"Lab@Home: A Paradigm shift in Communication and Signal Processing Research and Academics by Software Defined Radio"

Creating an Open frame work for Electronics and Communication Engineering for Research and Education using Open source software GNU Radio and Hardware Universal Software Radio Peripheral (USRP), RTL SDR.

Special Thanks to

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1.1 Motivation

- Engineering education in India is facing problems like lack in quality, industry readiness, interest in research and entrepreneurship.
- The key reason for all mentioned problems is deficiency in Understanding (‘U’ factor) the subjects learned and taught.
- Currently experimentation is costlier in Comm. & Signal Processing (mostly simulation based)
- Success of Open Source is Key (Eg.Android)
- Need of Real-time open source frame work for every researchers

1.2 Objective

- To explore the feasibility of turn-key ready low cost open source hardware and software framework of SDR (Lab@Home) to realize advanced signal processing and communication engineering applications which leads to innovative research and entrepreneurship.
- Developing new student affordable applications in unexplored domain such as Antenna radiation pattern measurements and RF based meteorological parameter measurement using SDR.
- To enhance the understanding of theoretical and mathematical aspects in pedagogy of current electronics and communication engineering by hands-on approach.

1.3.1 Literature Survey

- Indian Knowledge Commission, GOI Report says "the problem of employability of engineering graduates, largely because curriculum and syllabi are not quite compatible with industry requirements" [113]
- Solution suggested by commission "integrating skills such as problem solving and logical reasoning, process orientation, learning ability"
- Need real time low cost arrangements to improve learning ability.

1.3.2 Literature Survey

- India's higher education institutions are facing problem of quality, President Pranab Mukherjee on April 9, 2013, said the country was far behind China and the US in terms of innovation and pitched for "drastic action" to reform the system. He said quality, affordability and accessibility should be the mainstay of higher education to encourage innovation and research. [114]

1.3.3 Literature Survey

- Dr.R.Natarajan, Former Chairman, All India Council for Technical Education (AICTE) gave comments, "Lack of interest among graduating engineers to pursue research degree programs or teaching careers (because of the availability of attractive jobs in the IT and ITeS sectors without much technical background) [115]
- Solution : Experiencing subjects by doing.

1.3.4 Literature Survey

- Researchers and academicians have created framework to resolve the problem discussed above. Sharlene Katz, demonstrated communication and signal processing using GNU Radio as simulation model [116].
- Demonstration of communication and signal processing experiment done based on LabView with USRP by Thad B. Welch [59] at Boise State University. Sven G. Bilén et.al suggested how SDR can be used for integrated curriculum delivery in various Universities in USA [117].

1.3.5 Literature Survey

- Sabih Guzelgoz and Hiiseyin Arslan, suggested about the Modeling. Simulation, Testing, and Measurements of Wireless Communication Systems done based on MATLab to teach wireless communication subject at University of South Florida [118].
- Raquel G. Machado, demonstrated the realization of SDR using FPGA based ZedBoard with FMCOMMS2 RF frontend for academic purpose [119].

1.3.6 Literature Survey

- bladeRF is a Software Defined Radio (SDR) platform designed to enable a community of hobbyists, and professionals to explore and experiment with the multidisciplinary facets of RF communication [120].
- HackRF One from Great Scott Gadgets is a Software Defined Radio peripheral capable of transmission or reception of radio signals from 1 MHz to 6 GHz [121].
- Indian made, SDR STARTER KIT is a PC based software defined radio (SDR) platform for designing wireless communications systems. SDR STARTER KIT boards are developed for research and technology development for wireless communications, including both fixed and mobile, satellite and terrestrial based applications [4].

1.3.7 Literature Survey

- Many academic and research institutes has been following based on proprietary hardware and software such as MATLab and LabVIEW and related hardware. That leads to increase the investment cost for management.
- New innovative products based on these tools will increase the overall cost, even though idea may be simple which cannot be realized easily.
- Solution to this is open source hardware and software based on Software Defined Radio – GNU Radio.

1.4 SDR as Key

- Software Defined Radio is a domain where both communication and signal processing converges. By definition, “Radio in which some or all of the physical layer functions are software defined” [126].
- Traditional hardware based radio devices limit cross-functionality and can only be modified through physical intervention.
- This results in higher production costs and minimal flexibility in supporting multiple waveform standards.

SDR as Key

- Software defined radio technology provides an efficient and comparatively inexpensive solution to this problem, allowing multi-mode, multi-band and/or multi-functional wireless devices that can be enhanced using software upgrades.
- SDR comprises field programmable gate arrays (FPGA), digital signal processors (DSP), general purpose processors (GPP), programmable System on Chip (SoC).
- The use of these technologies allows new wireless features and capabilities to be added to existing radio systems without requiring new hardware.

Software tools for SDR

Commercial softwares

National Instruments
1. Labview

Math Works
1.Matlab
2.Simulink

Open-Source softwares

Software Communications Architecture
Scilab
Reference
Implementation (SCARI)

GNU Radio

OSSIE

Hardware for SDR

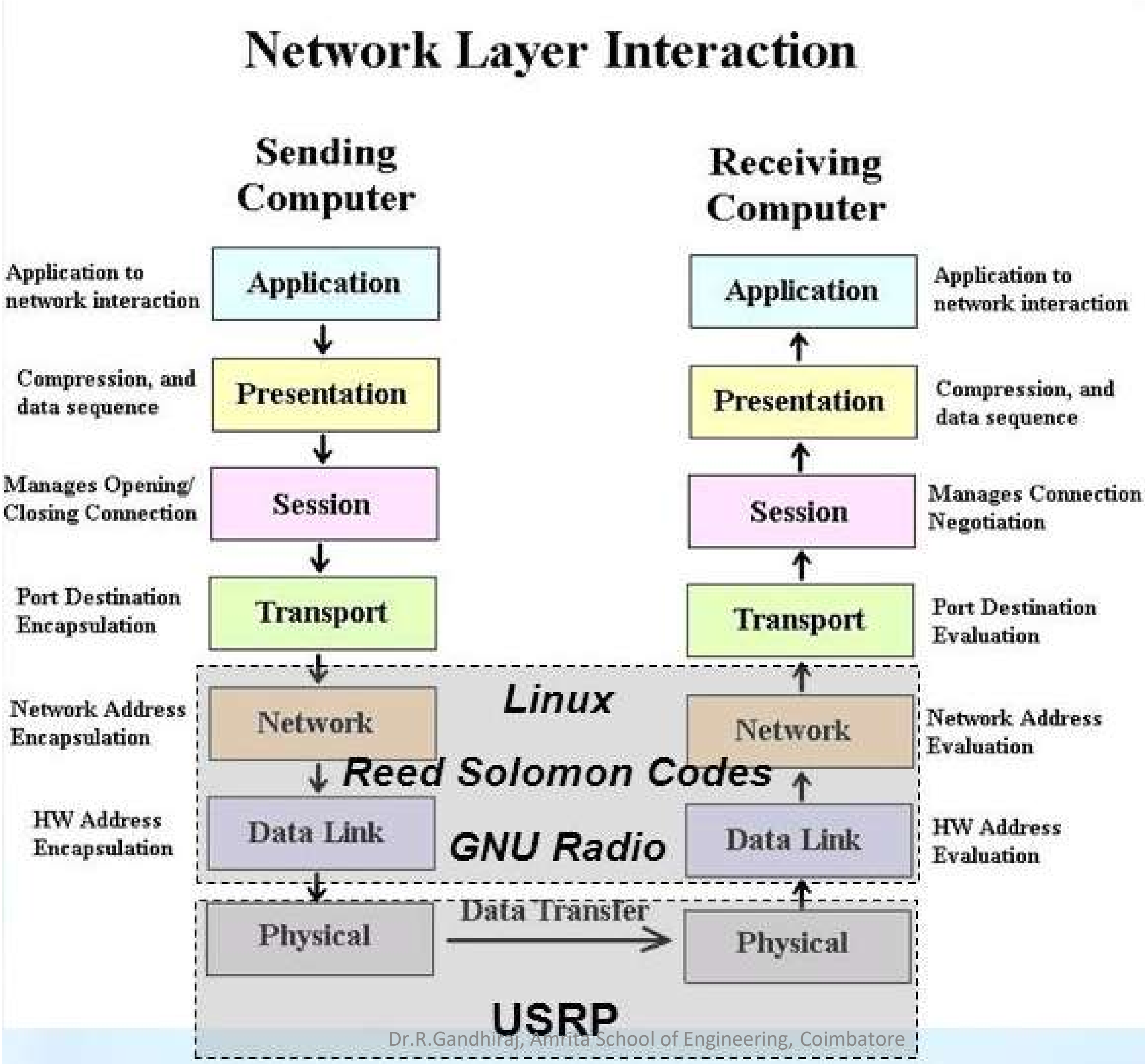
- Ettus Research (USF
  - Network series
  - Bus series
  - Embedded series

- National Instruments (
  - 2920
  - 2921
  - 2922
  - 2930
  - 2932

- NUAND
  - Blade RF (300MHZ to 3.8GHZ)

- OSSMANN
  - Hack RF (30MHZ to 6GHZ)

Power of SDR



Network Layer Interaction
Sending Computer
Receiving Computer
Application to network interaction
Application
Application
Application to network interaction
Compression, and data sequence
Presentation
Presentation
Compression, and data sequence
Manages Opening/ Closing Connection
Session
Session
Manages Connection Negotiation
Port Destination Encapsulation
Transport
Transport
Port Destination Evaluation
Linux
Network Address Encapsulation
Network
Network
Network Address Evaluation
Reed Solomon Codes
HW Address Encapsulation
Data Link
GNU Radio
Data Link
HW Address Evaluation
Physical
Data Transfer
Physical
USRP

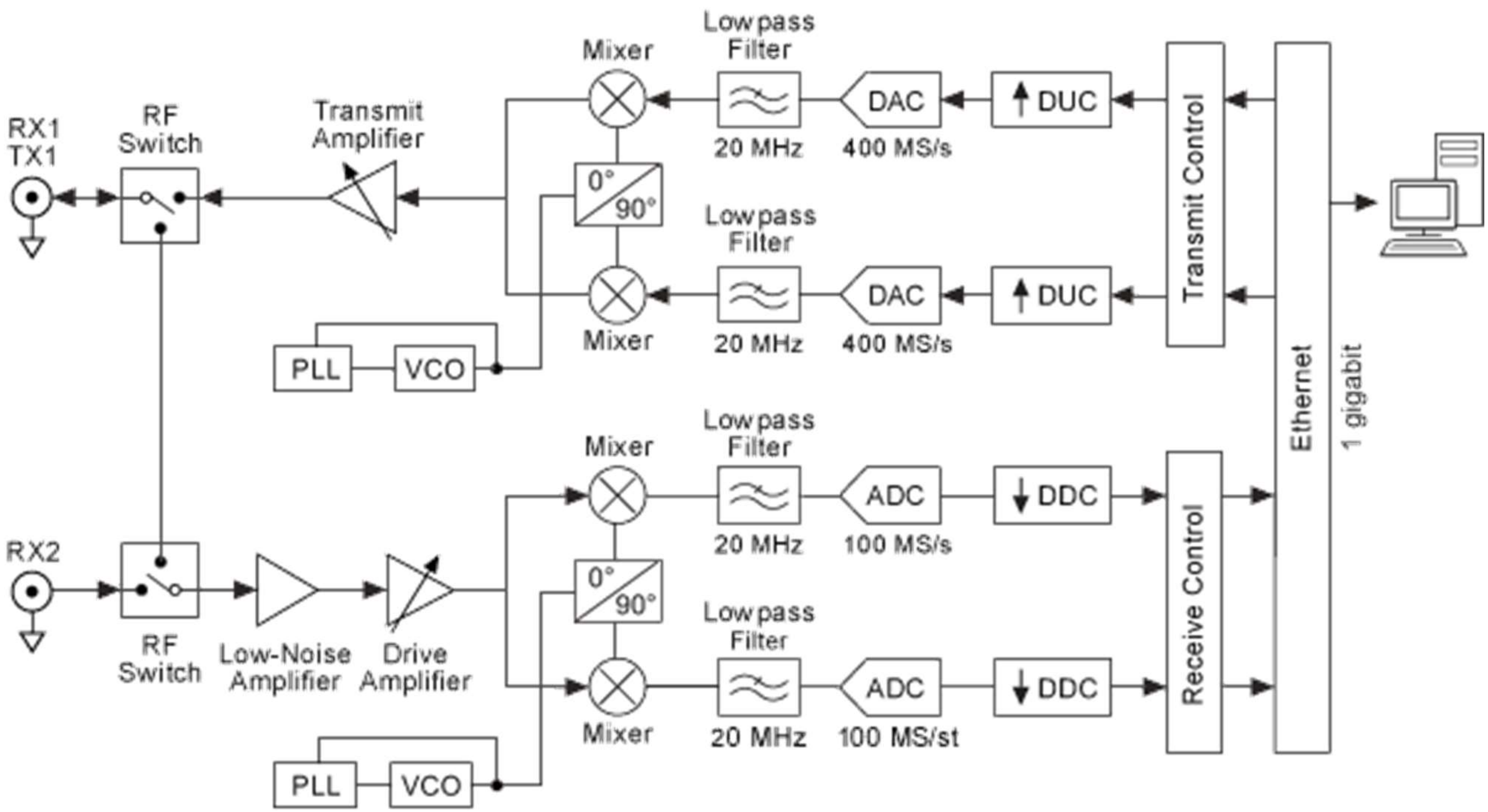
USRP

- Universal Software Radio Peripheral (USRP): The USRP family of products is designed for RF applications from DC to 6 GHz, including multiple antenna (MIMO) systems. Example application areas include white spaces, mobile phones, public safety, spectrum monitoring, radio networking, cognitive radio, satellite navigation, and amateur radio ("Ettus Research - About Ettus Research" 2016)

USRP Features

- Use with GNU Radio, LabVIEW and Simulink
- Modular Architecture: DC-6 GHz
- Dual 100 MS/s, 14-bit ADC
- Dual 400 MS/s, 16-bit DAC
- DDC/DUC with 25 mHz Resolution
- Up to 50 MS/s Gigabit Ethernet Streaming
- Fully-Coherent MIMO Capability
- Gigabit Ethernet Interface to Host
- 2 Gbps Expansion Interface
- Spartan 3A-DSP 1800 FPGA (N200)
- Spartan 3A-DSP 3400 FPGA (N210)
- 1 MB High-Speed SRAM
- Auxiliary Analog and Digital I/O
- 2.5 ppm TCXO Frequency Reference
- 0.01 ppm w/ GPSDO Option

USRP Architecture



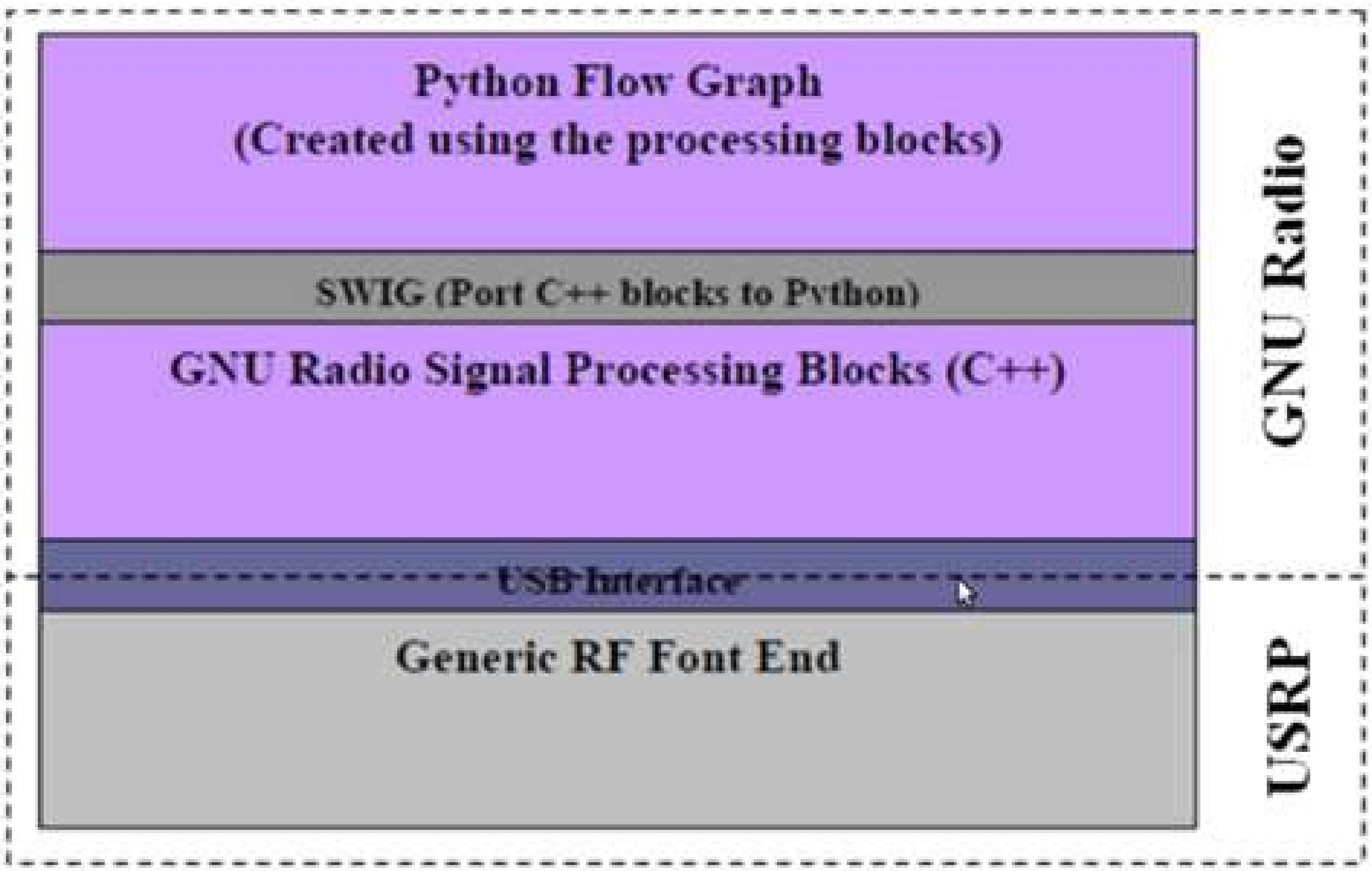
RTL-SDR

- RTL-SDR: RTL-SDR is a very cheap software defined radio that uses a DVB-T TV tuner dongle based on the RTL2832U chipset. With the combined efforts of Antti Palosaari, Eric Fry and Osmocom it was found that the signal I/Q data could be accessed directly, which allowed the DVB-T TV tuner to be converted into a wideband software defined radio via a new software driver.

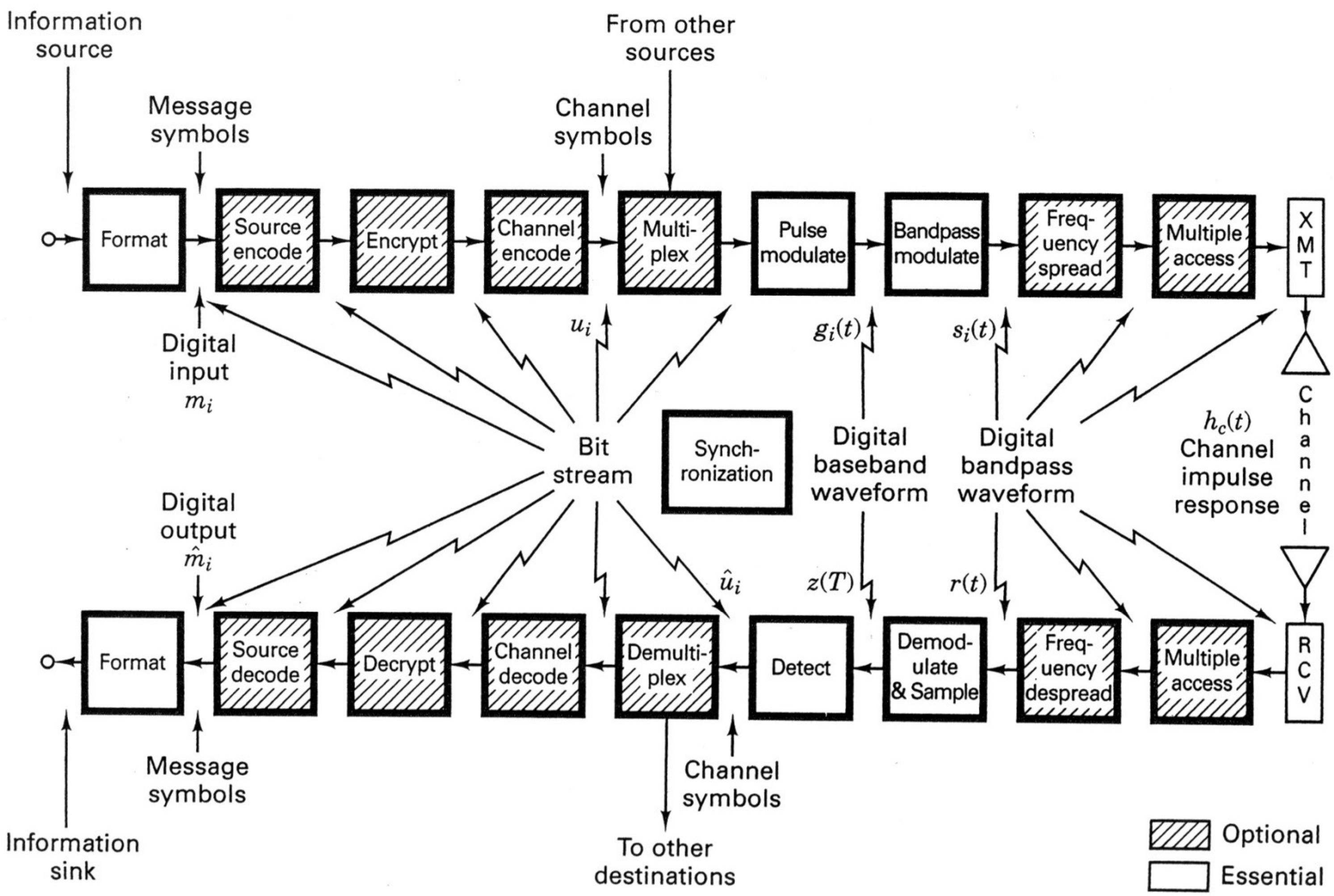
GNU Radio

- GNU Radio is a free & open-source software development toolkit that provides signal processing blocks to implement software radios.
- It can be used with readily-available low-cost external RF hardware to create software-defined radios, or without hardware in a simulation-like environment.
- It is widely used in hobbyist, academic and commercial environments to support both wireless communications research and real-world radio systems.
- GNU Radio is licensed under the GNU General Public License (GPL) version 3. The platform for GNU Radio contains Linux, C++ and Python

Hierarchy of Software and hardware interface



Physical Layer: Digital Comm. System



B. Sklar, *Digital communications: fundamentals and applications*, 3rd ed. Hoboken: Pearson Education, Inc, 2020.

PART I

2 Paradigm Shift in Pedagogy of Communication and Signal Processing

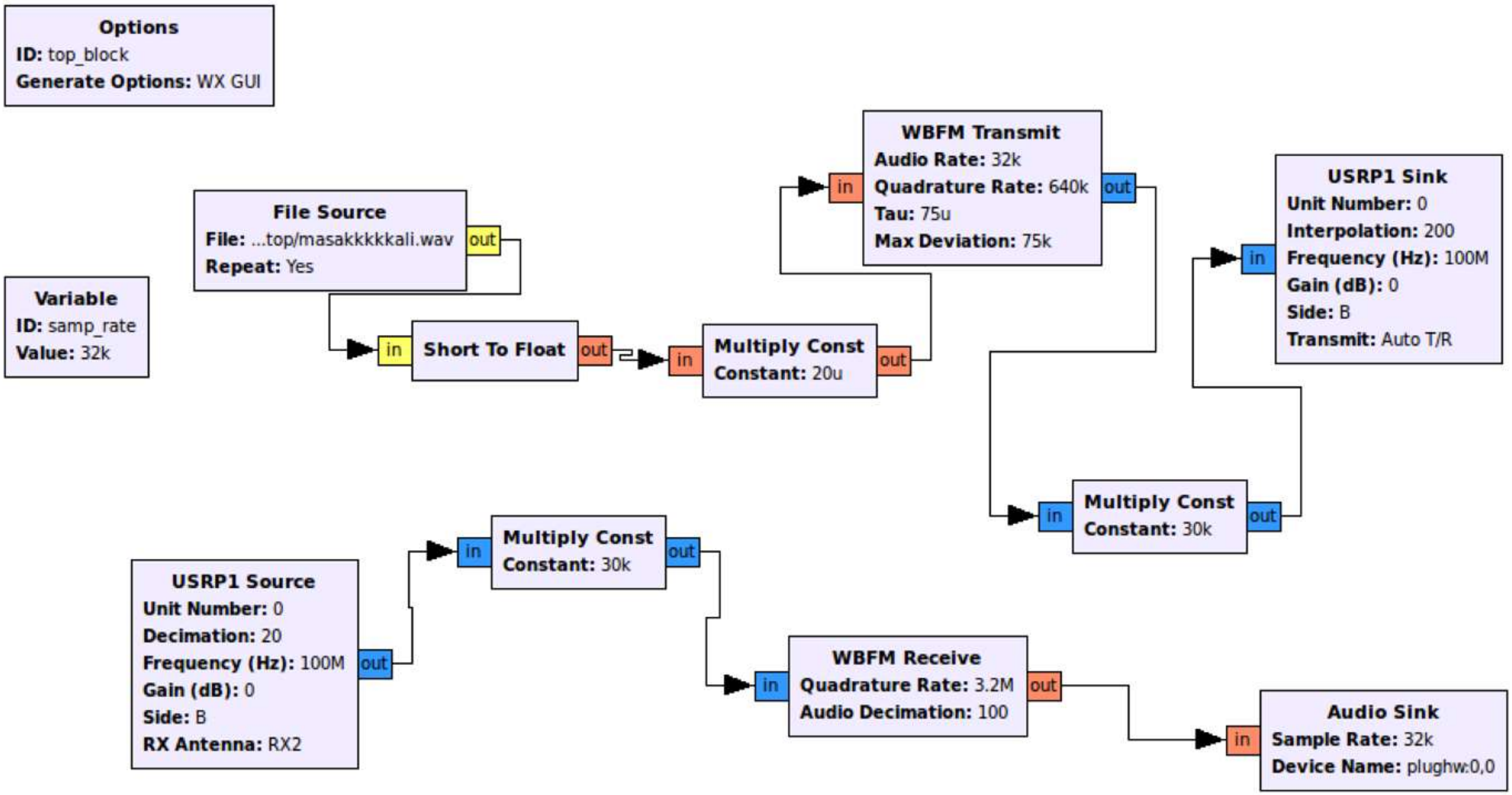
2.1 Modern analog and digital communication systems development using GNU Radio with USRP

- Community Radio scheme (FM radio)
- Radio data system (RDS)
- OFDM based data communication using USRP1
- Real-time performance analysis of OFDM communication system without Channel estimation

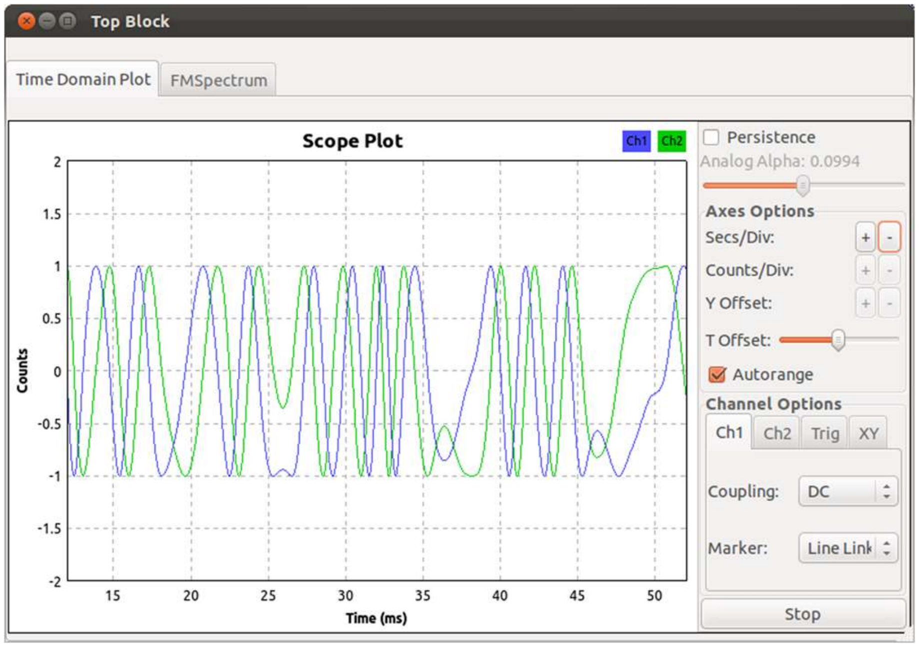
2.2 Multi rate signal processing by GNU Radio

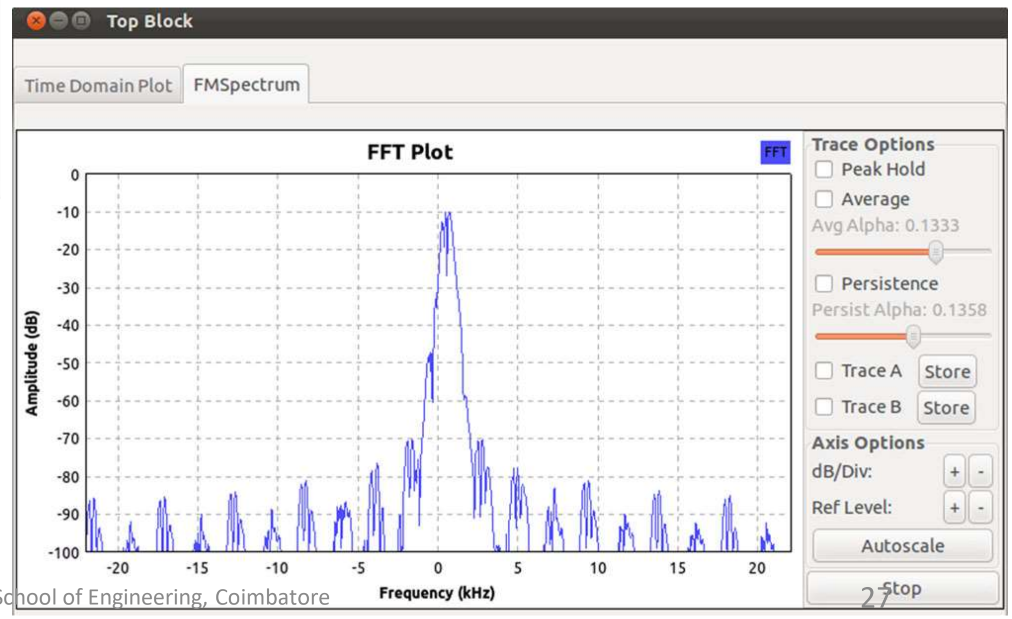
- Study of Polyphase Structure Made Easy Using GNU Radio
- Study of Multirate systems and filter banks using GNU Radio

2.1.1Community Radio scheme (FM radio)

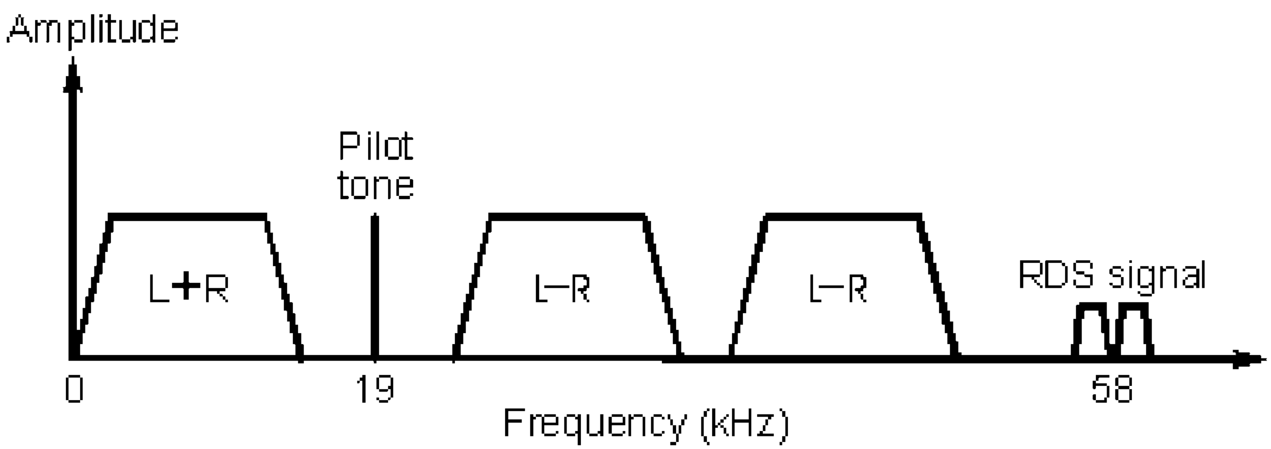


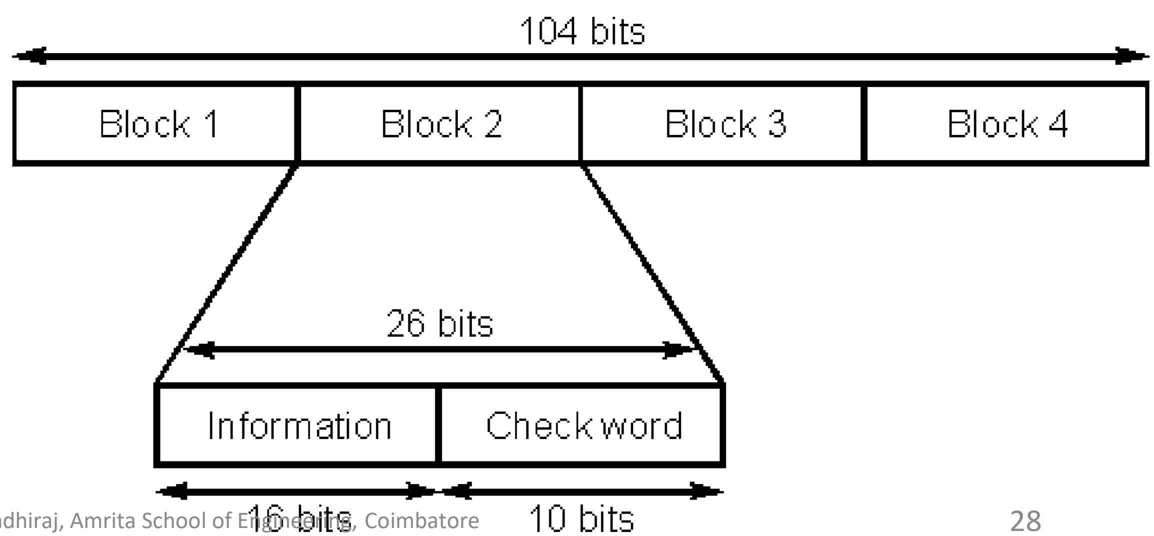
Outputs


Top Block
Time Domain Plot
FMSpectrum
Scope Plot
Ch1
Ch2
Counts
Time (ms)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
15
20
25
30
35
40
45
50
Persistence
Analog Alpha: 0.0994
Axes Options
Secs/Div:
Counts/Div:
Y Offset:
T Offset:
Autorange
Channel Options
Ch1
Ch2
Trig
XY
Coupling:
DC
Marker:
Line Link
Stop

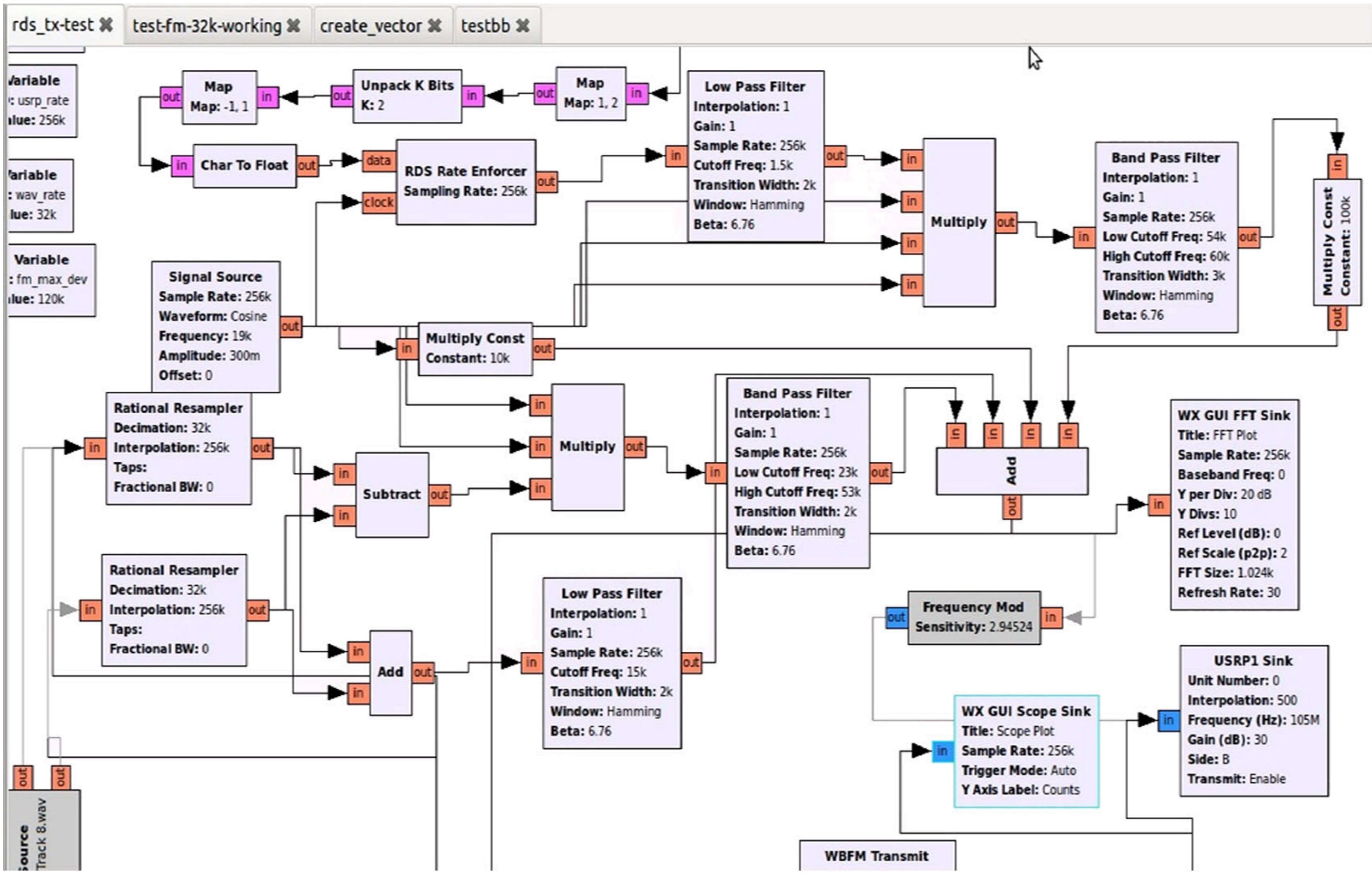

Top Block
Time Domain Plot
FMSpectrum
FFT Plot
FFT
Amplitude (dB)
Frequency (kHz)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-20
-15
-10
-5
0
5
10
15
20
Trace Options
Peak Hold
Average
Avg Alpha: 0.1333
Persistence
Persist Alpha: 0.1358
Trace A
Store
Trace B
Store
Axis Options
dB/Div:
Ref Level:
Autoscale
Stop

2.1.2 Radio Data System (RDS)





GRC Blocks

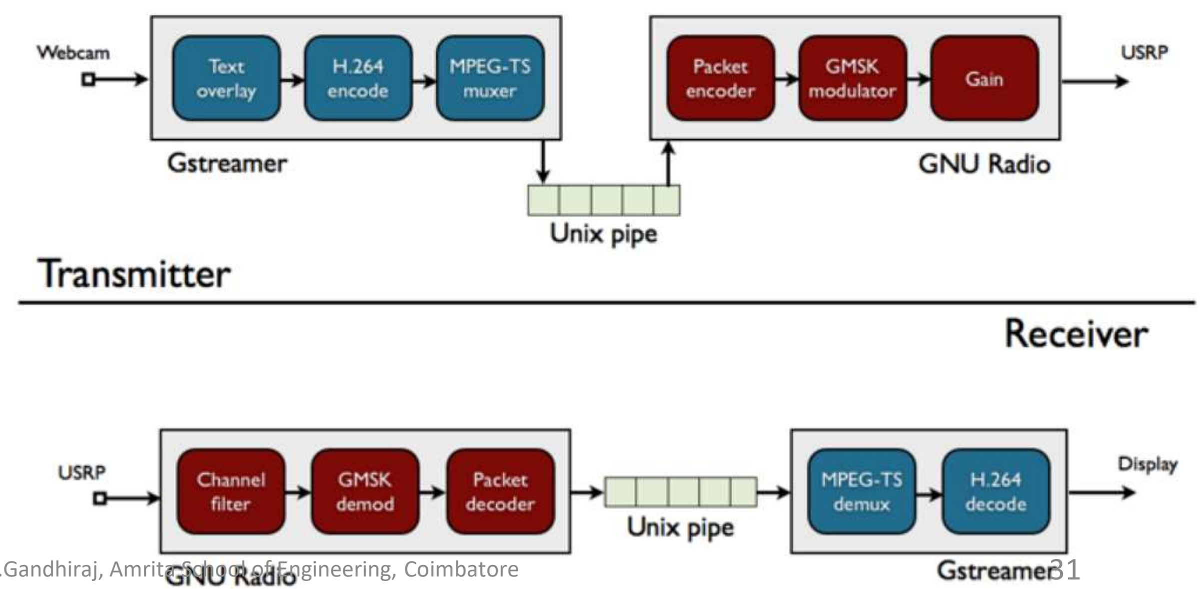

rds_tx-test
test-fm-32k-working
create_vector
testbb
Variable
usrp_rate
256k
Variable
wav_rate
32k
Variable
fm_max_dev
120k
Map
Map: -1, 1
Unpack K Bits
K: 2
Map
Map: 1, 2
Char To Float
RDS Rate Enforcer
Sampling Rate: 256k
Low Pass Filter
Interpolation: 1
Gain: 1
Sample Rate: 256k
Cutoff Freq: 1.5k
Transition Width: 2k
Window: Hamming
Beta: 6.76
Multiply
Band Pass Filter
Interpolation: 1
Gain: 1
Sample Rate: 256k
Low Cutoff Freq: 54k
High Cutoff Freq: 60k
Transition Width: 3k
Window: Hamming
Beta: 6.76
Multiply Const
Constant: 100k
Signal Source
Sample Rate: 256k
Waveform: Cosine
Frequency: 19k
Amplitude: 300m
Offset: 0
Multiply Const
Constant: 10k
Rational Resampler
Decimation: 32k
Interpolation: 256k
Taps:
Fractional BW: 0
Subtract
Multiply
Band Pass Filter
Interpolation: 1
Gain: 1
Sample Rate: 256k
Low Cutoff Freq: 23k
High Cutoff Freq: 53k
Transition Width: 2k
Window: Hamming
Beta: 6.76
Add
WX GUI FFT Sink
Title: FFT Plot
Sample Rate: 256k
Baseband Freq: 0
Y per Div: 20 dB
Y Divs: 10
Ref Level (dB): 0
Ref Scale (p2p): 2
FFT Size: 1.024k
Refresh Rate: 30
Rational Resampler
Decimation: 32k
Interpolation: 256k
Taps:
Fractional BW: 0
Add
Low Pass Filter
Interpolation: 1
Gain: 1
Sample Rate: 256k
Cutoff Freq: 15k
Transition Width: 2k
Window: Hamming
Beta: 6.76
Frequency Mod
Sensitivity: 2.94524
USRP1 Sink
Unit Number: 0
Interpolation: 500
Frequency (Hz): 105M
Gain (dB): 30
Side: B
Transmit: Enable
WX GUI Scope Sink
Title: Scope Plot
Sample Rate: 256k
Trigger Mode: Auto
Y Axis Label: Counts
Source
Track 8.wav
WBFM Transmit

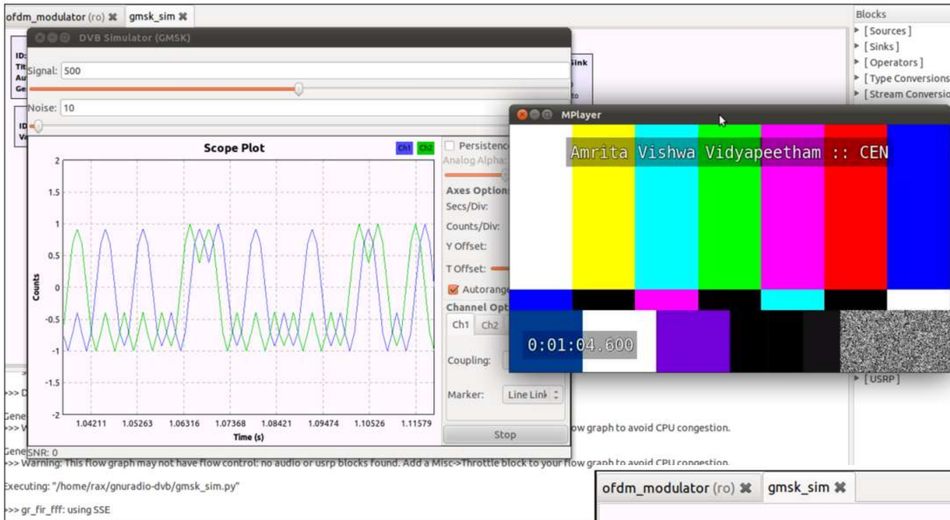
Setup & Result

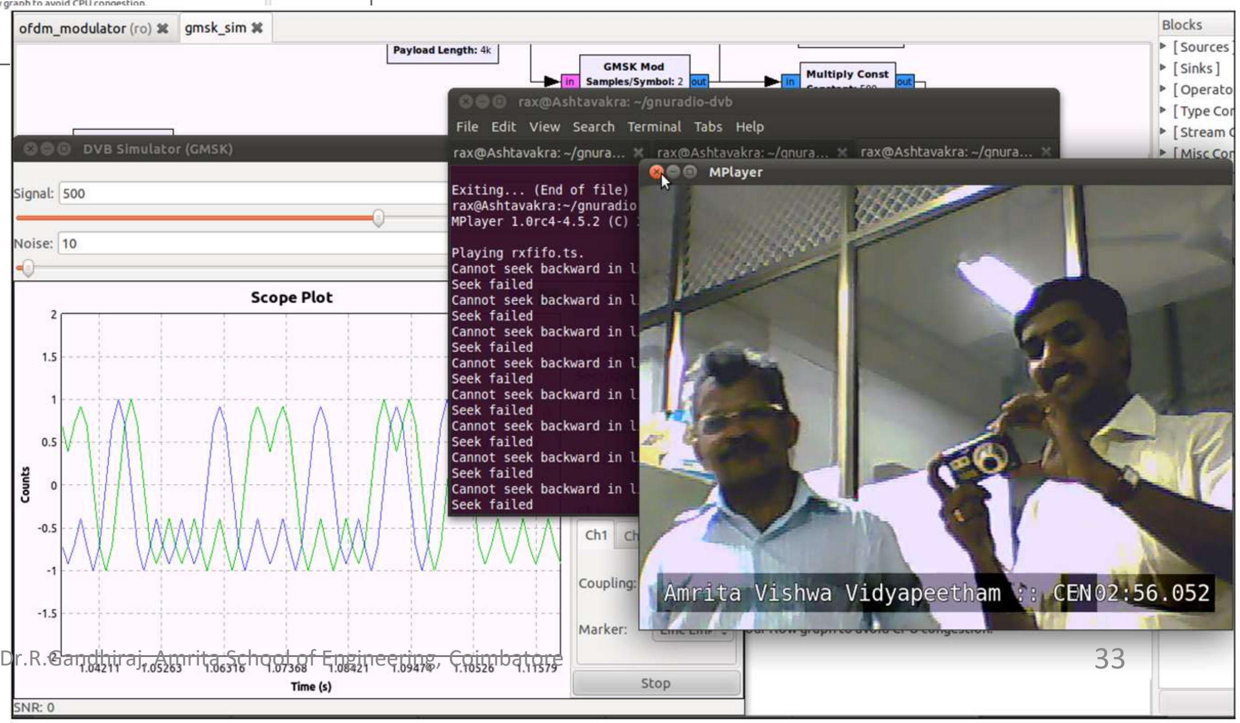
- Mother Board: USRP1
- Daughter Board: WBX Board
- Input data: Wave File, Sampled at 32000 Hz
- GNU Radio version: 3.4.2

RDS reception using FM enabled mobile phone

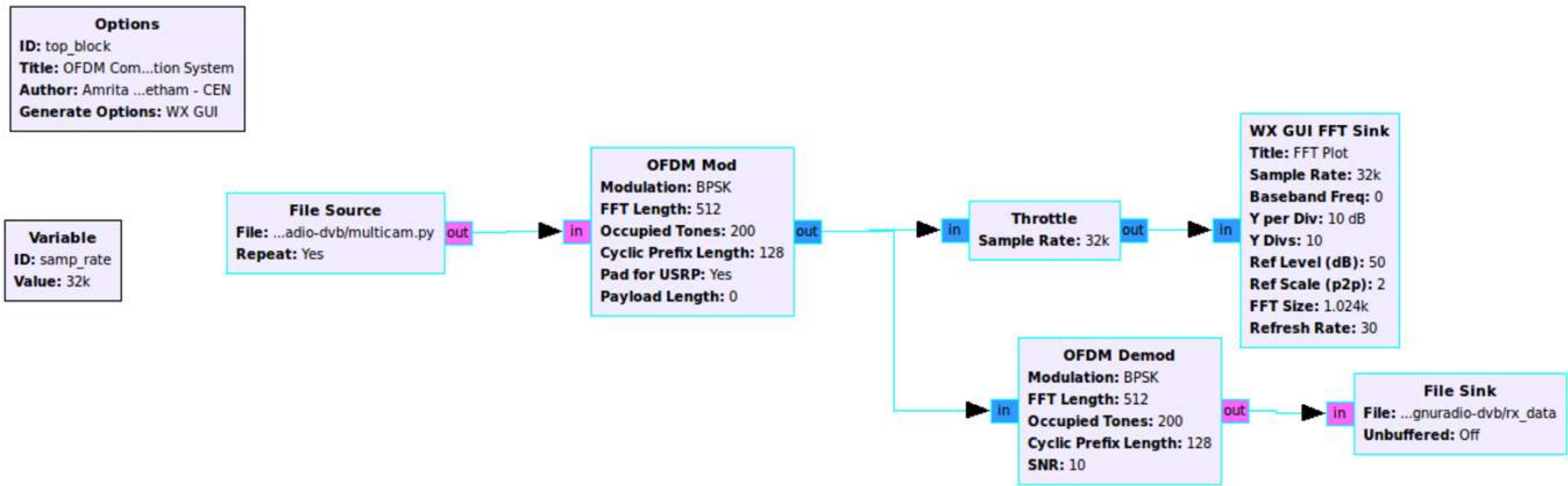
2.1.3 Simple DVB with GNU Radio

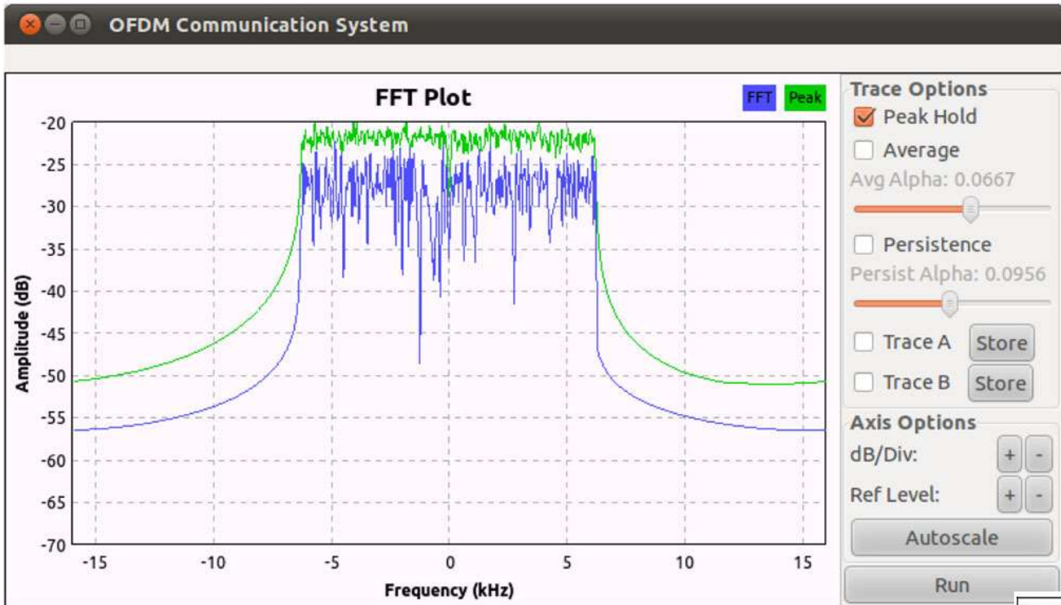



ofdm_modulator (ro)
gmsk_sim
DVB Simulator (GMSK)
Signal: 500
Noise: 10
Scope Plot
MPlayer
Amrita Vishwa Vidyapeetham :: CEN
0:01:04.600
Blocks
[Sources]
[Sinks]
[Operators]
[Type Conversions]
Time (s)
Counts
Stop
SNR: 0
Executing: "/home/rax/gnuradio-dvb/gmsk_sim.py"
>>> gr_fir_fff: using SSE


ofdm_modulator (ro)
gmsk_sim
Payload Length: 4k
GMSK Mod
Samples/Symbol: 2
Multiply Const
rax@Ashtavakra: ~/gnuradio-dvb
File Edit View Search Terminal Tabs Help
DVB Simulator (GMSK)
Signal: 500
Noise: 10
Scope Plot
Exiting... (End of file)
MPlayer 1.0rc4-4.5.2 (C)
Playing rxfifo.ts.
Seek failed
MPlayer
Amrita Vishwa Vidyapeetham :: CEN02:56.052
Time (s)
Counts
Coupling:
Marker:
Stop
SNR: 0
Blocks

2.1.4 OFDM based data communication

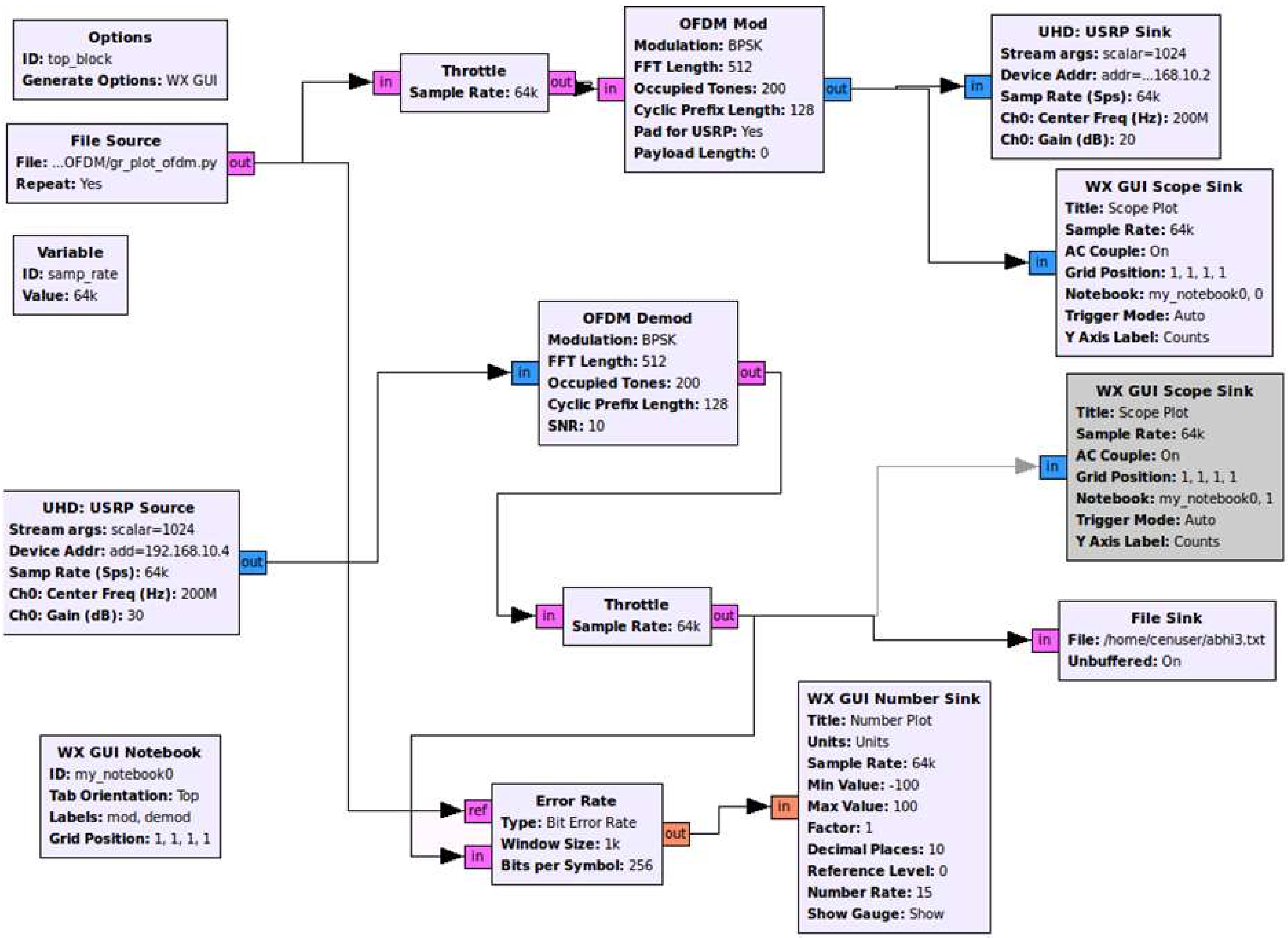




dial_tone.py

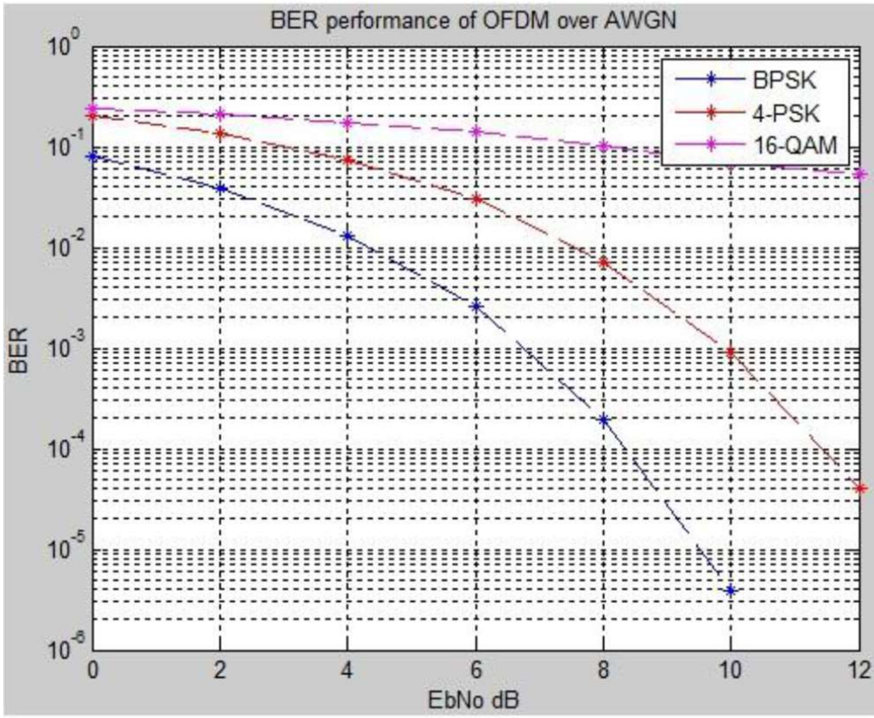
```
#
# You should have received a copy of the GNU General Public License
# along with GNU Radio; see the file COPYING.  If not, write to
# the Free Software Foundation, Inc., 51 Franklin Street,
# Boston, MA 02110-1301, USA.
#

from gnuradio import gr
from gnuradio import audio

class helloworld_block(gr.top_block):

    def __init__(self):
        gr.top_block.__init__(self)

        sample_rate = 32000
        ampl = 0.1

        src0 = gr.sig_source_f (sample_rate, gr.GR_SIN_WAVE, 350, ampl)
        src1 = gr.sig_source_f (sample_rate, gr.GR_SIN_WAVE, 440, ampl)

        adder = gr.add_ff()

        sink = audio.sink (sample_rate, options.audio_output)

        self.connect (src0, (adder, 0))
        self.connect (src1, (adder, 1))
        self.connect (adder, sink)

if __name__ == '__main__':
    try:
        helloworld_block().run()
    except KeyboardInterrupt:
```

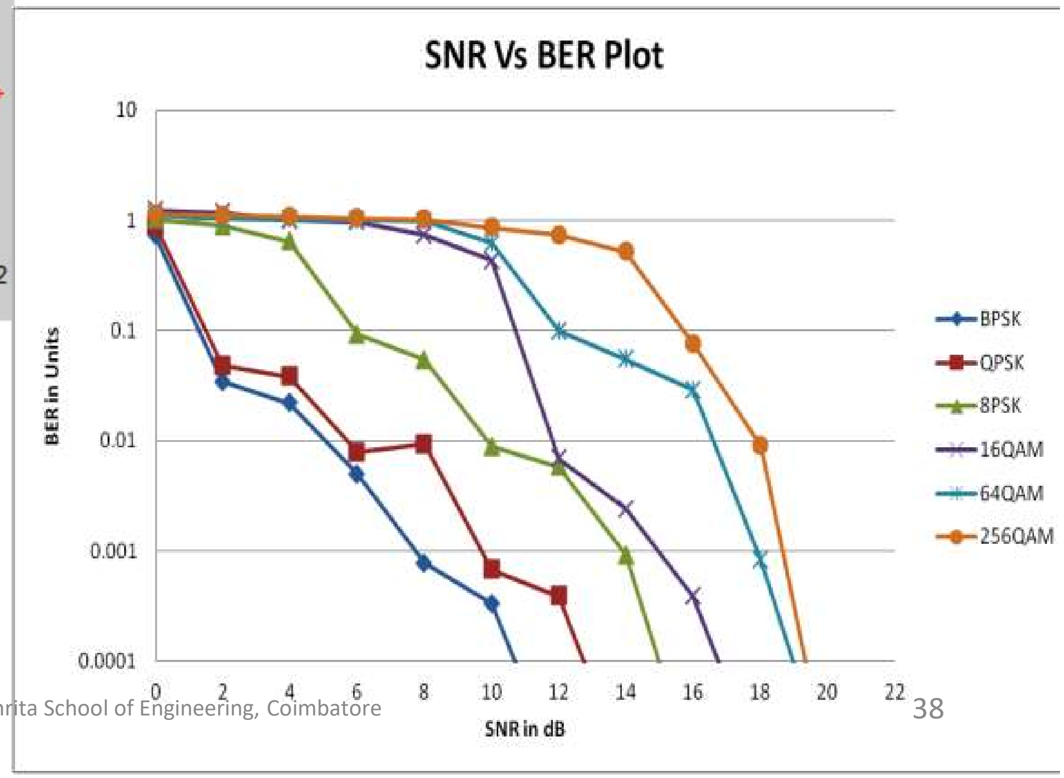
Performance analysis OFDM based comm. system



Setup

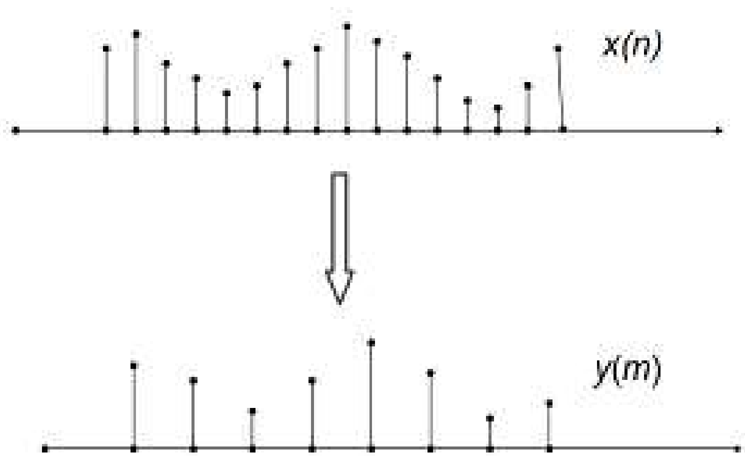
Simulation & Realtime



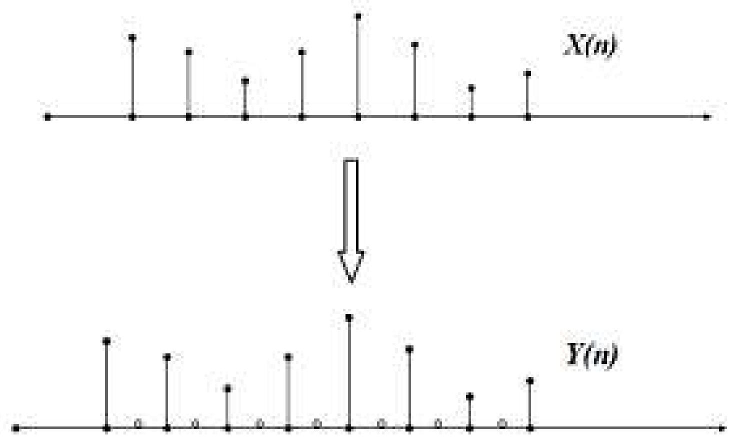


2.2 Multi rate signal processing by GNU Radio

- ***Study of Polyphase Structure Made Easy Using GNU Radio***

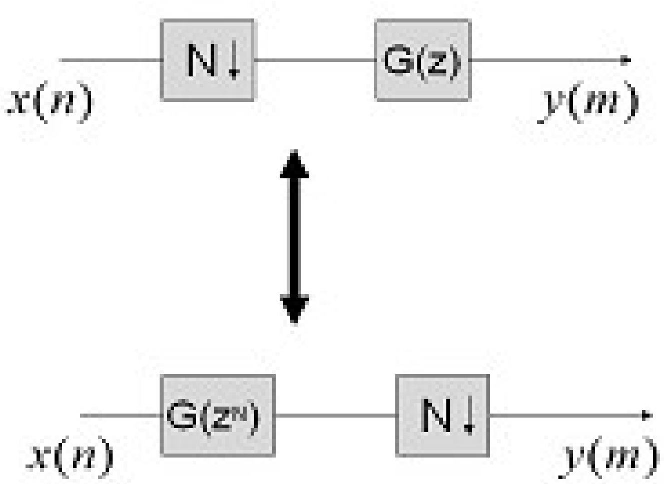


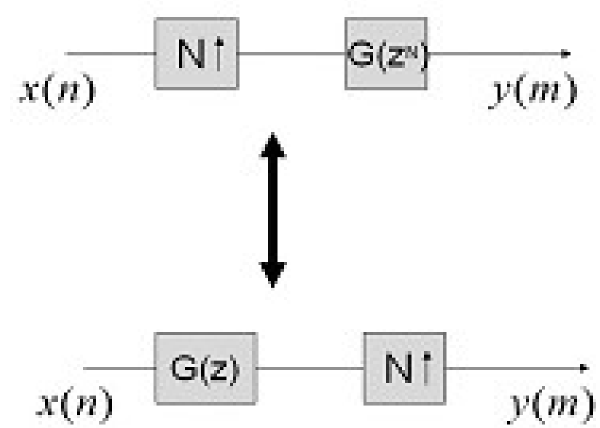
$$Y_L(n) = \begin{cases} x\left(\frac{n}{L}\right) & n = 0, \pm L, \pm 2L, \ldots \\ 0 & \text{otherwise} \end{cases}$$



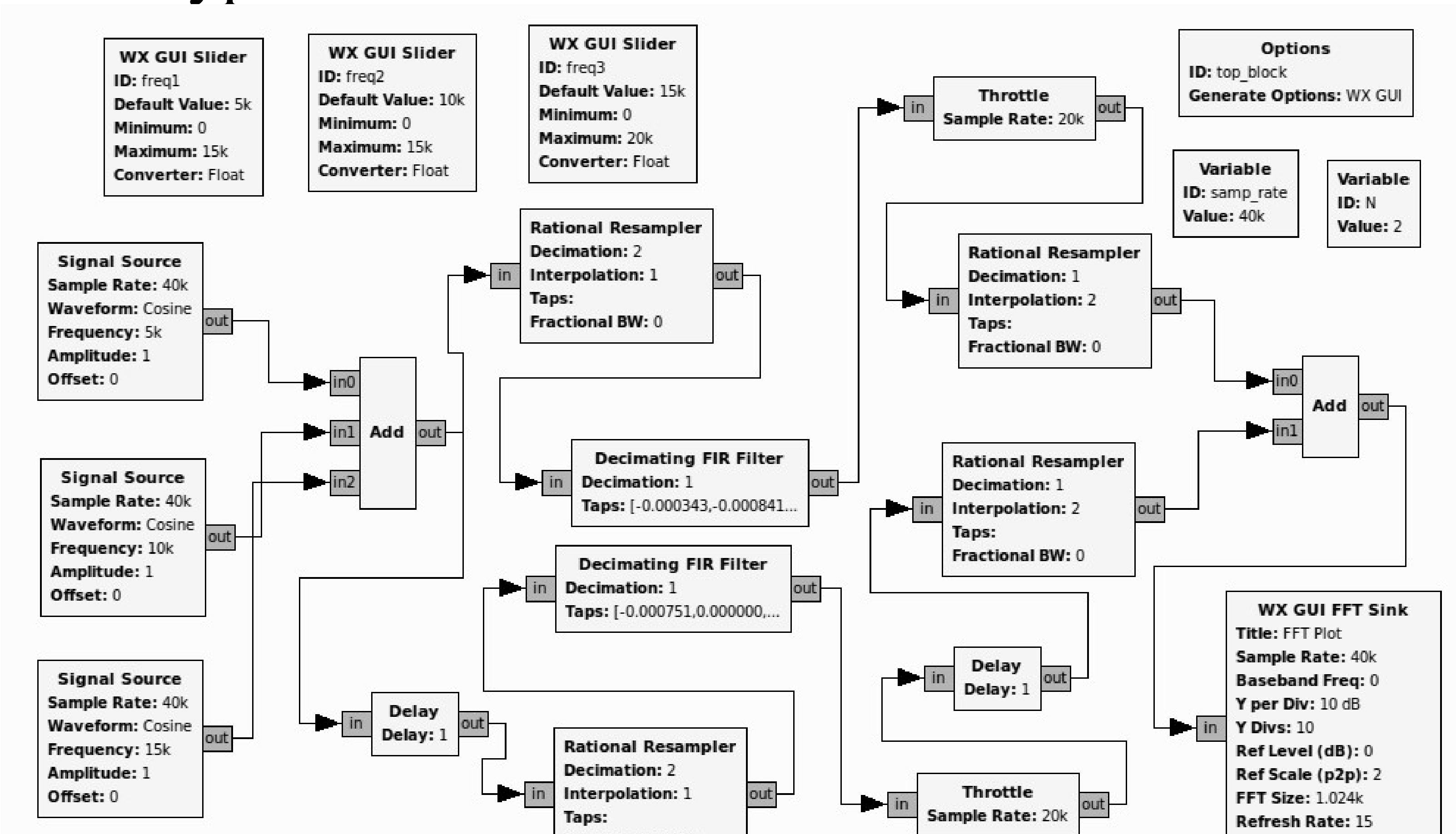
$$y_D(m) = \begin{cases} 1, \; for \;\; m = Dm, \; D \text{ is an integer} \\ 0, \; \text{otherwise} \end{cases}$$

- Noble Identities

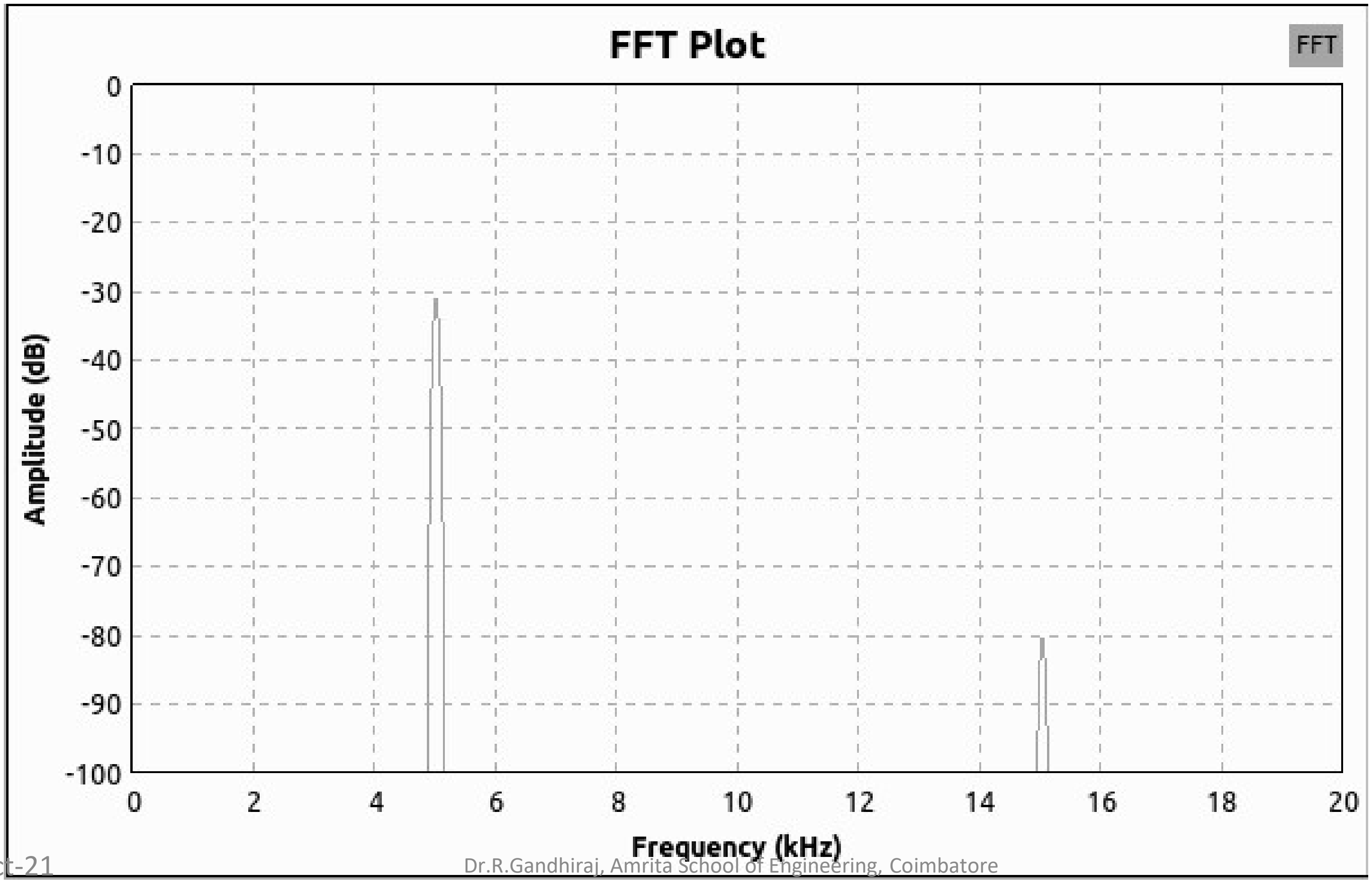




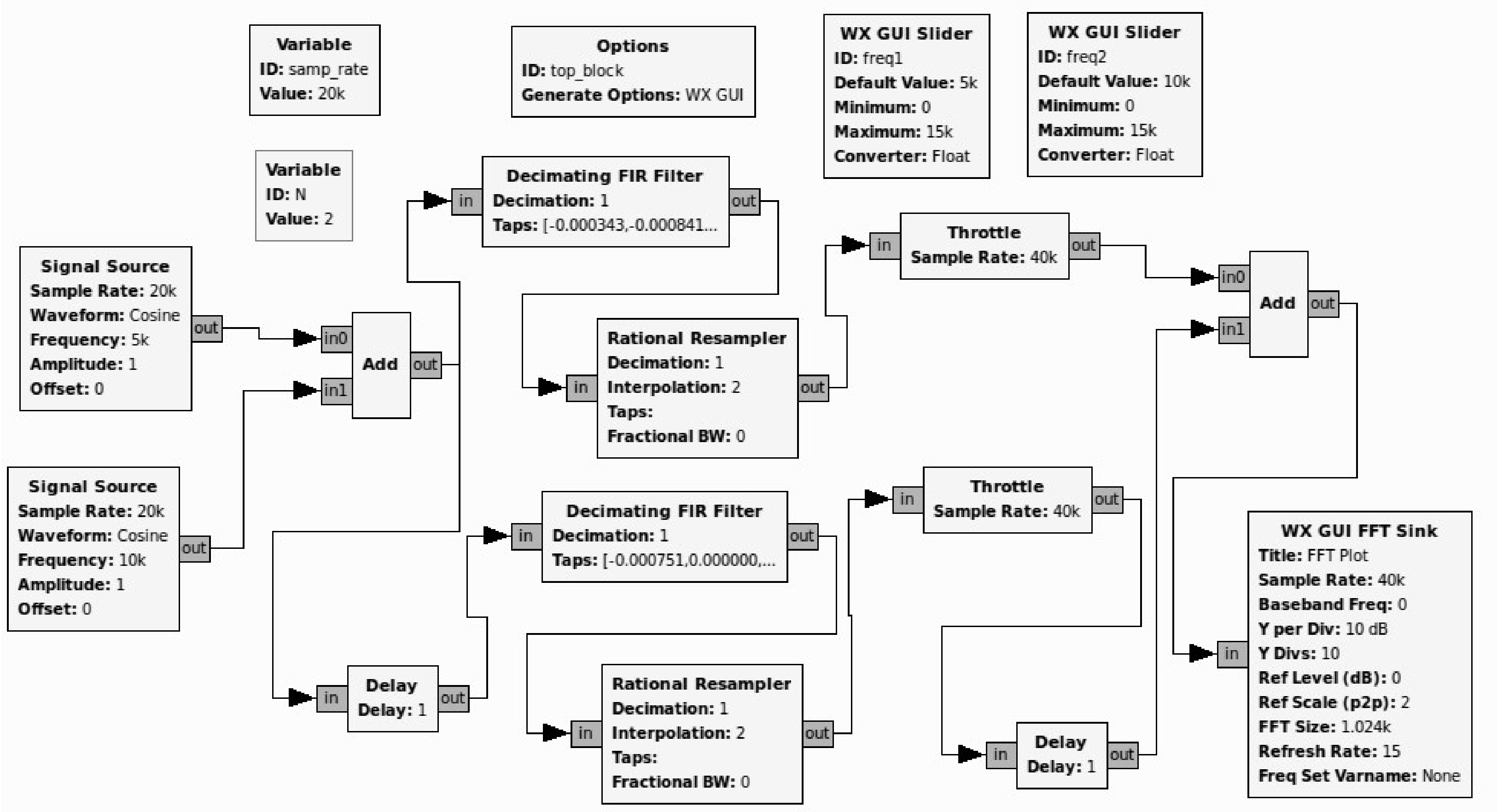
- Polyphase Decimator



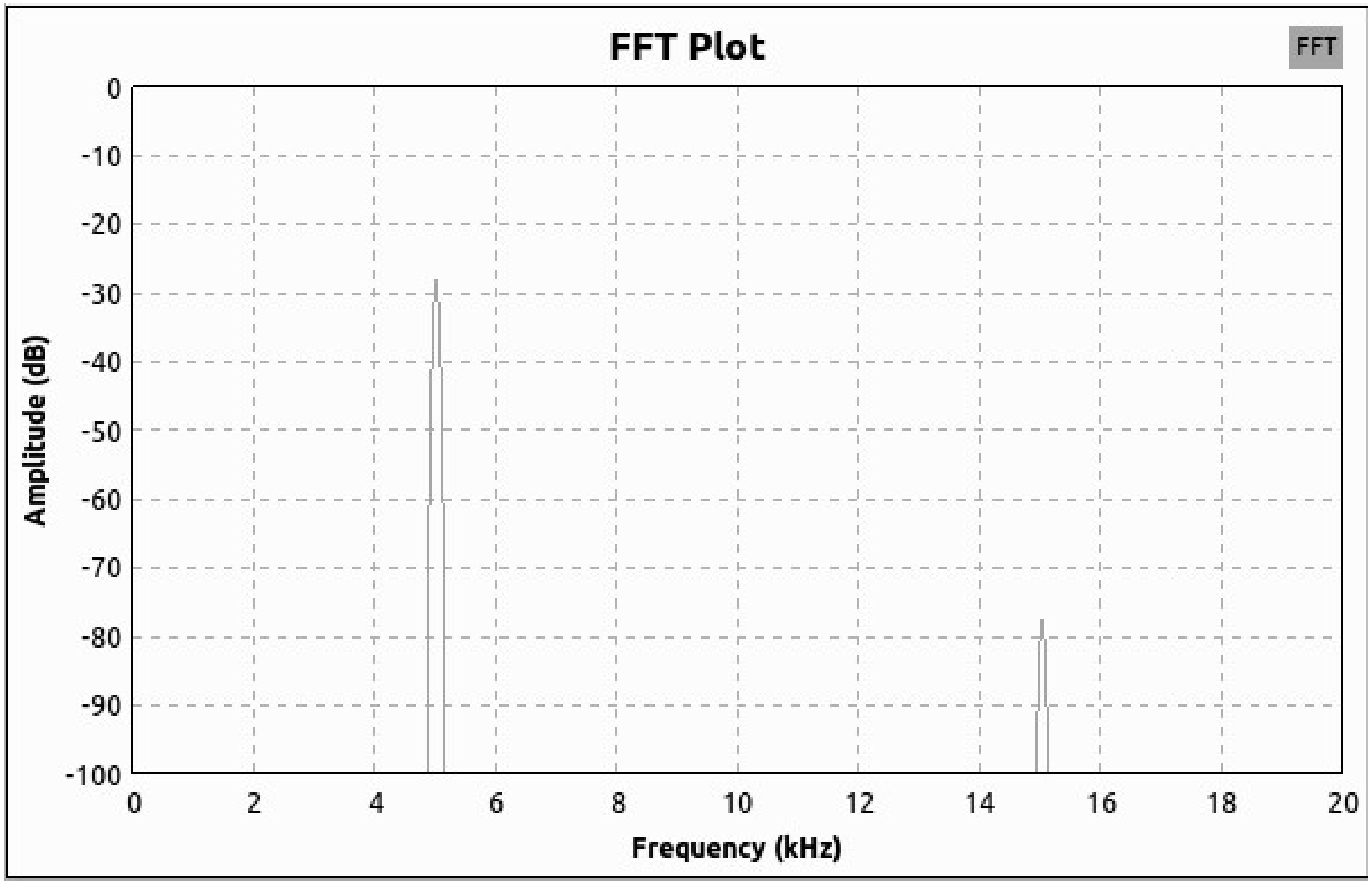
• Polyphase decimator output



- Poly phase Interpolator

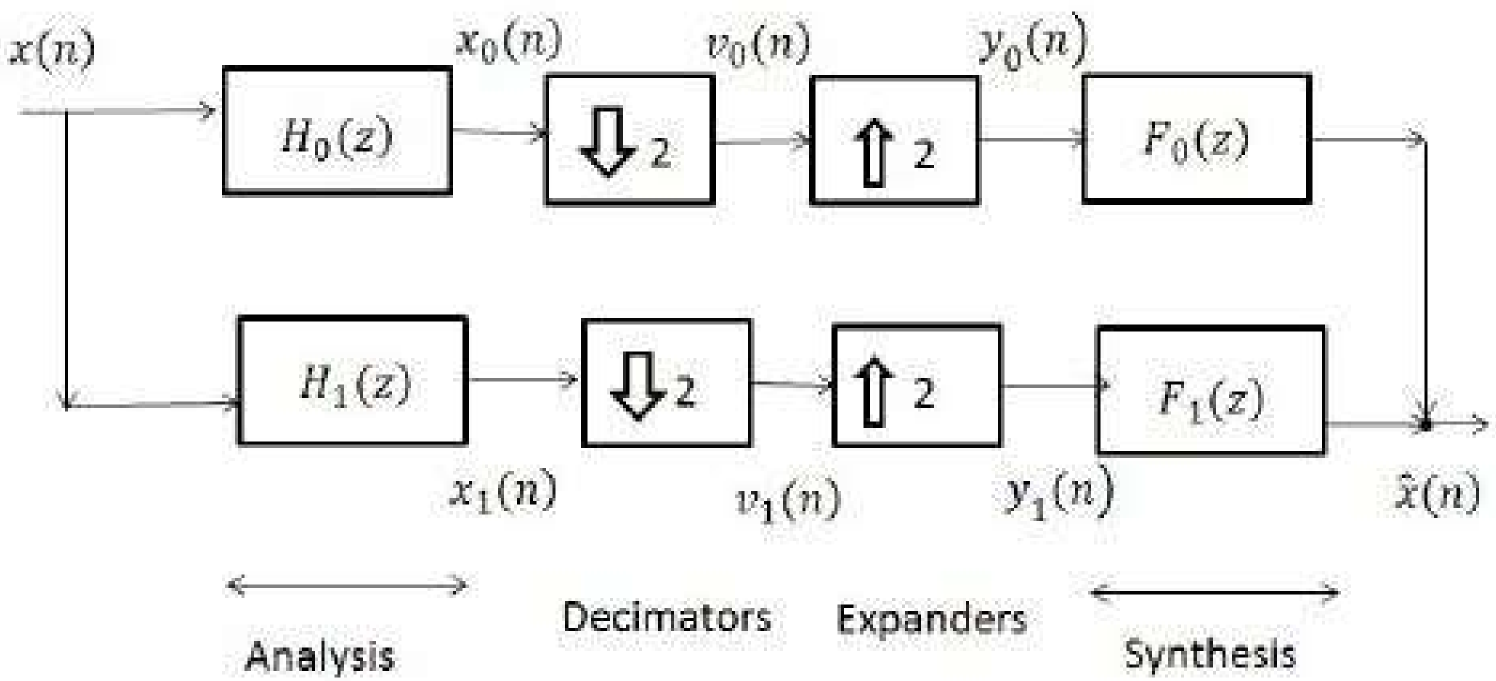


- Poly phase Interpolator output

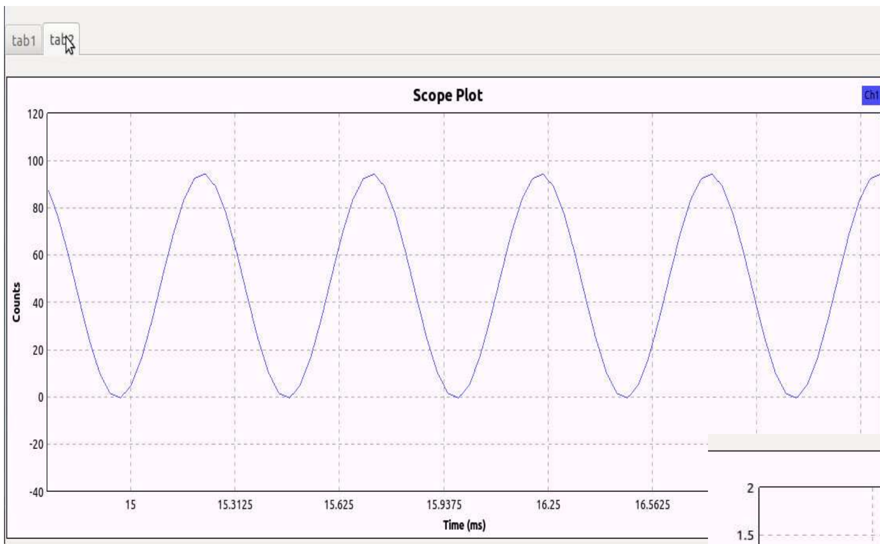


Study of Multirate system

- Quadrature Mirror Filter

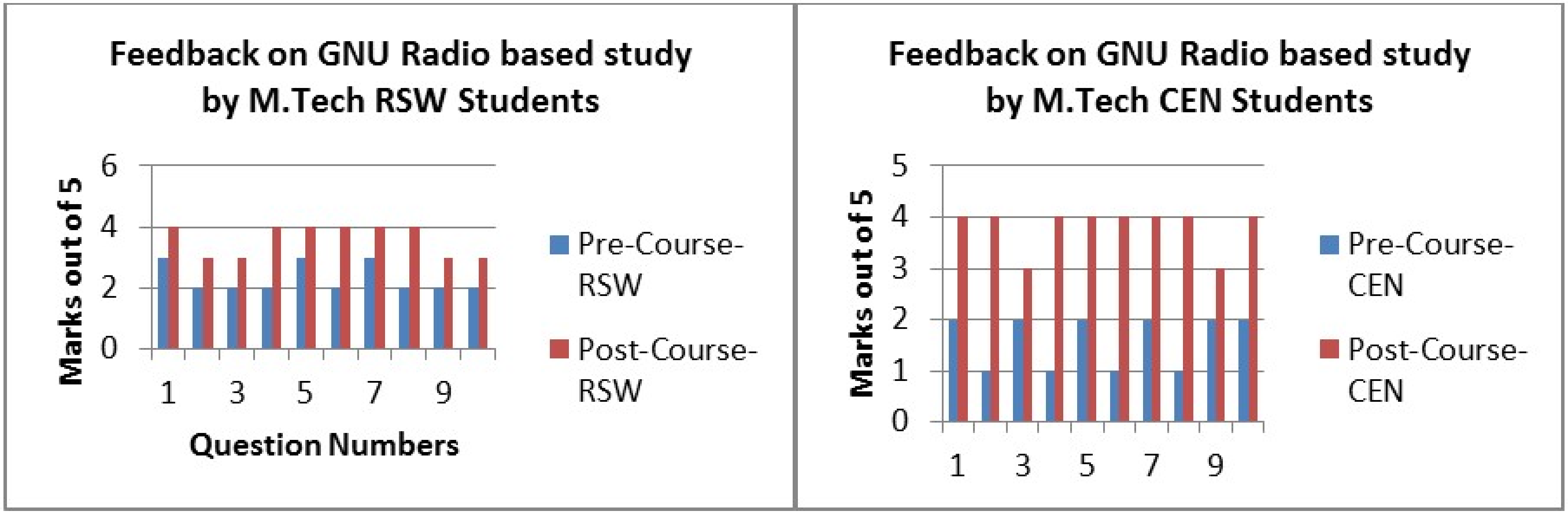


- Alias Free QMF output & Elimination of Amplitude distortion



Outcome of Paradigm Shift in Pedagogy of Communication and Signal Processing

- ***Student's feedback on GNU Radio based learning***



Events Organised

First of its kind in India to the mass

National Level Workshops organised for academicians and researchers

- "Sixth National workshop on Software Defined Radio and its Strategic Applications", on 21-22, January 2016, Amrita School of Engineering, Coimbatore. Web link: https://www.amrita.edu/site/sdrws/
- "Fifth National Workshop on Software Defined Radio (SDR) for Real-time Communication and Signal Processing" as part of ANOKHA 2014, Amrita School of Engineering, Coimbatore. Web Link: http://anokha.amrita.edu/workshop/?eName=Software%20Defined%20Radio
- "Fourth National Workshop on Software Defined Radio (SDR) for Realtime Communication and Signal Processing", 27 Feb 2014, at Amrita Viswha Vidyapeetham, Coimbatore. Web Link: http://www.amrita.edu/rtcsp/workshop.html
- "Third National Workshop on Software Defined Radio (SDR) for Realtime Communication and Signal Processing", 26-28 July 2013, at Amrita Viswha Vidyapeetham, Coimbatore. Web Link: http://nlp.amrita.edu:8080/SDR4U
- Second National Workshop on Software Defined Radio (SDR) for Realtime Communication and Signal Processing", 11 August 2012, orgnaised at Rajagiri School of Engineering and Technology, Cochin, Kerala. Web Link: http://acc-rajagiri.org/acc2012/SDR.asp
- "First National Workshop on Software Defined Radio (SDR) for Realtime Communication and Signal Processing", Supported by MHRD under NMEICT Scheme, March 17 -18, 2012, at Amrita Vishwa Vidyapeetham, Coimbatore. Web Link: http://nlp.amrita.edu:8080/sdr/index.html.

Part II

Paradigm Shift in Communication and Signal processing Research

3.1 Economical Test bed for Communication & signal processing research and study

3.1.1 Exploiting GNU Radio and USRP: An Economical Test Bed for Real Time Comm. Systems

- Existing Lab setup

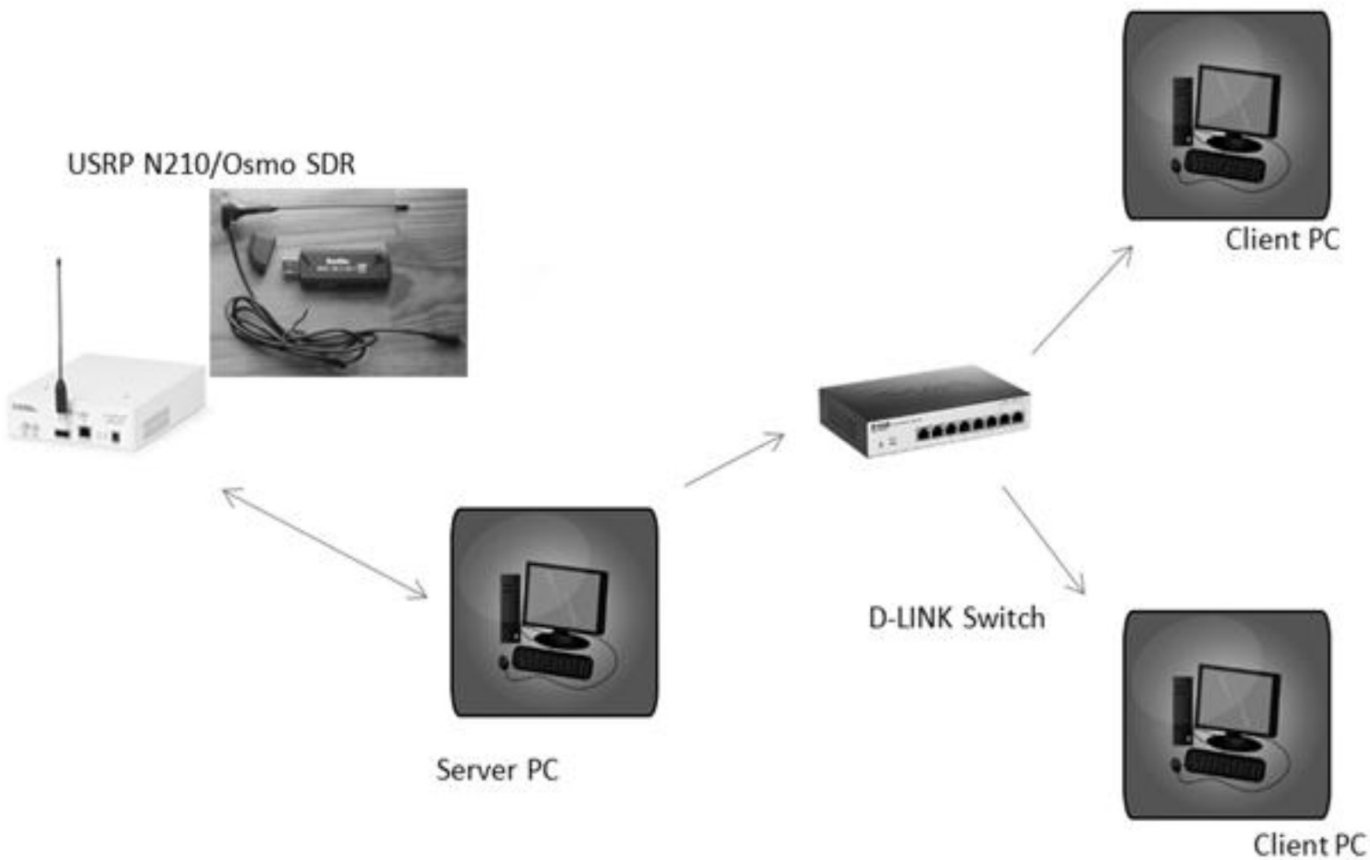
Experiments Name	Components required	Cost (Approx) in USD
SSB-Mod and Demod, DSB-SC Mod and Demod, ASK Mod and Demod, FSK Mod and Demod	Function Generator (Scientific) ($ 160 x15)	2,400
	Cathode Ray Oscilloscope (Scientific) ($ 302 x15)	4,530
	Power supply (Aplab, Mighty) ($ 89 x 15)	1,335
	Digital Storage Oscilloscope (textronics, Goodwill) ($ 853 x 15)	12,795
	Spectrum Analyzer (Megatech) ($ 1724 x 7) (One spectrum analyzer per 2 working table)	12,068
	Total Cost (for 15 working table)	33,128

3.1.1 Exploiting GNU Radio and USRP: An Economical Test Bed for Real Time Comm. Systems

- Proposed Lab setup

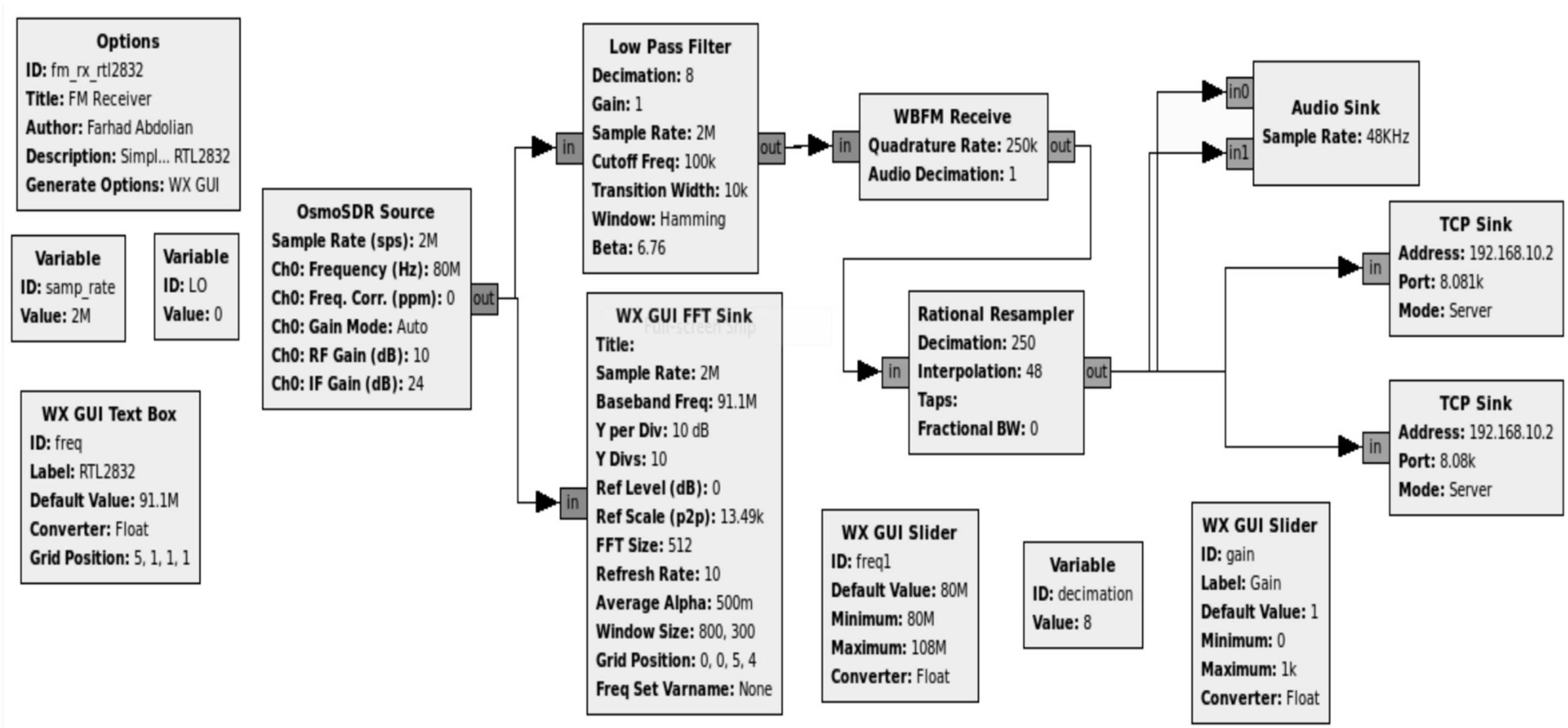
Experiments Name	Components required	Cost (Approx) in USD
SSB-Mod and Demod, DSB-SC Mod and Demod, ASK Mod and Demod, FSK Mod and Demod, GSM Base Transceiver System (Open BTS), MIMO Experiments, WiFi Localization, OFDM Experiments, Zigbee Protocol Implementation, BlueTooth Protocol Implementation	GRC	Open Source
	PC ($ 355 x 15)	355
	USRP ($ 1510 x 1)	1510
	RTL-SDR ($ 10 x 15)	150
	D-LINK Giga bit Ethernet Switch (16 port)	80
	Total Cost	2095

3.1.2 Simultaneous Access of RF front end from more clients using GNU Radio



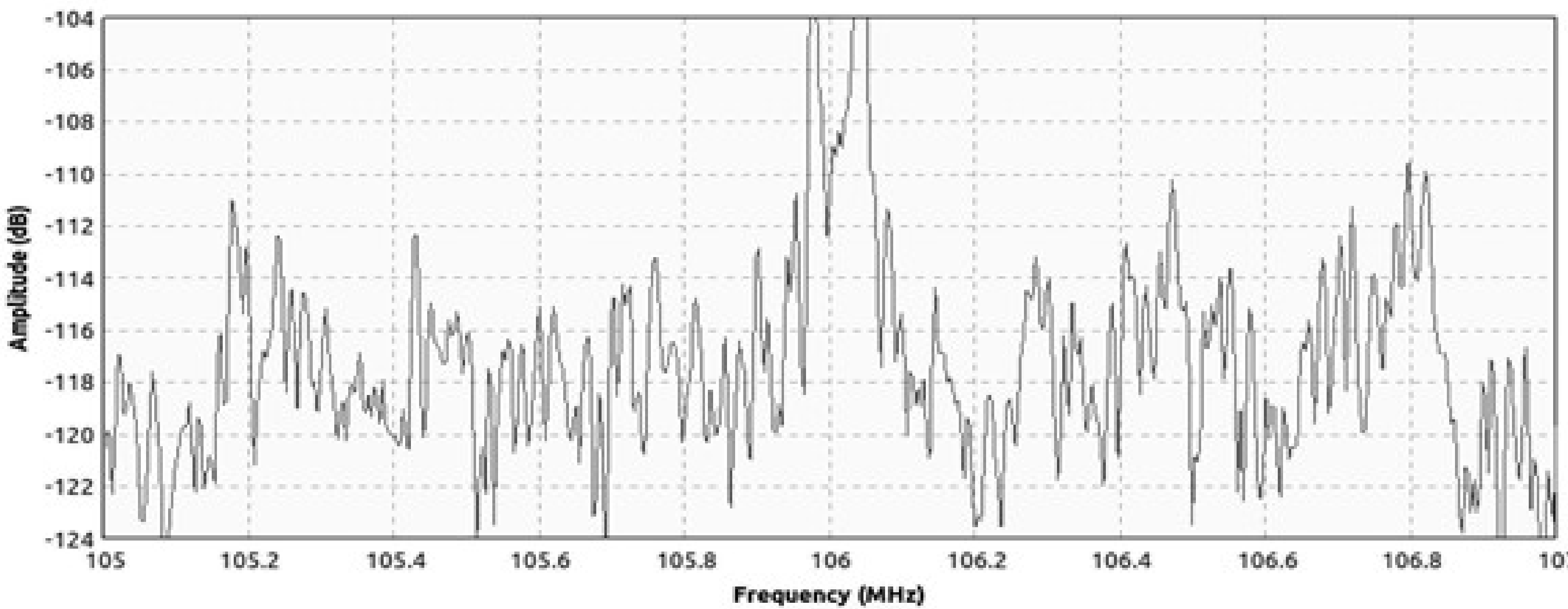
3.1.2 Simultaneous Access of RF front end from more clients using GNU Radio

- Block for receiving FM signal in server with TCP block (Make it available at Port 8080, 8081 and expandable to many ports simultaneously)



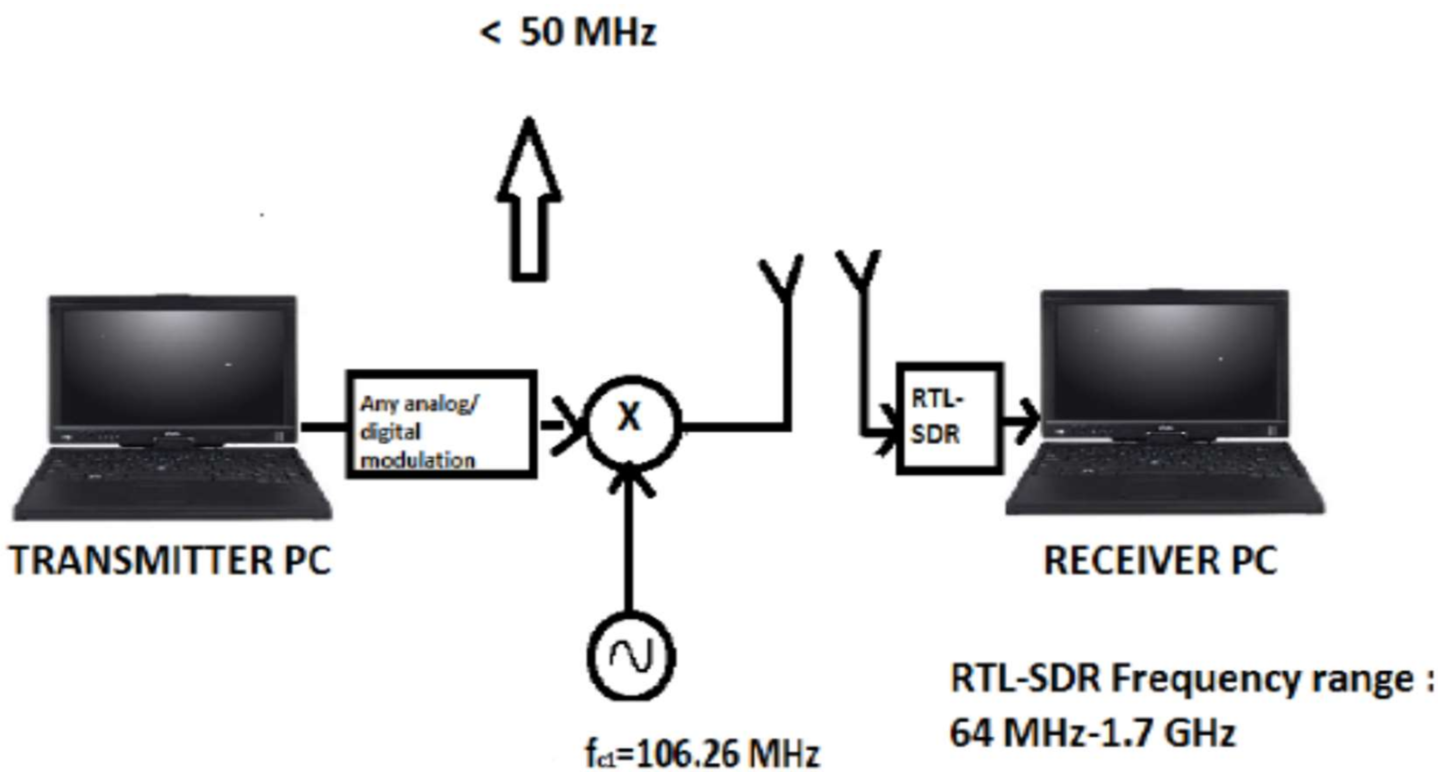
3.1.2 Simultaneous Access of RF front end from more clients using GNU Radio

- Frequency Spectrum of received Signal in server



3.1.3 Low cost digital transceiver design for SDR using RTL-SDR

- Proposed Functional block



3.1.3 Low cost digital transceiver design for SDR using RTL-SDR

- Overall System Design

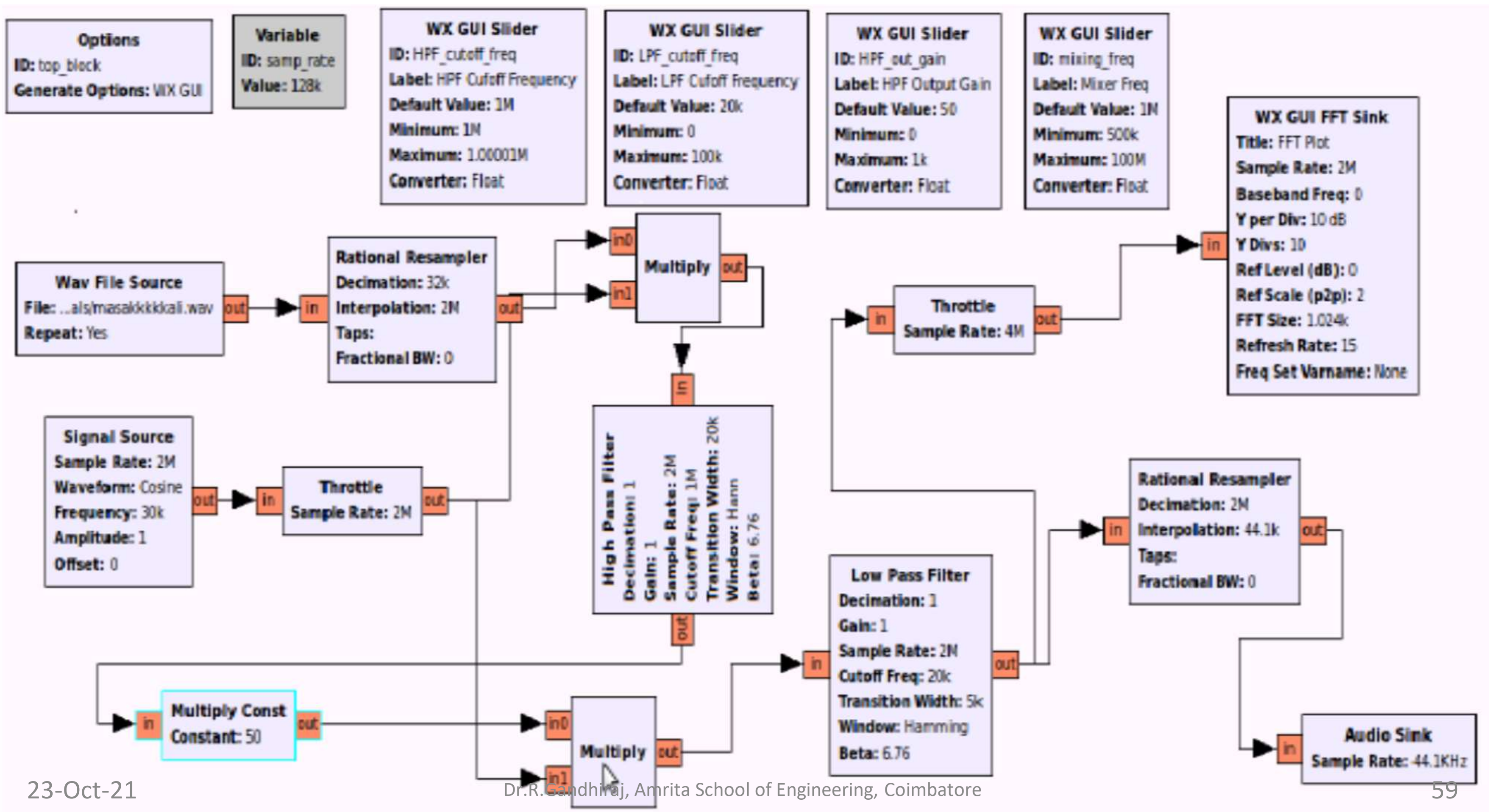
- Transmitting analog /digital signal using mixer and reception using RTL SDR with GNU radio frame work

3.1.3 Low cost digital transceiver design for SDR using RTL-SDR

- Real time experimental setup

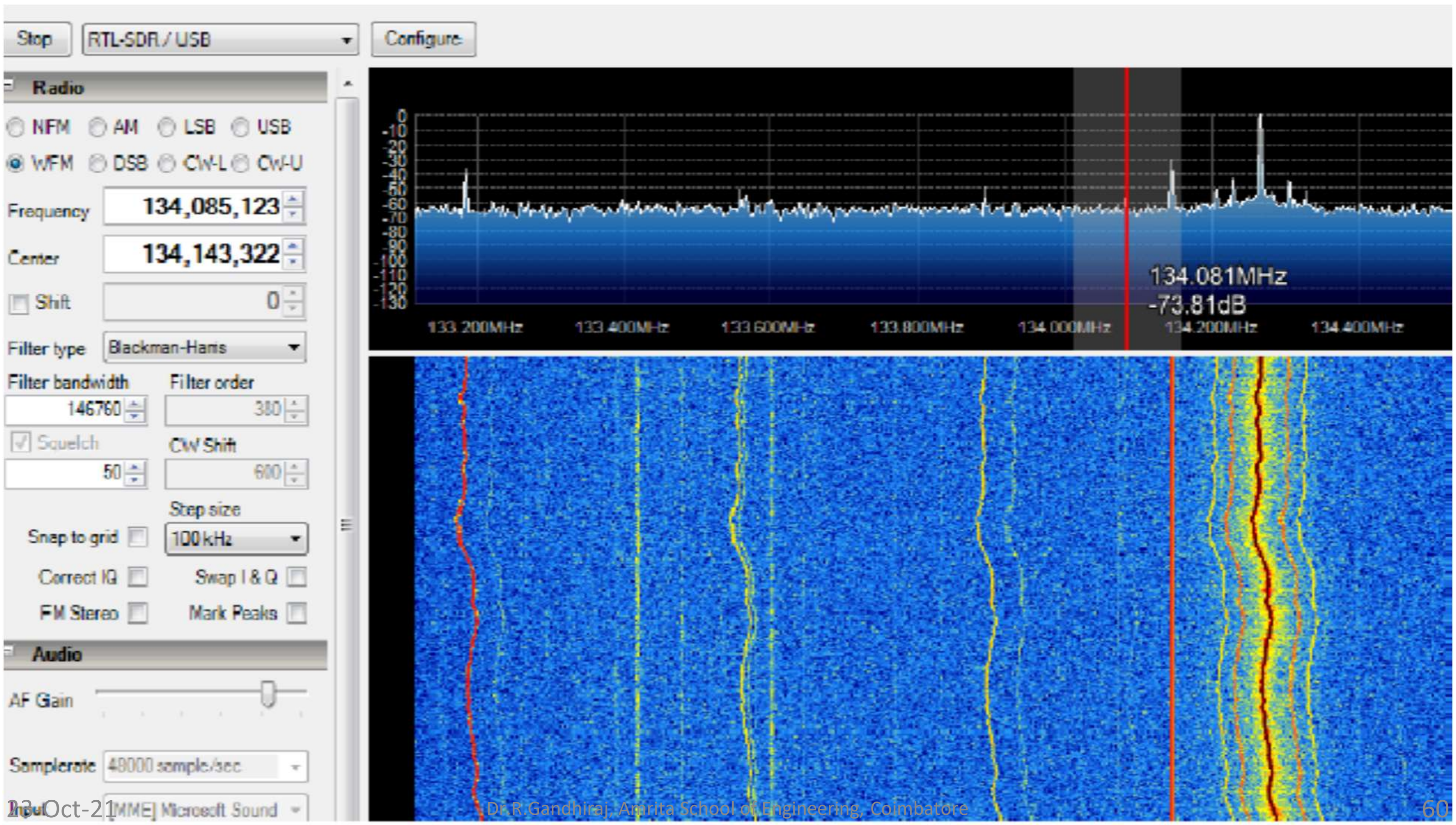
3.1.3 Low cost digital transceiver design for SDR using RTL-SDR

- GNU Radio blocks



3.1.3 Low cost digital transceiver design for SDR using RTL-SDR

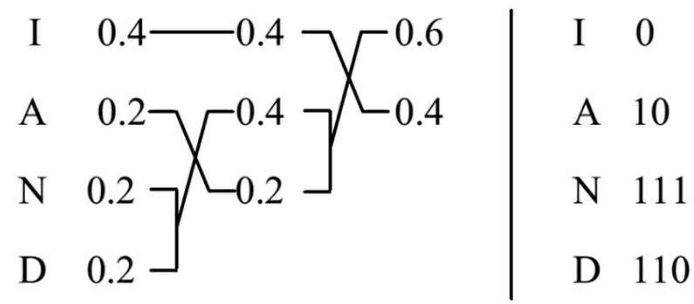
- Output Spectrogram using SDR#



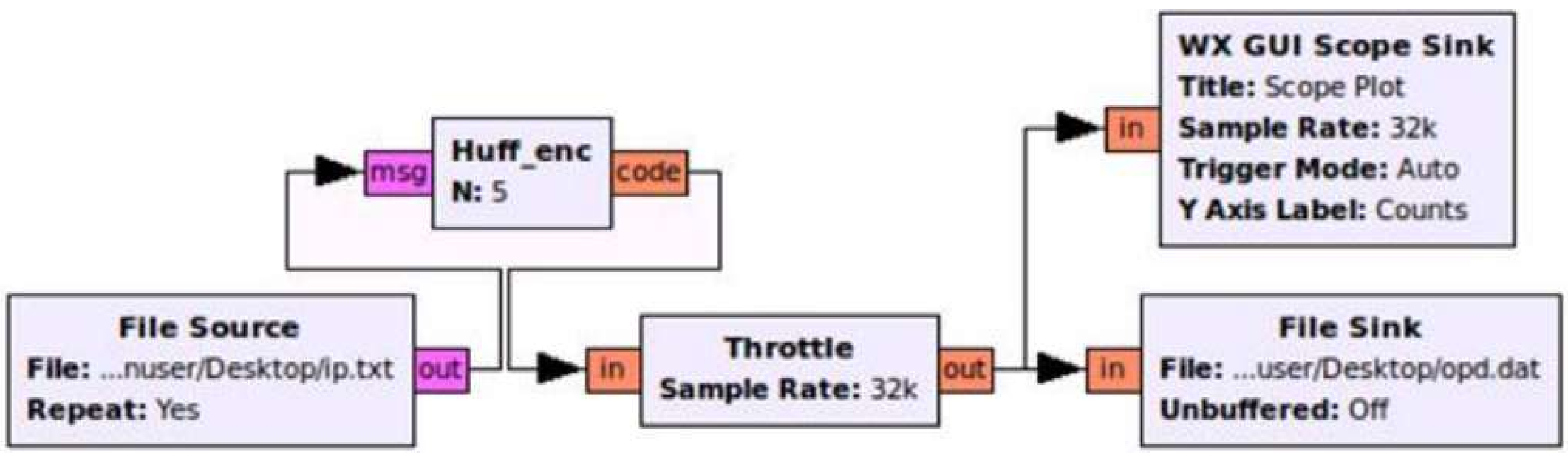
3.2 Customizing the research sub systems
- Block creation using C++ & Python

3.2.1 Plug-ins for GNU Radio Companion

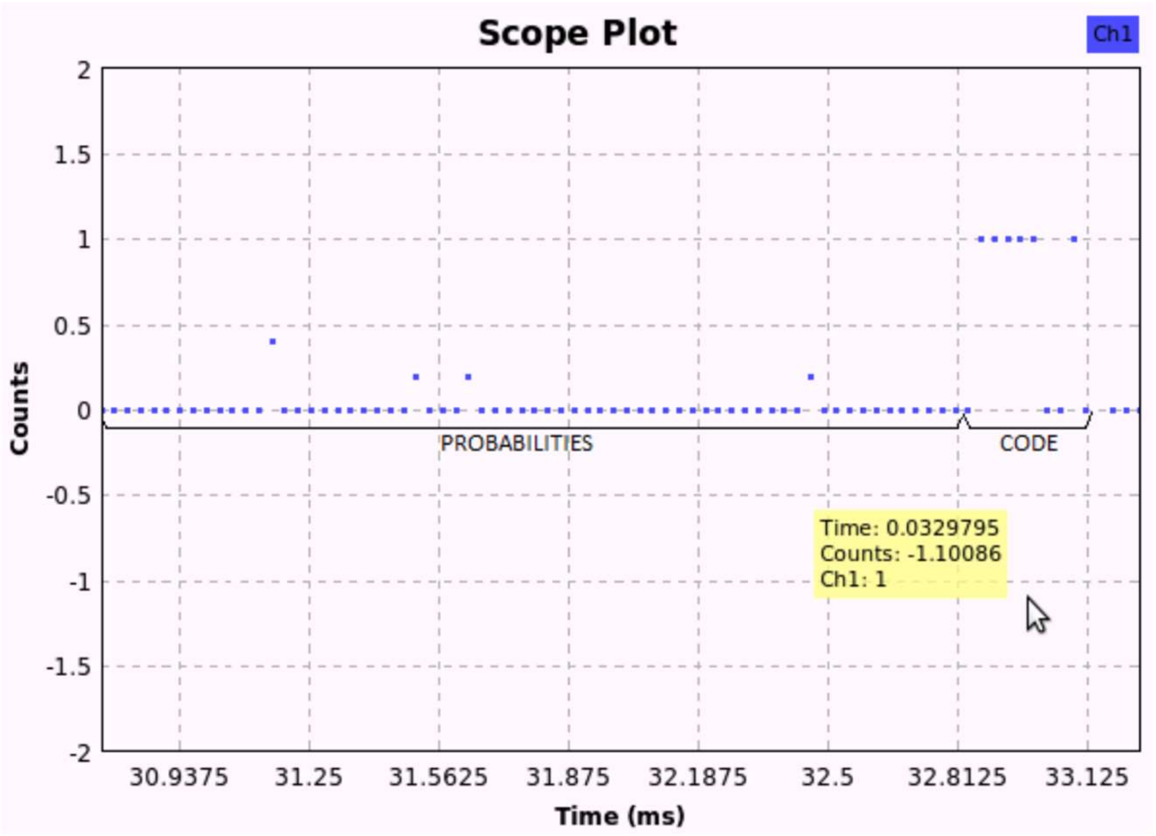
- Huffman Coding



- GRC implementation

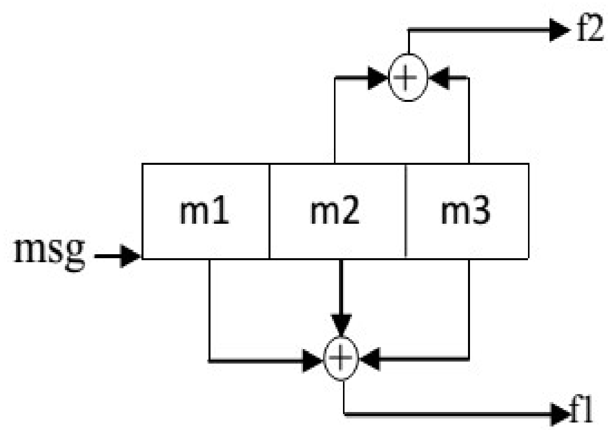


- 5.1.1 dot diagram showing Huffman Coder output for *INDIA* as input

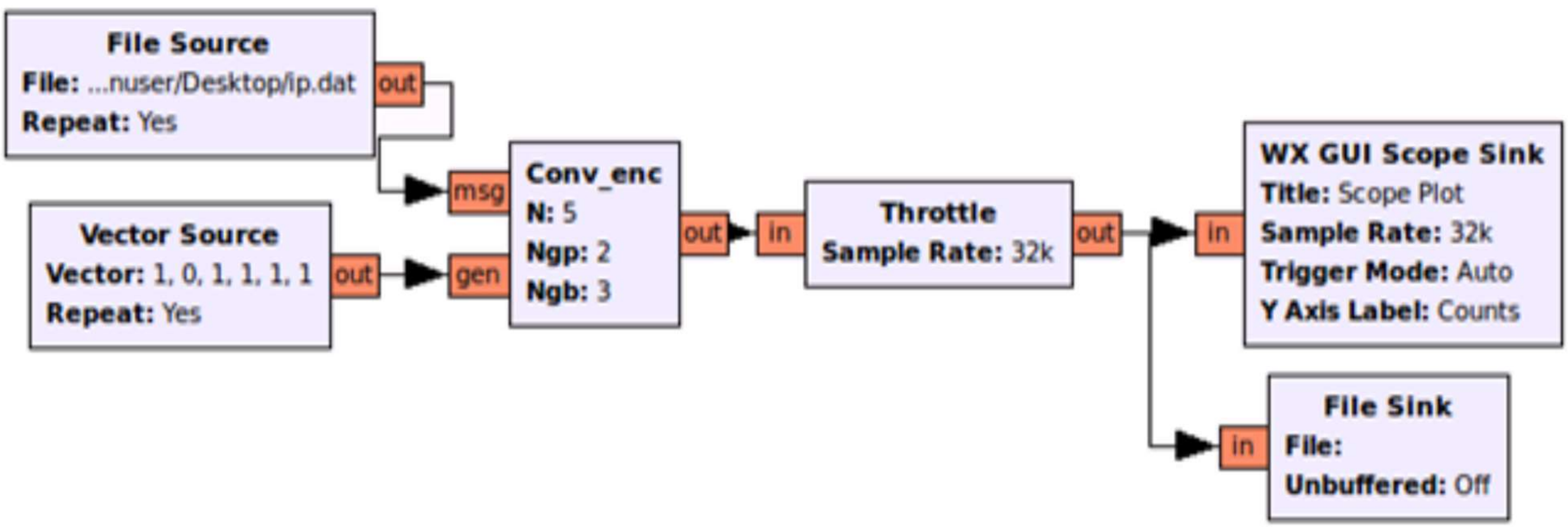


3.2.1 Plug-ins for GNU Radio Companion

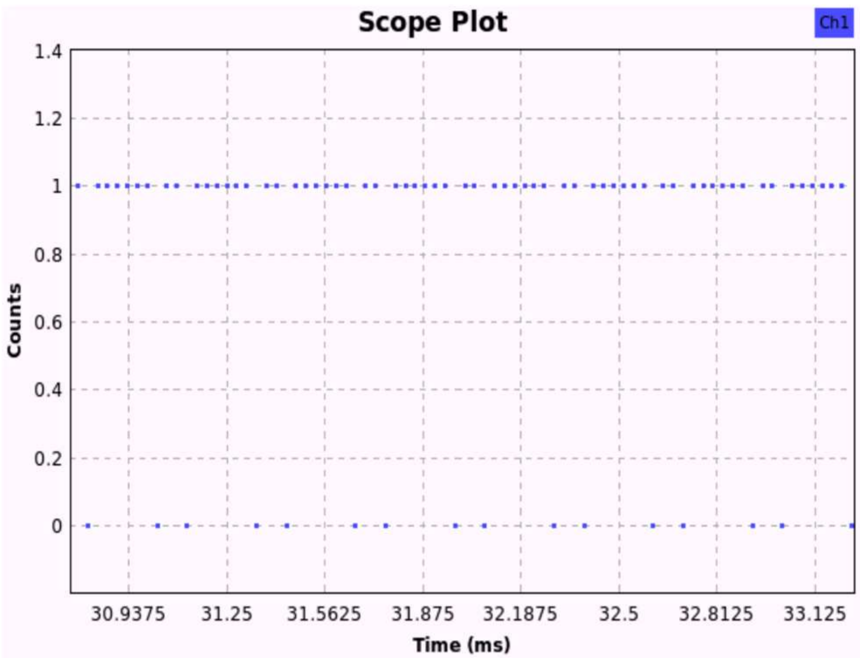
- Convolutional Code

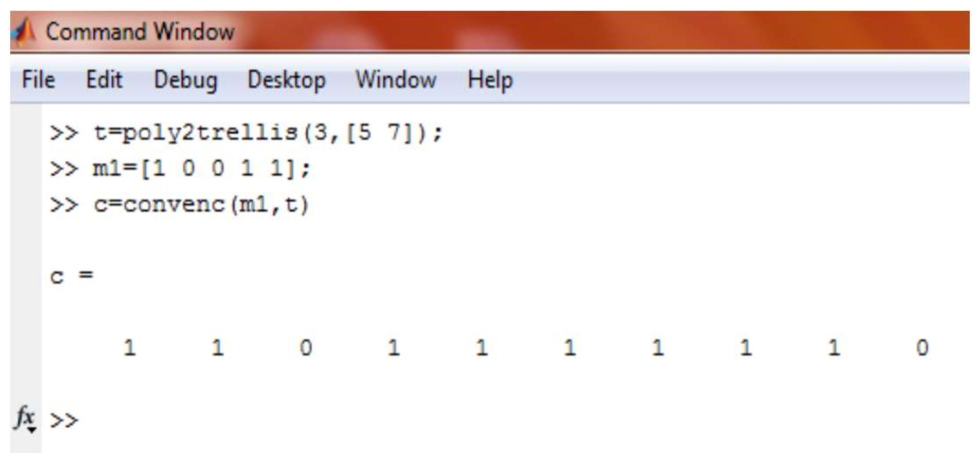


- GRC implementation



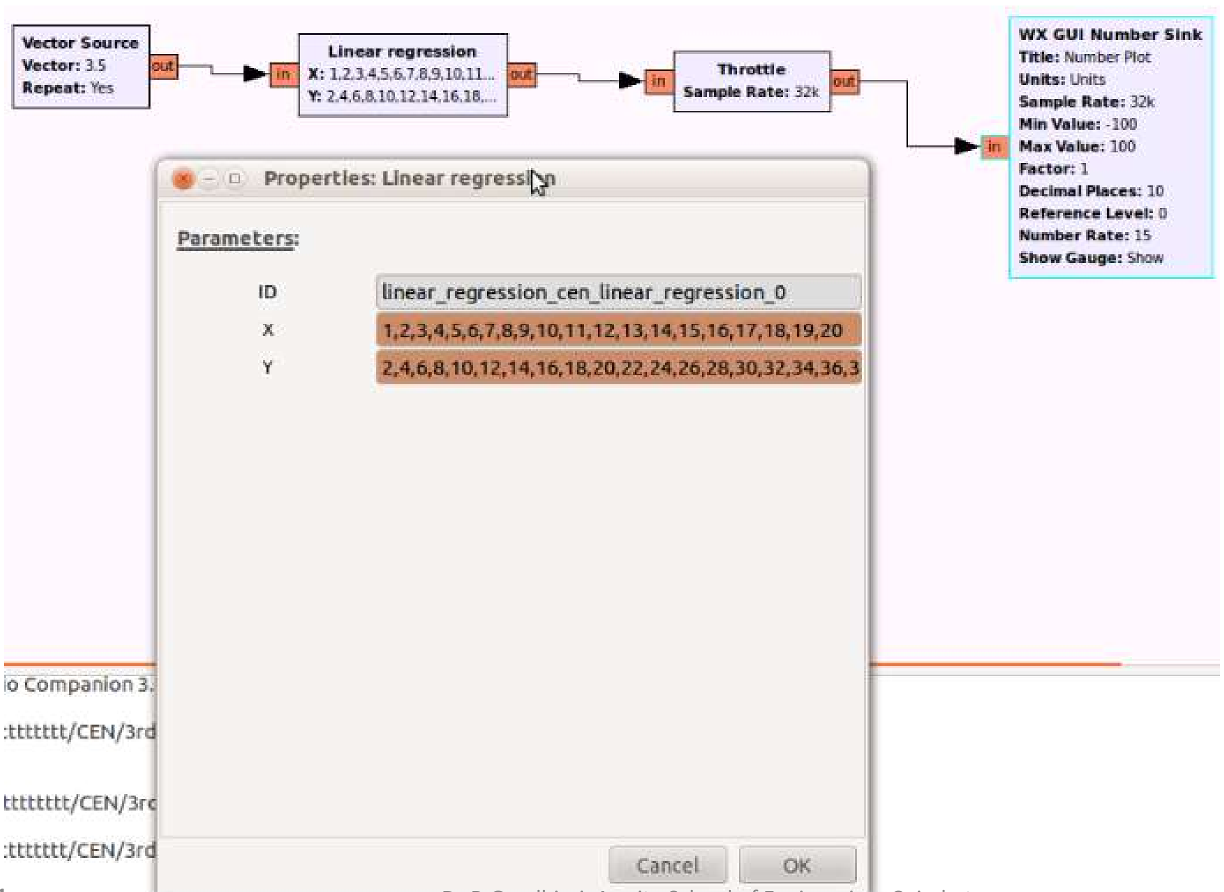
- Convolutional Code output result comparison using MatLab





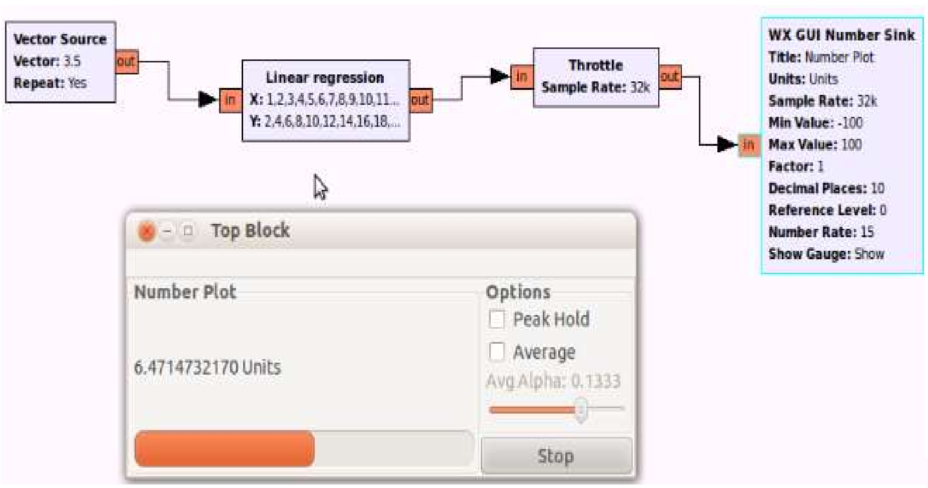
3.2.2 Machine Learning Plug-ins for GNU Radio Companion

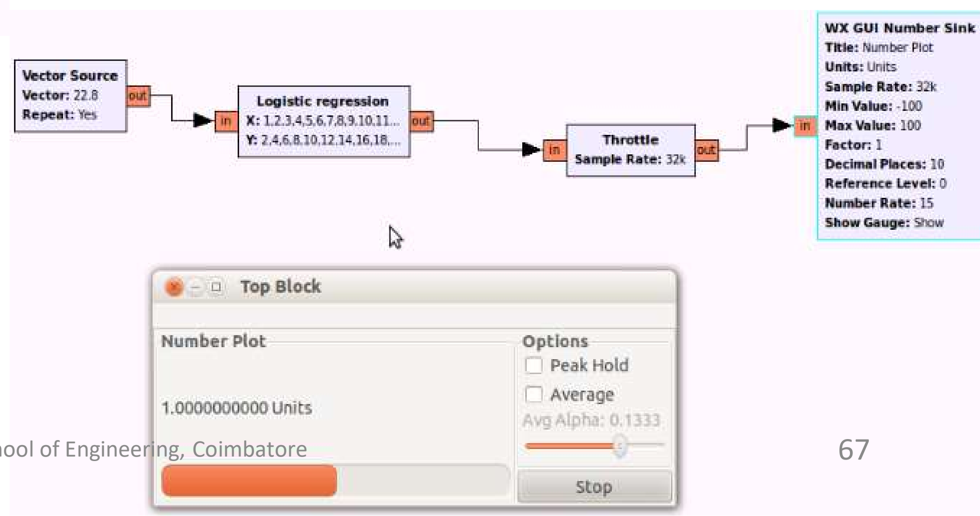
- Linear regression : Training



3.2.2 Machine Learning Plug-ins for GNU Radio Companion

- Linear & logistic regression Results



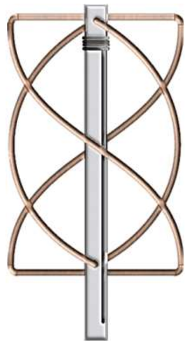


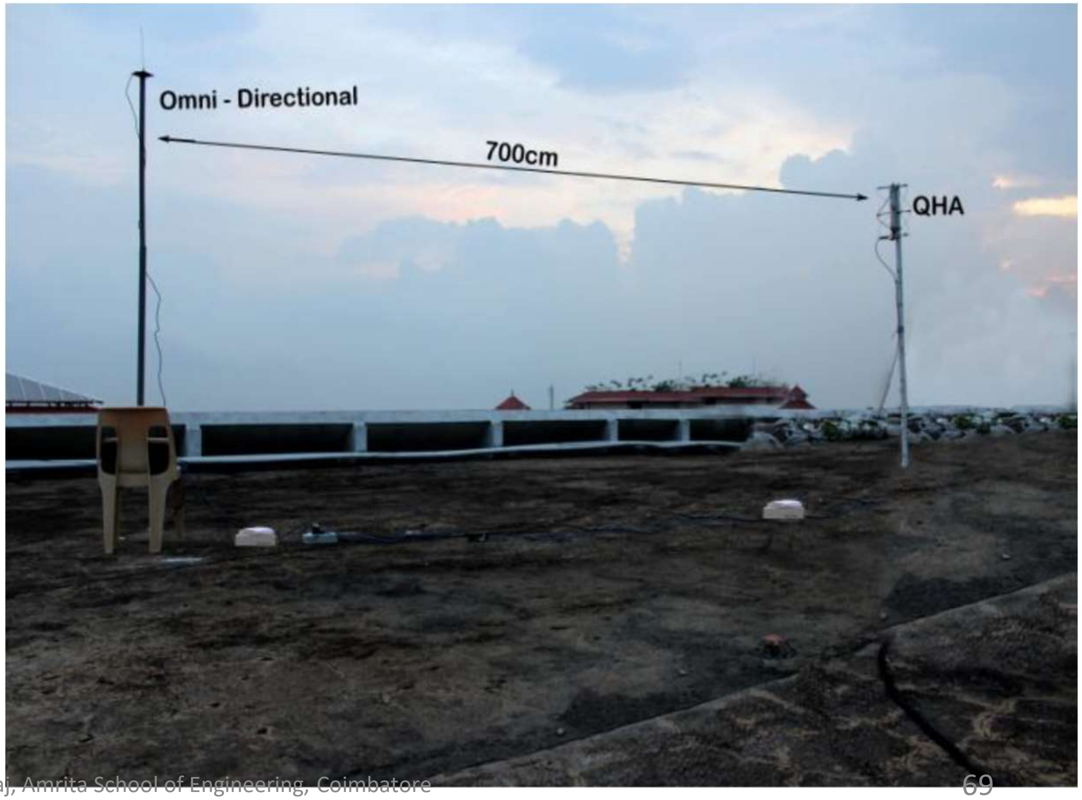
3.3. Radiation Measurement of Antennas

- 3.3.1 QHA (Quadrifilar Helical Antenna)
- 3.3.2 LPA (Log periodical antenna)
- 3.3.3 Yagi-Uda
- 3.3.4 Microstrip
- 3.3.5 CAN antenna V1 & V2

3.3.1 Radiation pattern measurement of Quadrifilar Helix Antenna (QHA)

- QHA Antenna & its parameters :: Setup
- Freq. Range : 128 – 148 MHz

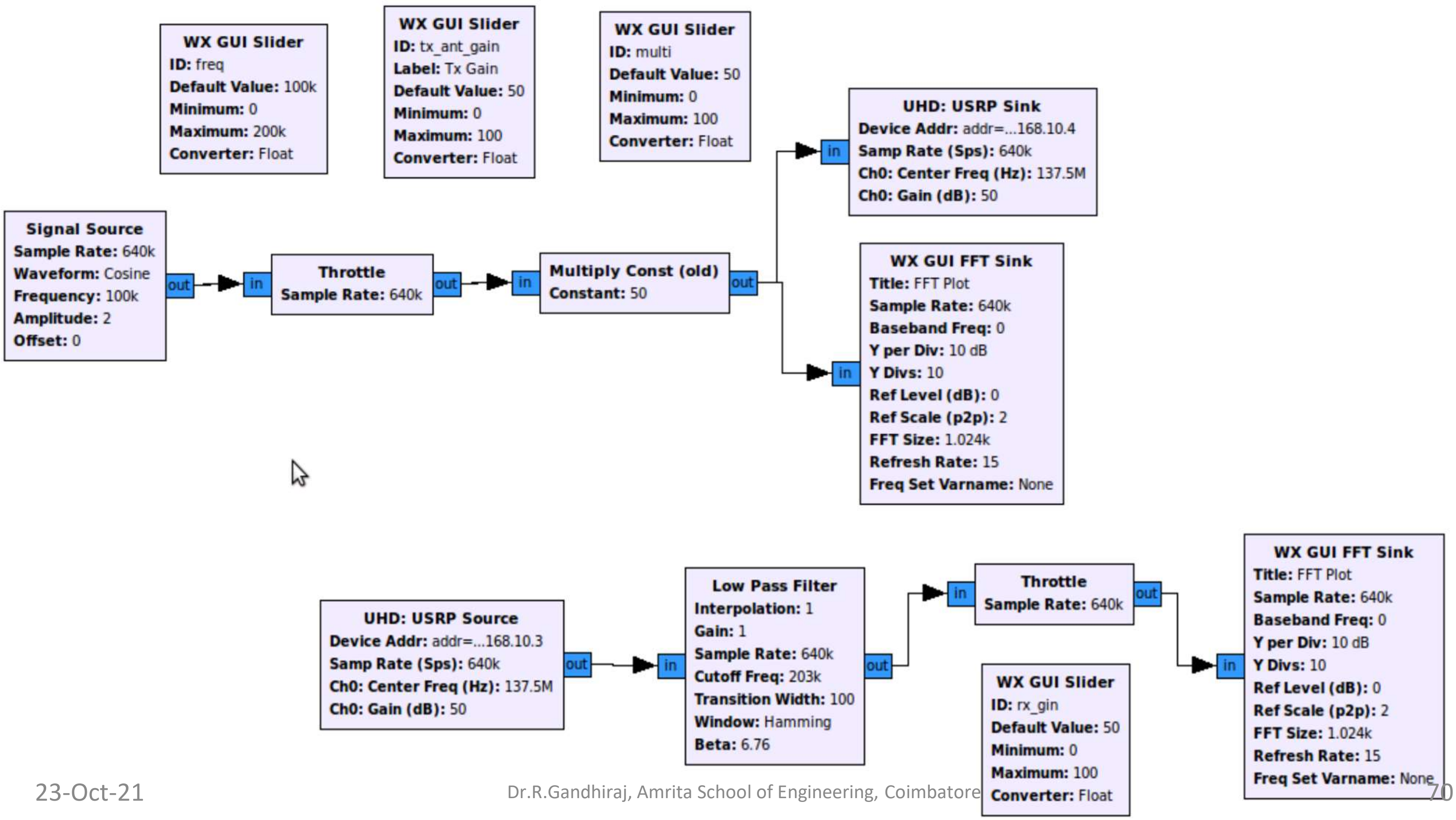




	Height(mm)	Diameter(mm)
Small Loop	527	347
Big loop	557	367

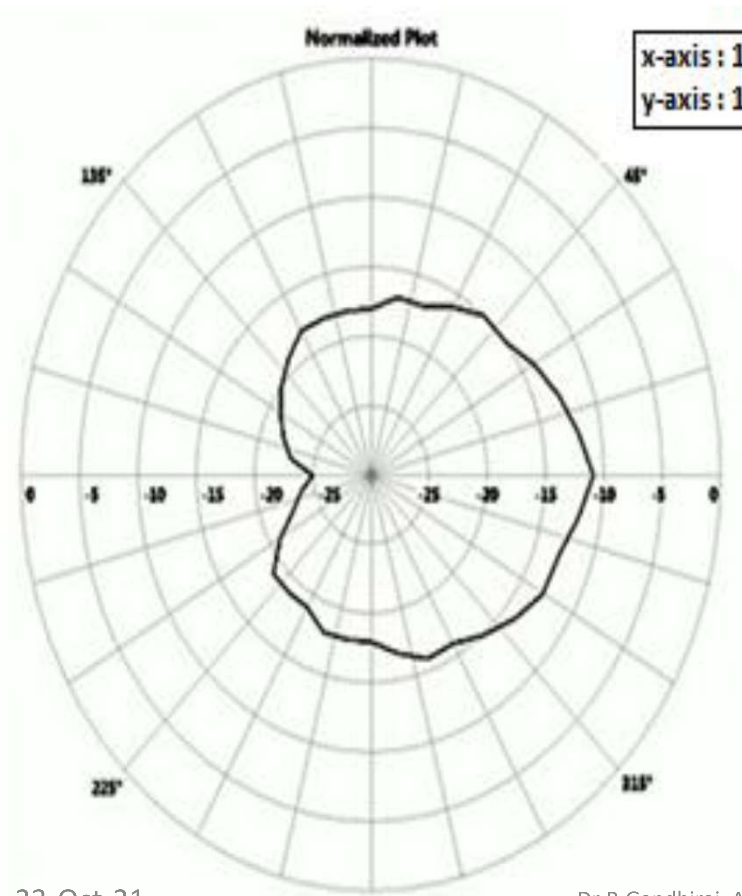
3.3.1 Radiation pattern measurement of Quadrifilar Helix Antenna (QHA)

- Experimental setup Transmission & receiver blocks



3.3.1 Radiation pattern measurement of Quadrifilar Helix Antenna (QHA)

- Radiation pattern and parameter estimation

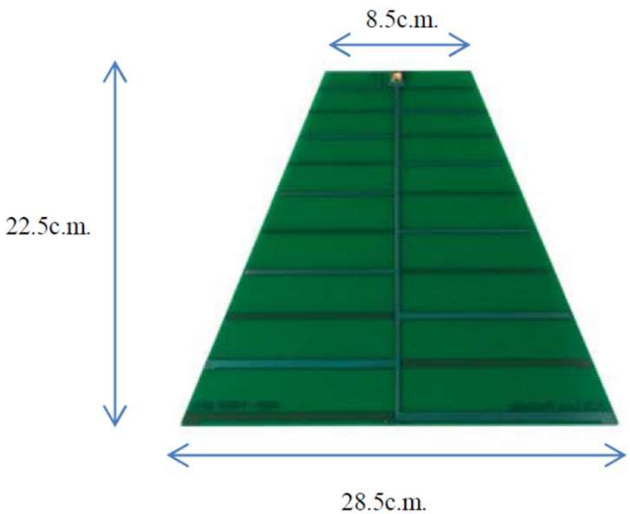


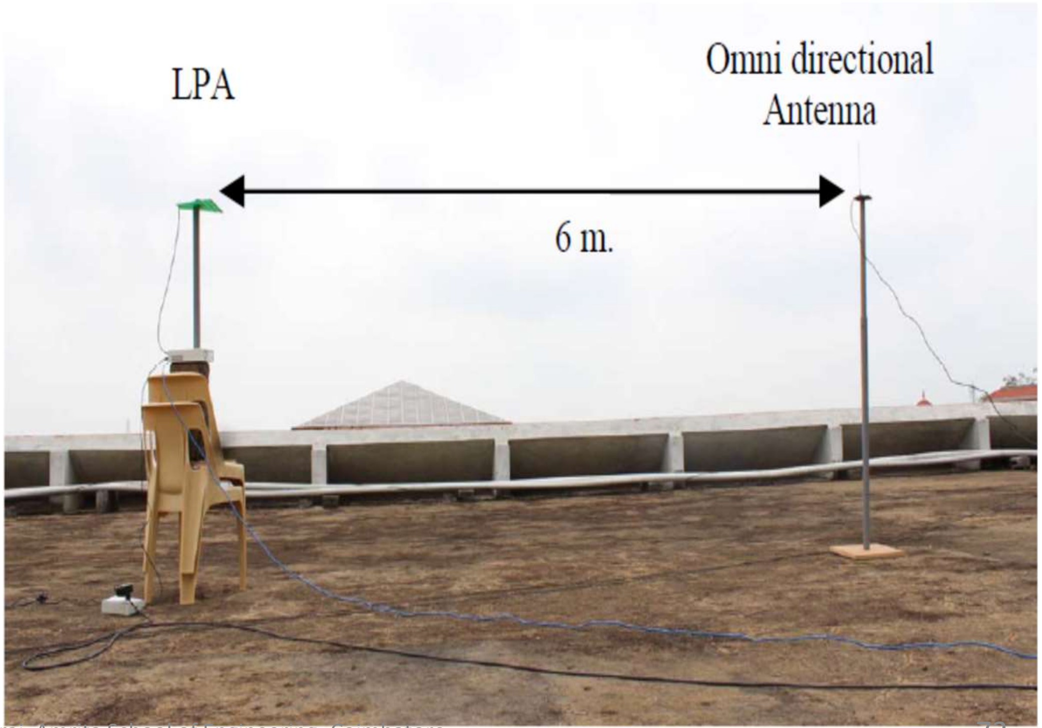
x-axis : 1 unit = 5dB
y-axis : 1unit = 15degree

Half Power Beam Width	70 degree
Front to Back Ratio	0.4166

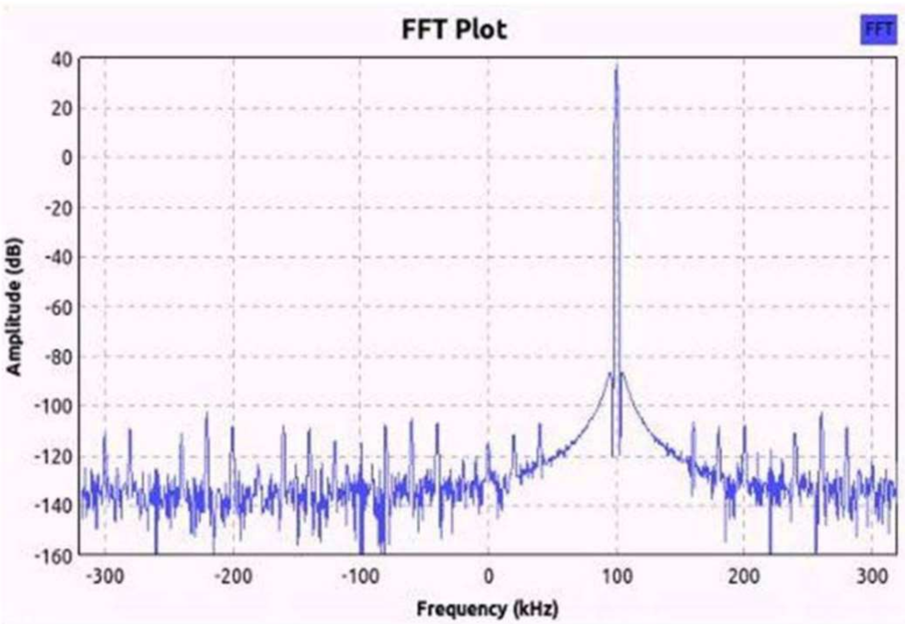
3.3.2 Radiation Pattern Measurement of Log-Periodic Antenna (LPA)

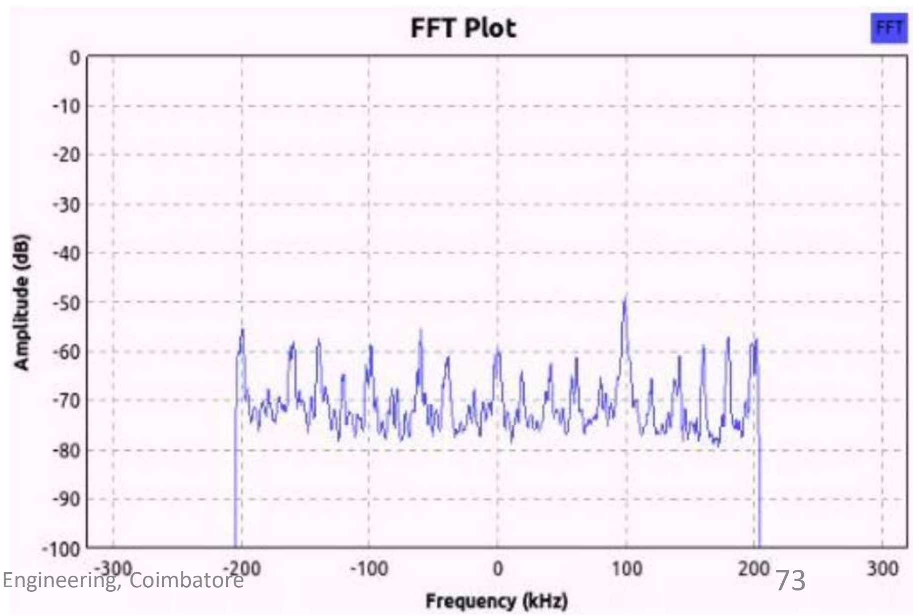
- LPA Antenna & its parameters :: Setup
- Freq. Range: 400 MHz to 1 GHz





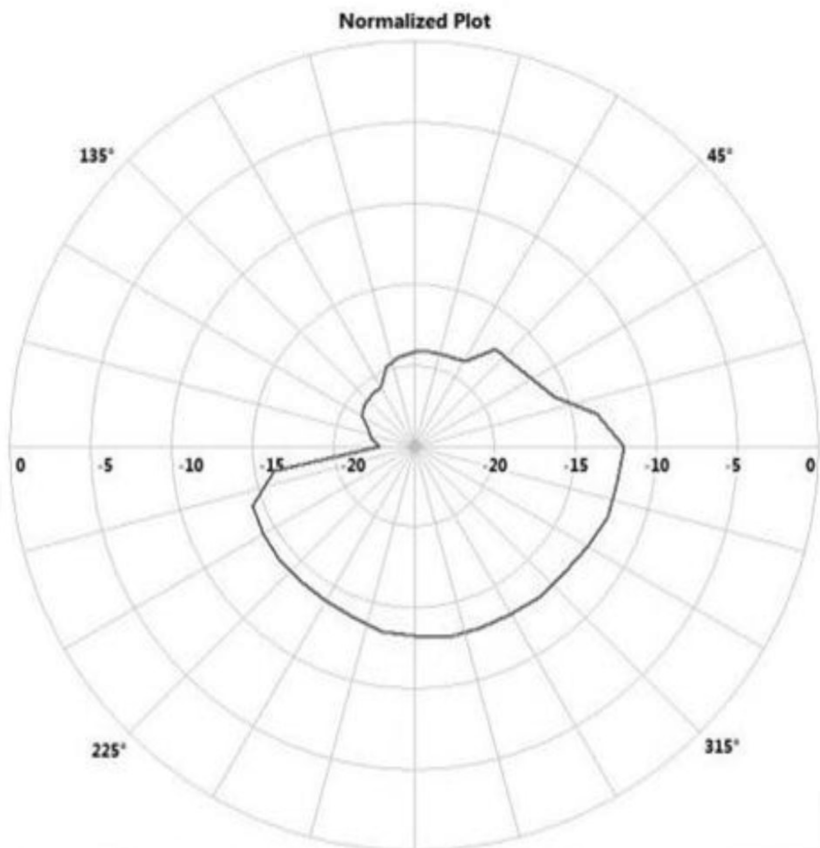
- Transmitted and Received Signal spectrum





3.3.2 Radiation Pattern Measurement of Log-Periodic Antenna (LPA)

- Transmitted and Received Signal spectrum

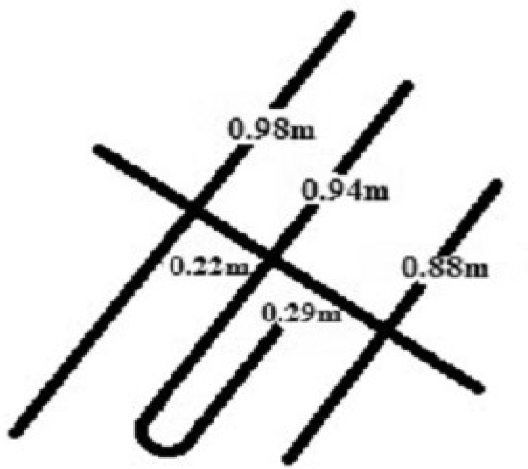


X-axis : 1unit = 5dB
Angle : 1unit = 15degree

Half Power beam width	**21.5 (in degree)**
Front to back end ratio	10.7(in dB)

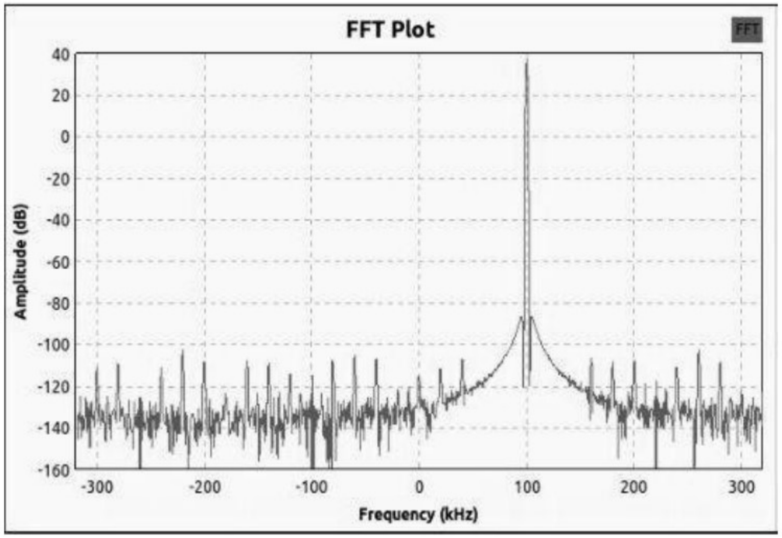
3.3.3 Radiation Pattern Measurement of Yagi-Uda

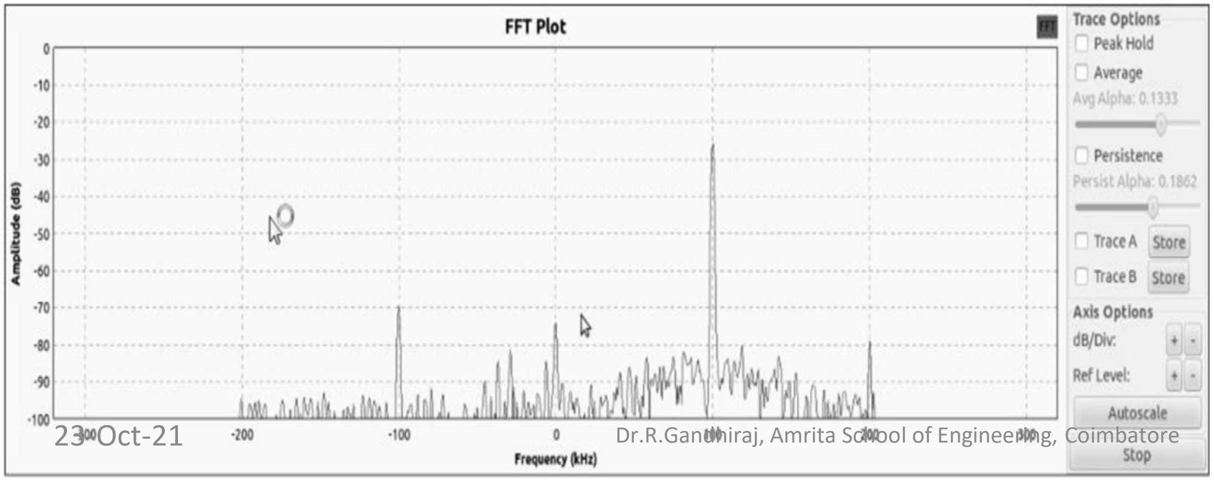
- Yagi Antenna & its parameters :: Setup
- Freq. range: 150 MHz



3.3.3 Radiation Pattern Measurement of Yagi-Uda

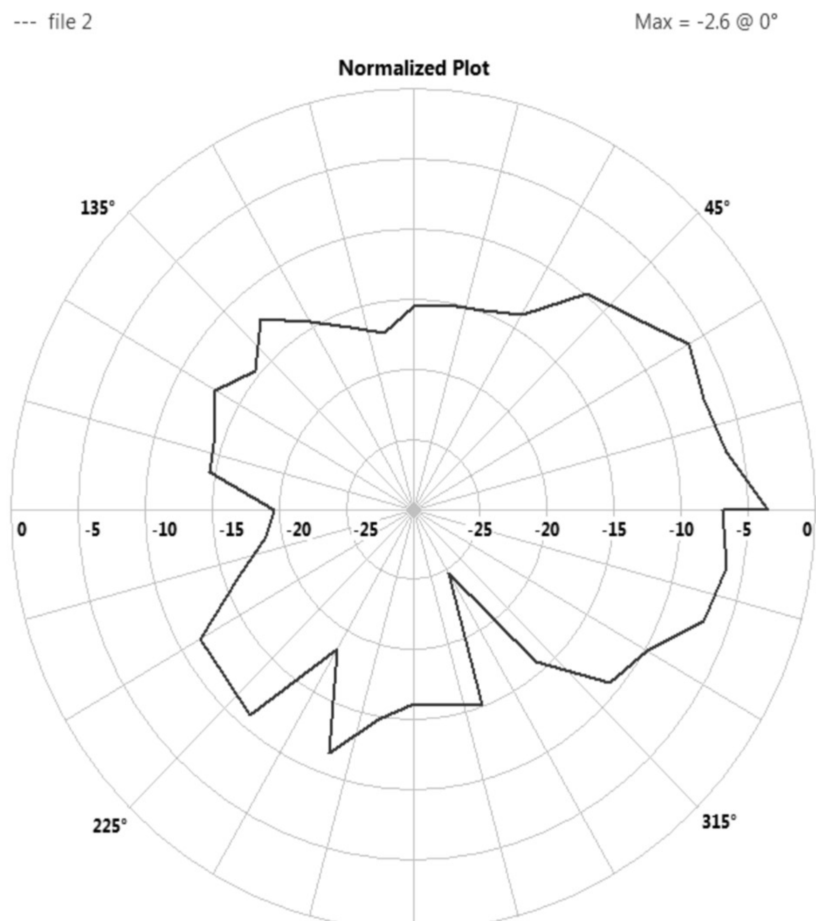
- Transmission & Reception signal spectrum





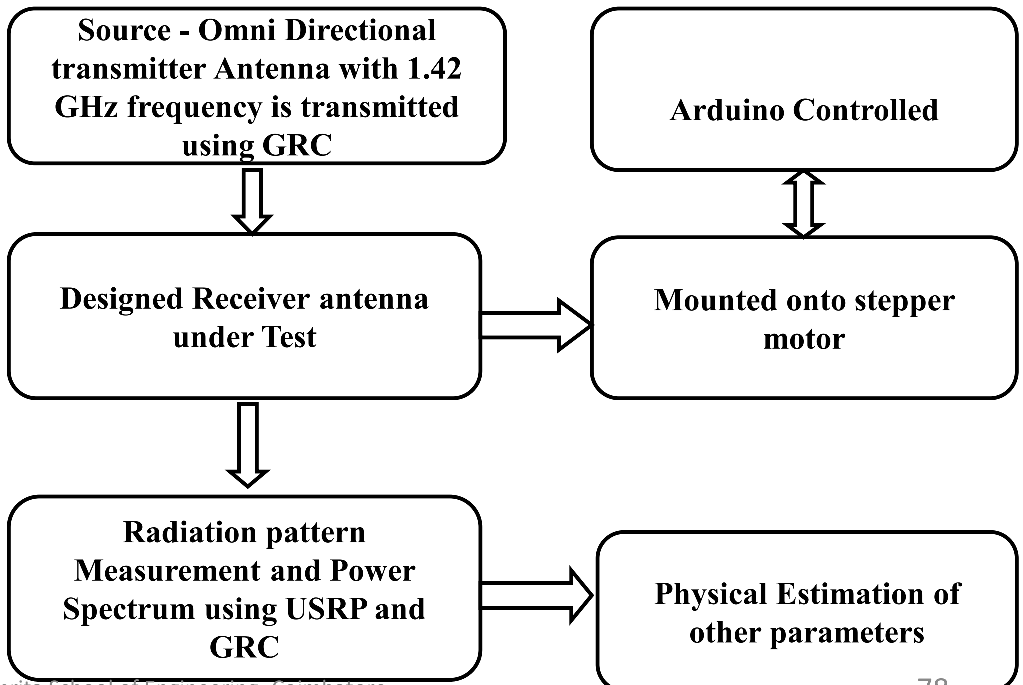
3.3.3 Radiation Pattern Measurement of Yagi-Uda

- Radiation Pattern (inside closed environment)



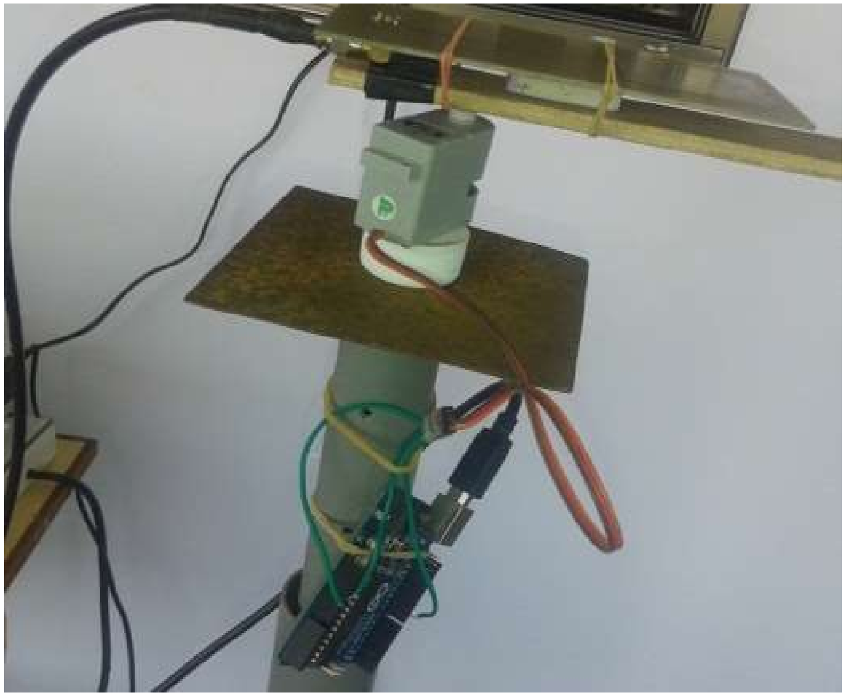
3.3.4 Performance analysis of Micro strip antenna

- Fabricated Microstrip antenna [68]: Procedure



3.3.4 Performance analysis of Micro strip antenna

- Experimental Setup with Arduino



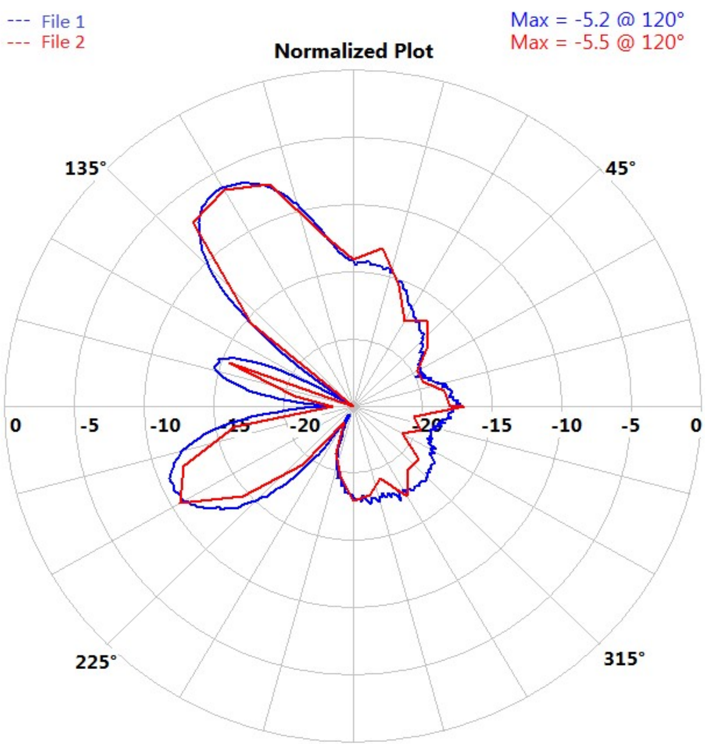
3.3.4 Performance analysis of Micro strip antenna

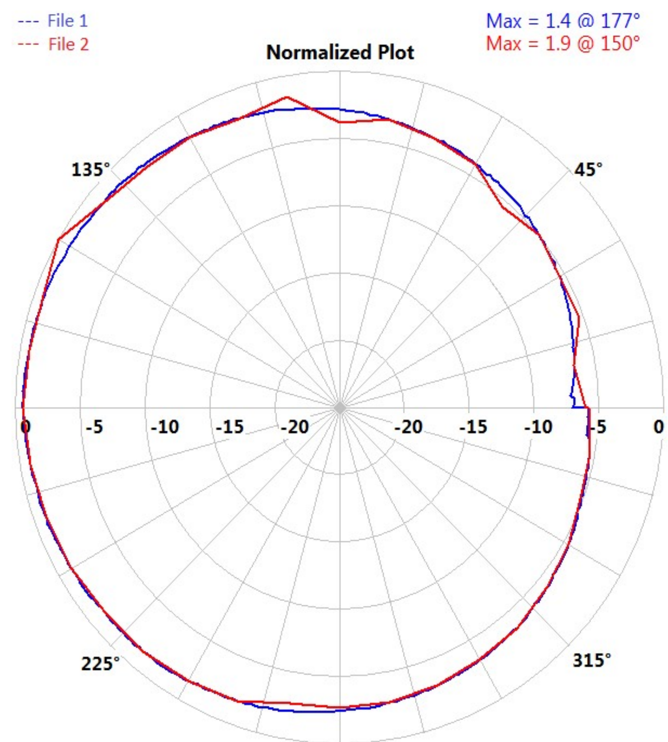
- Comparison with Anechoic Chamber

Sl.No	GNU Radio and USRP based measurement possible experiments and research	Anechoic chamber
1.	Antenna's performance analysis	Radiation pattern measurement of an antenna
2.	Personal area network establishment	
3.	Real time communication like AM, FM etc.	
4.	Linear algebra related problems	
5.	Image processing tasks	
6.	Own antenna network design	
7.	Open BTS establishment	
8.	Online Video Streaming	

3.3.4 Performance analysis of Micro strip antenna

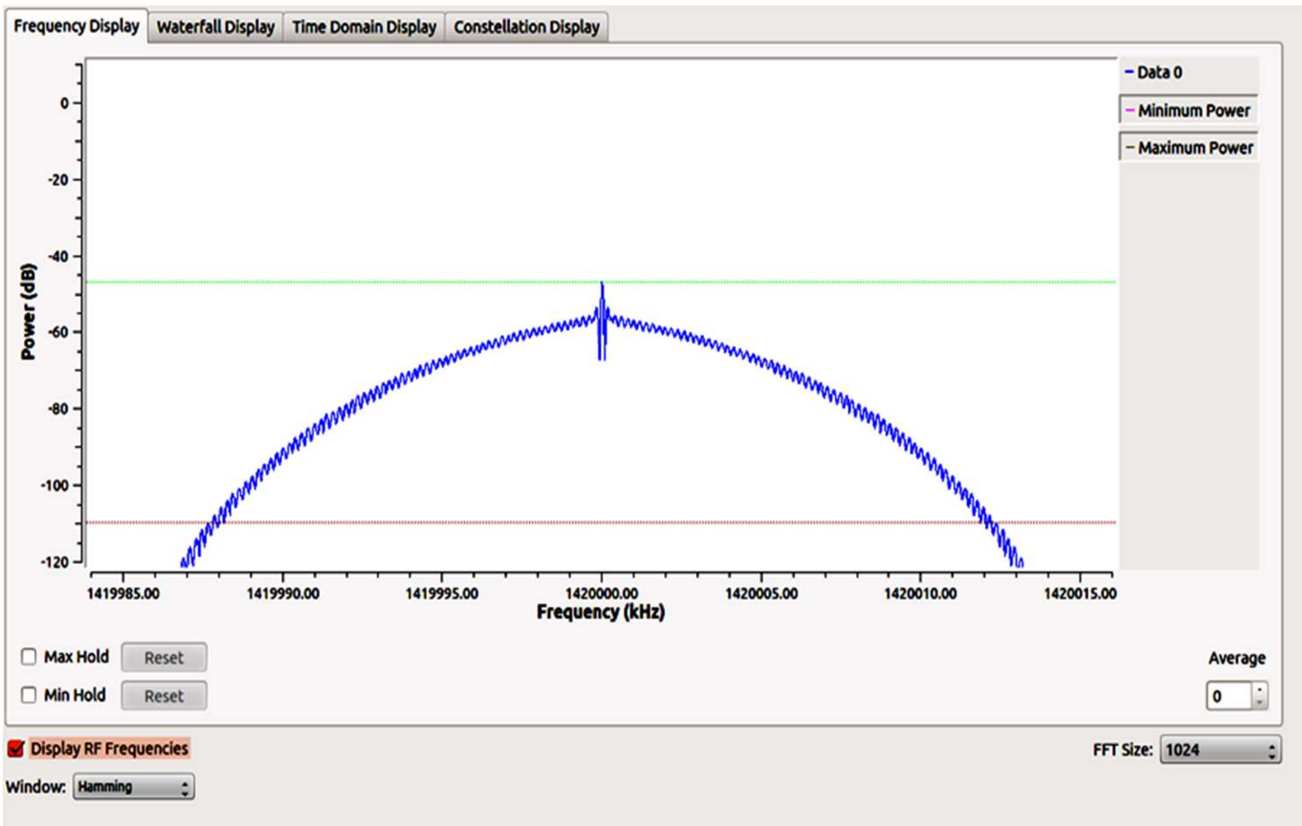
- Radiation pattern of E & H plane





3.3.4 Performance analysis of Micro strip antenna

- Power Spectrum measurement



3.3.4 Performance analysis of Micro strip antenna

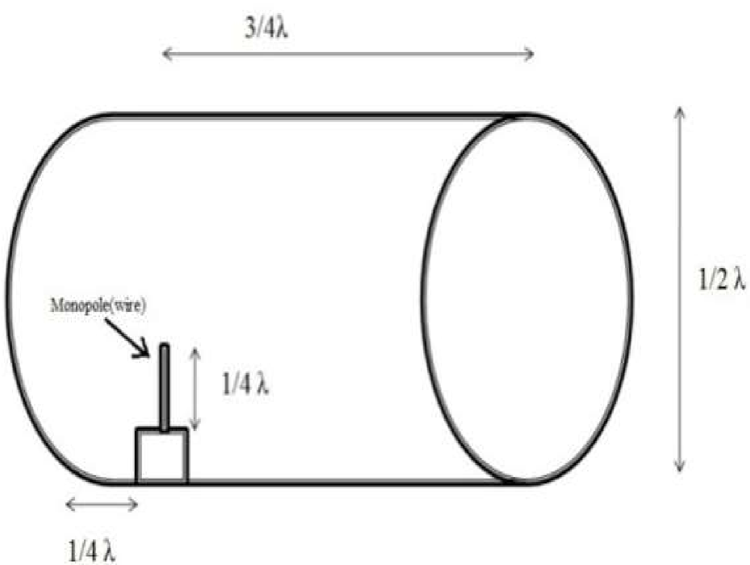
- Results

Half power beam width in Degree	Half power beam width in Degree	Received signal power in watts
Horizontal Plane using anechoic chamber based setup	Horizontal Plane using USRP and GNU Radio based setup	Horizontal plane
29.04	28.32	35.65

Front to back Ratio of anechoic in dB		Front to Back ratio of GNU Radio and USRP setup measurement in dB	
Horizontal Plane	Vertical Plane	Horizontal Plane	Vertical Plane
0.9987	0.704730	0.70366	0.9815

3.3.5 Radiation Pattern measurement of low cost CAN antenna V1.0

- Design & Fabrication : for 2 GHz

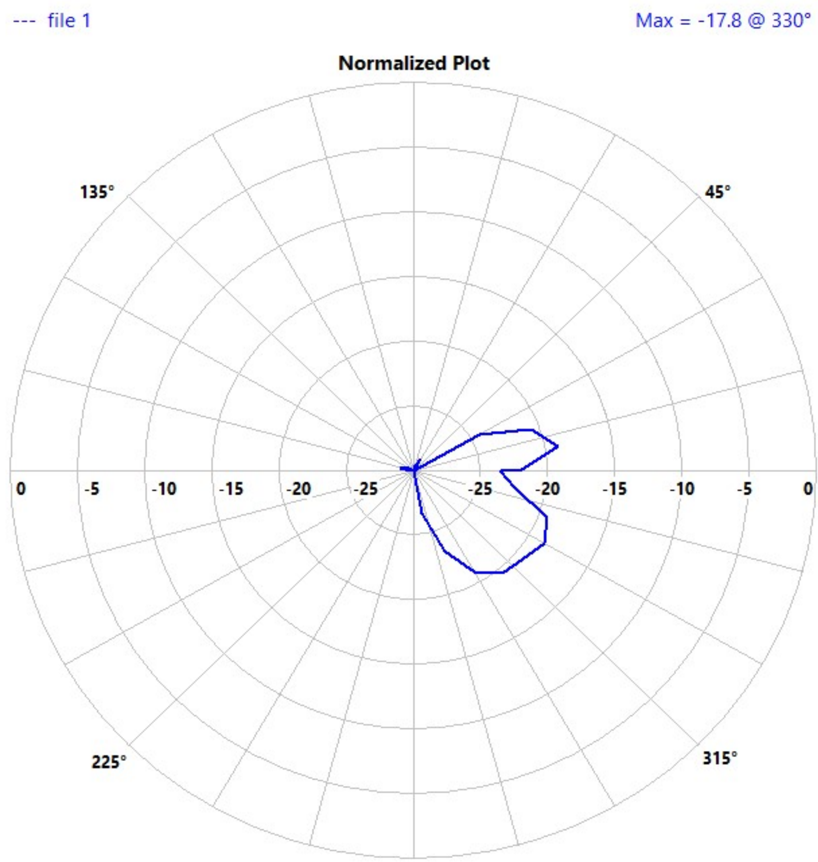


3.3.5 Radiation Pattern measurement of low cost CAN antenna

- Setup

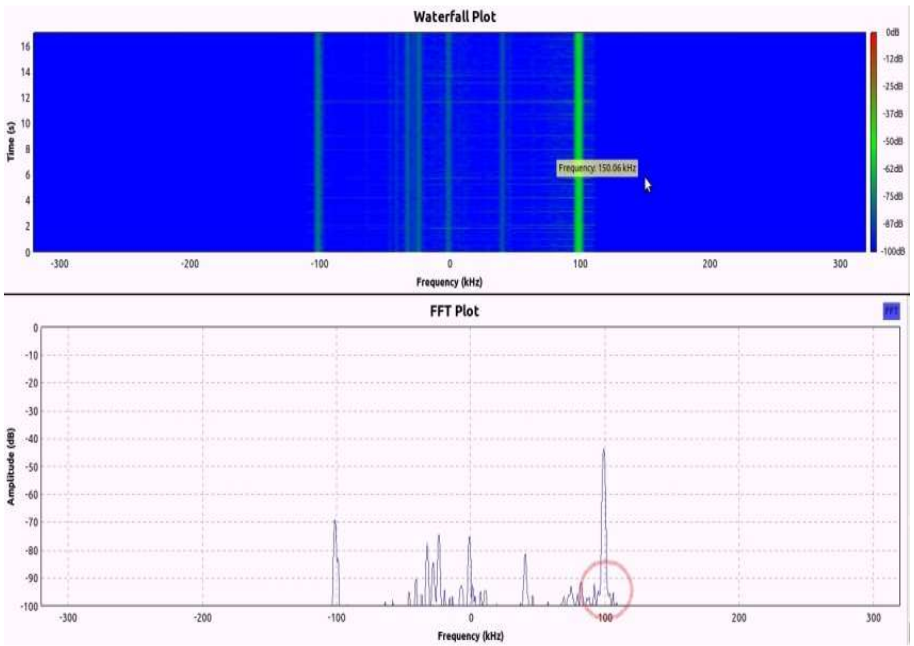
3.3.5 Radiation Pattern measurement of low cost CAN antenna

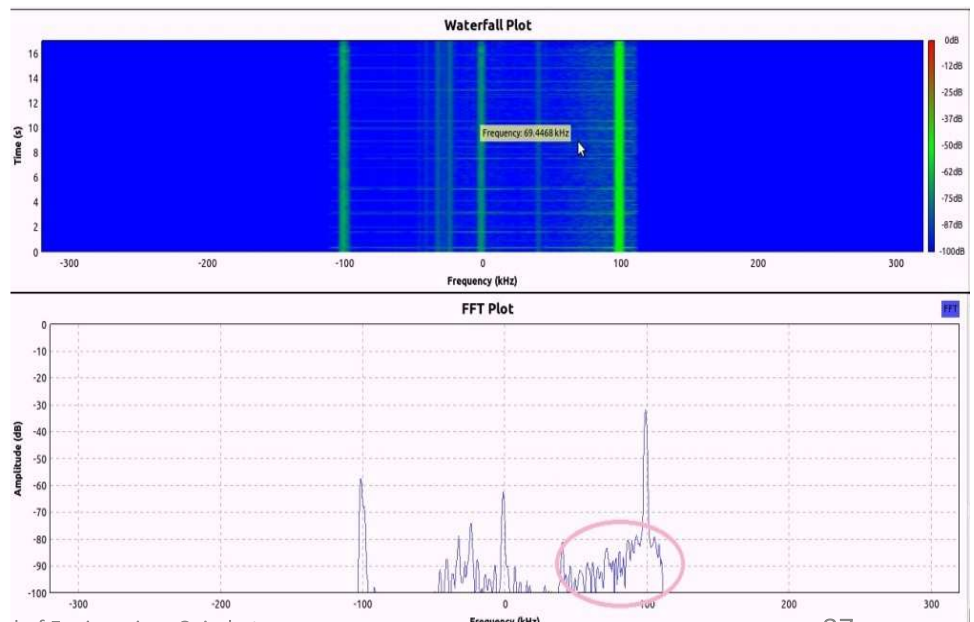
- Radiation Pattern



3.3.5 Radiation Pattern measurement of low cost CAN antenna

- Radar setup without and with obstacle





3.3.5 Radiation Pattern measurement of low cost CAN antenna V2.0 Design [111]

The frequency range of operation for the project is between 2.7 to 2.8 GHz. Thus for designing the antenna, the frequency of operation was considered to be 2.75 GHz. The wavelength is given by,

$$\lambda = f/c = (2.75 * 10^9) / (3*10^8) = 10.9 \text{ cm}$$

The formula to find the cut-off wavelength is,

$$\lambda_c = 1.705*D = 1.705*10 = 17.05 \text{ cm}$$

Hence, the cut-off frequency is

$$f_c = c/\lambda = (3*10^8) / (17.05 *10^{-2}) = 1.759 \text{ GHz}$$

The guided wavelength is calculated using the formula,

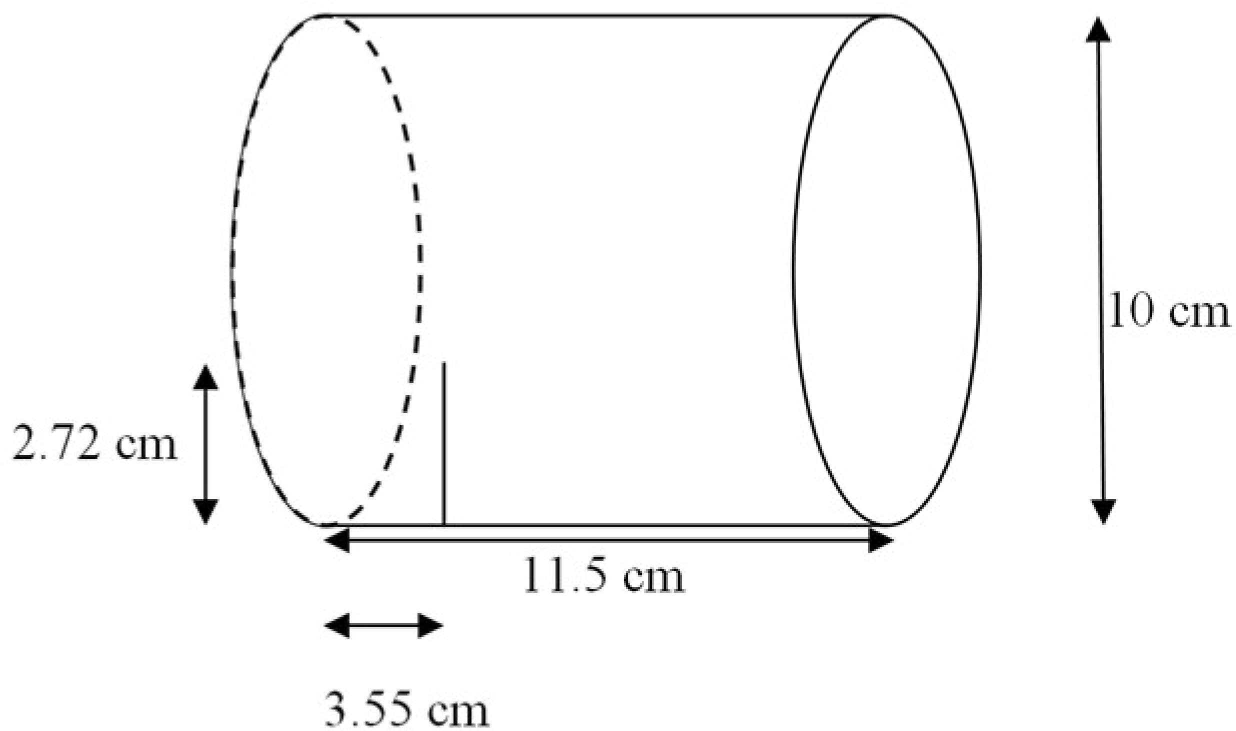
$$\lambda_g = \lambda/\text{sqrt}(1-(\lambda/\lambda_c)^2) = (10.9 * 10^{-2}) / \text{sqrt}(1- ((10.9 * 10^{-2}) / (17.05 * 10^{-2}))^2)$$

$$= 14.194 \text{ cm}$$

Hence, the length of the feed = $\lambda/4 = (10.9 * 10^{-2})/4 \approx 2.72$ cm

Distance of feed from the back wall = $\lambda_g/4 = (14.194 * 10^{-2})/4 \approx 3.55$ cm

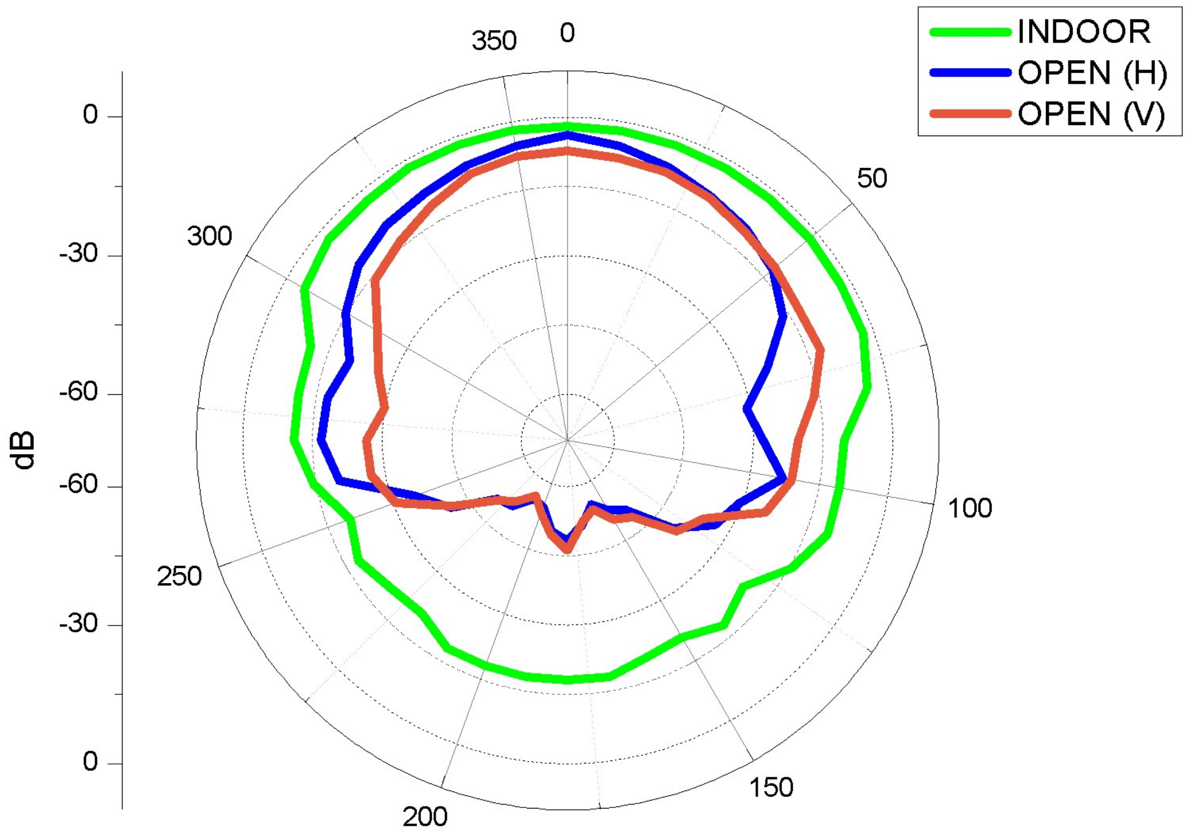
3.3.5 Radiation Pattern measurement of low cost CAN antenna V2.0 Design [111]
[For Meteorology measurement: Disdrometer, IITM, Pune]



Tin CAN antenna Version 2 for frequency 2.7 GHz

3.3.5 Radiation Pattern measurement of low cost CAN antenna V2.0 Experimental Setup

3.3.5 Radiation Pattern measurement of low cost CAN antenna V2.0
Radiation Pattern (Indoor & Outdoor)



3.4 System development using Raspberry Pi

3.4.1 Real-Time Communication System Design using RTL-SDR and Raspberry Pi

3.4.2 Accelerated FFT Computation for GNU Radio using GPU of Raspberry Pi

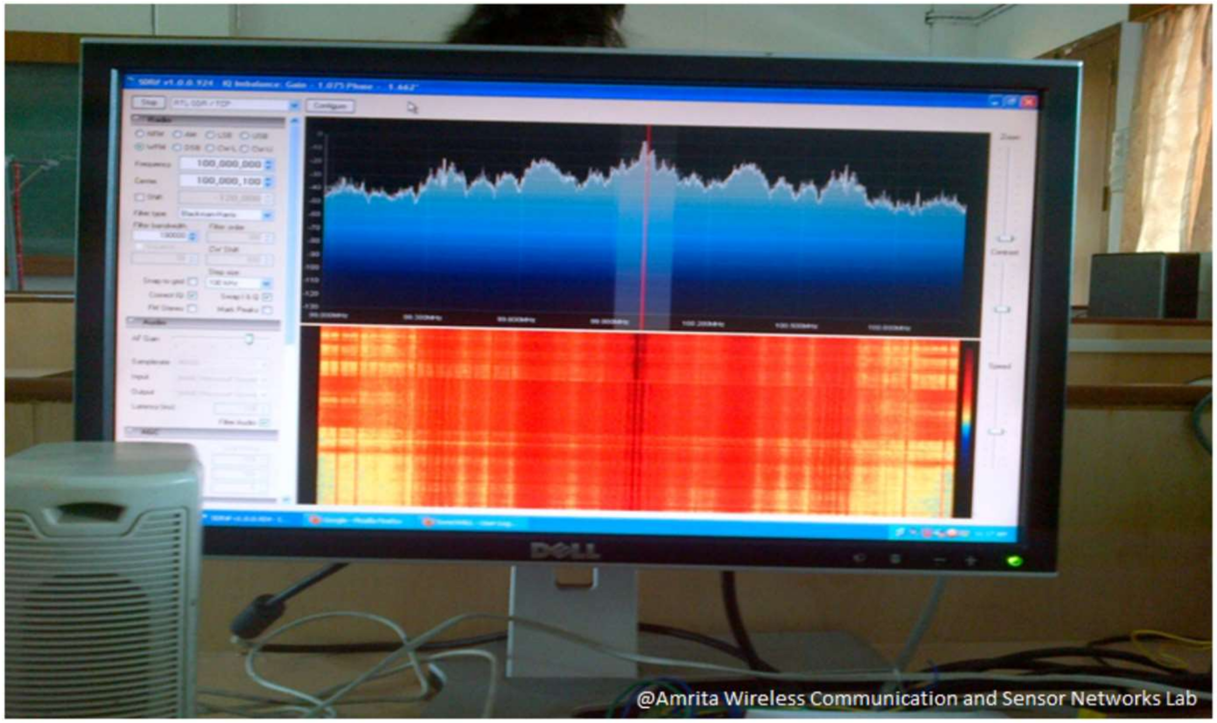
3.4.3 Outernet: A SatCom based Digital Library at no data cost for Indian Schools

3.4.1 Real-Time Communication System Design using RTL-SDR and Raspberry Pi

- Setup with Raspberry Pi & RTL SDR : As server

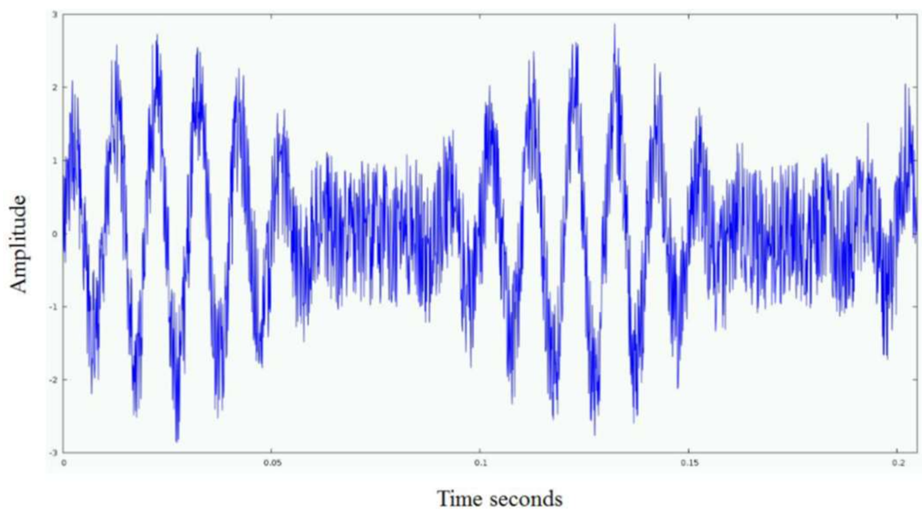
3.4.1 Real-Time Communication System Design using RTL-SDR and Raspberry Pi

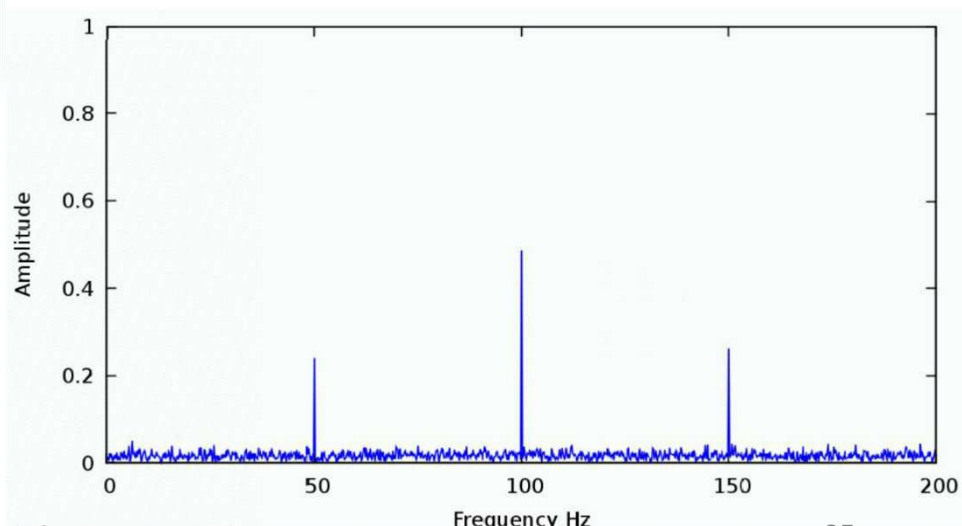
- FM Signal Reception using SDR# from Remote Client PC



3.4.2 Accelerated FFT Computation for GNU Radio using GPU of Raspberry Pi

- Noisy signal & its spectrum





3.4.2Accelerated FFT Computation for GNU Radio using GPU of Raspberry Pi

- Execution time of FFT in intel-COREi5 given in Seconds (Matlab)

	LENGTH OF FFT			
BATCHES	256	512	1024	2048
1	0.014089	0.052547	0.038113	0.086689
2	0.039796	0.043302	0.095895	0.188929
3	0.036306	0.075456	0.167499	0.278827
4	0.098299	0.081684	0.149205	0.320916

3.4.2 Accelerated FFT Computation for GNU Radio using GPU of Raspberry Pi

- Execution time of FFT in CPU of Raspberry Pi given in Seconds

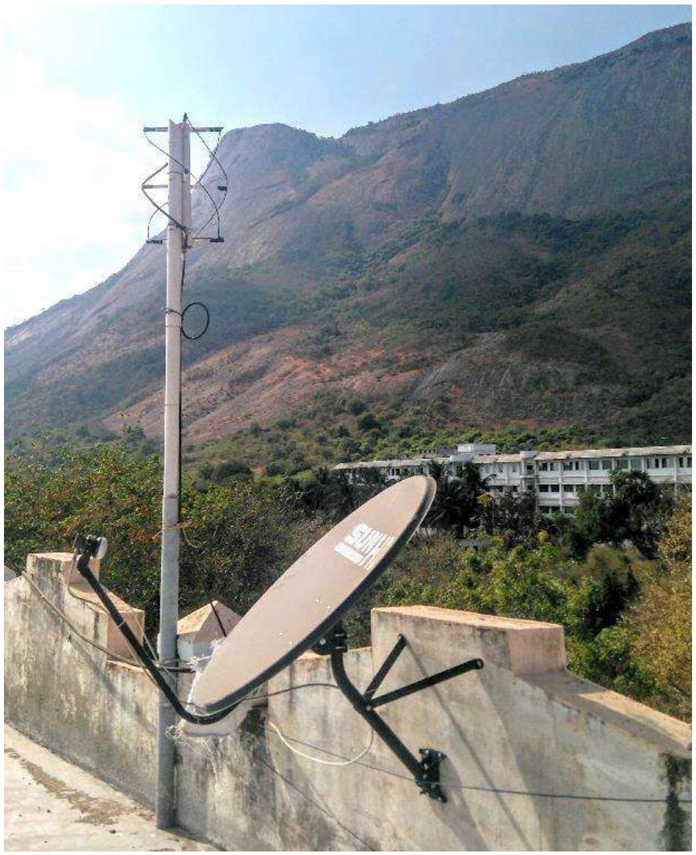
	LENGTH OF FFT			
BATCHES	256	512	1024	2048
1	0.2235	0.3134	0.534	1.0335
2	0.4229	0.7378	1.817	2.1096
3	0.6602	1.08	1.20	3.1788
4	0.9298	2	2.448	4.185

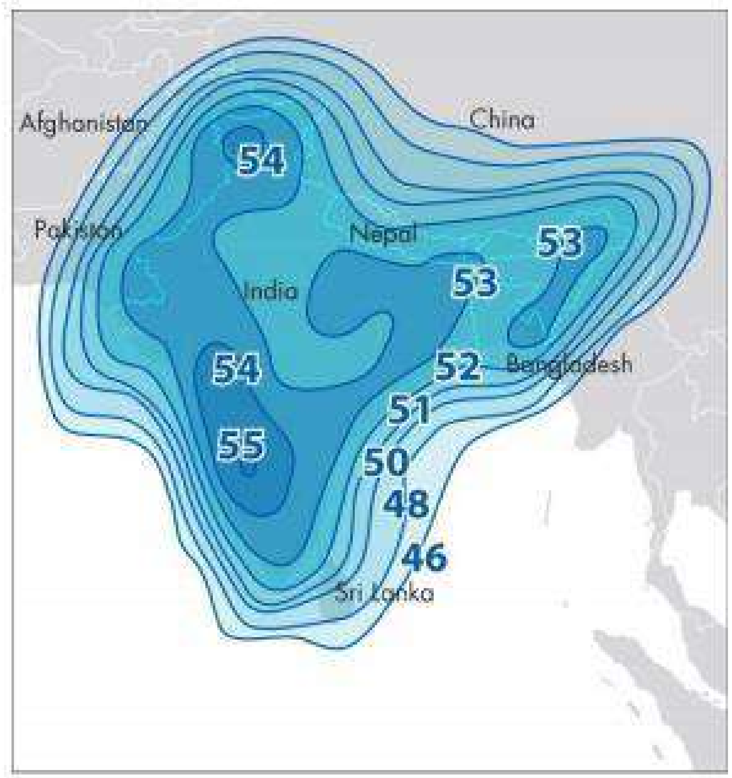
3.4.2 Accelerated FFT Computation for GNU Radio using GPU of Raspberry Pi

- Execution time of FFT in GPU of Raspberry Pi given in Seconds

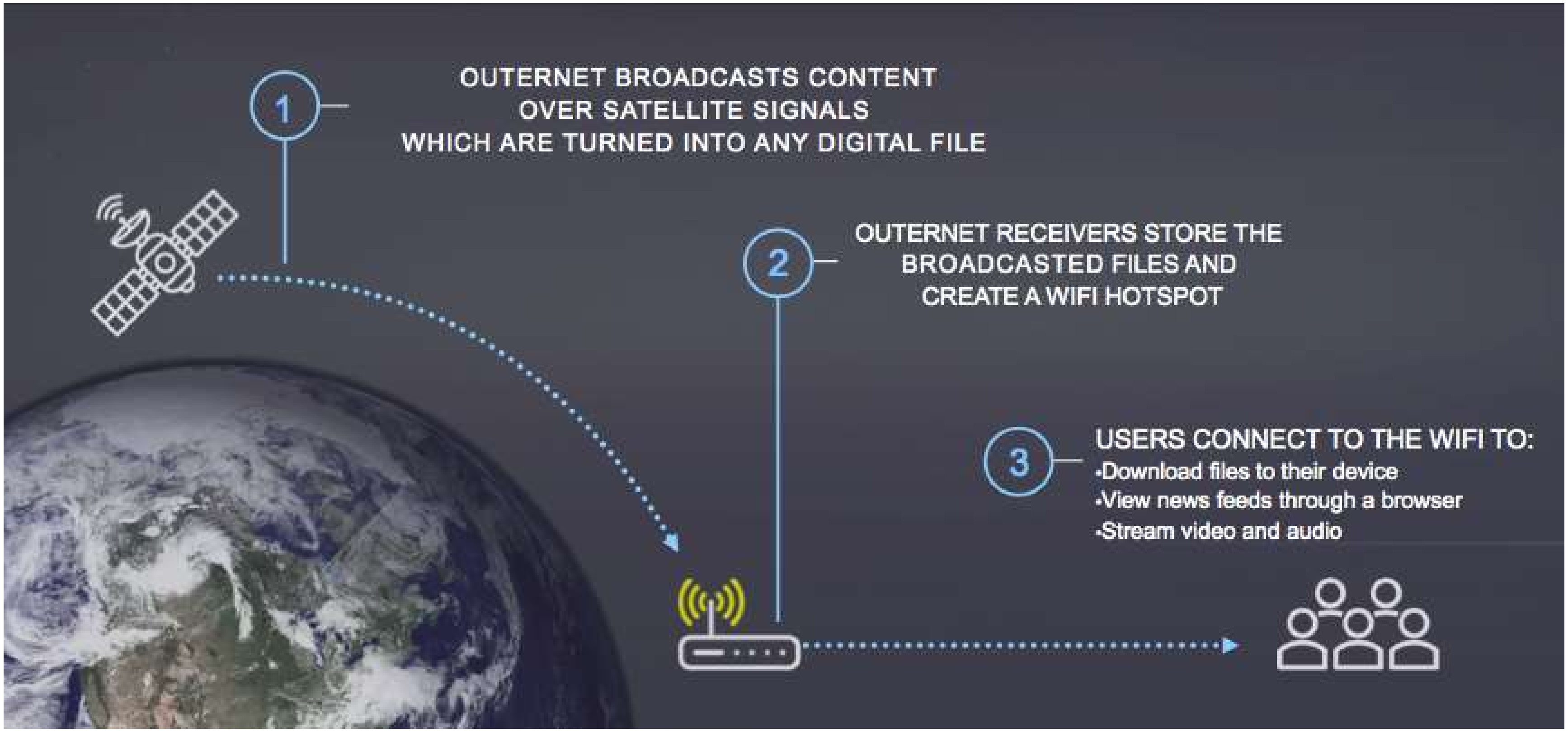
	LENGTH OF FFT			
BATCHES	256	512	1024	2048
1	0.23×10^{-6}	36×10^{-6}	57×10^{-6}	117×10^{-6}
2	46×10^{-6}	76×10^{-6}	112×10^{-6}	228×10^{-6}
3	72×10^{-6}	113×10^{-6}	174×10^{-6}	346×10^{-6}
4	114×10^{-6}	154×10^{-6}	238×10^{-6}	455×10^{-6}

3.4.3 Outernet: A SatCom based Digital Library at no data cost for Indian Schools





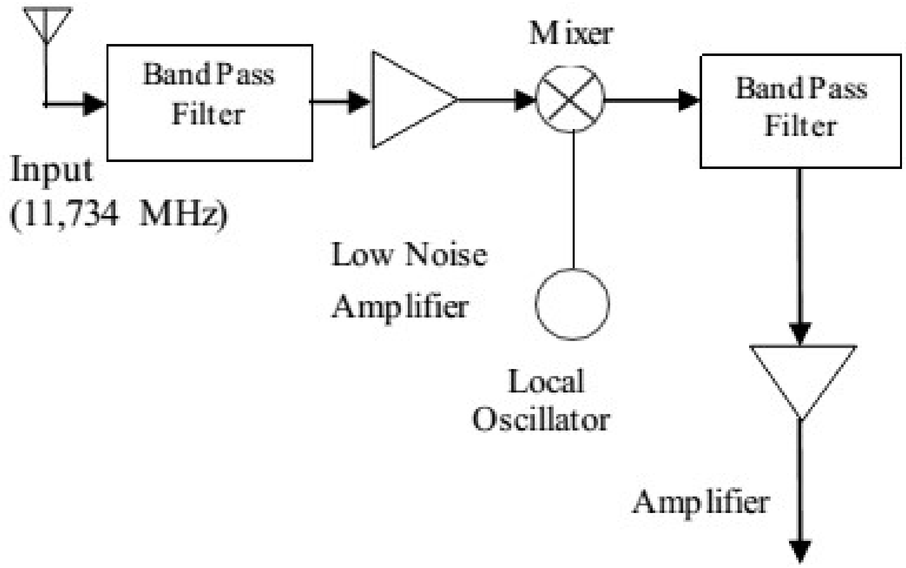
3.4.3 Outernet: A SatCom based Digital Library at no data cost for Indian Schools



3.4.3 Outernet: A SatCom based Digital Library at no data cost for Indian Schools

- Setup

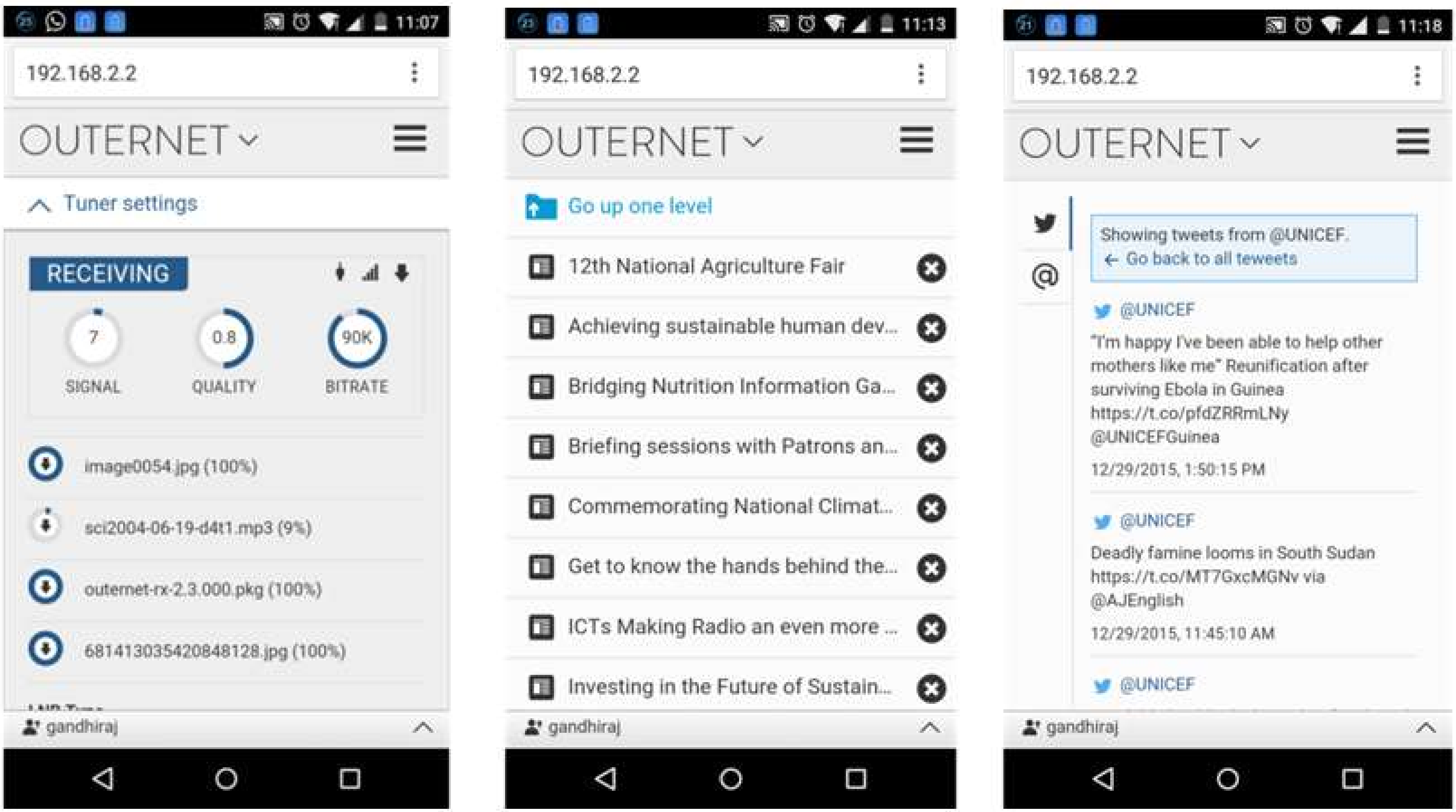
3.4.3 Specification



$$f_{IF} = f_{recv} - f_{LO}$$

Local oscillator	**10.75GHz**
Frequency	**11.70–12.20 GHz**
Noise figure	**1 dB typical**
Polarization	**Linear**

- Outernet



192.168.2.2
OUTERNET
Tuner settings
RECEIVING
7
SIGNAL
0.8
QUALITY
90K
BITRATE
image0054.jpg (100%)
sci2004-06-19-d4t1.mp3 (9%)
outernet-rx-2.3.000.pkg (100%)
681413035420848128.jpg (100%)
gandhiraj
Go up one level
12th National Agriculture Fair
Achieving sustainable human dev...
Bridging Nutrition Information Ga...
Briefing sessions with Patrons an...
Commemorating National Climat...
Get to know the hands behind the...
ICTs Making Radio an even more ...
Investing in the Future of Sustain...
Showing tweets from @UNICEF.
Go back to all teweets
@UNICEF
"I'm happy I've been able to help other mothers like me" Reunification after surviving Ebola in Guinea https://t.co/pfdZRRmLNy @UNICEFGuinea
12/29/2015, 1:50:15 PM
Deadly famine looms in South Sudan https://t.co/MT7GxcMGNv via @AJEnglish
12/29/2015, 11:45:10 AM

3.4.3 Cost comparison

Current System

Establishment cost

INFRASTRUCTURE	ANNUAL COST(in lakhs)
10 PCs (or one Server with 10 Terminals), 1 Projector, 1 Printer, 1 Scanner, 1 Web Camera, 1 modem, Broadband antenna, Generator/ Solar Package, UPS, video camera, etc.	5.10
Operating System & Application Software	0.20
Educational Software and CD ROMs	0.45
Furniture	0.25
Induction training to teachers for 10 days	0.40
Total	**6.40**

Running Cost

INFRASTRUCTURE	ANNUAL COST(in lakhs)
Electricity charges @ Rs. 1,000/- p.m.	0.12
Internet / Broadband charges	0.10
Telephone charges, teacher's salary, computer stationary, expenses on generator, management, monitoring and evaluation.	2.48
Total	**2.70**

Proposed System

Establishment cost

INFRASTRUCTURE	ANNUAL COST(in lakhs)
Existing infrastructure	6.40
Antenna Dish+ Tuner + Raspberry Pi	0.02+0.02+0.03 = 0.07
Total	6.47

Running Cost

INFRASTRUCTURE	ANNUAL COST(in lakhs)
Electricity charges @ Rs. 1,000/- p.m., Telephone charges, teacher's salary, computer stationary, expenses on generator, management, monitoring and evaluation.	2.38
Internet / Broadband charges	0.00
Total	2.38

3.4.3 Possible Saving to GOI
[Proposal to GOI is in Progress]

- Total schools funded under ICT [112] : 87033
- Total Internet cost / year : Rs.87.033 Crore
- Total Internet cost / 5 years : Rs.435.165 Crore

- Outernet establishment cost : Rs.0.07 Lakhs
- For all 87033 schools : Rs.60.92 Crore
- Total savings :
  - **Rs.435.165 Cr. – Rs. 60.92 Cr. = 374.2419 / 5 Years**

3.5 Research Outcome

Book chapter	- 3 (Scopus Indexed)
SCI indexed Journal	- 1 (Scopus Indexed)
International Journals	- 4 (Scopus Indexed) + 5 (Non-Scopus Indexed)
International Conference	- 13 (Scopus Indexed) + 4 (Non-Scopus Indexed)
National Conferences	- 7 (Non-Scopus Indexed)
Total	**- 21 (Scopus Indexed) + 16 (Non-Scopus Indexed)**

National Level workshop organised - 6

3.5.1 Other Outcome of Research

- "**Design and Evaluation of Digital Radio Frequency Memory (DRFM) Mitigation System**", USD 118,000.00 (INR 79 Lakhs) funded by National Instruments, USA on July 2016. Principal Investigator (PI): Dr. Shanmugha Sundaram GA, Co-PIs: Dr. KP Soman, Dr. T Rajagopalan, Dr. DS Harish Ram, Dr. B Binoy and **Mr. R. Gandhiraj**, Amrita School of Engineering, Coimbatore.

Web Link: http://ww.ni.com/white-paper/52613/en/

http://www.university.careers360.com/news/amrita-university-gets-usd-118k-grant-for-design-and-evaluation-of-drfm-mitigation-system-182635.

- "**Capacity and Bit Error Rate Analysis of MIMO based Satellite Communication for Higher Spectral Efficiency**", INR 12.2 Lakhs, sanctioned by **ISRO under RESPOND** scheme on June 2017. PI: Dr.S.Kirthiga, Co-PI: Dr.M.Jayakumar, Dr.M.Nirmala Devi**, R.Gandhiraj**, Department of ECE, Amrita School of Engineering, Coimbatore.

4.1 Conclusion

- The turn-key ready low cost open source hardware and software framework of SDR have been realized for advanced signal processing and communication engineering applications.
- The new student affordable applications in unexplored domain such as Antenna radiation pattern measurements of various RF antenna have been realized.
- Enhancement of the understanding of theoretical and mathematical aspects in pedagogy of current electronics and communication engineering by hands-on approach has been tested.

4.2 Scope for future work

- To overcome the processing time delay faced by PC or Raspberry Pi, using GNU Radio, USRP and RTL-SDR can be rectified by using the new RFNoC (Radio Frequency Network On Chip) technique developed by Ettus.
- Non-PHY layer application testbed creation
- Other possible application development using SDR
  - RF based meteorological parameter measurement
  - RADAR development
  - Under Water Acoustics modeling
  - Deep space communication
  - Spectrum sensing application
  - Software stack of IEEE 802.11 and 802.15.4 network
  - GSM and LTE base station
  - Digital Video Broadcasting Transmission (DVB-T)
  - Wireless sensor network test bed

Comments by External Examiner

Dr.Anand Santhanakrishnan,
Asst. Professor, Dept. of Electrical Engineering, New York Institute of Technology (NYIT)-Manhattan, USA.

- I really liked the idea of improving the quality of education. It is a serious concerns in India and many other countries and I am glad the author chose a topic that a strong societal impact. The whole implementation and the details provided are also very comprehensive and the results do show that the setup works. I am particularly pleased with the diverse areas covered by the author (like signal processing, telecommunications, networks and antenna design) using the proposed SDR setup. I always believed that design of a free space transceiver system should be mandatory part of every engineering program on telecommunication, which the thesis provides.
- I do believe that such a tool will improve learning under graduate and graduate level of education. This tool will definitely improve student participation and hands on learning. I also perceive that the proposed tool can lead to testbed implementation and prototyping of several research ideas. Overall the thesis is very well motivated and supported in terms of experimental results……

5 Publications

International Journals

Gandhiraj, R., & Soman, K. P. (2014). Modern analog and digital communication systems development using GNU Radio with USRP. *Telecommunication Systems*, *56*(3), 367–381. https://doi.org/10.1007/s11235-013-9850-7

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Abirami, M., **Gandhiraj, R**., & Soman, K. (2013). Performance analysis of real time OFDM based communication system using GNU radio and USRP. *International Journal of Advanced Research in Computer Science and Software Engineering, ISSN*, *2277*.

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Gandhiraj, R., Vinutana, T., Sai Bharath Kumar, B., Venu Sri Sushma, K., & Soman, K. P. (2017). Outernet: A digital Library at zero cost for Indian Schools. Presented at the 2017 IEEE International Conference on Communication and Signal Processing (ICCSP 2017), Chennai, Tamil Nadu, India: IEEE.

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Book Chapter

Reshma, U., Barathi Ganesh, H. B., Jyothi, J., **Gandhiraj, R**., & Soman, K. P. (2016). Wavelet Based RTL-SDR Real Time Signal Denoising in GNU Radio. In A. Nagar, D. P. Mohapatra, & N. Chaki (Eds.), *Proceedings of 3rd International Conference on Advanced Computing, Networking and Informatics* (Vol. 43, pp. 397–408). New Delhi: Springer India. Retrieved from http://link.springer.com/10.1007/978-81-322-2538-6_42

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