulation scheme itself. Besides this, they have also mentioned the use of a USRP GNU Radio peripheral in the experimental set up: the said element not only operated as the front end of the SDR platform, but also facilitated the functional operations of a up/down converter. The entire set up relied on a personal computer device (PC) for processing the incoming and outgoing signals, whereas the DQPSK modulator and demodulator were implemented on software platform. The experimental set up was designed specifically for observing the Packet Error Rate or the PER, the signal-to-noise ratio per bit (or the Eb/No), the carrier frequency, bit rate, gain, roll-off factor and the payload size of the system. The findings of the experiment indicate that the lowest PER value was obtained when the value of Eb/No was greater than 20 dB, the optimum bit rate being 200 kbps, optimum gain= 500 and payload size= 4000 bytes [27].

Researchers Hatai and Chakrabarti [28]. have reported the design and implementation of a set of high performance radio frequency signal modulator and de-modulator capable of supporting the operational functionalities of software defined radio (SDR) system. According to the authors, the above-mentioned elements have been designed in a manner such that they are capable of fulfilling all the technological and operational constraints associated with the broadcast of digital audio, along with that of in personal radio message communication. The modulator and demodulator, when implemented in FPGA, has outperformed the existing IC based digital FM modulators which is indicative of the efficiency and performance of the SDR platform utilizing the same [28].

In the research paper titled "Implementation of a Differential Chaos Shift Keying Communication system in GNU Radio", researchers Kaddoum [29]. report the realization of the Differential Chaos Shift Keying or DCSK system with the use of SDR systems, the GNU Radio platform to be very precise. The authors have utilized the said GNU Radio as a cost effective, open source and flexible platform for implementing a Differential Chaos Shift Keying (or DCSK) system that allows wireless transmission of data in real time over SDR platforms. A synchronization unit gas been utilized in the receiver end for allowing the system to work in real time and the system undoubtedly allows the modification of the central frequency, bandwidth and bitrate [29].

2.2.3. Implementation of Communication Protocols Using SDR And Other Application Specific Uses

Researchers are of the opinion that the most challenging aspect associated with the design and development of any configurable radio system is to ensure that the radio system can be easily reconfigured in accordance to the changes made in radio waveform. The authors also mention that same hardware radio set up can be utilized for operating in several different radio standards/ protocols, provided the setup has been implemented in an appropriate manner. Thus, they have proposed a generic SDR architecture with the aim of implementing smart SDR terminals capable of supporting multiple radio standards. The said generic architecture provides a standardized way for defining the various elements present in the MAC layer and the physical layer of any radio system, besides allowing the user to set the parameters that in turn facilitates the reconfiguration of the hardware and the software modules within a very short period. The connection between the various communication blocks, in case of the proposed architecture, is to be implemented in a centralized processing unit (instead of being implemented at the mobile radio terminals) thus reducing the cost of implementing the terminals. Besides this, the authors also claim that centralizing the configuration (and the standard designing) ensures that terminal users do not require the installation of costly third-party software licenses for being able to use several different radio waveforms.

In the technical report titled "Open Source Software-Defined Radio: A survey on GNU Radio and its applications", researcher Danilo Valerio [30]. have made an attempt of reviewing several of the successful attempts of implementing and using software defined radio systems that have been reported in the past. According to the author, at present, GNU radio allows the implementation of several digital communication standards, including the IEEE 802.11, the Bluetooth communication standards and the IEEE 802.15.4 protocols, along with the control and monitoring facility of the GSM protocols. The researcher has also commented that GNU Radio has already been utilized for the successful implementation of Analog Network Coding technique that makes use of network level information to successfully cancel out interference (at the signal level) in the receiving end of the radio device. The utilization of the GNU Radio in this particular research work was indeed an innovative and successful approach, as similar attempts of implementing the Analog Network Coding technique on FPGAs would have been much costlier and attempts of simulating the technique has already found to be less accurate [30].

GNU Radio, along with USRP boards have been utilized in developing a cross layer tested specifically designed for all wireless communication protocols. This particular test bed, popularly known as Hydra, allows the conducted of cross layer experimentation by supporting the interaction between the physical layers, data link layers and network layers. It is worth mentioning that the physical layer of this test bed is entire based on the functionalities of the GNU Radio [31].

The utilization of GNU Radio in several other sectors of communication has also been reported in the past. As for example, the GNU Radio platform and USRP devices have been reportedly utilized to successfully demonstrate the flaws in the privacy mechanisms utilized. On the other hand, GNU Radio has also been utilized for the implementation of physical layer based wireless system security techniques [32].

Researchers have reported the development of a Frequency Modulated – Continuous Wave radar or FMCW Radar with the use of the GNU Radio platform. The FMCW

Radar, which is primarily utilized for the purpose of weather surveillance, had gained much popularity in the recent past due to its capability of utilizing “solid state” amplifier devices. The authors have claimed to utilize the GNU radio platform for developing the software applications of the said radar, whereas for the implantation of the hardware part they have reportedly relied on the Universal Software Radio Peripheral (USRP) N210. The prototype of the Frequency Modulated – Continuous Wave radar when subjected to performance testing has demonstrated significant functional abilities while operating at a central frequency of 2 GHz and a bandwidth of 700 kHz.

On the other hand, in the article titled “Accuracy Analysis of FM Chirp in GNU Radio-based FMCW Radar for Multiple Target Detection”, researchers Amin, Suksmono and Munir [33]. have reported the successful analysis of the efficiency of FMCW Radars developed using GNU Radio platforms. The researchers had selected FMCW radars with FM chirp to analyze the accuracy of the process of detecting multiple targets, as supported by the GNU Radio platform [33].

2.2.4. Software Defined Radio: The Applications

In the article titled “Designing and Testing Software Defined Radio” researchers have provided descriptive discussions of the various possible manner of implementing the core elements of a software defined radio, namely the transmitter and the receiver sections. The authors have reviewed a large number of existing literary works, on the basis of which they suggest the use of super heterodyne receivers as SDR receivers. The authors have also highlighted the fact that the zero-IF receiver, which is basically a simpler form of the super heterodyne receiver architecture, is also popularly utilized as the receiver module of software defined radios. Besides this, the researcher have also mentioned the use of low-IF receiver and bandpass sampling receivers in software defined radios.

On the other hand, the authors have also mentioned the fact that the super heterodyne transmitters are also utilized SDRs, along with the direct-conversion transmitters .

Besides this, the authors have also highlighted the steps required for testing the functionalities of the SDR.

Researcher Tore Ulversøy [34]. has made an emphasis on the challenges and opportunities that are associated with the implementation and use of software defined radio. The researcher has have identified such factors due to which the development and application of software defied radio systems appears to be one challenging work. Some of these factors include the following: the challenges associated with developing the software architecture of the SDR platform, the challenges associated with the hardware and software elements required for supporting the computational activities associated with running the SDR, the security issues and challenges associated with the exchange of radio information through the SDR platform and the regulatory issues associated with setting up and operation of software defined radio communication systems.

Researchers Li, Mao and Rexford [35]. have proposed an architecture for an effective and efficient mobile cellular network that utilize the operational functionalities of a software defined radio system. The authors are of the opinion that a SDR based cellular communication network system would be of much help in resolving some of the key issues that are currently associated with the LTE networks. Some such issues, as identified by the authors, are being outlined in the section below:

a. SDN based cellular networks can be utilized to reduce the load of traffic that middle-boxes have to bear at present, thus enhancing the efficiency of the data networks to a significant extent.
b. Monitoring the network elements would be much easier with SDN based cellular networks, as the implementation of business and operational rules on the software-based nodes of the system. As a result of this enhanced control over network elements, the task of controlling the network elements and the billing operations for data usage would also ease out by several degrees.

The researchers have also commented that implementation of software defined radio based cellular network systems would essentially ensure seamless mobility for the subscribers, enhanced access control and quality control policies, enhanced mechanism for the management of inter cell interference.

S. Sezer [36].,in their article titled “Are we ready for SDN? Implementation challenges for software-defined networks,” have shed some light on handful of factor that are prohibiting the practical implementation of SDN or software defined radio based cellular communication networks. The researchers are of the opinion that the practical implementation of software defined communication network systems would only be possible when the solutions to the under mentioned issue/ risks have been identified and/ or implemented:

a. The successful development and implementation of programmable switches have not yet been achieved. This still remains one of the key challenges associated with the practical demonstration of SDN.
b. Solutions to the challenge of making the controller elements of a working cellular network so as to allow a view of the global network has also not been achieved as of now.
c. Last but not the least, the methods/ techniques/ technologies to be utilized for securing software defined cellular networks from malicious software attacks have yet not been identified. This is the second most pressing issue that has to be solved before the software defined radio based cellular communication networks can be successfully implemented [37].

CHAPTER 3

THEORETICAL BACKGROUND

3.1. INTRODUCTION

The scholarly papers reviewed in chapter 2 of this report highlighted the progress made in the domain of software defined radio systems and their efficient application in different domain of communication. Besides this, the articles reviewed in the above mentioned articles also provide detailed information regarding the manner in which FM transmissions can be conducted with the help of software defined radio communication systems. However, in order to identify these benefits of SDR systems, an in-depth study of associated communication systems had be conducted prior to the literature review phase. This particular section of the report would shed some light on the background information collected during the research work.

3.2. COMMUNICATION SYSTEMS

3.2.1. Communication Systems: A Definition

communication is that particular domain of study that takes into consideration the transmission of data or information, from one particular node (transmitter) to another (receiver) through several means. The researchers are also of the opinion that communication systems can easily considered as the technological devices, networks and systems utilized for the transmission of messages from one node to another [35].

On the other hand, author S. Sezer [36]. define the term ’communication’ as the process associated with the establishment of links and connections in between two nodes for the purpose of information exchange between the two. Thus, the electronic equipments that are associate with this exchange of information, are essentially termed as communication equipments and an assemblage of several such communication equipments (needless to say, for the transmission of messages) is known as a communication system [30].

Some of the typical examples of electronic communication systems include wired and wireless telephony systems, wired and non-wired (radio) telegraphy systems, radio communication systems, point to point and broadcasting communication systems, radar communication systems, computer communications [36].

3.2.2. Communication System Block Diagram

The diagram provided in the section below provides an insight into the core or basic components or equipments of any communication system:

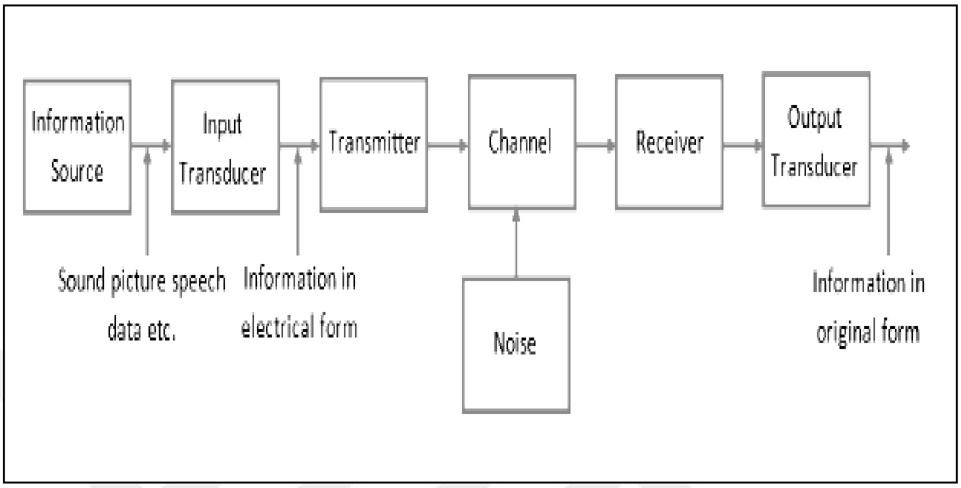

Figure 3.1. Essential components of any communication system.

As shown in the diagram above the, the essential elements of any communication system include a source of information, the input transducer, the transmitter, the communication channel through which the information is transmitted , the receiver and the destination node. A brief description of these components would be provided in the section below:

a. Information source: According to Patil and Patil [37]. a communication system essential serves the purpose of communicating or transmitting information or messages from one node to another. Needless to say, these messages are generated a particular node, often known as the source node or the information source. Thus, the primary function of an information sources can be considered to produce or generate the messages that can be transmitted through the communication system [37].

b. The Input Transducer: According to Cheng et al [38]. a transducer is an electronic device or equipment that is capable of converting energy of one form to another. The researchers highlight the fact that the input message or information to be transmitted through the communication system are, in most of the times, not electrical in nature: hence the transducer included in a communication system for allowing the conversion of non-electrical signals into electrical ones.

As for example, in case of radio broadcasting transmission systems, a microphone is utilized for the conversion of the information messages (which at that point of time is essentially a sound wave) into electrical signals [36].

c. The transmitter: As commented by Baldini [39]. the functional operation of a transmitter involves the processing of any electrical signal. Considering the case of radio broadcasting communication system, the transmitter associated with the system is utilized to process the electrical signal in a manner such that the output signal remains well within the radio frequency range.

On the other hand, researchers Oyeyemi and Wynn [40]. have commented that the main functionality of transmitter is to conduct the process of signal modulation, a process through which the input signal is superimposed on a high frequency signal known as the carrier signal.

d. The communication channel or the transmission medium: The term 'communication channel' essentially denotes the medium through which the message or information is transmitted. Thus, it can be said that the sole function of the communication channel is act as the physical connectivity between the source and destination nodes [25].

   Examples of communication channels include optical fibers, wired line, microwave links and so on and so forth.

e. Receiver: The receiver is that particular element of any communication system that allows the generation of an electrical signal from the distorted signal available from the communication channel. Authors Baldini [39]. highlight the point that the receive block associated with any communication system essentially performs the process of demodulation for the restoration of the electrical signal from the incoming signal. On the other hand, according to Pei et al [39]. the demodulation process is essentially a reverse process of the modulation techniques utilized by the transmitters [41].

f. Destination node: The destination node is associated with the conversion of the incoming electrical signal into the original format of the information message [41]. As for example, in case of radio broadcasting communication systems, the destination node consists of a loudspeaker device that converts the incoming electrical signal into the audio wave that was transmitted by the information source [37].

3.2.3. Signal: A definition

In the domain of communication engineering, the electromagnetic wave or the electrical wave that travels through the communication channel (with the aim of transmitting any information) is termed a signal [42]. Researchers Uengtrakul and Bunnjaweht [41]. comment that based on their characteristics, communication signals can be broadly classified into two groups: analog signals and digital signals. Both analog and digital signals can further be classified into the following types: periodic and a-periodic [42]. The following diagram provides a brief description of the different types of signals that are utilized in communication systems:

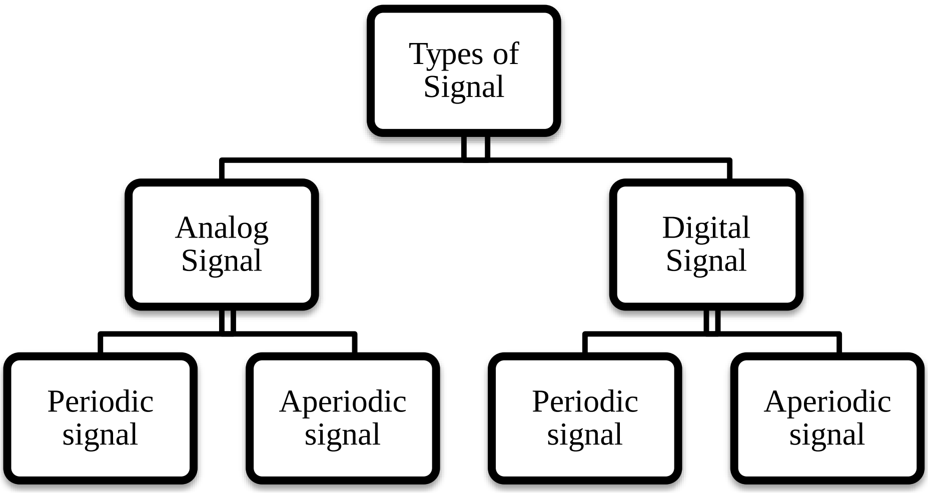

Figure 3.2. Types of signal utilized in communication systems.

In the following section of the report, we highlight the theoretical definition of the terms introduce in the diagram above.

a. Analog signals: The term ‘Analog signal’ is utilized to refer to any continuous and time varying signal. Authors Patil and Patil [37]. have highlighted the fact that the instantaneous value of the signal keeps on varying with respect to time.

As for example, let us consider that a tap can fill up a tank of capacity 100 liters within hour, particularly from 6am to 7 am in the morning. However, the flow of the tap is not uniform, which results in the portion of the tank filled up with water to vary with the time elapsed. As for example, at 6.15 am, it has been found that only one-fourth of the tank has been filled up, whereas at 6.45 am, as much as three quarters of the tank is found to be filled up.

If we make an attempt to plot the portion of the tank being filled up with respect to time, we arrive at the following graph:

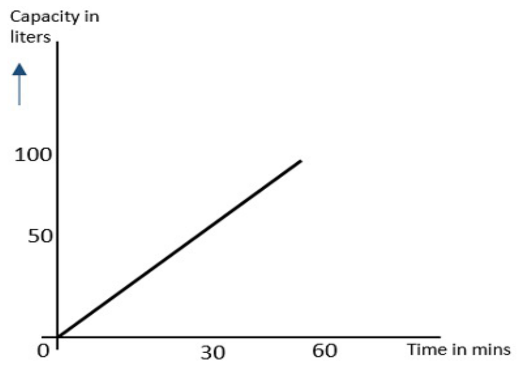

Figure 3.3. Portion of the tank being filled up with respect to time [43].

The resultant image consists of a straight line passing through the origin (0, 0) and can essentially be considered as an analog signal.

Researchers Grancharova [44].have emphasized on the point that any communication conducted with the use of analog signals is considered as analog communication.

b. Digital Signal: According to researchers Wang et al [45]. any signal which is discrete or non-continuous in nature can be considered to be a digital signal. On the other hand, Authors Patil and Patil [37].highlight the fact that the instantaneous values of digital signals can be denoted separately as they do not depend on any of the previous values [44].

In the following section of the report, we have made an attempt to plot the number of students who were present in the class for 6 days of a week.

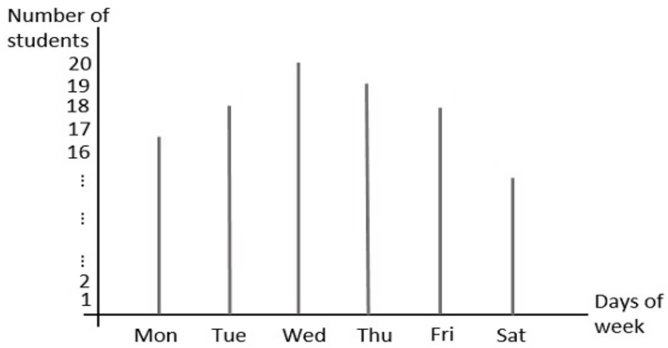

Figure 3.4. Number of students present in the class for all six days of the week [43].

As depicted in the graph above, the number of students present in the school in each day is essentially an individual value, as it does not depend on the number of students who were present the day before. Therefore, the said values can be considered as discrete.

On the other, according to Dubuc and Grenier [42]. binary digits having the values 0 and 1 are considered as digital values and the signals carrying such values are known as ‘digital signals’. Therefore, the communication system that relies solely on digital signals (carrying digital) values is known as a digital communication system.

c. Periodic signal: The phrase ‘periodic signal’, according to Petropoulou et al. [46]. is utilized to refer to any signal (be it analog or digital) that repeats any particular pattern from time to time. Researchers Naeem et al [47]. have highlighted the point that two of the most essential characteristics of such signals are that – a) the signal repeats the pattern in a repeated manner and b) making calculations or assumptions regarding such signals is far easier than that of those signals that do not follow any particular pattern [45].

The following diagram provides a graphical representation of a periodic (analog) signal:

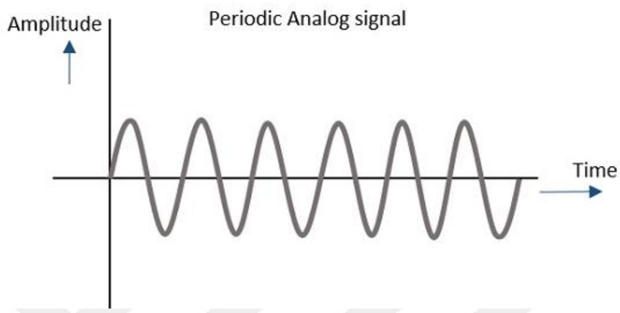

Figure 3.5. Graphical representation of a periodic (analog) signal [43].

d. Aperiodic Signal: As the name suggests, signals that do not follow or repeat any particular pattern from time to time, are known as a-periodic signals [45].

in sharp contrast to periodic signals, aperiodic signals follow particular pattern for an elongated period of time, but any repetition of the same is not observed, thus making the task of performing calculations and assumptions on the same much more difficult.

The following figure provides a pictorial representation of an aperiodic (digital) signal:

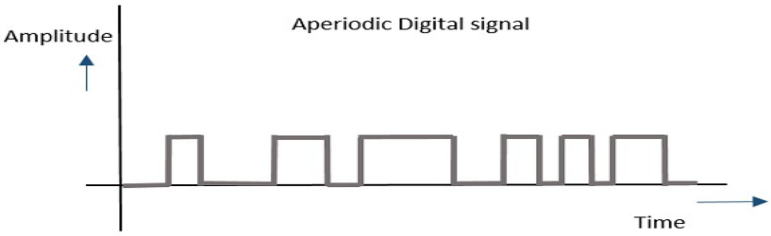

Figure 3.6. Graphical representation of an a-periodic (digital) signal [43].

3.2.4. Noise

According to Wang et al [45]. during the transmission or receival of information carrying signals through any communication system, it may so happen that any unwanted message signal gets incorporated, thus making the output at the receiver end unpleasant and distorted. Such unwanted signals that affect the quality of the received signal are considered as Noise signal [46]. Therefore, noise can be defined as an unwanted signal that possesses the capacity of interfering with the information carrying incoming signal, thus corrupting the contents of the same [47].

The following diagram provides an insight into the characteristics of a noise signal:

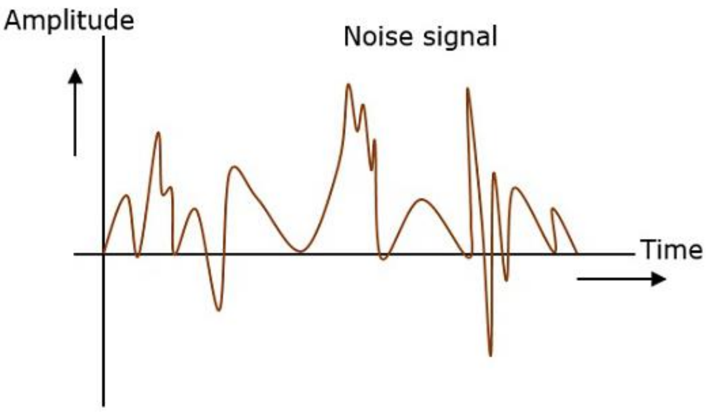

Figure 3.7. Graphical representation of a noisy signal [43].

A close look at the image presented above indicates that a noise can be defined as signal that does not follow any pattern, nor has any constant amplitude and frequency. It is essentially a random signal, unpredictable in nature. According to

Gandhiraj and Soman [7]. there exist several measures for reducing the ill effects of noise on the original signal, but none exists for the complete elimination of the same from the communication system. The authors have also pointed out some of the most common types of noise signals that observed in communication systems, namely:

a. The hissing sounds observed in radio transmission systems [48]
b. The buzz sounds that are commonly observed during telephonic conversations
c. Flicker sounds observed in television communication processes [48].

3.2.4.1. Types of Noise

Based on the source of the noise and its imminent effect at the receiver end, noise signals can be classified as the following:

a. External sources: The noise that are generated from the sources external to the communication system, are termed as 'external noise'. Such noise signals are generally found to occur in the channel of communication and thus cannot be eliminated. According to Miko and Nemeth [49]. the best possible way to mitigate its effects is to reduce the effect of the same on the incoming signals.

The most common examples of external noise are being outlined in the section below:

i. Noises introduced in the communication channel due to irregularities in the atmospheric condition [24].
ii. Cosmic and solar noises, also known as extra terrestrial noises.
iii. Industrial noise prevalent in the atmosphere [50].

b. Internal sources: Noise signals that are generated due to the functional operations of receiver units are considered as internal noises [51]. According to Alves and Cartaxo [50]. since this particular type of noise signals are generated due to the continuous functioning of the receiver circuits, proper maintenance of the same would be immensely helpful in lowering the effects of the same.

Some of the most common examples of internal noise are:

i. Thermal agitation noise or Johnson noise [44].
ii. Shot noise generated due to the movement of the holes and the electrons.
iii. The noise generated during transition [48].
iv. Various other noises including resistance effect, noise signals generated by the mixer, flickers in the circuit and so on and so forth [52].

3.2.4.2. Effects of Noisy Signals on Communication Systems

The discussions made in the section above indicate that noisy signal are essentially unwanted in any communication system, as they are capable of introducing inconvenient features in the system, besides reducing the efficiency of the system. In the section below, we highlight some of the major ill effects of noisy signals on any communication system.

1. *Limitations on the operating range of the system:* the presence of noisy signals puts a limit on the functional operation of a receive, thus reducing its capability of amplifying the weakest signals emitted by the source. This in turn, reduces the operating range of the said communication system.
2. *Effects on the sensitivity of receive devices*: Researchers Franchi, Fischer, and Weigel [51]. define the term sensitivity as that particular amount of input signal that a receiver device requires for generating quality output. The authors are also of the opinion the presence of noisy signal affects the sensitivity of the receiver, thus deteriorating the output of the receivers.

3.2.4.3. Signal to Noise Ratio

The Signal-to-Noise Ratio or SNR can be defined as the ratio between the signal power and the noise power and can be calculated with the use of the following formulas [52].

a. InputSNR= $(SNR)_I$ = Average power of modulating signal/ Average power of noise at input.
b. OutputSNR= $(SNR)_O$ = Average power of demodulated signal/ Average power of noise at output.
c. ChannelSNR= $(SNR)_C$ = Average power of modulated signal/ Average power of noise in message bandwidth.

Researchers Wang et al [45]. are of the opinion that greater values of Signal to Noise Ratio denote higher quality of the signals received.

3.2.4.4. Figure of Merit

The term Figure of Merit is often utilized for defining the ratio between the output SNR of a communication system to its input SNR [53]. The ratio is denoted by the letter F and is utilized for providing an idea regarding the performance of any communication device.

According to AldayaArag, and Campuzano [53]. the Figure of Merit of transmitter is:

$$F= (SNR)_O / (SNR)_I \qquad (3.1)$$

In addition, the Figure of Merit of Receiver is:

$$F= (SNR)_O / (SNR)_C \qquad (3.2)$$

An interesting point has to be noted in the equation above that the Channel SNR has been input SNR of the receiver. This is because the channel itself is the input to the receiver device of the communication system [54].

3.2.5. Signal: Modulation and De-Modulation

In order to make any signal travel over long distances, it is essential to take advantage of techniques that can be utilized to add strength the signal, without making any changes in the original parameters of the same. In the following section of the report, discussions would be made on the modulation and demodulation techniques that are essential for the transmission of signals over long distances and the retrieval of the same.

3.2.5.1. Signal Modulation

According to Salous [55]. an information carrying signal has to take the help of a high frequency carrier signal when the same has to be transmitted over long geographical distances and establish a reliable communication over the same, provide the carrier signal does not bring about any changes in the characteristics of the message signal. Researchers Beas et al [56]. have pointed out the fact that the message content of a signal gets altered significantly in case the characteristics of the same are altered under any circumstances. On the other hand, high frequency signals have the ability to travel to large distance without being affected by external disturbance. Thus, it is essential to take the help of such carrier signals to make a message carrying signal to travel to long distances without incorporating any changes in the message content of the signal [57].

Researchers Franchi, Fischer, and Weigel [51]. are of the opinion that modulation is the very process of inducing changes in the characteristics of any carrier signal such that becomes capable of carrying the instantaneous values of the message signal.

The need for modulation: As Miko and Nemeth [49]. point out, the information carrying signals, also known as baseband signals, are not suitable for transmission over considerable distances. In order to make them suitable for transmission over long ranges, the strength of the same has to be increased significantly- a state obtained by modulating it with a carrier wave of high frequency [57].

3.2.5.2. Benefits of Modulation

According to Alves and Cartaxo [50]. following are the primary benefits of the modulation process:

a. *Reduction in the size of antenna*: As commented by Borah and Boucouvalas [58]. in case baseband signal had to be transmitted over significantly long distances, antenna of enormous sizes would have to be utilized. However, the exploitation of modulation techniques ensures that the sizes of the antennas are reduced significantly.

b. *Increase in range of communication*: In case baseband signals are transmitted over any communication medium without any modulation, the same would not be able to travel to significant distances without getting distorted. However, the utilization of modulation techniques facilitates the expansion of the range of communication [51].

c. Modulation also allows the multiplexing of signals.

d. The quality or reception increases.

e. Modulation also allows alterations in the bandwidth of the signals [57].

3.2.5.3. Signals Associated with The Process of Modulation

The following section of the report would be utilized for providing the definitions of the various types of signals that are associated with the process of modulation.

a. *The message carrying signal or the modulating signal:* As commented by Franchi, Fischer, and Weigel [51]. the signal that contains the information or message to be transmitted is known as the message signal. As the message signal is essentially a baseband signal, it has to undergo the modulation process so as to become transmission ready. Thus, the message-carrying signal is also known as the modulating signal [58].

b. *Carrier Signal:* The high frequency signal which in spite of having a certain amplitude, phase and frequency does not have any information content is considered as a carrier signal. The carrier signal, as Alves and Cartaxo [50]. point out, is utilized for carrying the information content of the modulating signal to the receiver block post modulation.

c. *Modulated Signal:* The combination of the carrier signal with that of the modulating signal, obtained as the result of the modulation process, is known as the modulated signal [24].

3.2.5.4. Modulation and Its Types

Depending upon the techniques utilized for generating the modulated wave, modulation techniques can be classified under the following groups [57].

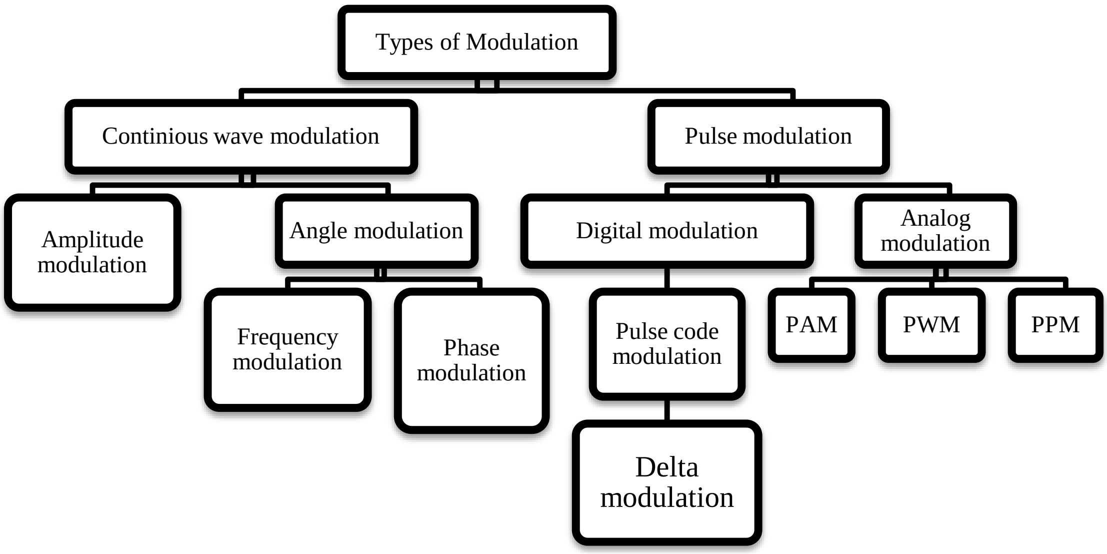

Figure 3.8. Graphical representation of a noisy signal.

As depicted in the table above, the modulation techniques can be broadly classified into the following types:

Continuous wave modulation: In this method, a sine wave of very high frequency is utilized for the transmission of message signals to significant distances.

According to Franchi, Fischer, and Weigel [51]. continuous wave modulation technique can be further classified into the following types:

a. Amplitude modulation*:* Researchers Miko and Nemeth [49]. comment that when the amplitude of the high frequency carrier wave has to be modulated with respect to the amplitude of the message signal, the technique is known as amplitude modulation.
b. Angle modulation*:* Researchers Gandhiraj and Soman [7]. comment that when the angle of the high frequency carrier sine wave has to be modulated with respect to the angle of the message signal, the technique is known as Angle modulation.

Angle modulation techniques can further be subdivided into the following types:

i. Frequency Modulation: According to Wang et al [45]. when the frequency of the high frequency carrier sine wave has to be modulated with respect to the message signal, the technique is to be transmitted, the process is known as Frequency modulation.
ii. Phase Modulation: when the phase of the high frequency carrier sine wave has to be modulated with respect to the message signal, the technique is to be transmitted, the process is known as Frequency modulation.
iii. *Pulse modulation:* Researchers Franchi, Fischer, and Weigel [51]. are of the opinion that when a “periodic sequence of rectangular pulses” are utilized as the carrier signal for the transportation of the information carrying signal, the technique is referred to as pulse modulation.

On the other hand, authors Selva et al [59]. illustrate that pulse modulation techniques can further be subdivided into two types: analog pulse modulation technique and digital pulse modulation technique. A detailed discussion of these two types would be provided in the section below:

a. Analog pulse modulation technique: In case of analog modulation, if the duration of the pulse wave is varied with respect to the information carrying modulating signal, the technique is referred to as the Pulse Duration/Width Modulation (PDM/PWM) [56].

In a very similar fashion, in case the position of the pulse wave is varied with respect to the information carrying modulating signal, the technique is referred to as the Pulse Position Modulation or the PPM [57].

Likewise, when the amplitude of the pulse wave is varied with respect to the information carrying modulating signal, the technique is referred to as the Pulse Amplitude Modulation or the PAM [56].

b. Digital modulation technique: In case of digital modulation, the analog signal is at first converted into a digital signal consisting of 0's and 1's. According to researchers Miko and Nemeth [49]. as the outcome of the process is a coded pulse train, the modulation technique is known as Pulse Code Modulation or PCM [59].

The Delta modulation technique can be considered as an improvement over the Pulse Code Modulation technique, which involves the very same techniques that have been discussed in the section above.

In the following section of the report, discussion would be made on Frequency Modulation techniques and devices, such that basic knowledge utilized for the development of the Software Defined Radio can be highlighted.

3.3. FREQUENCY MODULATION

Researchers Wang et al [45]. have commented that while varying the amplitude of the carrier signal in accordance to the instantaneous values of the modulating signal, changes can also be incorporated in the frequency of the said high frequency carrier wave so as to make it suitable for transmission over long distances. In fact, frequency modulation is commonly utilized for the transmission of signals having frequencies higher than 30 MHZ, as utilized for the process of Very High Frequency FM broadcasting or VHF FM broadcasting [60].

In addition to the high frequency FM broadcasting process, Frequency Modulation techniques are also utilized in several other both way or duple radio communication systems, including mobile telephony and radio systems [58].

3.3.1. Frequency Modulation: A Definition

In order to generate a frequency modulated wave, the frequency of carrier wave is varied, so as to match the amplitude of the radio signal to be transmitted. The following diagram provides a pictorial representation of the final output of the frequency modulation process.

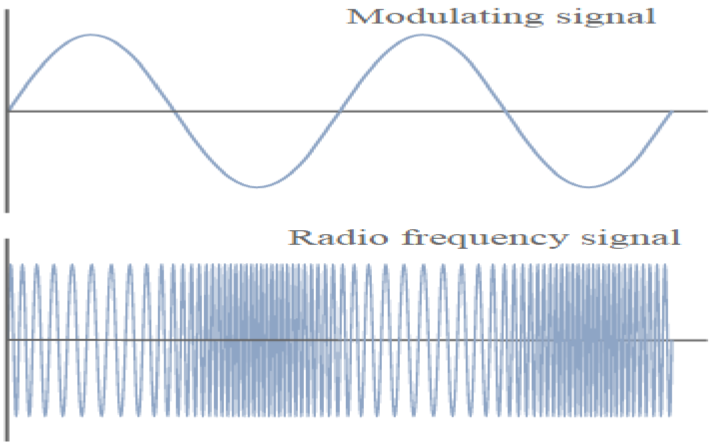

Figure 3.9. Frequency Modulation.

As depicted in the diagram above, during the modulation process, the output signal makes upward and downward movements with respect to the amplitude of the modulating signal. The extent to which the output signal makes the upward and downward movements is considered to be of the most important parameters of a frequency modulation process and is known as the 'deviation' [50].

Radio broadcasting stations that take advantage of the very high frequency range of the radio frequency spectrum (in between 88.5 to 108 MHz) utilize deviations in the range of -75 kHz to +75 kHz. Radio signals having such high deviation are often termed as *Wide Band FM (WBFM)* [52]. The major advantage of utilizing these radio frequency signals is that they support transmissions of very high quality: however, the bandwidth required for the transmission process is significantly large [61].

On the other hand, the radio waves utilized for the purpose of communication are much lesser amount of bandwidth: such signals are known as *Narrow Band FM* (or *NBFM*) and commonly utilize deviations in the range of -3 kHz to +3 kHz [54].

The narrow band FM is not capable of supporting the high-quality transmission like that of Wide Band FM, however the bandwidth consumption of this particular type of signal is considerably lower than that of WBFM. Thus, Narrow Band FM signals are utilized specifically for mobile radio/ telephonic communication purposes [62].

3.3.2. Frequency Modulators

In the following section of the report, discussions would be made on the well-known methods that are utilized for the purpose of generating frequency modulated signals.

a. Direct method of FM generation: The diet method of FM generation involves varying the instantaneous frequency of the high frequency carrier wave with respect to the message content of the input signal: the variation being performed with the help of the voltage controlled oscillator or VCO device [46].

In its simplest form the modulator utilized for direct FM, generation consists of an oscillator circuit, which in turn utilizes a varactor diode for the purpose of determining the variations in frequency [38]. The following figure provides the graphical representation of a Hartley oscillator being utilized FM generation using direct methods.

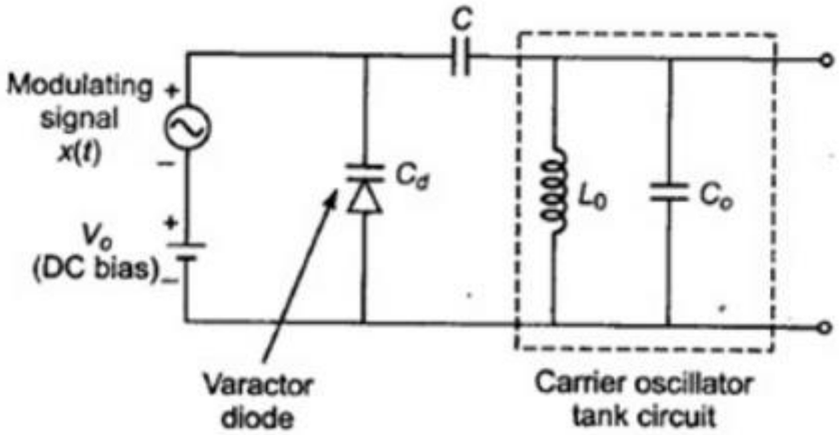

Figure 3.10. FM generation (direct method) using Hartley oscillator [63].

Let, the cv_o denote the capacitance of the varactor diode before the application of the modulating signal m(t).

Therefore, after the application of the modulating signal m(t), the numerical value of the capacitance of the varactor diode can be calculated using the following formula [64].

$$CV_O=CV_O+k_c\,m(t) \quad (3.3)$$

where k_c denotes the sensitivity of the diode

Therefore, the total capacitance of the LC circuit would be:

$$c(t)=c_{FIXED}-k_c m(t) \quad (3.4)$$

where, c_{FIXED} is the equivalent capacitance of c_o, c and v_o.

When $m(t)=0$ and $c(t)= c_{FIXED}$. The frequency of oscillation becomes equal to that of the carrier frequency. The numeric value of this frequency of oscillation can be obtained through the following equation:

$$f_c=1/2\pi\sqrt{.}L_o c_{FIXED} \tag{3.5}$$

But, after the application of the modulating signal m(t), the instantaneous frequency becomes:

$$f_i(t)=1/2\pi\sqrt{}L_o(c_{FIXED}-k_c m(t)) \tag{3.6}$$

or,

$$f_i(t)=1/2\pi\sqrt{}\ (L_o c_{FIXED}(1-k_c m(t)/\ c_{FIXED})) \tag{3.7}$$

Further simplifications of the above equation leads to the following equation:

$$f_i(t)=f_c+k_f m(t) \tag{3.8}$$

where $k_f=k_c f_c/2cFIXED$

Needless to say, equation (vi) depicts the basic equation of FM waves.

b. In-direct method of FM generation:Armstrong proposed the techniques used in the indirect method of FM generation: thus, the frequency modulator utilized for this purpose is known as the Armstrong modulator [36].

According to Selva et al [59]. the indirect method of FM generation consists of the following two steps:

i. Generating a narrow band FM (NBFM) from a modulating wave [41]
ii. Utilizing a frequency multiplier for the purpose of converting the narrow band FM into wide band FM.

The following diagram provides a graphical representation of the various steps utilized developing a frequency modulated signal in the indirect method [40].

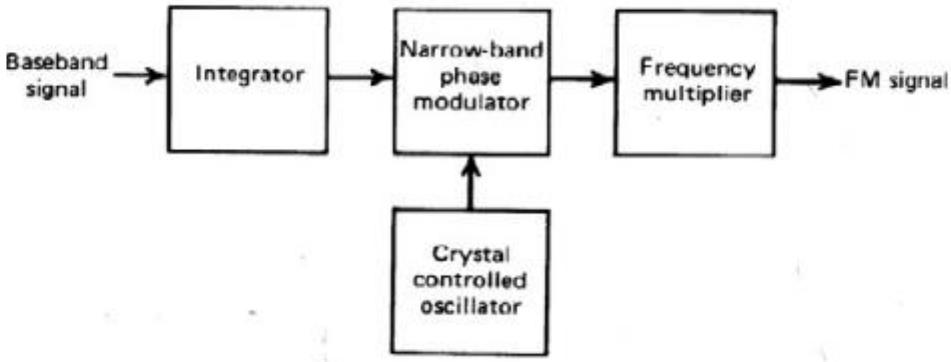

Figure 3.11. FM generation (in-direct method).

3.3.3. Frequency Modulation: Advantages and Disadvantages

The following sections of the report would provide detailed information regarding the advantages and disadvantages of frequency modulation techniques in communication systems.

3.3.3.1. Advantages Of Frequency Modulation

a. *Noise resilient:* In frequency modulation systems, the information content of the modulating signal is transmitted in form of variations in the frequency of the carrier signal. Thus, any variations in the level of the signal (as long as it does not become impossible for the receiver device to detect) have negligible effect on the quality of the output audio signal [36]. On the other hand, this very characteristic of the frequency modulated signals makes them resilient to a wide range of signal interferences and noises. Thus, frequency modulated waves are considered to be most suitable for both mobile radio communication systems and radio broadcasting communication systems [65].

b. *Utilization of RF amplifiers*: According to Franchi, Fischer, and Weigel [51]. RF transmitters can be effectively utilized to the amplification of FM signals. The authors comment that since RF amplifiers consume much less power than that of linear amplifiers, FM systems are much more preferable for all mobile radio communication systems.

3.3.3.2. Disadvantages Of Frequency Modulation

Irrespective of the advantages mentioned in the section above, frequency modulated signals have several other distinctive disadvantages over signals generated through other modulation techniques. Some of such limitations are being enlisted in the section below:

a. The spectral efficiency of frequency modulated systems is much less than that of phase modulation and quadrature amplitude modulation. Thus, the former technique cannot be utilized for efficient data transmission systems [53].

b. The demodulator utilized in the receiving ends of the FM communications systems are much more complex and expensive than those utilized in case of other modulation techniques [57].

3.4. FREQUENCY MODULATION (FM) RADIO SYSTEMS

As discussed in the sections above, frequency modulation is widely utilized in television and radio communication systems. In the following section of the report, discussions would made with the aim of providing the audience with the very basic concepts of the transmitters and receivers utilized in FM communication systems.

3.4.1. The FM Transmitter

According to Franchi, Fischer, and Weigel [51]. the entire unit that consider a incoming message containing signal as the primary input and processes the same to generate a FM modulated signal, ready for transmission, should be considered as the transmitter unit of the radio communication system. The following image provides a graphical representation of the six core elements of a FM transmitter:

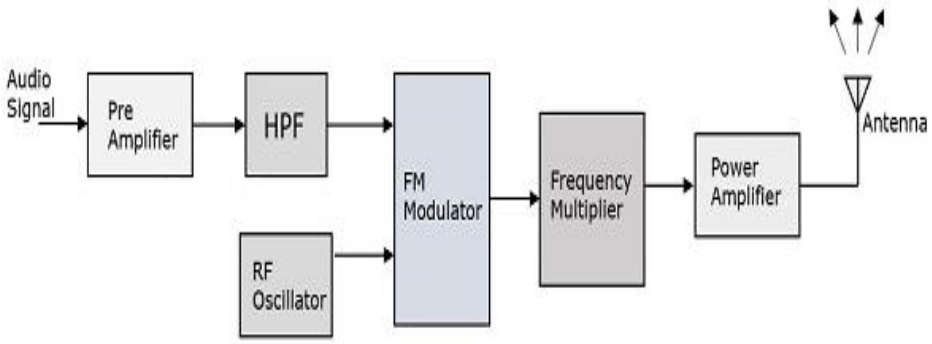

Figure 3.12. Block Diagram of a FM Transmitter.

The transmission of a FM signal occurs through the following stages:

a. In the very first step, the audio signal generated by the microphone is fed into the pre-amplifier. The pre-amplifier in turn amplifies the audio signal by boosting the incoming modulating signal to the next higher level [60].

b. The amplified signal is then fed into a high pass filter. The high pass filter performs the function of the pre-emphasis network and facilitates the process of filtering the noise signals present in the incoming signal [26]. This particular stage of the transmitter circuit essentially improves the signal to noise ratio of the modulating signal.

c. The output of the high pass filter is then passed to the FM modulator circuit. The oscillator circuit present within the FM modulator circuit generates the high frequency carrier wave and modulates it in accordance to the instantaneous values of the modulating signal [58].

d. The modulated signal generated by the FM modulator circuit is then passé through a frequency multiplier which helps in increasing the operating frequency of the modulated signal.

e. Last but not the least, the RF power amplifier is utilized for enhancing the power level of the signal. Transmission of the amplified signal occurs through the antenna attached with the transmitter block [56].

3.4.2. The FM Receiver

According to Johnson et al [57]. the entire unit that considers a incoming modulated signal as the primary input and processes the same to generate an audio signal as output should be considered as the transmitter unit of the radio communication system. The following image provides a graphical representation of the five core elements of a **super heterodyne** FM receiver:

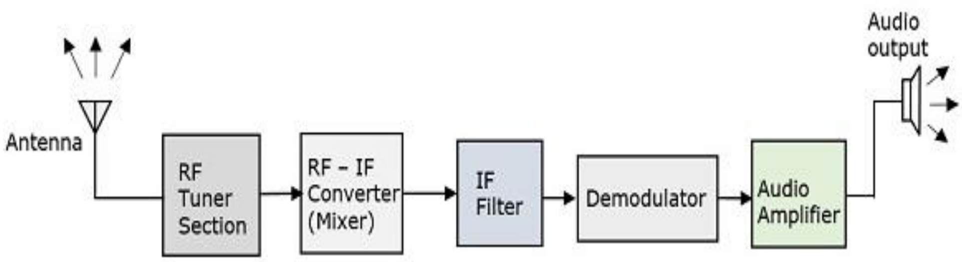

Figure 3.13. Block Diagram of a super heterodyne FM receiver.

The super heterodyne FM receiver operates in the following manner:

Step 1: The input signal to the receiver circuit (as received by the antenna) is primarily passed on to the RF Tuner Section, which essentially selects the frequency that would be demodulated by the receiver [45]. The RF Tuner Section also takes part in the task of tuning the RF filter and the local oscillator associated with the receiver circuit [57].

Step 2: The output of the RF Tuner Section is fed to the RF-IF converter, which performs the task functionalities of a signal mixer. The RF-IF converter essentially consists of a local oscillator: the RF-IF converter thus mixes the incoming modulated signal with the constant frequency generated by the local oscillator [60]. The resultant frequency is often termed as the Intermediate Frequency or the IF [46].

Step 3: The IF filter is basically a band pass filter that helps in the elimination of all the interference or noises present in the incoming signal, thus improving the Signal to Noise Ratio (or SNR) of the incoming signal [22].

Step 4: The demodulation of the incoming signal is conducted in this stage. It is quite interesting that the process utilized for the demodulation is very similar to the modulation process utilized in the transmitter side [64].

Step 5: The output of the demodulator is fed to the audio amplifier as enhance the audio levels of the output signal [37].

CHAPTER 4

METHODOLOGY

4.1. METHODOLOGY

The following section of the thesis report would be dedicated solely to the discussion of the methods that have been utilized in demonstrating the practical applications of the software define radio system. The discussions made in chapters 2 and 3 of the report have lead the identification of the most essential hardware and software elements requited for the implementation of any software define radio system, out of which the hardware parts, namely personal computing devices with high processing power were readily available in the laboratory.

However, in order to receive the signals with the help of the high-end processors included in the computing devices, effective software modules capable of receiving and transmitting radio signals had to be installed. Two well known software modules were utilized for the same, namely the HDSDR program and the SDRSharp program. On the other hand, the GNU radio platform was utilized for the process of transmitting the radio signals processed by the computing device. It is worth mentioning that the HackRF One, a well known open source SDR platform was also utilized in the project.

Detailed discussions on the above mentioned software modules would be made in the sections below, along with the step by step process in which the receival and transmission of radio signals have been achieved successfully, along with the preliminary requirements of these modules and the circuit utilized for the purpose.

4.2. DESIGN DIAGRAM

In this section of the report, discussions would be made on the software modules utilized for receiving and transmitting the radio signals, along with the hardware elements on which the software modules were run.

4.2.1. Hardware Elements Utilized In The Project: The Hackrf One Bundle

The HackRF One is one of the most well known inbuilt Software-Defined Radio platforms that facilitate the accurate and fast transmission of signals in the radio frequency range. The hardware platform has been designed in manner such that it is capable of receiving and transmitting radio signals in the range of 1 MHz to 6 GHz.

According to the information available on the official product page of HackRF One Bundle http:// hackerwarehouse. com/ product/ hackrf-one-kit/), the device acts as an open source platform capable of transmitting radio signals in the range of 1 MHz to 6 GHz, besides having the capability of operating like that of a USB peripheral. It has also been mentioned in the very same page that this particular hardware platform can be programmed according to the specific requirements of any project, thus making it suitable for use as a standalone device.

On the other hand, according to B. Bloessl [4]. the capability of the HackRF One Bundle to operate as a USB peripheral makes it possible to utilize the device like that of the sound card of any personal computing device. The device has the capability of processing radio signals besides transforming them into digital signals and vice versa, thus supporting the integration among the various phases associated with communication networks or systems of large scale. Needless to say, the device is widely utilized for the purpose of testing, developing, improvising and modifying radio communication systems.

Researchers Klumperink and Nauta [66]. have highlighted yet another aspect of this particular open source platform that make it the primary choice of radio signal processing works. The authors comment that at present , we are being surrounded by a wide variety of digital technologies and radio waves, like that of WiFi, broadcasting stations, smart phones, bluetooth, IT infrastructures and GPS: the HackRF One is one such open source software defined radio platform that has the unique capability of interacting all of the above. In fact , the standalone hardware platform has been provided with the capacity of trans-receiving a vast majority of the wireless signals that are utilized for the purpose of communication in the modern age: the key idea behind including such capabilities being the development of one such pen source platform that can be utilized for providing assistance to researchers and communication engineers in implementing more effective and acute wireless radio communication systems [65].

The HackRF One Bundle consists of essentially the HackRF One hardware platform and an ANT500 Telescopic Antenna. The ANT500 Telescopic Antenna is capable of receiving and transmitting radio frequencies lying in the range of 75 MHz to 1000 MHz. The said antenna has a resistance of 50 ohm: the total length of the antenna is 20cm (when collapsed) and 88 cm when extended fully.

The features of the other component e of the bundle, that is the HackRF One hardware platform itself, is being include in the section below:

Characteristic features of the HackRF One platform:

1. Transmitting or receiving any radio signal that lies within the range between 1 MHz and 6000 MHz
2. Half-duplex transceiver
3. Supports a maximum sample rate of 20 Maps
4. Supports 8-bit quadrature samples : both 8-bit Q and 8-bit I
5. Supports a High Speed USB Interface
6. Drives Power through USB bus
7. compatible with SDR#, GNU Radio, , and several other similar platforms
8. The RX and TX baseband filter and gain are software-configurable
9. antenna port power (50 mA at 3.3 V) is software-controlled

10. Includes SMA female antenna connector
11. Includes SMA female clock input and output for supporting synchronization
12. Includes convenient buttons that can be utilized for the purpose of programming
13. includes internal pin headers that can be utilized for further expansion
14. Weight of the device: 1 lbs
15. Dimension of the hardware setup: 6 inches x 4 inches x 1 inch
16. Developed and marketed by: Great Scott Gadgets

Figure 4.1. The HackRF One Bundle.

Figure 4.2. The HackRF One hardware.

Figure 4.3. The ANT500 Telescopic Antenna included in the HackRF One Bundle.

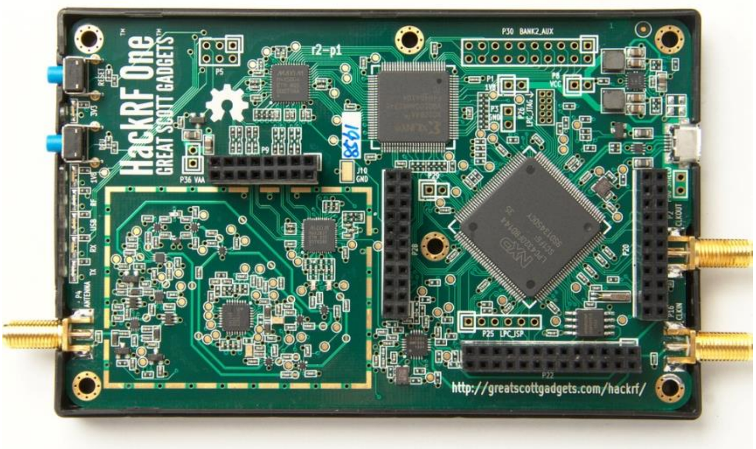

Figure 4.4. The internal circuit of the HackRF One.

Advantage of HackRF One platform over other similar hardware platforms:

Researcher Fähnle [67].is of the opinion that there exist several other open source software defined radio platforms that clam to provide similar advantages like that of the HackRF One: the USRP and the BladeRF being two of the most well-known ones. However, the authors have also pointed out the fact that BladeRF and other similar platforms are capable of receiving and transmitting radio signals in the range of 1 Mhz to 3.8 GHz only. Besides this, the said platforms (USRP and the BladeRF) still operate on Schematics and Host Code. These two platforms are also priced at a much higher range: from 675 USD to 1100 USD and up [66].

Therefore, the primary advantages of using the HackRF One platform over other similar hardware platforms can be outlined as the following:

1. Available at a very low cost as compared with the competitors (HackRF One is currently available at price of 330 USD only)
2. Capability of transmitting and receiving radio signals lying in within a larger domain (from 1 MHz up to 6 GHz)
3. Being open source, the platform need not rely on any other software platform for efficient operations [67].

4.2.2. The Software Platform Utilized in This Project

As mentioned in section 4. 1 of this chapter, for the process of transmitting and receiving the radio signals, three particular software modules were utilized the HDSDR program and the SDRSharp program were utilized for the purpose of radio signal receiving, whereas the GNU radio was utilized for the process of radio signal transmission.

In the following sections of the chapter, discussions would be made on each of software modules that have been utilized for the process of transmission and receival of radio signals.

4.2.2.1. Software Modules Utilized for Receiving Radio Signals

<u>The HDSDR program</u>

The HDSDR program is an open source, freeware SDR (Software defined Radio) program that has been designed specifically to be installed on the windows platform. The typical applications that are supported by this software module include the following: Radio listening, SWL, Ham Radio, Radio Astronomy, Spectrum analysis and NDB-hunting.

The current version of HDSDR is supported by a wide range of windows-based platforms, including the Microsoft Windows 2000, Microsoft Windows XP, Microsoft Windows Vista, Microsoft Windows 7, Microsoft Windows 8, Microsoft Windows 8.1 and the latest Microsoft Windows 10. It is worth mentioning that the HDSDR is essentially an advanced version of the widely known Winrad designed and developed by Alberto di Bene.

The key features of the HDSDR program are being outlined in the following section of the thesis.

Characteristic features of the HDSDR program

1. The waterfall display and large spectrum for each input and output signal is available separately
2. It is possible to and is optically zoom the waterfall and the AF & RF spectrum to fit the width of the window, the entire process being independent of the FFT resolution bandwidth (RBW)
3. The screen area can be efficiently and flexibly used (from 640x480 (Netbooks) up to 8k)
4. The software module supports extremely low-speed waterfall, which is helpful for the detection of noise patterns and/ or short-wave condition monitoring
5. The following demodulation modes are supported: AM, FM, SSB, ECSS and CW
6. The basic transmit (TX) supports functionality in the following modes SSB, FM, AM, & CW
7. The I/Q modulated signal pair this is utilized for the TX input signal (or the Microphone signal) is re-produced on the output of the TX or the microphone
8. The software module under consideration supports the following features: noise reduction, squelch, noise blanker, anti-alias filter, automatic notch filter adjustable band pass filter and up to 10 other notch filters that are manually adjustable
9. The software module under consideration also supports playback and record RF, AF and IF WAV files, along with scheduled recording for the same.
10. The HDSDR program supports transmission and receival of radio signals in the following bands: Ham Bands, Frequency Manager for Eibi, User frequency lists, Radio Bands, etc
11. The HDSDR program supports DDE client for Ham Radio Deluxe, WXtrack, Orbitron, SatPC32, PstRotator (Howto) and Wisp
12. The HDSDR program includes Omni-Rig support (CAT) for controlling additional hardware
13. The HDSDR program supports several other hardware through the utilization of the Alberto's (I2PHD) ExtIO DLL interface
14. ExtIO frequency options for Downconverter, IF-Adapter, Upconverter, calibration and Under sampling are also supported by the HDSDR program

15. All program options available with the HDSDR can be easily stored and loaded by creating specific "profiles": this feature makes it easier to utilize various receivers
16. The HDSDR program has inbuilt options for autocorrelation and cestrum display of the demodulated audio waves
17. Some of the command line options available with the HDSDR program facilitates the process of profile management

The SDRSharp (SDR #) program

The SDRSharp (or the SDR #) program is small, effective, simple an intuitive personal computer based Digital Signal Processing application that supports the functionalities of a software defined radio. The entire application has been developed in C# (hence the name SDR #) and currently supports the following devices:

a. Any SDR front end that is sound card based
b. FiFiSDR
c. FUNcube Dongle
d. FUNcube Dongle Pro+
e. I/Q wav files
f. LazyDog's LD-1
g. RTL2832U / RTLSDR (external)
h. SDR-14
i. SDR-4
j. SDR-IQ
k. SoftRock

The SDRSharp (or SDR #) program was also utilized for developing a software defined radio: the detailed description of the steps and processes that were utilized in the same would be discussed in section 4.4 of the report. It is worth mentioning that the RTL-SDR dongle R820T/R820T2 was purchase and utilized for the said setup.

4.2.2.2. The Software Modules Utilized for Receiving Radio Signals: The GNU Radio

According to authors Gandhiraj, Ram, and Soman [7]. the GNU Radio is essentially an open source and free software toolkit that incorporates a range of signal processing blocks that are essential for supporting the functional operation of software defined radios. The researchers have also highlighted the fact that the GNU radio can be integrated with readily available inexpensive external radio frequency hardware or can also be utilized within a simulation like environment that does not include any hardware setup.

The GNU radio platform was utilized with the aim of developing a software defined radio: the details of this design phase, along with the procedure utilized for the installation of the GNU radio would be discussed in brief in section 4.4 of the report.

4.3. REQUIREMENTS

The hardware elements that were essential for the installation and implementation of the software modules utilized in this project are being enlisted in The following points :

1. The HackRF One hardware: For the development of the SDR module
    - 1.1 - Transmitting or receiving any radio signal that lies within the range between 1 MHz and 6000 MHz
    - 1.2 - Half-duplex transceiver
    - 1.3 - Supports a maximum sample rate of 20 MSps
    - 1.4 - Supports 8-bit quadrature samples: both 8-bit Q and 8-bit I
    - 1.5 - Supports a High-Speed USB Interface
    - 1.6 - Drives Power through USB bus
    - 1.7 - compatible with SDR#, GNU Radio, and several other similar platforms

2. Microsoft windows platform: For running the HDSDR program

    2.1 - Microsoft Windows 7, 64-bit operating system

3. Microsoft windows platform: For running the SDRSharp (SDR #) **program**

    3.1 - Microsoft Windows 10, 64-bit operating system, Microsoft .NET 4.6 redistributable

4. Linux OS system: For running the GNU radio

    4.1. - N/A

4.4. DESIGN

4.4.1. Installing and Running the HDSDR Software

The primary characteristics of the HDSDR software have been already highlighted in the section above. In the sections below, in-depth discussions would be made on the step that have been utilized for the installation of the HDSDR platform and receiving radio signals with the help of the same.

1. Installing the HDSDR Software.

The HDSDR software was installed in the personal computer through the following steps:

a. Microsoft based Windows 7 was installed in the PC: however, the HDSDR program is also supported by all higher versions of windows including Windows 8, 8.1 and 10.
b. An Si570-based Local Oscillator was attached to the RX Rig. Besides this, the I and Q outputs of the rig were wired in accordance to the build instructions.
c. The HDSDR software module was downloaded from the website link http://www.hdsdr.de/

d. The downloaded software was then installed with all default options
e. The installation location of the HDSDR was noted.
f. In the next step, the CFGSDR was downloaded from the website link http://pe0fko.nl/CFGSR/#download. The program was installed with all default options, and the installation location was also noted. Once the installation was completed, the said location was visited with the aim of copying the file name extIO.dll. This particular file was the pasted at the installation folder of the HDSDR program, so as to ensure efficient communication with the later.

2. Configuring the HDSDR.

The HDSDR was configured in the PC through the following steps:

a. The program was initiated by clicking on the HDSDR icon present on the desktop
b. Once the program was initiated, the control panel option were manipulated in the following manner:

i. *Soundcard selection:* The soundcard option was clicked on, after which the RX soundcard option was elected (I and Q were selected for input whereas the Output option was selected for speaker).

ii. *Bandwidth selection:* In the bandwidth dialogue box, 48000 was entered as the input bandwidth, the default option was selected for the output. As a result of these selections, a tuning range of -48 kHz to +48 kHz was achieved as the Local Oscillator frequency or the central frequency.

iii. *Option selection:* In the dialogue box for option selection, the Soft rock Si570 was selected as the input. Next, the option sited as “Swap I and Q Channels for RX Input” was also selected, with the aim of setting the USB and LSB of the incoming SSB signal [67].

The following figures provide an insight into the various options that were selected during the configuration phase of the HDSDR.

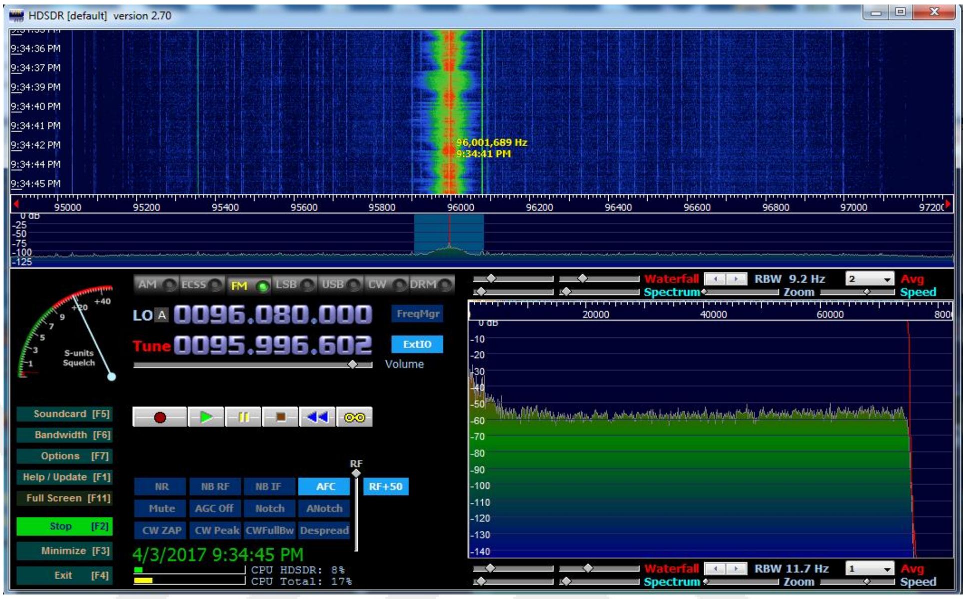

Figure 4.5. The HDSDR interface.

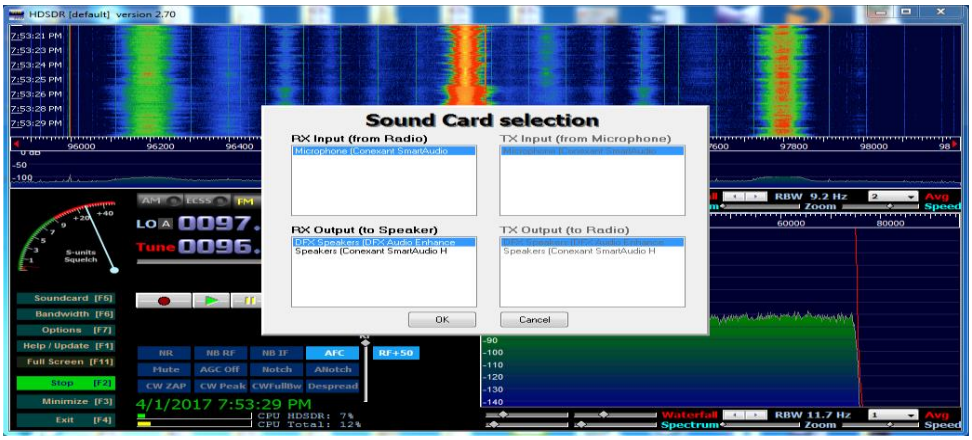

Figure 4.6. Selecting the soundcard on the HDSDR interface.

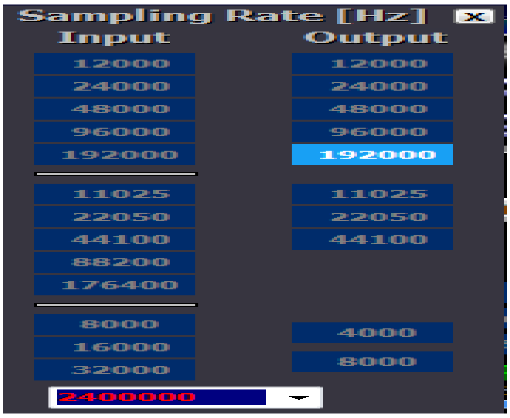

Figure 4.7. Selecting the sampling rate on the HDSDR interface.

The Start (F2) button present on the HDSDR interface was clicked on for starting the HDSDR program. The very same key was also utilized for stopping the program.

4.4.2. Installing and Running the Sdrsharp (SDR #) Program

SDRSharp (SDR #) software was installed in the personal computer through the following steps:

a. The R820T/R820T2 dongle was purchased and connected to a personal computer running on Microsoft windows 10. It is worth mentioning that since the Microsoft .NET 4.6 redistributable is essential for the installation of the SDRSharp (SDR #) program, it was made sure that the same has been installed in the PC.
b. The SDR Software Package available at www.airspy.com was downloaded. The zipped file thus obtained was extracted or unzipped so as to facilitate the further processes of installing the software.
c. Once the extraction of the downloaded zipped file was completed, the install-rtlsdr.bat file was clicked on (double click). Clicking on the said file resulted in the generation of a command prompt which ultimately lead to the successful download of all the drivers required for the functional operations of the SDRSharp (SDR #) program. The command prompt closed down automatically after several driver files, including zadig.exe and rtlsdr.dll were downloaded in the SDRSharp (SDR #) directory. However, in

case the same are not downloaded automatically, manual driver installation can also be performed.

d. The R820T/R820T2 dongle was connected to the PC: however, none of the software packages that were provided with it were installed. Instead, the zadig.exe file that was downloaded in the SDRSharp (SDR #) directory was right-clicked on and the ‘Run as administrator’ option was chosen.

e. In Zadig, ‘Options->List All Devices-> Bulk-In, Interface (Interface 0)’ were selected.

f. In the next step, the ‘replace driver’ option was selected, followed by the installation of the WinUSB driver.

g. The SDRSharp.exe was opened. The drop-down box in the ‘source tab; was set to RTL-SDR (USB).

h. The SDR Sharp started operating once the play button was pressed.

The following figures provide an insight into the various processes that were utilized during the installation and configuration phase of the SDR Sharp.

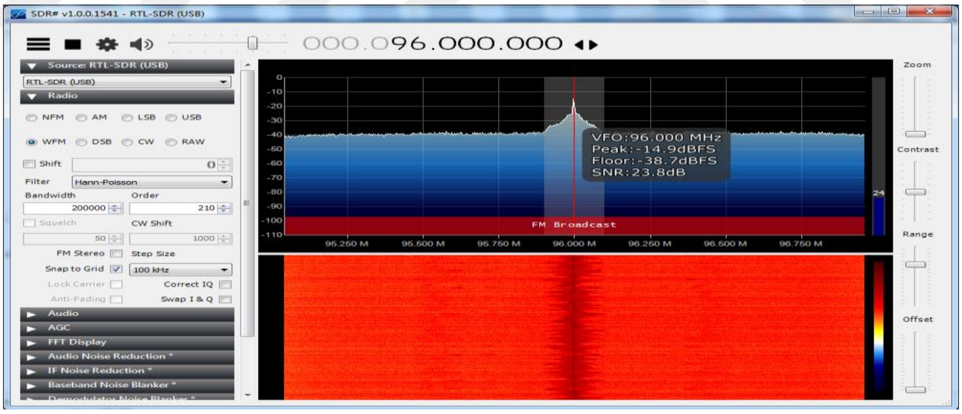

Figure 4.8. The SDR Sharp interface.

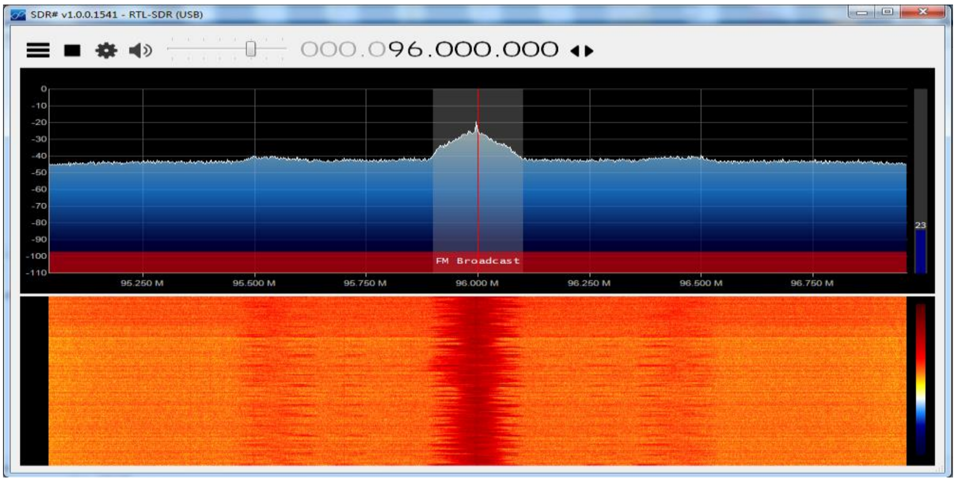

Figure 4.9. A closer view of the SDR Sharp interface.

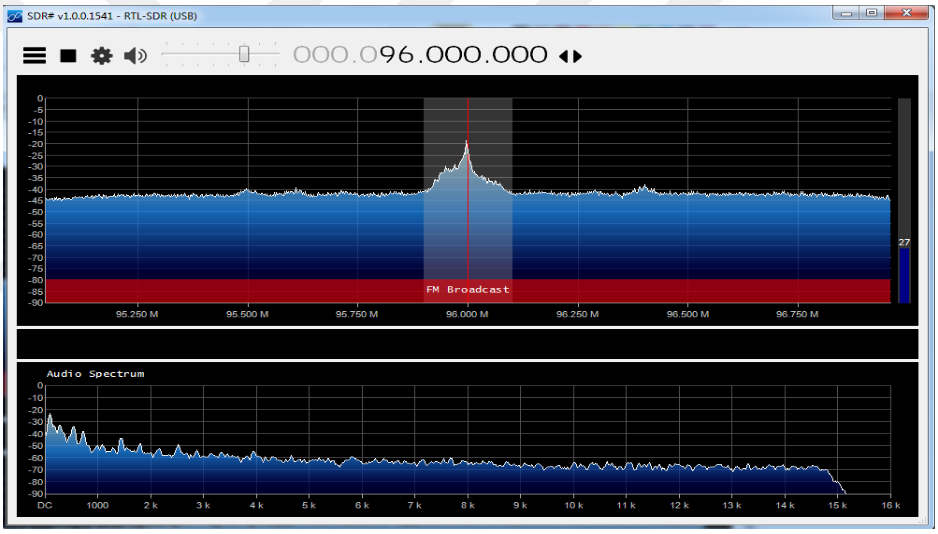

Figure 4.10. A closer view of the audio spectrum in SDR Sharp interface.

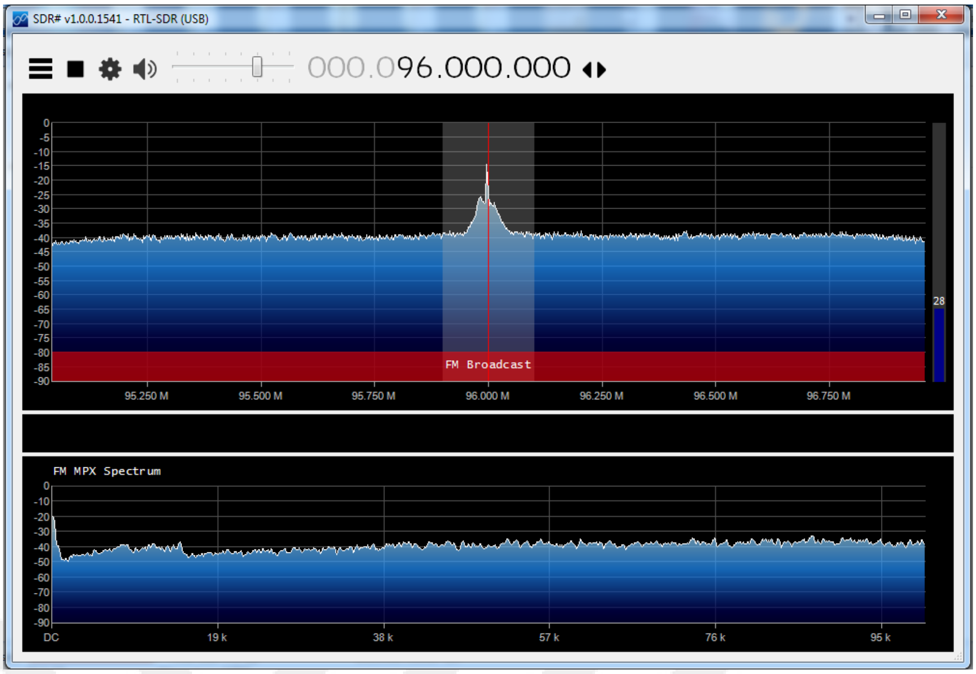

Figure 4.11. A closer view of the FM MPX spectrum in SDR Sharp interface.

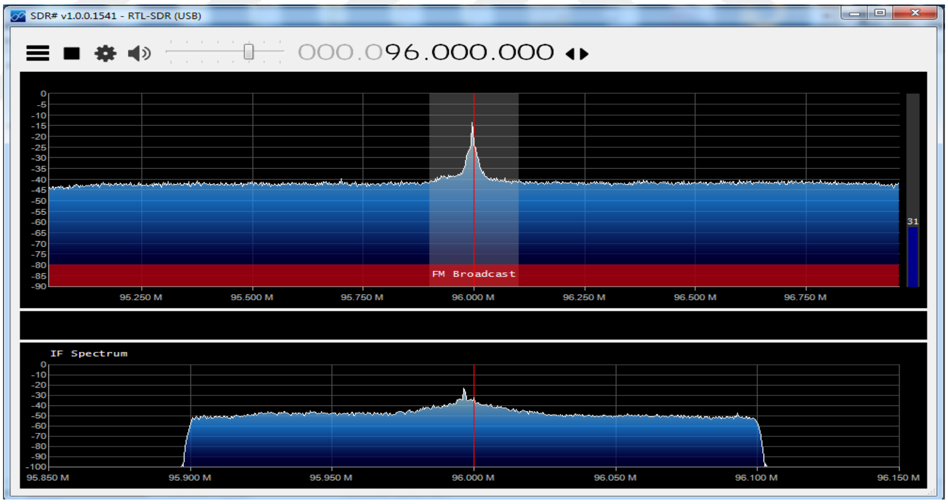

Figure 4.12. A closer view of the IF spectrum in SDR Sharp interface.

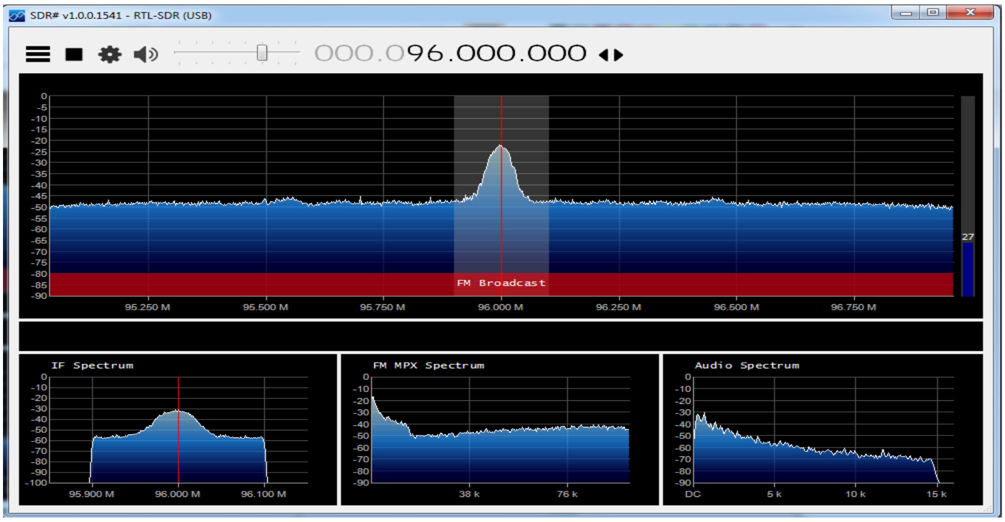

Figure 4.13. IF+ FM MPX+ FM+ Audio spectrum in SDR Sharp interface.

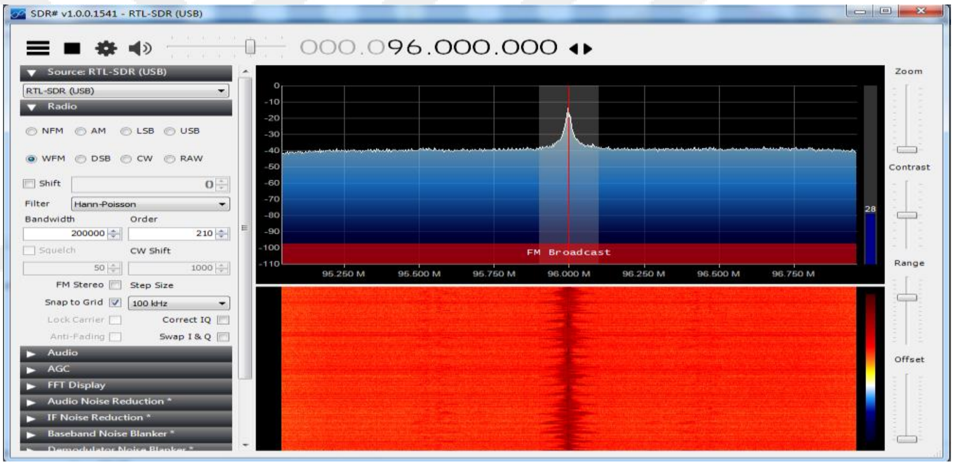

Figure 4.14. A closer view of the receiver functionality of the SDR Sharp interface.

4.4.3. Installing And Running The GNU Radio Program

A. Installing the GNU radio

According to authors S. Bassam *et al* [3].the most recommended manner of installing the GNU radio is to do the same from the gnuradio package included in the standard repositories of the Linux distributor.

In the project under consideration, both the Ubuntu, Fedora and Debian platforms were utilized for implementing the GNU radio. In case of the Ubuntu platform, the following command was utilized for the purpose of package installation:

>> $ apt-get installs gnuradio

The installation process was quite similar in the Debian platform. On the other hand, in order to install the GNU radio package, the following command had to be run:

>> $ yum install gnuradio

B. Observing GNU Radio Properties

After the installation of the GNU radio, we started with observing the various inbuilt functionalities included in the package. Some of the features that we were capable of identifying have been provided in the section below:

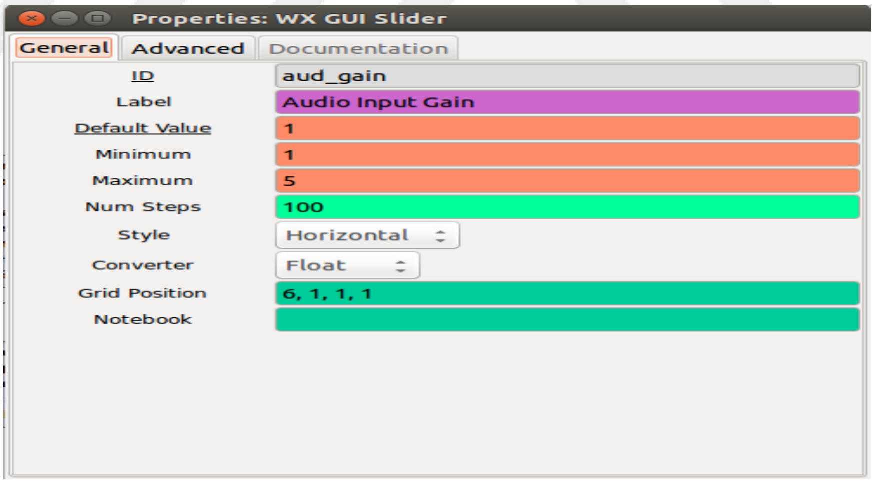

Figure 4.15. Observing the Audio Gain property of GNU radio.

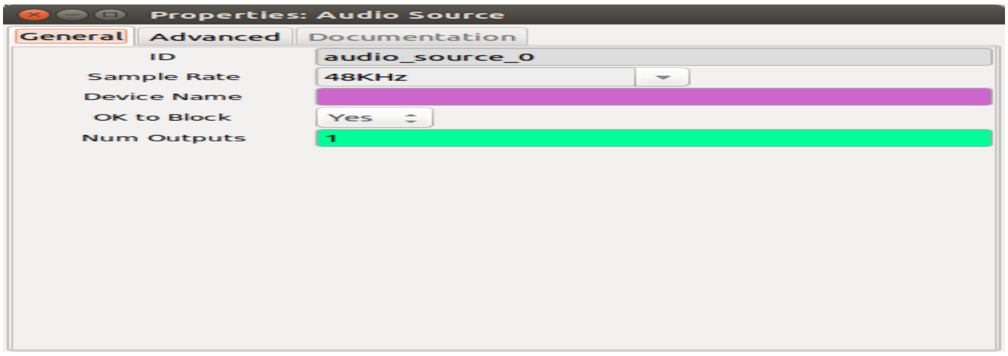

Figure 4.16 Observing the Audio Source property of GNU radio.

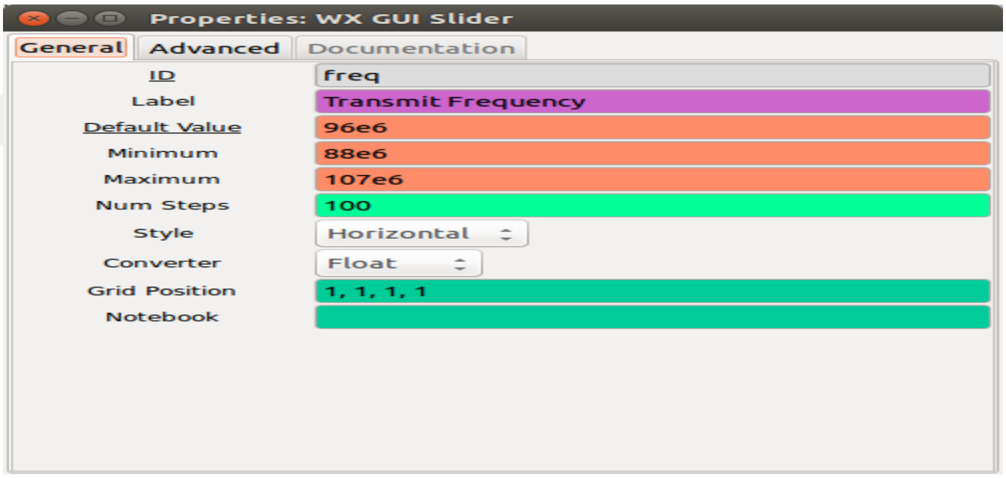

Figure 4.17. Observing the frequency property of GNU radio.

Figure 4.18. Observing the IF Gain property of GNU radio.

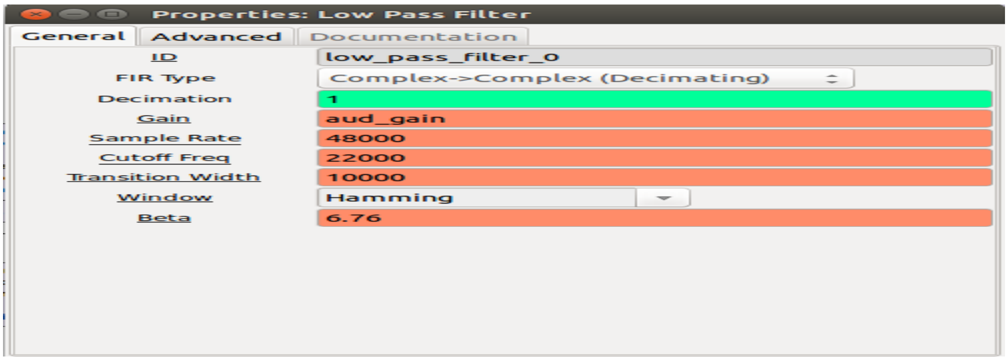

Figure 4.19. Observing the Low pass filter property of GNU radio.

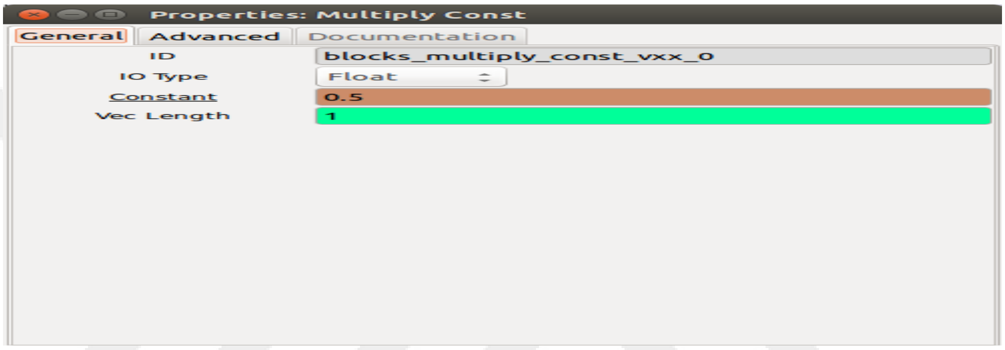

Figure 4.20. Observing the multiply const property of GNU radio.

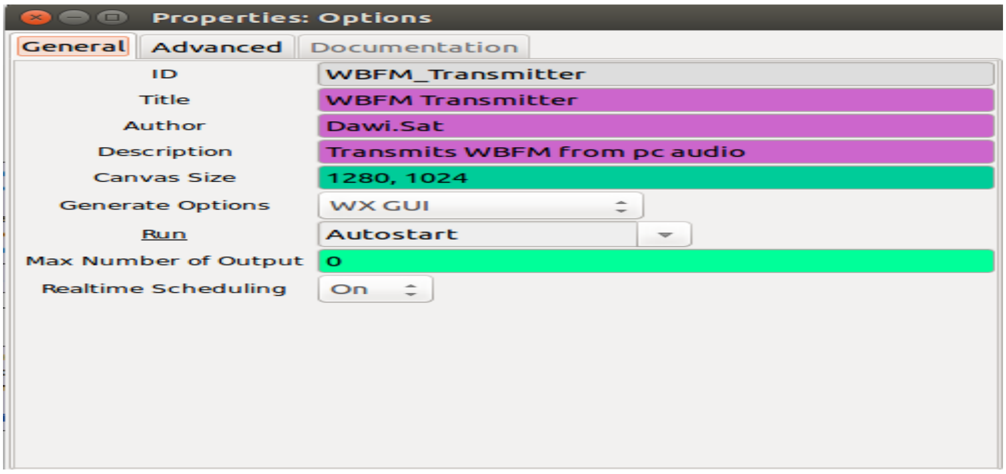

Figure 4.21. Observing the WBFM Transmitter property of GNU radio.

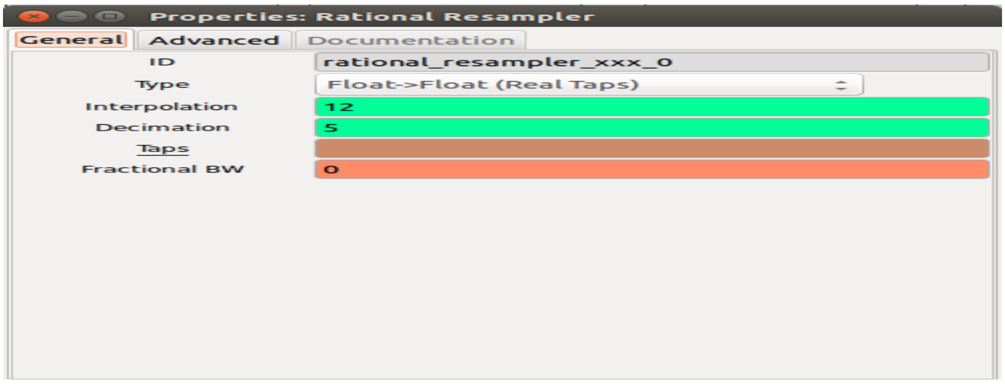

Figure 4.22. Observing the rational_resampler_ 1 property of GNU radio.

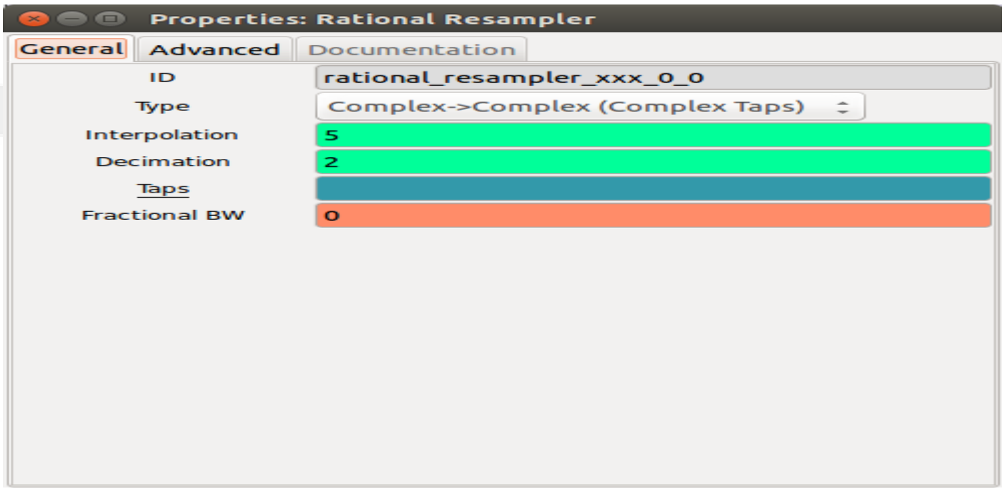

Figure 4.23. Observing the rational_resampler_ 2 property of GNU radio.

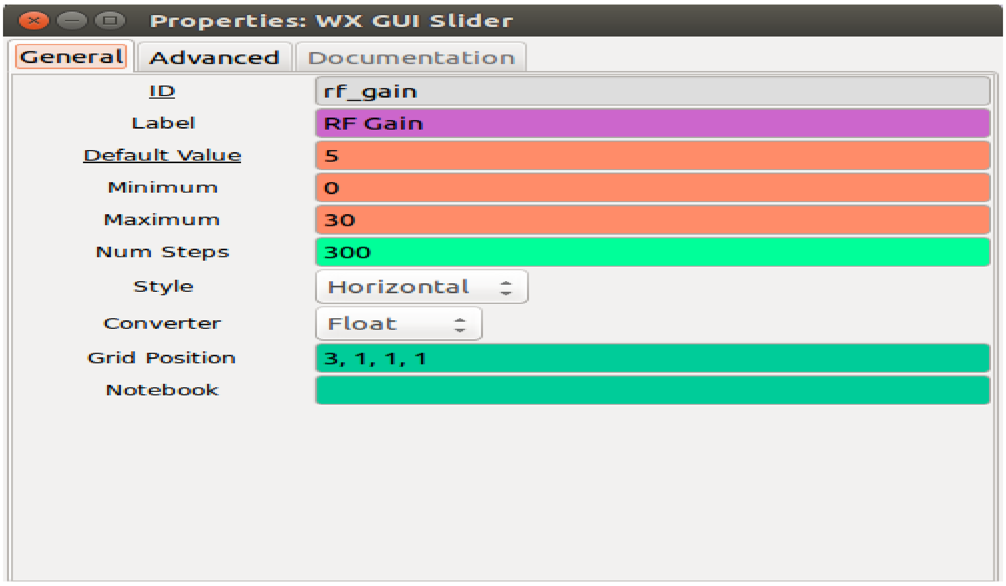

Figure 4.24. Observing the RF Gain property of GNU radio.

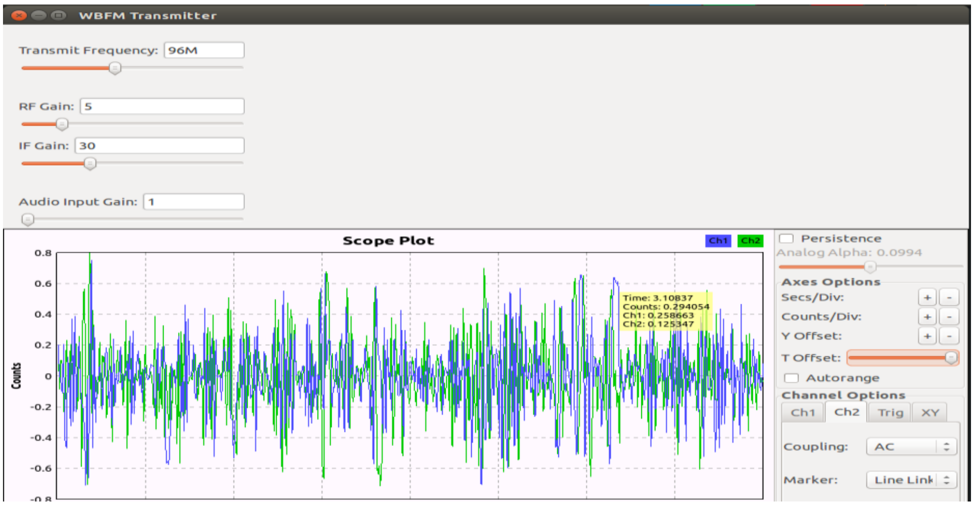

Figure 4.25. Observing the scope plot property of GNU radio.

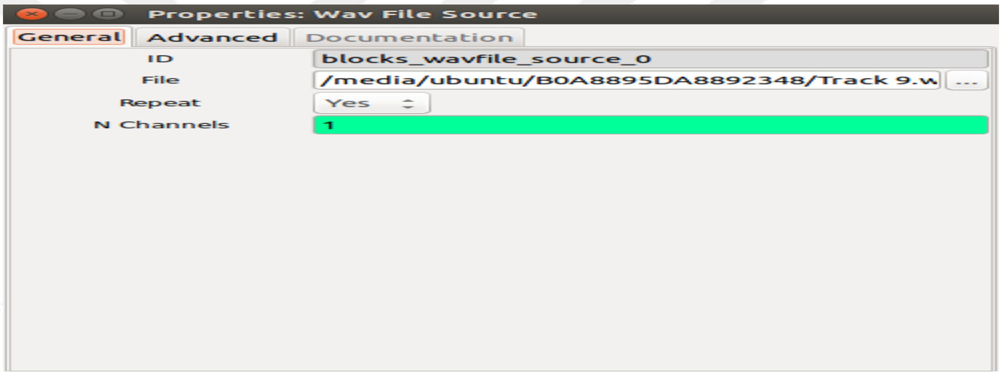

Figure 4.26. The wave File Source.

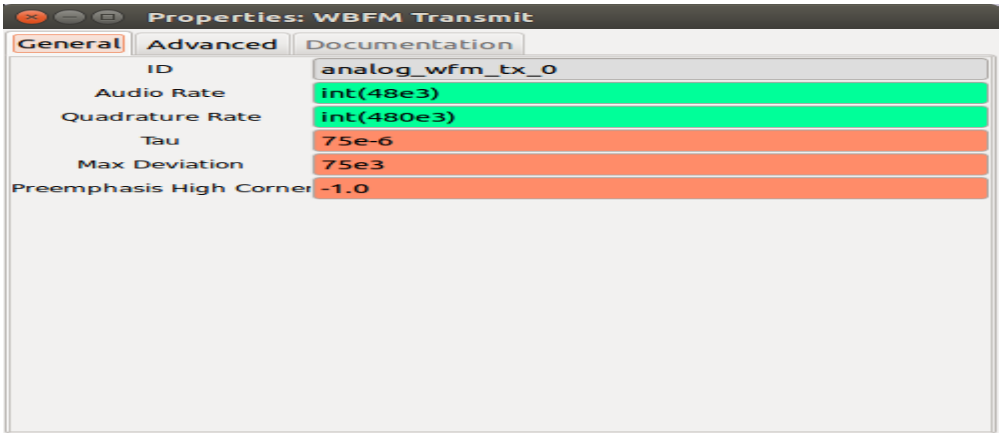

Figure 4.27. The WBFM transmitter.

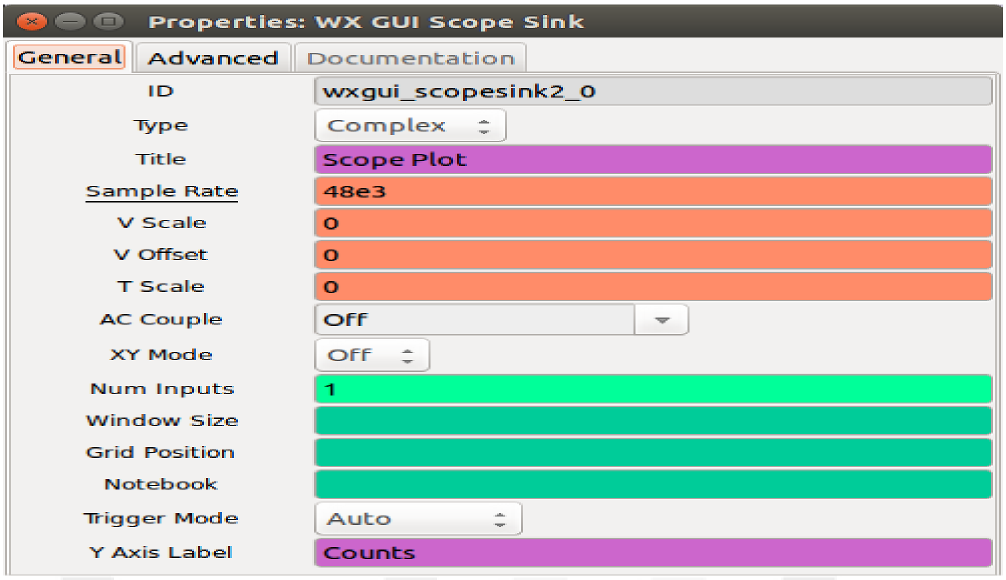

Figure 4.28. Observing the WX GUI SCOPE SiNK property of GNU radio.

Developing the SDR circuit using the inbuilt GNU Radio Properties

After observing the inbuilt communication blocks included within the GNU radio package, we proceeded with the development of the software defined radio circuit. The communication blocks that were reviewed earlier (screenshots attached in the section above) were utilized in the same, and the circuit diagram is being attached in the section below.

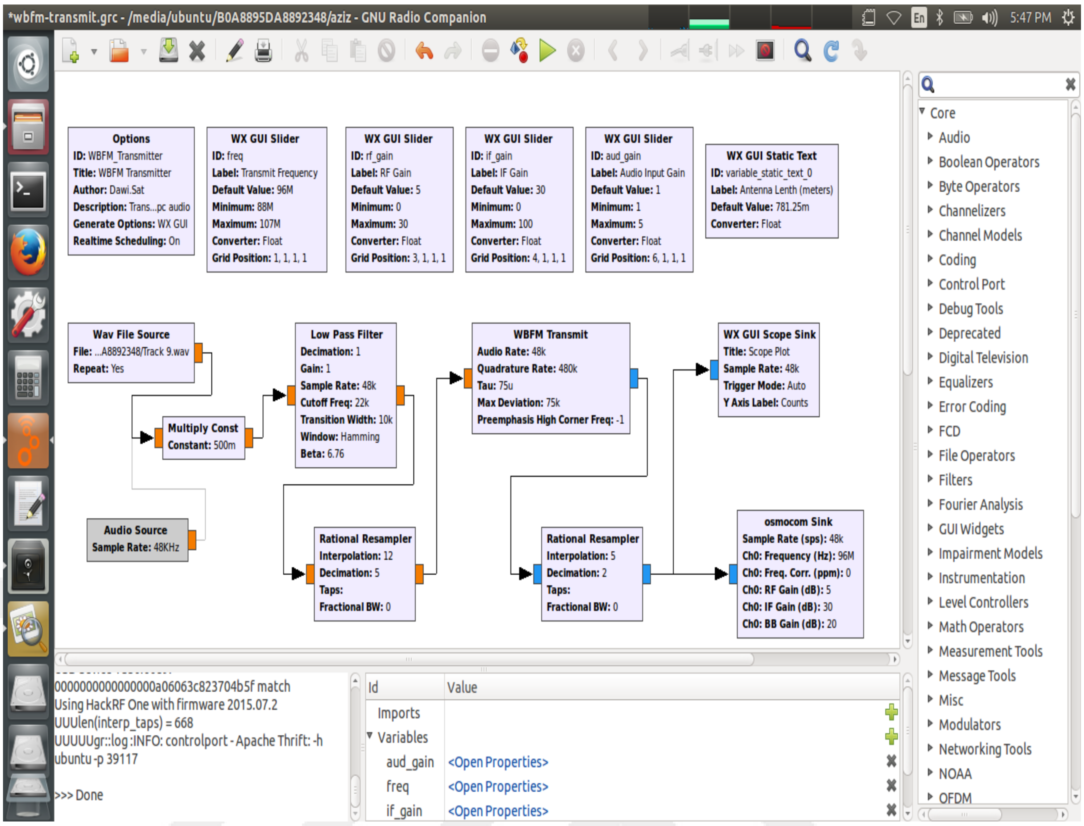

Figure 4.29 The SDR circuit diagram as developed in the GNU radio platform.

As demonstrated in the figure above, the contents of the WAV source file is fed into the Multiply Constant block. The outputs of this block then pass through the low pass filter and the rational resampler 1. The output of the rational resampler 2 is then fed into the WBFM transmitter and the rational resampler 2. The output signal from the rational resampler 2 is finally passed to the WX GUI Scope Sink and the osmocom Sink.

WAV File Source:

It creates a data source from the audio wave file. The file can be captured in GNU radoop with the WAV File Sink that is created in the audio editor like Audacity with proper WAV options in MATLAB utilizing the wavwrite command It specifies if it is required to play continuously in the loop or not. It makes specification in the number of channels from the particular file. The Wav files are usually mono channel and represents single data stream as well. On the other hand, representing single data stream and including in the phase as well as elements of the complex system are included in the channel. It helps to develop the phase and elements for the service.

Low Pass Filter: The filter is convenience wrapper for FIR filter as well as firdes the taps that generates functions. The sample rate and cut off frequency as well as transitions of width are included in Hertz. The beta parameter applies to Kaiser Window. On the other hand, FIR tupes specifies the data type of input as well as output streams that are included in the option of decimation. Input as well as output streams are complicated with the options for decimating the output. Decimation and interpolation are selected through FIR type parameter. Decimation as well as interpolation are selected with the help of FIR type parameter and obtain the filter.

Rational Resampler: It is combined interpolator as well as decimator. The particular block is utilized in order to convert from a sample rate to another for long time related through ratio. The type specifies data type of input as well as output streams. There are complicated systems that specify the type of filter, which can be applied. Input and output streams are complicated and antialiasing filter, which has complicated taps. Input as well as output streams are complicated and have filter for real taps.

Audio Source: It represents audio input hardware within the flow graph of GRC, the signal needs to be included in the input of microphone on the front level of the system. It is required to adjust the input obtain for best possible performance. The sample rate makes specification for the sampling rate for using. The rates of sampling are usually supported through the audio hardware. 48 KHz makes specification for sampling rate to utilize. Outputs specify the number of value for mono input.

CHAPTER 5

CONCLUSION

5.1. CONCLUSION

A software defined radio or a SDR is often described as that radio communication system that takes the advantage of specific software-based modules for the receival and transmission of radio signals instead of taking advantage of hardware-based signal receiver and transmission systems. The primary aim of conducting this academic research work was to identify the utilities of a software define radio system in the modern communication systems, besides gaining a hands –on experience on the practical implementation of software defined radio systems. It is worth mentioning that the sole objective of conducting this research work was implement a software defined radio communication system on HACKRF ONE, a well-known embedded hardware system that has specifically been developed for the purpose of software based FM transmission..

With the aim of obtaining background information regarding the operational functionalities of a software defined radio communication system, the first and foremost activity that was undertaken was to review as many as 37 literary and scholarly articles that have been published in the recent past. An in-depth study of the said scholarly papers and articles facilitated the collection of information in certain specific topics of the study, namely the modulation and demodulation techniques/ methods utilized for r receival/ transmission of FM signals using SDR, the techniques utilized for the implementation of communication protocols using Software Defined Radio, along with the other application specific uses of thee system and the applications of SDR in domains other than radio frequency communication.

In the next phase, a detailed study of the theoretical aspects of the project was conducted with the aim of gaining further information regarding the concept of FM transmission. The theoretical background study facilitated the process of identifying the essential elements of any communication system, along with the fundamental theories associated with the receival and transmission of frequency modulated signals. This study also provide us with in-depth information regarding the hardware elements (transmitter and receivers) that form an integral part of any communication system and the steps through which these elements operate.

Based on the information gathered from the literature review and the theoretical background study phase, attempts were made to practically implement a software defined radio signal capable of receiving and transmitting FM signals. The HACKRF ONE hardware set up was connected to the personal computers available in the computer laboratory of the institute and three well known software modules (the HDSDR Software, the SDR Sharp and the GNU radio) were utilized for the transmission and receival of FM waves.

In the following section of the thesis report, discussions would be made with the aim of shedding some light of the efforts made towards achieving the primary objectives of the project. It is worth mentioning that the discussions would be to identify the extent to which the objectives of this academic project have been achieved through the activities undertaken during the life cycle of the study.

5.2. LINKING WITH OBJECTIVES

In the following section of the thesis reports, effort would be directed towards linking the findings of this research study with the research objectives set out in the introductory sections of the report. It is expected that the discussions would facilitate the process of identifying the shortcomings of the research work in term of meeting the project objectives, thus highlighting the domain in which future studies can be conducted.

Research objective 1: to identify the open source software radio toolkits that can be utilized for the practical implementation of software-based radio system.

The first and foremost objective of this particular research project was to identify those open source software radio toolkits that can be utilized for the practical implementation of software-based radio system.

With an aim of identifying the open source software radio toolkits that are widely being utilized for the practical implementation of software defined radio, a detailed study of the current literature was conducted. Based on the information included in the literary works under review, the following open source free software modules were identified:

a. the HDSDR Software,
b. the SDR Sharp and
c. the GNU radio

The above mentioned software modules are open source and free to use , the third one being included in several UNIX installation as an integral package. Thus, it can be concluded that this particular objective of the research work was achieved in a successful manner.

Research objective 2: to select one from the above-mentioned toolkits and install the same on linux based operating systems.

The second objective that was outlined in the introductory section of the thesis report was to select one from the identified software based radio system toolkits and install the same on Linux based operating systems. It was already mentioned the section above that the literature review and background study work led to the identification of as many as 3such open source freeware tools that can be effectively utilized for the practical demonstration of software-based radio system: the tools being the following –

a. the HDSDR Software.
b. the SDR Sharp Software.
c. the GNU radio Software.

Out of the above-mentioned software modules, the GNU radio was found to be available with almost all UNIX installations as an integral package.

Three different variations of the UNIX platform were utilized with the aim of installing the GNU radio package, detailed discussion regarding which have been included in section 4.4.3 of the report.

Thus, it can be said that this vey objective of the project was also met with.

Research objective 3: to demonstrate the process of installing the radio software module in a step by step manner, and describe the manner in which the fm signals are obtained and processed in the said module

The last and final objective of the academic research work, as outlined in the introductory section of the thesis report was to demonstrate the process of installing the radio software module in a step by step manner and describe the manner in which the FM signals are obtained and processed in the said module.

It has already been mentioned in the preceding sections of the report that the literature review and background study conducted during the very initial stages of the project led to the identification of the under mentioned software tools:

a. the HDSDR Software,
b. the SDR Sharp and
c. the GNU radio

Out of the above-mentioned software modules, the first two utilized specifically for the purpose of receiving FM transmissions. These software modules were installed on personal computers supported by Microsoft based operating systems and the detailed description of the steps followed for the installation and utilization of the same in receiving frequency modulate signals have been provided in section 4.4.1 and 4.4.2 of the thesis report.

On the other hand, the GNU radio package was installed on three different types of UNIX based Operating systems, namely UBUNTU, Debian and Fedora and the details of the same have been discussed in section 4.4.3 of the report. Besides this, a detailed description of the SDR circuit designed on the GNU radio platform has also been included in this section.

Thus, it can be said that the third objective of the project was achieved in a successful manner.

5.3. FUTURE RESEARCH

The discussions made in the sections above are indicative of the fact that the core objectives of the project, namely the identification of the open source software radio toolkits that can be utilized for the practical implementation of software based radio system, the selection one from the above mentioned toolkits and install the same on Linux based operating systems and the demonstration of the process of installing the radio software module in a step by step manner have successfully been achieved through all the activities conducted during the lifecycle of the project. However, the following domains can be considered for conducting research work in the future:

a. Attempts can be directed towards achieving successful receival and transmission of frequency modulated radio wave through all the SDR toolkits that have been identified and utilized in this project.
b. The information collected from the literature survey indicates that software defined radio based cellular networks can be utilized for the finding solutions to a wide range of issues that are currently experienced with LTE cellular data networks. Research works can be conducted in the future with the aim of implementing such SDN cellular platforms.

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RESUME

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