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Implementation of Reconfigurable Transceiver using GNU Radio and HackRF One

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Abstract

Relying on the past technology radio reception through hardware needs front end tuning which in turn internally changes the frequency of the capacitor. Thus the conventional radio can capture the required frequency by tuning manually. As the technology advances the wireless technology shown the light of cognition through which real time data transmission and reception are implemented using reconfigurable radio i.e., Software Defined Radio (SDR) whose physical layer functions are mainly or fully defined by software. In this paper, HackRFOne (Software defined Radio SDR) is tuned to the required radio frequency by employing GNU Radio Companion and Gqrx (spectrum viewer), where both GNU Radio and Gqrx are an open ended software. Cognitive Radio have revealed that by varying the software, the hardware adjustment is possible only within a fraction of the time. However, this requires more knowledge on signal processing blocks so that adjusting certain parameters like gain and frequency of filter can be made in the receiver side. The goal of this paper is to focus on the signal processing blocks which plays vital role in implementing the transmitter / receiver for reconfigurable wireless communication system.

Keywords GNU radio companion (GRC) · Software defined radio (SDR) · CR · HackRFOne · Gqrx

1 Introduction

Wireless communication had a massive impact on the globe demanding advanced multimedia and high data rate services with reasonable cost. Wireless Innovation Forum defined SDR as "radio in which some or all of the functions of the physical layer are defined by software". SDR has emerged as a revolutionary approach developing reconfigurable wireless communication system replacing the traditional implementation of hardware communication devices.

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In conventional radio communication system as shown in Fig. 1. The radio waves which are received by antenna, are filtered to extract the desired frequency, thus followed demodulator circuit and an amplifier to recover audio signal and further boosting purpose. Usually the conventional radio receiver are specially designed with fixed hardware to reproduce the sound sent by the broadcasting stations, and the FM Broadcast Radio Frequency is permitted between 88 MHz to 108 MHz. Being the focus of this paper, for the establishment of cognitive radio a simple preliminary step is, tuning the internal hardware to nearby local radio frequency, for transmitting/receiving the audio signals. Tuning the hardware using software demands signal processing knowledge that could offers all the required facilities for effective implementation and design of wireless communication system. Signal processing blocks and its sequence of arrangement to implement AM, FM, NBFM, WBFM modulation techniques at the transmitter/ receiving side , demands relative sequence and selection of DSP blocks in the flow graph. And parameters within the block need to be adjusted according to the modulation and desired frequency.

CR [10] has been incorporated with intelligent system which is directed by algorithm are proved[1] that it can sense, analyze and allot the channels to the users to resolve communication problems. Not only radio signal reception [11] but also new capabilities with more economically accessible for multiple applications and performance improvement in wireless communication system could be achieved by using novel architecture called Software Defined Radio.

Software Defined Radio [16] introduced a flexible wireless communication system that works on protocol instead of hardware. GNU Radio an open source software with Graphical User Interface Provides signal processing blocks to implement software-defined radio. For continuous improvement and quality maintenance in wireless communication, cognitive radio along with GNU Radio [4] software and Hardware HackRF One Great Scott Gadget are proved that these tools are capable to capture and process real time signals [3].

The radio implementation process includes filtering i,e setting the pass and stop band frequency, Digital Quadrature transformation, output/input data rate adjustment using up / down sampling process.

The remaining sections of the paper are organized as follows. Literature survey in Sect. 2, Whereas Sect. 3 address the introduction to cognitive radio, and software defined radio, with Sect. 4 HackRF One the Hardware employed to implement the radio communication. Sect. 5 signal processing blocks to implement transceiver using GRC., followed by Sect. 6 on experimental setup which includes GRC (GNU Radio Companion), Pentoo soft-ware, HackRF One. Sect. 7 About Spectrum Viewer Gqrx, Sect. 8 discusses the related issue of radio transmission. Section 9 are devoted to Simulation Results, and Conclusion in Sect. 10.

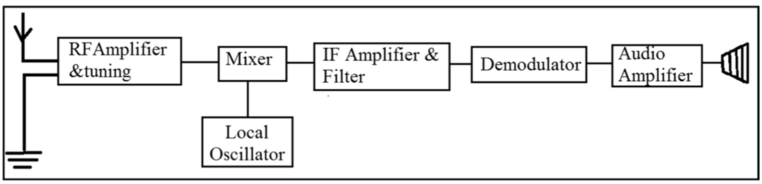


Fig. 1 General radio receiver

2 Literature Survey

To satisfy more users in the present technology spectrum efficiency and spectrum management can be more effectively implemented by cognitive radio. The various modulation schemes such as ASK, FSK, PSK all are implemented Using USRP and GNU Radio by replacing traditional radio [17]. By comparing Conventional radio system with cognitive radio, hence to prove that various Modulation such as PSK,QAM,GMSK,OFDM are implemented in short time by changing the software flow graph using GNU Radio and USRP [18]. By using Software Defined Radio it is possible to implement wireless standards by using the technique called sample rate Conversion, and also discussed regarding the significance of tuning the filter for good recovery of the signal [19]. The communication system, its basic signal operation, multi rate operation, analog and digital modulation schemes are presented using GNU Radio which is an effective tool kit for implementing the SDR [20, 21]. The flexibility of HackRF One [22] allows to conduct experiment by placing the transceiver in four different positions and conditions to analyse the signal power and observed the 12 dB, 10 dB, 9 dB, and 5 dB and for different scenarios. As GNU Radio Companion software is a most efficient tool kit [23], Power efficiency, SNR, Channel linearity, BER and various performances can be evaluated for QPSK,GMSK and QAM modulation techniques using SDR.

3 Cognitive Radio

Cognitive Radio(CR) improve the performance of the radio by continuous monitoring and adaptation from the environment, instead of building extra circuitry to handle different types of radio signals a relatively generic hardware is required. It would be so difficult to build a new circuitry any time in order to do the hardware upgrade [12]. SDR allows reusing identical hardware platform for many terminals with different protocols, which reduce the time to market and development cost [8]. The below are the different alternatives for implementing SDR. Transceiver can be implemented through general purpose processor defined by a soft or programmable medium and radio consists of antenna, Front-End RF Hardware.

The received or transmitted analog RF signal over antennas, are directly connected via coaxial RF connector to the ports of RF frontend called daughterboard as shown in Fig. 2. The upper path (arrow towards the daughterboard) marks the receive path (Rx), the lower path describes the transmit path (Tx). The analog signals are converted to digital samples and mixed down to baseband within the FPGA. Then the signal is decimated, data sampled are sent to the host by USB or Gigabit Ethernet respectively. The changes in the software results in implementing the protocol stack and the physical layer functions on the common hardware. High-speed A/D- and D/A-converters, universal RF frontend, various transmission formats (e.g. Bluetooth, WLAN, DECT, Zigbee) are supported by SDR.

The Software Defined Radio [2] and [7] for wide applications need different operating frequency ranges. The available hardware for implementation of cognitive radio are given below in Table 1.

The several types [2] of Software tools available i.e., open source and closed source for communciation [7] have been listed in the Table 2.

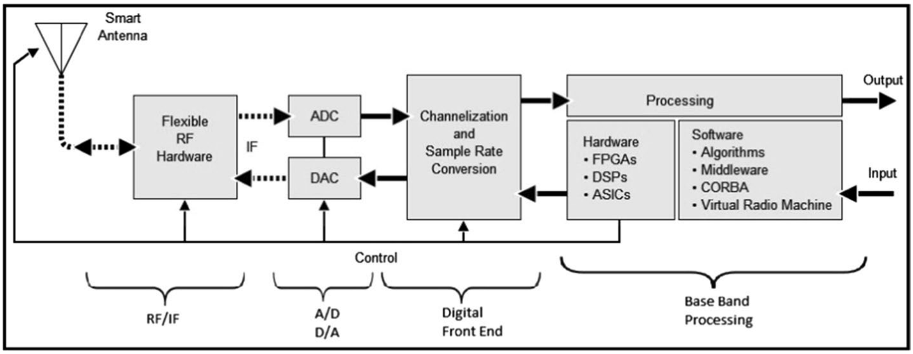


Fig. 2 Blocks in software defined radio

Table 1 Software defined radio

Software available for SDR		
GNU radio	Tool kit used by most SDR. Includes GNU Radio Companion	Open source
GrOsmoSDR	Library used to interface with Hardware	Open source
Linrad	Spectrum Viewer	Open source
Mac and Linux		
Gqrx	Spectrum viewer	Open source
Windows		
SDR#	Spectrum viewer	Open source
HDSDR	Spectrum viewer	Open source

Table 2 Available hardware for implementing cognitive radio

Available SDR hardware	Frequency range
RTL2832U Realtek SDR dongle	24–1766 MHz
FunCube donglePro+	150 KHz–2.05GHz
HackRF One	1 MHz–6 GHz
Blade RF	300 MHz–3.8 GHz
USRP B200	70 MHz–6 GHz
USRP B210	70 MHz–6 GHz
UmTRX	300 MHz–3.8 GHz
Matchstiq	300 MHz–3.8 GHz

4 HackRF One

HackRF One is a Software Defined Radio peripheral Com-patible with GNU Radio [7]. HackRF One is a hardware platform designed to enable Half-Duplex Transmission, of 20 million samples per second for the radio signals , providing operating range from 1 MHz

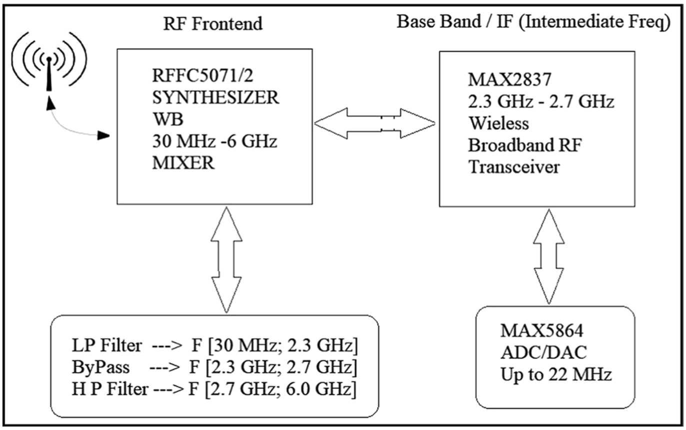
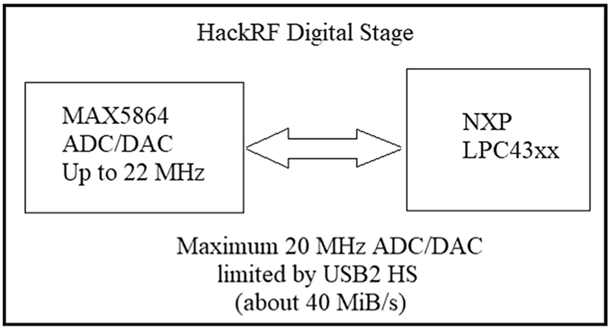


Fig. 3 HackRF One front end/baseband

Fig. 4 HackRF digital stage



to 6 GHz , with Software-Controlled Antenna port power (50 mA at 3.3 V). HackRF One front End and Degital stage are shown in Figs. 3 and 4.

5 Signal Processing Blocks

For RF real-time applications signal processing blocks which is a backend to a hardware device will be provided by GNU Radio stand-alone software package. In GNU Radio which is a graphical interface, programs are written in both C++ and Python, and are compiled and run on most general purpose processors (GPP's) with operating systems (e.g. Linux, Mac OSX, and Windows XP).Typically, the highest level of programming done in GNU Radio is written in Python (i.e. initialization and control for the signal processing components), and any time sensitive processing is done in C++.

The SDR experimental set up (shown in Fig. 10) is equipped by using a GRC (GNU Radio Companion) installed in a laptop an Intel Core i3 processor. In GNU radio all the signal processing blocks can be written in C++ and connected by Python language. If a user requires some new processing blocks, those can be created by the user by using C++ and Python languages and can integrate to the GNU software.

The basic structure of GNU Radio flow graph consist of signal source, signal processing and signal sink shown in Fig. 5. Signal processing block [5] consist of parameters like Interpolation, Decimation, RF Gain, IF Gain, Base Band Gain, for adjustment, and facility to vary or adjust or even automate according to the real time requirement. In GNU radio all the signal processing blocks are written in C++ and connected by Python language [6].

There are various DSP Concepts [3] that are employed in GRC Flowgraph for implementation of Receiver/Transmitter. As the RF signal is captured, the concept of Nyquist theorem is applied for sampling and proper recovery of signal. To view the signal in frequency domain the concept of FFT Operation is applied and it can viewed by deploying FFT Sink Block, every transmit and receive chain includes modulation and demodulation concepts based on application and requirement a particular technique is used, more over the significant role played in side the blocks are correct rate of sampling, and it is achieved by the concept called Decimation and Interpolation for required sample rate conversion.

The signal processing blocks plays vital role in building the receiver and connects the interdependent parameters and directs the signal flow through each block. Additional blocks need to be incorporated while using different modulation techniques at the receiver part. For instance AGC (Automatic Gain Control) block, while using in AM receiver. Chooser, Slider, Notebook, provides additional facilities and flexibility's. Based on the required output view like frequency spectrum, magnitude, and scope different types of the sink are been used. The signal flow graph connection and options chosen bring out the different type and range of receiver.

Radio signals can be received by using any of demodulation blocks like AM Receiver, FM Receiver, NBFM Receiver, WBFM Receiver. SDR allows the user to tune the Filter frequency,for selecting different channel and it can also be visualized in time/ frequency domain using GUI Sink.

Decimation Down sampling can be implemented by using the block named Decimate, or 1 to N block . Decimation option is also provided in LPF block. The increase in decimation reduces the bandwidth, therefore while plotting the graph using FFT Sink, the attribute (called samp rate) value need to be adjusted according to down sampling performed.

Osmocom Source The Source block captures or receives the signal defined by samp rate and amplify it and with defined frequency. Osmocom source is capable of handling different types of hardware and operates on complex data and produces the output type I and Q samples. The properties of this includes Samp rate, amplifier(RF Gain ,IF Gain), channel frequency. For tuning the channel frequency, Chooser block is used. The selection of the Samp rate determines the preceding blocks and also Sink block.

Low Pass Filter Any Type of filter mainly characterized or defined by the Selectivity,two important function Gain and Down Sampling together are called Decimation. The selectivity of the filter is defined by Cutoff, and Transition width. The ratio of samp rate to down rate gives the value of the decimation. .

Receiver We can use any of these receiver blocks viz, AMDemodulator, FMDemodulator, WBFMReceiver, NBFM Reciever based on the application and signal quality

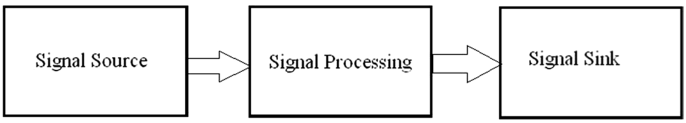


Fig. 5 Basic structure of GNU radio flow graph

expected. While using any of the receiver quadrature rate need to be defined. Rational Resampler can be used to fulfil the function of interpolation and decimation in order to meet the frequency rate of Audio Sink.

Audio Sink The audio sink is the destination block in the flow graph to recover the audio signal, with different audio fre-quency range options been provided. Based on the audio frequency the decimation and interpolation values are adjusted in Rational Resampler Block to connect the signal coming from the source.

5.1 Receiver Using AM Demodulation Block

Out of different signals sent from different radio transmitters, the RF filter selects the desired station. It is tunable so that the frequency is selected and applied to the mixer. The mixer form a frequency changer circuit. The output from the mixer is the Intermediate Frequency (IF) which is fed to the demodulator is shown in Fig. 6. This circuit recovers the audio signal and discards the RF carrier .Some of the audio is fed back to the IF amplifier as an Automatic Gain Control (AGC) voltage. This ensures that when tuning from a weak station to a strong one, the loudness from the loudspeaker stays the same. Here by using GNU Radio software the parameters RF Gain, IF Gain, Samp rate, LPF, AGC have been set.

5.2 Receiver Using FM Demodulator

FM receiver consist of Selector(to adjust center frequency), De-emphasis RF amplifier, IF amplifier, LPF, FM Demodulator blocks are shown in Fig. 7. The other common blocks in implementing receiver are, Osmocom source, Decimating FIR Filter, FM Demodulation, FM De-emphasis, Low Pass Filter, Frequency Xlating FIR Filter, and Audio Sink. The Internal parameters of the receiver are Samp rate, decimation factor, center frequency, RF Gain, IF Gain, cut off frequency, tran-sition width need to be assigned properly. Frequency Xlating Performs frequency translation, filtering, and decimation all in single block and this can be used to perform Channelization.

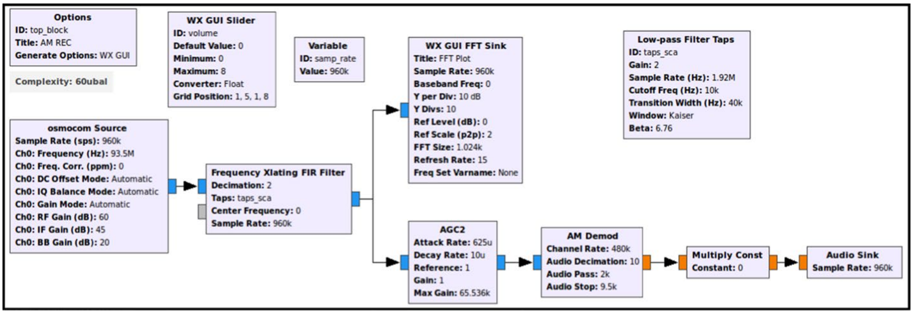


Fig. 6 Radio receiver using AM demodulator block

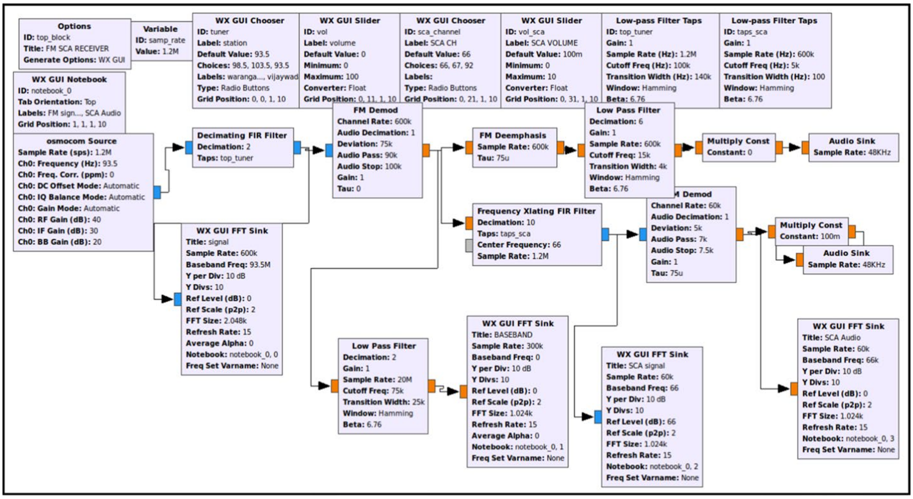


Fig. 7 Radio receiver using FM demod block

5.3 Radio Receiver Using WBFM Receiver

The DSP blocks in GRC performs one or more functions in software domain [13]. FM wave with infinite number of bands called to be wide band FM and its implementation flow graph in shown Fig. 8. The sample rate at the receiver front end is adjusted to 2MHZ, facilitating slider for RF Gain varying (5-100), LPF the decimation is set to 8 with cut off and transition width 100k and 10k respectively. Quadrature rate should be the same as a signal sample rate (in our case is 240 KHz), with audio decimation (down sample) factor, and it plays vital of adjusting sample rate for running the 'audio sink. Following block are the Rational Re-sample block and its properties of this block are set as interpolation is 24, decimation is 250k, audio output signal which can be easily converted to 24KHz.

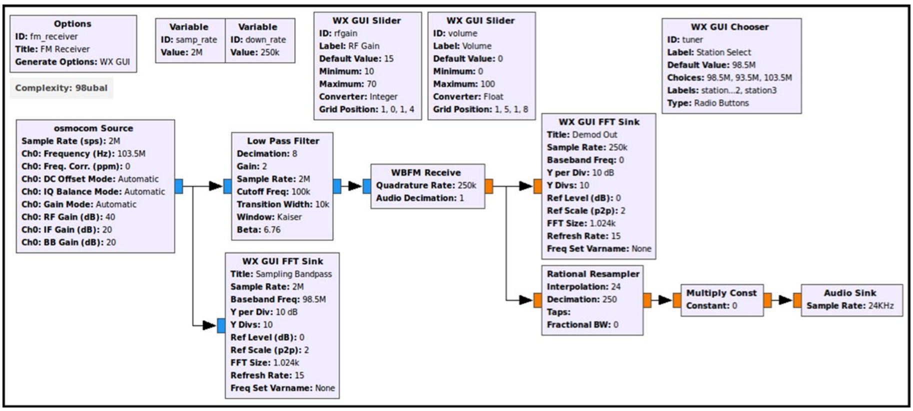


Fig. 8 Radio receiver using WBFM receiver block

5.4 Receiver Using NBFM Receiver

Narrow band means transmitted energy concentrates on a smaller portion of the spectrum, in other words which offers small frequency deviation. The implementation of NBFM includes Osmocom source, LPF, Fractional Resampler, NBFM Receiver, Multiply constant, and Audio Sink shown in Fig. 9.

The signal received through the antenna are grasped by Osmocom source in which the selected frequency band mentioned by centre frequency and the received signal is filtered by low Pass Filter, Fractional Rsampler block is used to convert from one sample rate to another as long as they can be related by a ratio

$$Fs_{out} = Fs_{in} * (Interpolation/Decimation)$$

NBFM block make it easy to listen narrow analog and digital channels that use FM or FSK.

6 Experimenral Setup

For Proposed work the experimental set up requires GRC (GNU Radio Companion), Pentoo software, HackRF One hardware shown in Fig. 10. Pentoo, a Linux distribution with full support for HackRF One and GNU Radio.

When the USB port of HackRF One has connected the 3V3, 1V8, RF, and USB LEDs should all be illuminated and are various colors. GNU Radio is the primary software platform supporting the drivers for the HackRF One on a personal computer. The GNU Radio [3] consists of different signal processing blocks which can be used for real time applications.

GRC Flow graph allows further changes in between the blocks for different type of outputs. An open source package SWIG (Simplified Wrapper and Interface Generator) convert C++ classes into Python compatible classes used by GNU Radio [9].

In designing the GRC signal flow graph various Parameters like low pass filter, decimation value, gain of the amplifier, and for further tuning purpose slider are also connected. It has been executed and obtained the FFT Plots. Slider is also included in the flow chart to adjust the gain.

The following sequences of commands have been followed for this experiment:-

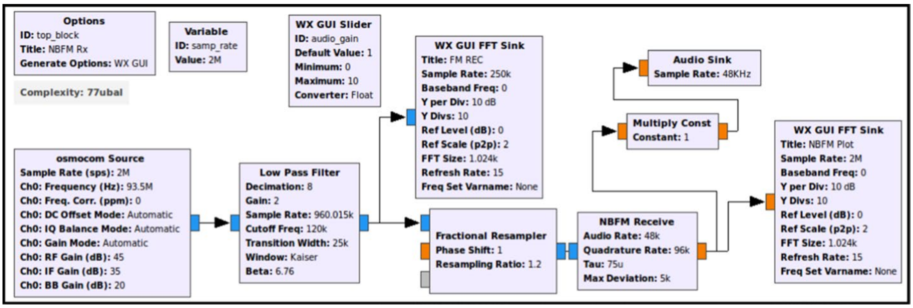


Fig. 9 Receiver using NBFM receiver block

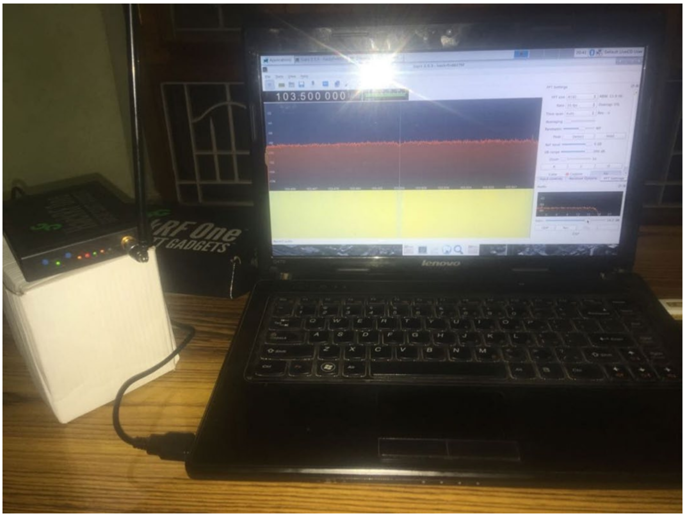


Fig. 10 The experimental setup

- Type startx at the command line to launch a desktop environment which is useful for GNU Radio Companion.
- Type Gnuradio-companion at the command line to create flow graph .
- Type hackrf_info at the command line. It produce a few lines of output including.
  - "Found HackRF board0"
  - IDNumber:2(HackRFOne)
  - Firmware Version :2017.02.1
  - Part ID numder:0xa0000b3c 0x005 F4F62
- BY using GRC, the flow graphs have constructed and its execution produces an FFT plot of received signal.

7 Spectrum Viewer

Gqrx is a Spectrum viewer, open source Qt graphical toolkit also supports HackRF One. Gqrx offers features like:

- Discover devices attached to the computer.
- Process I/Q data from the supported devices.
- Change frequency, gain and apply various corrections (frequency, I/Q balance).
- AM, SSB, CW, FM-N and FM-W (Mono and Stereo) demodulators.
- Special FM mode for NOAA APT.
- Variable band pass filter.
- AGC, squelch and noise blankers.
- FFT plot and waterfall.
- Record and playback audio to/from WAV file.

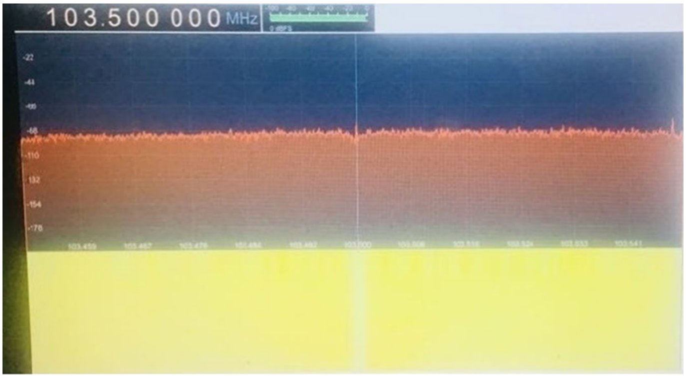
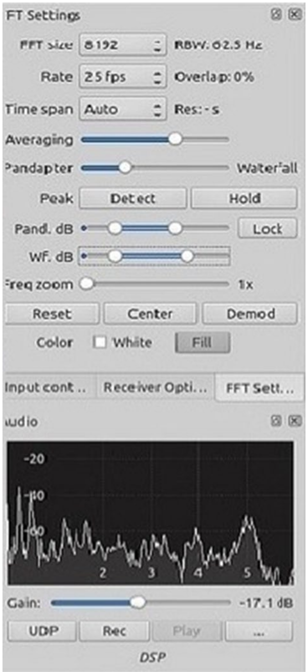


Fig. 11 Gqrx software visualizing the FM signal

Fig. 12 Gqrx parameters



The spectrum viewer also provided with various parameters to tune the frequency, like low pass filter, decimation value, gain of the amplifie. After tuning the slider to the desired frequecny. The HackRF One antenna receives the radio signal been plotted using Gqrx.

Slider in spectrum viewer is used to adjust the gain as showm in Fig. 12. Type Gqrx at the command line that opens a waterfall window, providing the following options for frequency selection (Fig. 11).

- Input Control, Receiver Options, FFT settings
- DEVICE :HACKRF ONE

- Frequency 103.5MHZ
- Name of Station: All India Radio, Warangal.
- FFT Size -8132
- Mode –WFM Stereo
- AGC-Fast
- Squelch-150.0 dBFS
- Antenna-RX

8 Transmission

SDR [14] opened the door to extend into a high re-configurable platform for communication system [9], it also requires signal processing method, to be deployed by using the same set of hardware (HackRFOne/USRP)and software (such as GNU Radio). Digital transceiver [15] are now available with flexibility by effective application of digital signal processing. For WBFM transmission the entire process need to pass through various blocks, like modulating the base band signal (Audio), adjusting the RF and IF gain and up/down sampling as shown in Fig. 13.

FM transmitter follow the sequence of process, the signal is sampled the audio at 48 KHz, and then converted it to high frequency using WBFM block and it is sent for interpolation and decimation of signal to the Rational Resampler block. Then signal get multiplied by multiply block to reduce the effect of noise at high frequency. By using osmocom sink the RF and IF gain is adjusted and the signal is transmitted. Similar to NBFM receiver the transmitter is also implemented and is shown in Fig. 14.

9 Simulation Results and Discussion

It is by using Hack RF One and GNU radio the FFT graph of various demodulation techniques is show in Figs. 15, 16, 17, 18, 19, 20. Various frequency bands such as at 93.5 MHz, 98.3 MHz ,103.5MHz, by and 100 MHz frequency are tuned and received the signal.

All the modulation techniques such as AM, FM NBFM, WBFM and its transmitter and receiver chain have been implemented by using GNU Radio and Generic Hardware Hack

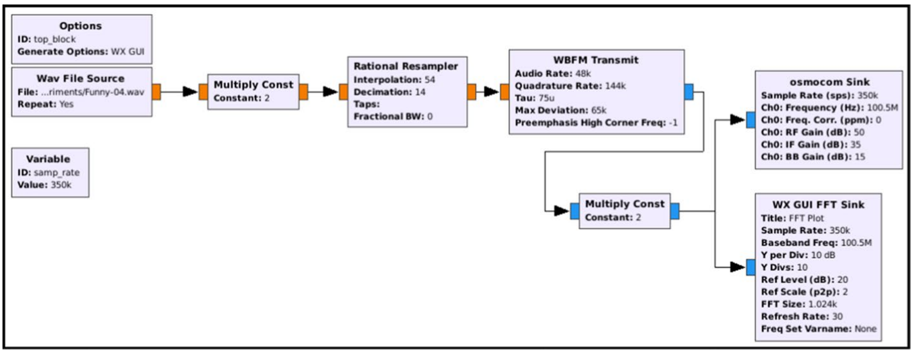


Fig. 13 GRC of signal transmission using WBFM

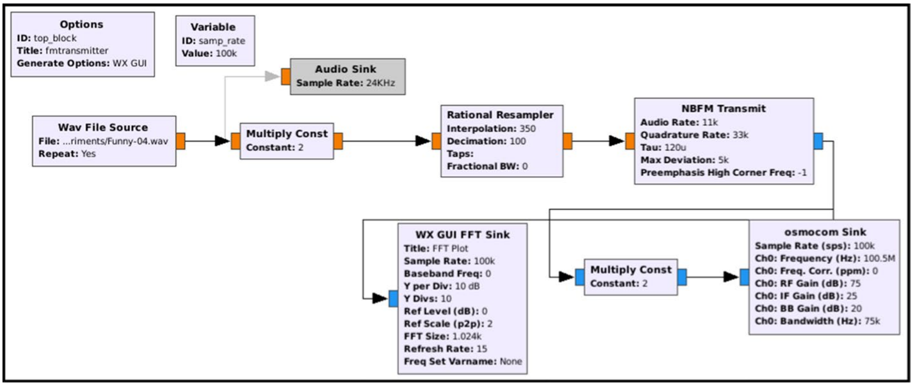


Fig. 14 GRC of signal transmission using NBFM

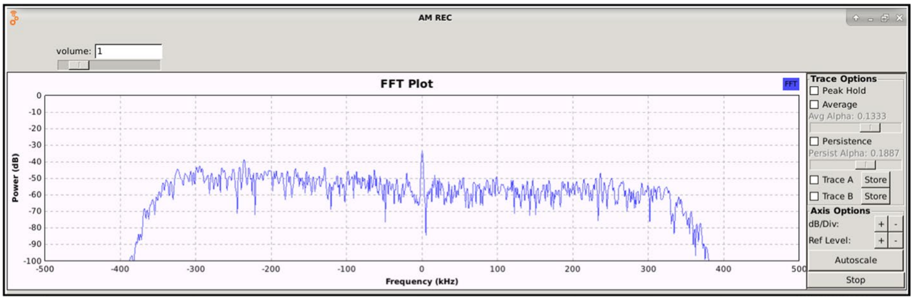


Fig. 15 AM receiver FFT graph

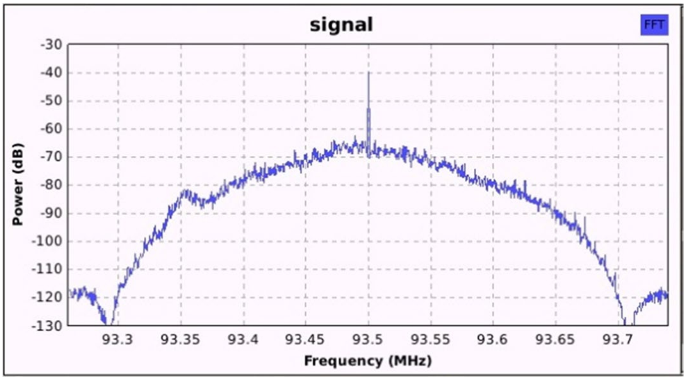


Fig. 16 FM receiver FFT graph

RF One. While verifying the signal quality using different modulation techniques, AM Demodulator by virtue of the technique depends on amplitude it is more susceptible to noise, where as WBFM is less prone to noise, with lower BW and is applicable for broadcast with good sound quality. While transmitting an audio signal from HackRF One to a

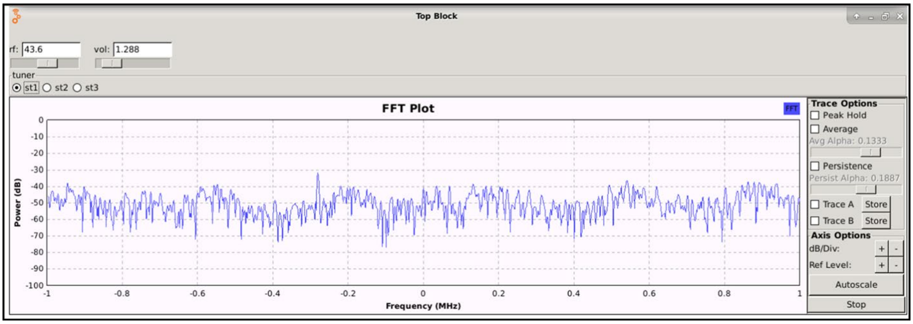


Fig. 17 WBFM receiver FFT graph

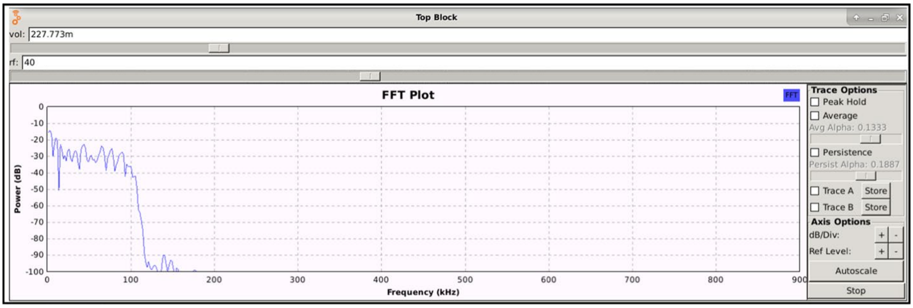


Fig. 18 NBFM receiver FFT graph

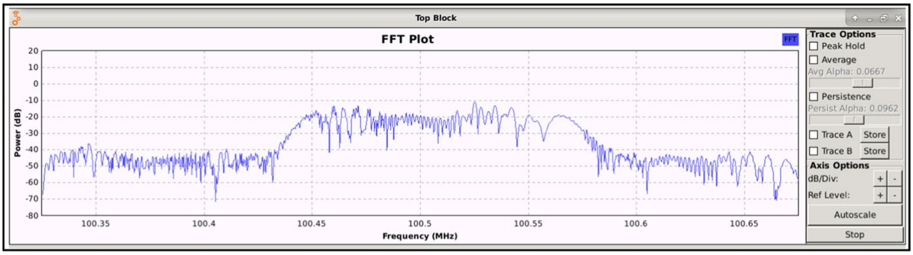


Fig. 19 Mobile transmit WBFM FFT graph

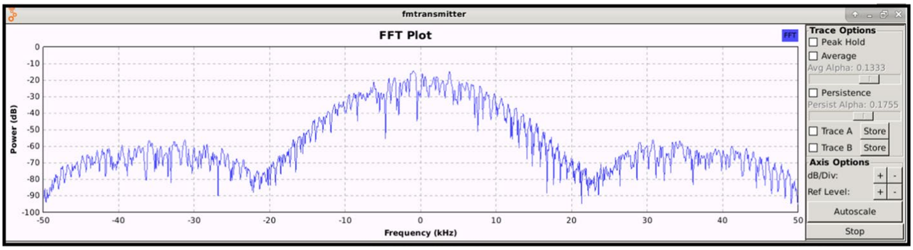


Fig. 20 Mobile transmit NBFM FFT graph

mobile phone both NBFM and WBFM modulation technique are used and it is received by the mobile phone with good clarity. GQRX is a spectrum viewer helps to read signal time and frequency on the waterfall, which allows the users to shift to any required frequency. As increasing the length of the antenna size the signals can be received with good sound quality and clarity.

10 Conclusion

The low cost SDR HackRF One can be a good platform for implementing Wireless communication system. Receiving the frequency with different operational parameters, and different modulation techniques is possible with SDR in no time In this approach various parameters on the Gqrx have been assigned and the center frequency have been tuned to the 103.5FM shown in Fig. 11. Different broadcast stations frequency are also tuned and received by HackRF One by using Different Demodulators blocks. The GNU Radio allows to change the flow chart sequence, and parameters like cutoff, pass band, stop band frequency, Up/Down sampling. And these parameters are adjusted with software only and thus implemented the transceiver. Finally the FFT is clearly visualized by the graphical software platform GNU Radio and Gqrx.

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