Exploiting USRP for RF Block Designing of CDMA Signal Transmission

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***Abstract*—This report presents the theoretical analysis of Code-Division Multiple Access (CDMA) transmission and FM transceiver implementation in GNU radio companion in Universal Software Radio Peripheral (USRP) N210 with investigation and selection of existing daughter boards. Background and concepts for CDMA and Frequency Modulation (FM) technology is explained for wireless communication system. This is followed by USRP N210 hardware structure as well as its daughter boards and running software of this radio frequency block. The motivation for this software design of FM transceiver was to aid CDMA implementation to USRP N210. The transceiver prototype was implemented using Genuinely Not Unix (GNU) radio companion (software defined radio) with frequency ranges of 88 to 108 MHz. Software designed FM transceiver was implemented into Radio Frequency block for audio transmission and external FM broadcast receive applications. Relating this modulation design to future development of CDMA transmission is given in this report.**

***Index Terms*—USRP, SDR, CDMA, Radio Frequencies, Signal Transmission**

I. Introduction

A. Background

Wireless communication is, by any measure, the fastest growing segment of the communication industry. Particularly, cellular communication system technology and demand has grown exponentially over the past decades and there are over three billion users worldwide. Accordingly, wireless communication systems have become the most significant area of technological development in the field of telecommunications today. In cellular system, digital modulation for communication is widely used due to demand for increased capacity in these networks. Since multiple users require simultaneous access to the communication channel in a digital communication system, a share of the available communication resources must be assigned to each user. The most widely used multiple access technique in digital cellular system is CDMA which will be discussed in the later section of this report [1]. On the other hand, Frequency Modulation (FM) communication technique is widely used in analogue modulation due to its resilient to noise, resilient to signal strength variations, no need for linear amplifiers in the transmitter side and greater efficiency.

The aim of the research is to investigate Radio Frequency block available for transceiver implementation and software design for CDMA transmission.

B. System Overview

Figure 1 is showing basic wireless FM communication structure which it is composed of transmitter side and receiver side and defined into two parts, software defined part and Radio Frequency Block. Top part is the transmitter, where PC is working as a source of data transmission and through the gigabit Ethernet cable. This baseband transmitted signal from the source is up converted by Digital Up Conversion to desired frequency inside the Radio Frequency block and then converted from digital to analogue and transmitted through the antenna. Similarly in the receiver side, analogue signal is received through the antenna and down converted into baseband frequency by Digital Down Converter function block and finally received or displayed by the receiver such as a computer or cell phones. This report is structured in the following way. Initially the overview of CDMA communication system for the digital modulation and Frequency Modulation for analogue system is discussed. And then, hardware description of USRP N210 with details of daughter board and its running software GNU radio companion. The design of the implemented transceiver is then described, along with the explanation of the software block diagram and evaluation of the system. Finally, the result of the performance analysis undertaken are presented and discussed in this context.

II. Communication System

The fundamental purpose of a communication system is to transmit information-bearing signals from a sender to a receiver. Digital data transmission is the physical transfer of discrete messages over a point-to-point communication channel. The message are either represented by a sequence of pulses by means of a line code, or by a limited set of continuously varying wave forms, using digital modulation method [1]. While analogue transmission is the transfer of a continuous signal which varies in amplitude or phase.

A. Code Division Multiple Access

Code Division Multiple Access communication method has arose due to exponential increase in number of cellular

phone which caused limitation of analogue communication system such as 3G. CDMA theory was established in 1950 and American company called Qualcomm who succeeded in implementing CDMA communication system in cellular phone system. CDMA is a digital cellular system which multiple users are able to access and share time and frequency domain. CDMA is categorized in spread-spectrum technology [2]. Spread spectrum technology is a method by which a signal generated with a particular bandwidth is deliberately spread in the frequency domain, resulting in a signal with a wider bandwidth. Wider bandwidth is achieved by spread code which results high security and high resistance to fading. Figure 2 is showing graphical explanation of spread spectrum in frequency and time domain. As shown in figure 3 below, CDMA system is mainly classified into Mobile Switching center, Base station and Mobile station. Telecommunication exchange board is connected to control mechanism of base station and consists of element such as private data of mobile subscriber and confirmation data. It is also responsible for connection to other channels. Base station is made of Base station controller, Base Transceiver system and repeaters. Concept of CDMA transceiver will be discussed at the later section of the report.

B. Frequency Modulation

Frequency modulation (FM) is analogue communication system which conveys information over a carrier wave by varying its instantaneous frequency. FM is widely used for broadcasting music and speech, two way radio system, magnetic tape-recording systems and some video-transmission systems [3]. In FM system, message signal is modulated with carrier signal. Figure 4 is showing time domain representation of message signal, carrier signal and modulated signal. As seen in figure 4, frequency of carrier signal increase as the amplitude of the modulating signal rises while decreases as the amplitude of the modulating voltage drops down [3]. The rate of frequency deviation depends on signal frequency. And modulation index (measure of modulated variable of the carrier signal varies around its unmodulated level [4]) is given by

$$\beta = \Delta f / f_m \tag{1}$$

where β is modulation index, Δf is frequency deviation and f_m indicates modulating frequency. In this research project, wideband FM transmitter and receiver will be implemented where $\beta > 0.2$.

III. Radio Frequency block

A. Universal Software Radio Peripheral N210

USRP N210 is radio frequency block hardware suited for radio frequency streaming performance covering advanced physical layer of design and prototyping, dynamic spectrum access and cognitive radio which is a product of Ettus Research. USRP N210 is structured according to the figure 5. Received signals or signals for transmission goes through the Ethernet physical layer as in figure 5. Due to this fact, USRP N210 external physical ports for Field Programmable Gate Array (FPGA) /Digital Signal Processor (DSP) and Personal Computer (PC) connectivity ports. This physical layer enables transfer of data at a rate of gigabit per second [5]. Universal Hard Drive (UHD) is followed by Ethernet physical layer. This hard drive is controlled by 32-bit Reduced Instruction Set Computer processor. As mentioned in section 1.2 DDC and DUC perform up conversion and down conversion of the signal. In addition, 14 bits Dual 100 MSPS (mega samples per second) Analogue to Digital converter and 16 bits Dual 400 MSPS gives high speed and high resolution to meet high frequency applications and dynamic range. For transceiver applications, investigation of external daughter boards was carried out for selection of transmitter and receiver daughter according to the frequency range of transmission and receiver application. Figure 6 is showing basic transmitter daughter board with frequency capability of 1-250 MHz [6]. This USRP radio frequency daughter board takes input signals from Digital to Analogue converters and provides the output via 2 output channel transformers. Figure 7 is hardware of receiver daughter board TVRX2 selected for the application. It includes two independent down converter chains, allowing reception in two different bands, simultaneously. The TVRX2 is ideal for receive-only applications that require access to a number of bands in High Frequency, Very High Frequency and Ultra High Frequency ranges [7]. This daughter board has frequency capability of 50- 860MHz. As shown in figure 1 and mentioned in section 1.1, transceiver implementation which is discussed in the later section of the report is defined to have a frequency range of 88-108 MHz. For this reason basic TX and TVRX2 daughter boards were selected for transceiver applications [8].

IV. Genuinely Not Unix Radio Companion

Genuinely Not Unix (GNU) Radio is a signal processing package for easy understanding and usage using electromagnetic spectrum for radio spectrum analysis. GNU radio companion is a graphical tool for building GNU radio flow graph distributed by GNU radio. The idea of implementing radio or communication systems on a software configured basis was first introduced in 1970s by the U.S military [9]. The term software defined radio can be classified as a group of reprogrammable or reconfigurable radio hardware. On practical perspectives, software defined radio is a device that performs various functions for various purposes. For instance, GNU radio companion can be used in application of GPS (Global Positioning System). Watch local broadcast stations and send data [9]. For particular Universal Hard Drive installed in USRP N210, GNU radio framework software is supported. This frame work uses a combination of C, C++ and Python to optimize micro-controller performance. Also, GNU radio companion provides graphical user interface for easy to use programming environment [10]. While figure 9 is showing example of graphical interface of GNU radio companion for building GNU radio flow graphs. Users can drag and drop GNU radio blocks into an editable flowgraph, and connect the blocks, and edit various block parameters [11]. GNU radio companion provides functional blocks such as filters,

modulators, graphical scopes, conversion of data type and source and sinks. Arrow in the diagram indicates signal process direction. Figure 10 is showing floating functional blocks. These blocks are called parameter blocks which define global variables like sampling rate, frequency range and global gains. These can be referred to as header files in coding system. In addition, GNU radio companion also provides graphical representation of Fast Fourier Transform (FFT) spectrum and time domain representation of the signal. Below figure shows typical FFT plot from GNU radio companion. Using GNU radio companion, software design of FM transmitter and receiver were implemented for the project and embedded into USRP N210 for data transmission and receiver application.

V. CDMA TRANSCEIVER DESIGN

This section of the report explains modulation of data using CDMA technology, send it into another work station and recover the signal. The receiver will perform non-coherent demodulation and PN-sequence synchronization to recover the signal [12]. The design of this scheme is to be implemented using GNU radio companion. However, software implementation is not done in this research project. Thus, only theoretical perspectives of CDMA transceiver will be discussed in this context to provide overview of transmitter and receiver applications using CDMA technology. Figure 12 is showing block diagram of receiver. Received signal from the transmitter is demodulated using non-coherent method with Phase Change Detection which determines if the phase change was big enough for symbol change [13]. For example, phase change in integer from 1 to -1 or -1 to 1. Since the symbols will come in groups of four, this module will check if there is an error in the output. Before the data can be read, the signal has to be multiplied by PN sequence by the PN sequence synchronization. In the transmitter side, incoming input data is modulated using differential binary modulation method. And then, the signal is multiplied by unique pseudo-random sequence. Measure of success will be whether signal is received correctly without any errors. Since the design will include limited error-correcting capabilities, there will be 0% tolerance for error.

VI. FM TRANSCEIVER

In this section, software design of FM transmitter and receiver using GNU radio companion and implementation to USRP N210 is explained in detail with investigation resultant spectrum analysis of the signal. In the transmitter side, audio file is transmitted from the PC and processed in the RF block USRP N210 and transmitted through the antenna at specified frequency of 88-108 MHz. By adjusting a receiver such as a cell phone to center frequency of USRP N210, transmitted audio or music can be listen to. Appendix A is showing full block diagram of FM transmitter design with GNU radio companion. In the input source, there are two inputs of WAV audio file with actual sample rate of 192 kps. Implemented sample rate of the transmitter is set to 500 kps. This is done to meet the Nyquist sampling rate which is approximately 2.5 bigger than its actual sample rate to prevent any aliasing of the signal. This audio file is in float data type format which indicates that this is a digital signal processed in the PC. This signal is then passed onto rational resampler for sample rate resampling process. Rational resampler updates the sample rate of incoming signal according to the ratio of Interpolation / Decimation. GNU radio specifies integer values for Decimation factor M and Interpolation facto L in resampling functional block. When $M = 1$ and $L > 1$ resampler is rational interpolation and $L = 1$ and $M > 1$ the resampler is ration decimation. Updated signal is passed onto Wide band FM transmit block where float data type is converted into complex data type (color change from orange to blue) which is now suitable for input to USRP sink. Before it is processed into USRP sink for transmission, it is modulated with complex cosine carrier wave with frequency = 1 MHz. USRP N210 is currently set to center frequency of 104 MHz. Thus, baseband modulated signal is up converted inside the RF block to frequency of 104 MHz. Figure 13 is Fast Fourier Transform (FFT) plot of baseband signal captured by WX Graphical User Interface (GUI) FFT Sink provided by GNU radio companion. Baseband signal has center frequency at 300 KHz and -300 KHz respectively. In the receiver application, external FM broadcast in frequency range of 88-108 MHz signal is received through the USRP N210 and played through the PC with its volume controlled by dB gain. Appendix B is showing full block diagram of FM broadcast receiving station. In the receiver side USRP N210 is acting as a source of transmitting its externally received signal into the PC. Center frequency is set to 106.9 MHz with dB gain of 15. Thus, external FM broadcast station with frequency of 106.9 MHz is received by the antenna of USRP N210. Signal with frequency of 106.9 MHz is down converted by DDC within the RF block to baseband for the PC to receive. This received complex data type signal is processed initially to Finite Impulse Filter with decimation factor of 1 which filters undesired signals with bandwidth of 120 KHz. Similarly to the transmitter, filtered signal is processed to Wide band receive function block where complex data type from the USRP is converted into float data type and to rational resampler for sample rate update. Then, the signal is multiplied by the constant function to increase more gain and finally to the audio hardware of the receiving computer. The sample rate of audio sink corresponds to actual sample rate supported by the audio hardware of the computer. Figure 14 is FFT plot of baseband signal after FIR filter with center frequency at 0 Hz with bandwidth of 120 KHz. frequency of 106.9 MHz is received by the antenna of USRP N210. Signal with frequency of 106.9 MHz is down converted by DDC within the RF block to baseband for the PC to receive. This received complex data type signal is processed initially to Finite Impulse Filter with decimation factor of 1 which filters undesired signals with bandwidth of 120 KHz. Similarly to the transmitter, filtered signal is processed to Wide band receive function block where complex data type from the USRP is converted into float data type and to rational resampler for sample rate update. Then, the signal is multiplied

by the constant function to increase more gain and finally to the audio hardware of the receiving computer. The sample rate of audio sink corresponds to actual sample rate supported by the audio hardware of the computer. Figure 14 is FFT plot of baseband signal after FIR filter with center frequency at 0 Hz with bandwidth of 120 KHz.

VII. Discussions

In digital communication, CDMA system has many advantages over other digital modulation systems such as Continuous Phase Modulation (CPM), Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA). Unlike TDMA or FDMA, CDMA does not rely on orthogonal frequency and time slots. In TDMA and FDMA systems time and frequency slots are wasted when nothing was sent with difficulties in dynamic allocations [14]. On the other hand, CDMA provides less interference when nothing was sent, and transmission time is halved which doubles the capacity for more users [15]. It is suggested in the future to develop digital modulations using GNU radio companion such as Continuous Phase Modulation or Frequency Shift Keying for transmission of data in digital domain rather than analogue transmission. Such modulation schemes are to be work in high frequency by selecting other daughter boards like WBX radio frequency block. WBX works both in transmitter side and receiver side, with frequency range of 50 MHz to 2.2 GHz for reception or transmission which makes it suitable for digital transmission due to high frequency range. Furthermore, not only the PC as a source, other digital processor boards like DSP board implementation for data transmission.

VIII. Conclusion

In this paper, the software design and testing of a FM transmitter and receiver system implemented on radio frequency block USRP N210 were presented in this report. The prototype was developed using software defined radio GNUradio companion distributed by GNU radio based on Python language and tested on the target radio frequency block USRP N210 from Ettus Research. Basic Tx and TVRX2 daughter boards distributed by Ettus Research with VERT 900 antenna were used for this low frequency applications. WAV audio file is transmitted by FM transmitter design ranges from 88 to 108 MHz. The transmitted audio file is audible by a frequency adjustable cell phone. In the receiver side, FM broadcast ranges from 88 to 108 MHz is received through radio frequency block and also audible by the PC. The results of FFT plot matches with expected baseband frequency modulated signal. From this frequency modulation view point, we may conclude that other digital modulation scheme is viable for CDMA transmission implementation using GNU radio companion. However, selection of other daughter boards of high frequency capabilities must be investigated with high frequency applications. The available radio frequency block USRP N210 provides satisfactory result for FM transmissions due to its high bandwidth and high dynamic range processing capabilities. Due to this fact, we may conclude that this radio frequency block is suitable for CDMA transmission implementations. Proposed future work in developing radio frequency block design includes the implementation of CDMA synchronization block and the external wireless connection with external DSP or FPGA board. This CDMA implementation should also be compared with FM implementation. Ideally, there may be possibilities of combining each advantage in individual modulation technique by combined software design using GNU radio companion.

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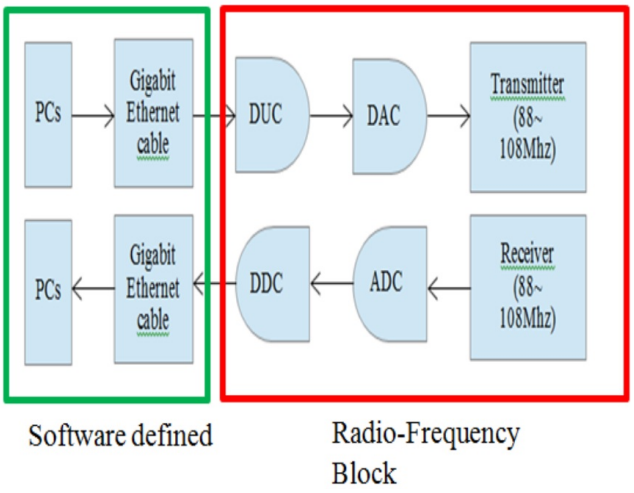

Fig. 1. Basic wireless communication system structure

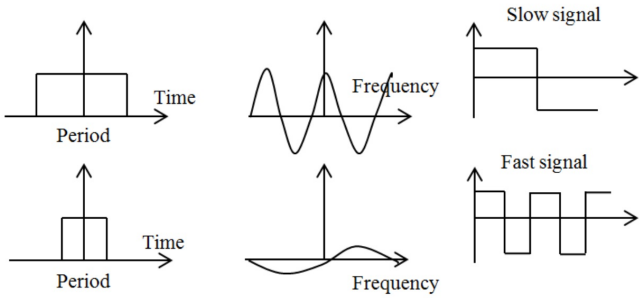

Fig. 2. Frequency and time domain analysis of spread spectrum

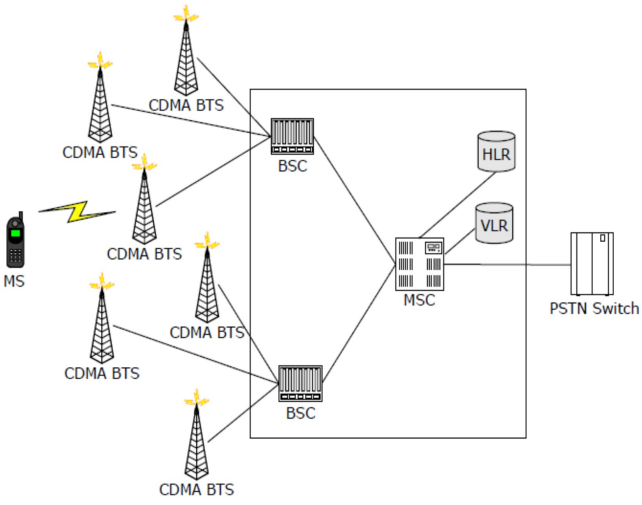

Fig. 3. Frequency Modulation scheme

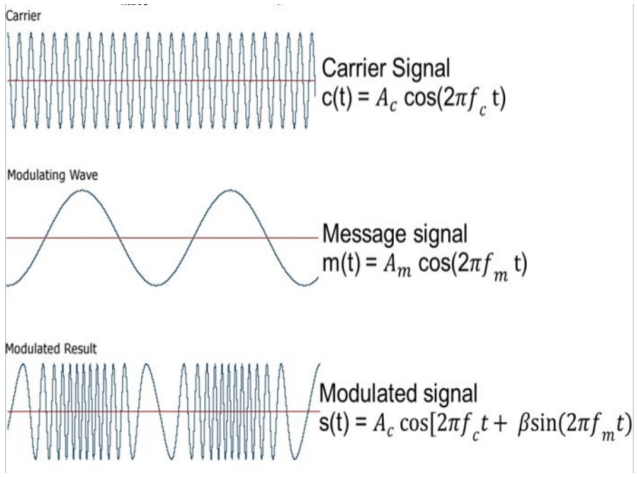

Fig. 4. Frequency Modulation scheme

Fig. 5. Basic TX board

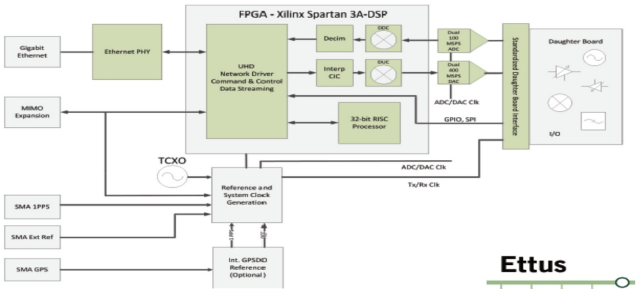

Fig. 6. USRP N210 functional block diagram

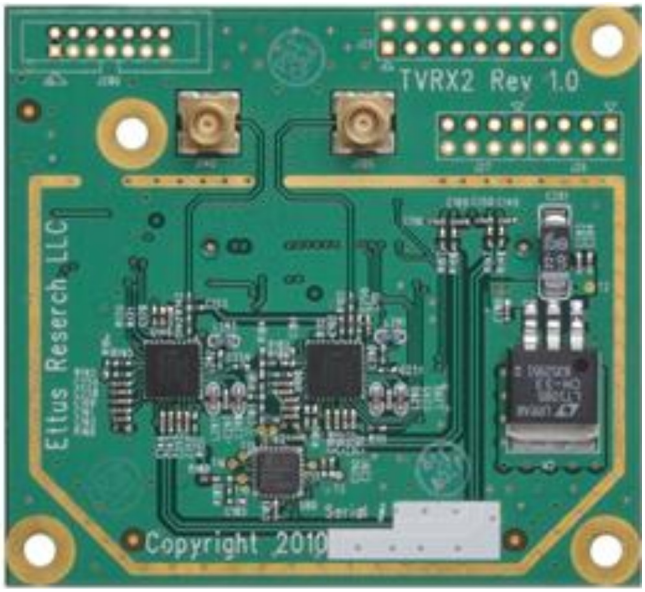

Fig. 7. TVRX2 receiver daughter board

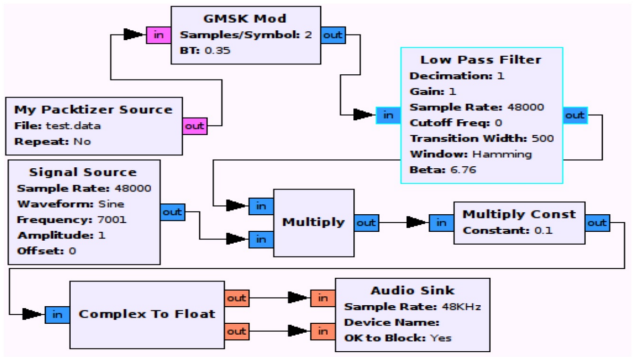

Fig. 8. Flow graph of GNUradio companion

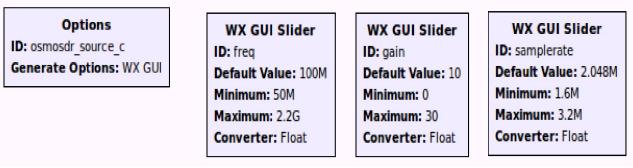

Fig. 9. ParameterBlock

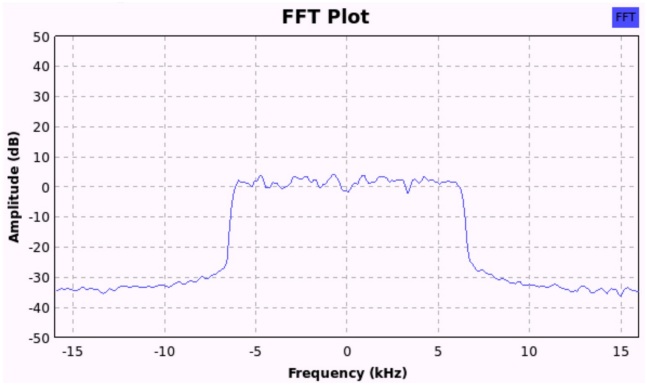

Fig. 10. Fast Fourier Transform plot

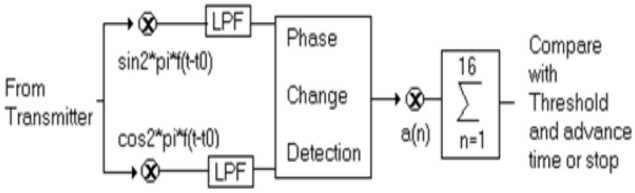

Fig. 11. Receiver diagram

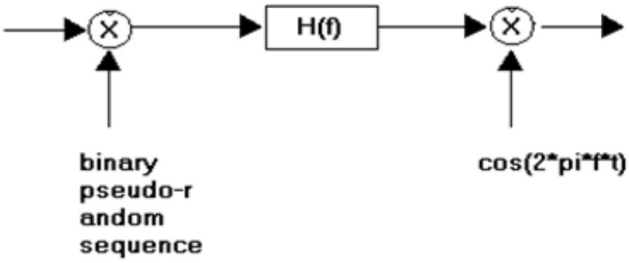

Fig. 12. Transmitter diagram

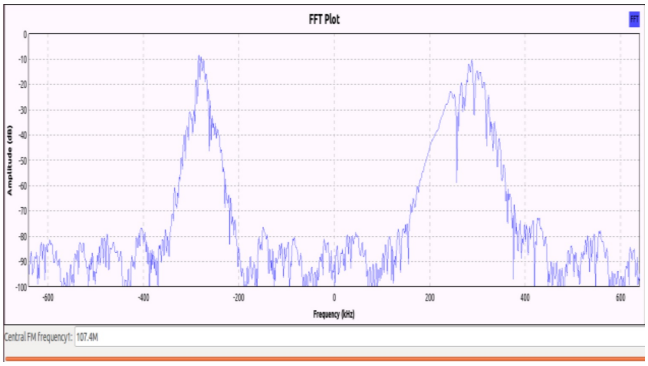

Fig. 13. FFT plot of baseband signal

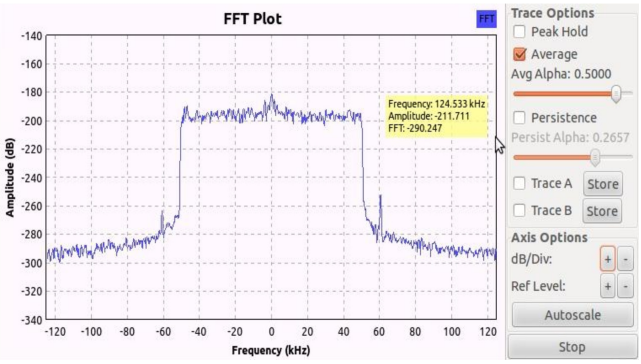

Fig. 14. FFT plot of baseband signal