SPECTRUM SENSING FOR TV WHITE SPACES

B.E (T.C) PROJECT REPORT

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ABSTRACT

Electromagnetic waves or spectrum is a useful natural resource. It must be utilized in an efficient way. To be able to use scarce spectrum efficiently, devices must be made intelligent to automatically adapt to surrounding situation of electromagnetic radiations. Recent research shows that TV bands are utilized very ineffectively and they are underutilized spatially and temporally. This creates an opportunity to be able to utilize TV bands for other applications also with secondary rights on transmission.

Our prime goal was to learn detection methods and implement a suitable detection method on DVB-T standard. Energy Detection was preferred for implementation due to its ability to detect signals without prior knowledge of signal. This detection method was also tested with real transmission of DVB-T signal using air as a channel.

ACKNOWLEDGEMENTS

Above all, we would like to thank Almighty Allah to provide us with the strength and understanding to complete this work.

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CHAPTER 1

Introduction

In this chapter we introduce some terminologies that will be useful to understand the idea of the project. These definitions also include software and hardware used in the project.

1.1 Software Defined Radio

Software Defined Radio or simply SDR is a relatively new technology that is supposed to be the future of radio communication. Traditionally, communication tasks such as modulation, encoding, decoding, filtration etc. are done by hardware and only the processed data is provided to the software, whereas in SDRs these tasks must be performed using a software platform. Hardware involved in SDR includes processing only up to mixer stage. They are called RF front ends.

Software Defined radio provides flexibility in the tasks performed by software that by using hardware is impossible to achieve. Complex tasks and techniques can be performed with help of general-purpose processors.

1.2 GNU Radio and GNU Radio Companion

GNU Radio is GUI based software included in GNU Radio package. It is Simulink-like software and already contains most of the block packages required for common communication protocols. A flow graph is designed by making connections between different blocks which represents the flow of data. Parameters of a signal such as sample rate must be consistent and connections must be logical in order to design a meaningful flow graph.

1.3 Universal Software Radio Peripheral

USRP is developed by Ettus Research and is one of the most popular RF front ends designed for flexible use. There is a series of production that provide different operational ranges of frequency, processing speeds, sampling frequency etc. USRP N210 (used in our project) has a Xilinx FPGA motherboard and it can operate from DC to 6 GHz of frequency. It can be connected directly with a personal computer using a Gigabit Ethernet port provided in it. Figure 1 presents picture of USRP and GNU Radio running on Linux.

1.4 RTL SDR

RTL SDR also known as DVB T tuner is an inexpensive and simple device for SDR application. It is able to receive signals approximately in the range of 24 to 1800 MHz with sample rates up to 3.2 Million Samples per second. It is connected with PCs using usb port and a simple monopole antenna is included in the kit. The chipset used RTL2832U was primarily designed as a DVB T tuner but now it is also used as an SDR receiver using Rafael Micro R820T2 as a tuner.

Fig. 1 USRP N210 with a flow graph running on GRC at PNEC NUST

CHAPTER 2

Spectrum Sensing Algorithms

Spectrum Sensing is a process in which occupancy of a certain portion of spectrum is measured. The idea behind spectrum sensing is to decide whether a useful signal (primary signal) is already present or the spectrum can be used to transmit another signal (secondary signal). A signal detector must be able to decide one of these possibilities i.e. a useful signal is present or absent.[11] There is always a degree of uncertainty attached to this decision making due to the presence of indeterminate noise. So it can be regarded as a case of probability and should be solved with this approach

2.1 Introduction to Spectrum Sensing

There can be two distinct hypotheses based on presence or absence of signal defined as:

H1: Only noise is present with no useful signal.

H2: Useful signal is also present with noise.

Using these hypotheses as our initial decision criteria we can define two pdfs of a received signal 'x' as follows:

$P(x|H1)$= pdf of signal when only noise is present.

$P(x|H2)$= pdf of signal when useful signal and noise is present.

Based on the decisions that a detector make and the actual scenario of presence or absence of signal, there are certain probabilities of interest that is used to characterize the performance of detector. They can be defined as:

pd: Probability of detection is that the hypothesis H2 is selected when actually a signal was present.

PFa: Probability of false alarm is that hypothesis H2 is selected when only noise was present.

These two probabilities are frequently used to define the performance of a detector along with the time and computation required for decision making. There are some other useful probabilities as well but they can be derived with these two fundamental probabilities.

PMD: Probability of missed detection states that hypothesis H1 is selected when a useful signal was present (PMD=1-PD).

PO: Probability of opportunity is that hypothesis H1 is selected when only noise was present (PO=1-PFA).

This probability is of prime importance in spectrum sensing case since it allows the opportunity for secondary signal to be transmitted. How frequently a signal will be transmitted in this opportunity window is dependent on the number of secondary users. If there are more than one secondary user that are viable to interfere with each other's signal then a contention scheme is required between secondary users.

2.2 Neyman Pearson Detection Rule

The Neyman Pearson rule is a special case of Bayes detection criterion. In Bayes criterion risks and costs are assigned to all four possibilities based on presence and absence of signal and two possible decisions. The Neyman Pearson rule provides a method to achieve maximum PD for a restriction of maximum PFA. This method is more practical to solve spectrum sensing issues since typically a limiting PFA is decided first then attempts are made to increase PD using parameters discussed later.

2.3 Likelihood Ratio test

Neyman Pearson criterion is to maximize PD for a restriction of minimum PFA. Using Lagrange multiplier a decision criterion can be created using pdfs of received signal ‘x’ described earlier. The criterion is known as likelihood ratio test.

$$\frac{P(x|H2)}{P(x|H1)} \gtreqless -\tau$$

If this ratio of pdfs exceed the threshold ‘τ’ than hypothesis H2 is selected, and if it is lower than the threshold than hypothesis H1 is selected. This test can be modeled with an example of a signal in zero mean Gaussian noise[1]. Consider a case in which a constant signal with amplitude ‘a’ is transmitted in an environment where noise can be modeled as zero mean Gaussian noise, N samples of signal are taken for decision process and variance of noise is σ^2.

The two hypotheses in this situation will be more precisely described as:

H1: $x \sim N(0_N, \sigma^2 I_N)$

H2: $x \sim N(a1_N, \sigma^2 I_N)$

Here $0_N, 1_N, I_N$ are vectors of zeros, ones and identity matrix of order N. Pdfs used in likelihood ratio test can be written as:

$$P(x|H1) = \sum_{i=1}^{N} \frac{e^{-\frac{1}{2}(\frac{yi}{\sigma})^2}}{\sigma\sqrt{2\pi}}$$

$$P(x|H2) = \sum_{i=1}^{N} \frac{e^{-\frac{1}{2}(\frac{yi-a}{\sigma})^2}}{\sigma\sqrt{2\pi}}$$

Using these normally distributed pdfs, Likelihood ratio test can be re-evaluated as:

$$\sum_{i=1}^{N} yi \gtreqless \frac{\sigma^2}{a}\ln(-\tau) + \frac{Na}{2}$$

Or,

$$\sum_{i=1}^{N} yi \gtreqless \Psi$$

Now, using Neyman Pearson rule applying a limit to PFA which can be measured as follows:

$$PFA = \int_{\Psi}^{\infty} \frac{e^{\frac{-yi^2}{2N\sigma^2}}}{\sigma\sqrt{2\pi N}} dy_i$$

The threshold can be evaluated by solving this integral:

$$\Psi = \sigma\sqrt{2N}\, erf^{-1}(1 - 2PFA)$$

Error function (erf), inverse error function (erf^{-1}), and complement error function (erfc=1-erf) are predefined functions in MATLAB defined as:

$$erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-\lambda^2}\, d\lambda$$

Probability of detection for given value of probability of false alarm can be calculated as:

$$PD = \frac{1}{2}\{1 - \mathrm{erf}(\frac{\Psi - aN}{\sigma\sqrt{2N}})\}$$

This equation can also be illustrated in a more meaningful way showing relation of PD with PFA and SNR of signal, since relation of these two probabilities is usually of more interest and SNR is a design parameter which can be altered to increase detection probability. SNR is dependent on power, noise and number of samples. Since increasing power is not preferable in most scenarios since it increases cost of primary users and may cause interference with other signals and noise is random and can only be limited to certain extent. Number of samples which is proportional to processing time is mostly considered another trade off along with PD and PFA.

$$PD = \frac{1}{2} erfc\{erfc^{-1}(1 - 2PFA) - \sqrt{\frac{SNR}{2}}\}$$

2.4 Demonstration using MATLAB

A Matlab code was built that used above formulas to calculate the threshold and probability of detection for a specified value of probability of false alarm. The code also generates the pdfs of both hypotheses in the form of histogram graphs. The pdf of hypotheses H1 is centered on a value of zero whereas the pdf of hypotheses H2 is centered on a constant value. The Sample size N can be increased to get a higher probability of detection for the same probability of false alarm but it will increase processing time significantly causing delay in spectrum sensing.

2.4.1 Matlab Code

```
% Example finding a constant in Gaussian Noise
N=1024;
variance=1;
PFA=0.05;
a=1;
SNR=(a*N)^2/(N*variance);
% white gaussian noise and noise +signal
mat0=zeros(N,1);
mat1=ones(N,1);
mati=eye(N);
w=sqrt(variance).*randn(N,1);
x0=w;
x1=(a*mat1)+w;

% plotting both distributions
figure;
histogram(x0);
title('white noise only');
figure;
histogram(x1);
```

```
title('constant + noise');


% finding threshold

T=sqrt(2*N*variance)*erfinv(1-2*PFA);


%finding Probability of detection

PD=(1/2)*(1-erf((T-N*a)/sqrt(2*N*variance)));


% probabilities in percentage

Pfa100=PFA*100;

Pd100=PD*100;
```

2.4.2 Results

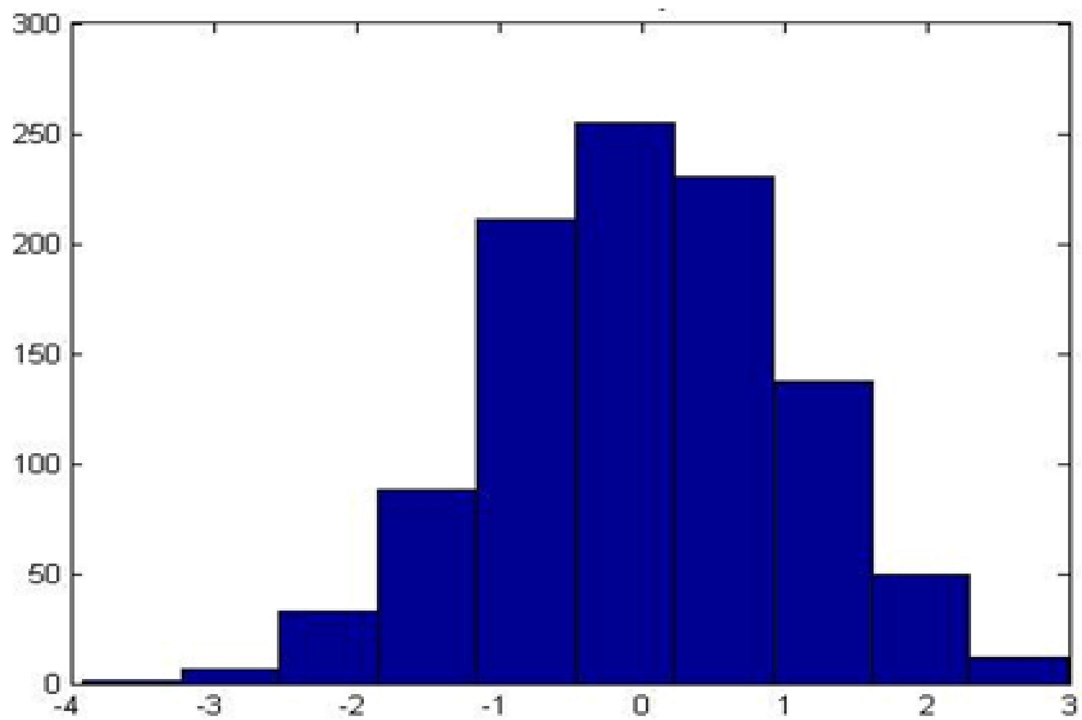


Fig. 2.1 Histogram representing pdf of Gaussian noise

The histogram shown in figure 2.1 generated first displays the pdf of a Gaussian noise signal with its mean at zero. The number of samples ‘N’ is 1024 in this case. The command used for generation of Gaussian noise is ‘randn’ and it is generating a vector of N float numbers centered at zero.

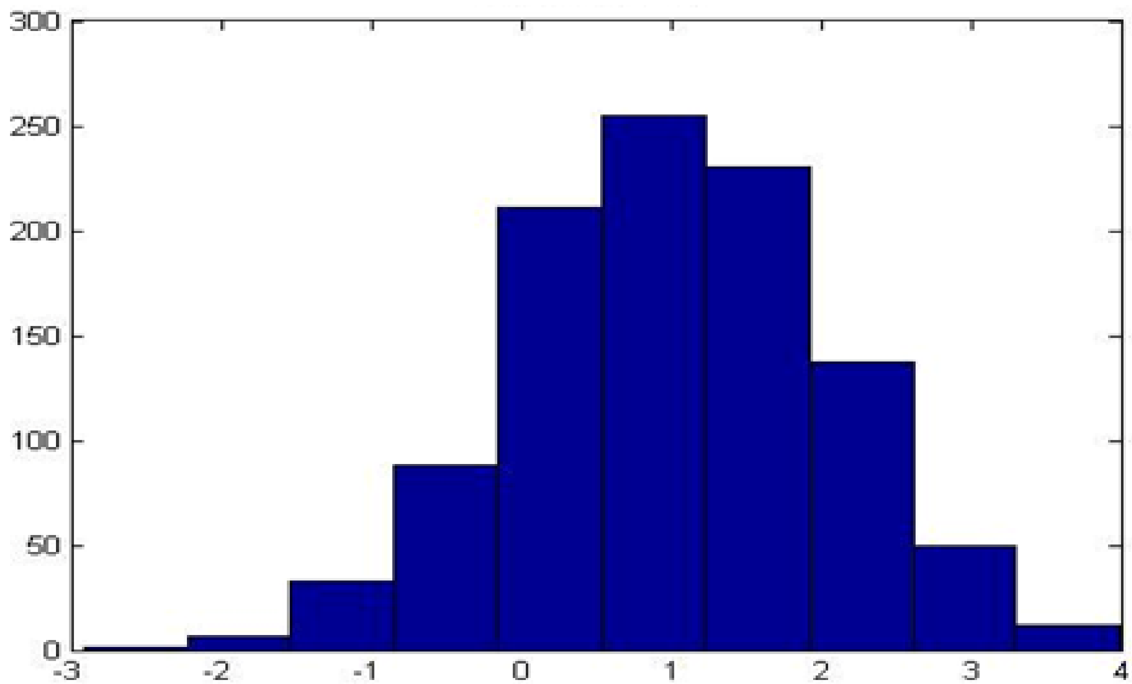


Fig. 2.2 Histogram representing pdf of a constant in Gaussian noise

The histogram in figure 2.2 displays the pdf of Gaussian noise with a constant representing a signal. The histogram is centered on a mean value of 1 since the constant or signal is 1 in this scenario. The sample size used is same for both histograms.

2.5 Simulation of Transmission and Detection

Another Mat lab code was designed to simulate actual transmission, detection and storing of decision in a variable. This code is based on fictional data which can be designed by a programmer but it provides a hint of real transmission and detection scenario in spectrum sensing process. In this code some part of transmission was with signal and Gaussian noise and other part was with only Gaussian noise generated with Mat lab ‘randn’ command. Then threshold is estimated with an assumption on variance of noise (variance of noise was known in our case but in real scenarios it must be estimated to determine the optimum threshold). The received signal was compared with the threshold and decision was taken and stored in Boolean form where 0 represents that hypothesis H1 is selected and 1 represents that hypothesis H2 is selected. This decision is ultimately stored in a vector and displayed on the screen. This vector can be used to verify the probabilities of detection and false alarm by comparing it with the actual transmission.

2.5.1 Matlab Code

```
N=25; %No. of samples
variance=1;
PFA=10^-6;
a=1; %Constant to find in noise
nTx=1000; %no. of transmitted samples
%Transmitted signal
w1=sqrt(variance).*randn(nTx,1);
% signal and noise
for x1=1:200
   Tx(x1)= a + w1(x1);
end
 for x2=201:400
   Tx(x2)= a+w1(x2);
 end
%noise only
 for x3=401:1000
   Tx(x3)= w1(x3);
 end
 % Detection
 T=sqrt(2*N*variance)*erfinv(1-2*PFA);
% detections with sample size N
```

```
 for y=1:nTx/N
    Rx=0;
    for n=1:N
        Rx = Rx+Tx(n*y);
    end
    if Rx>T
        bool(y)=1; %Hypothesis H1 selected
    else
        bool(y)=0; %Hypothesis H0 selected
    end
 end
 bool
 %calculated Probability of detection
PD=(1/2)*(1-erf((T-N*a)/sqrt(2*N*variance)));
% calculated Pmd
PMD=1-PD;
% calculated probabilities in percentage
Pfa100=PFA*100;
Pd100=PD*100;
Pmd100=PMD*100;
```

2.5.2 Results

In this code result was a vector having Boolean values representing absence or presence of signal. This code was tested with an SNR of 25 and a very low value of PFA (10^{-6}) as shown in figure 2.3. It was discussed earlier that PD and PFA are directly proportional, probability of detection is dropped to almost 60%. The detections displayed in the diagram when compared with the transmissions in code also conforms the calculated results.

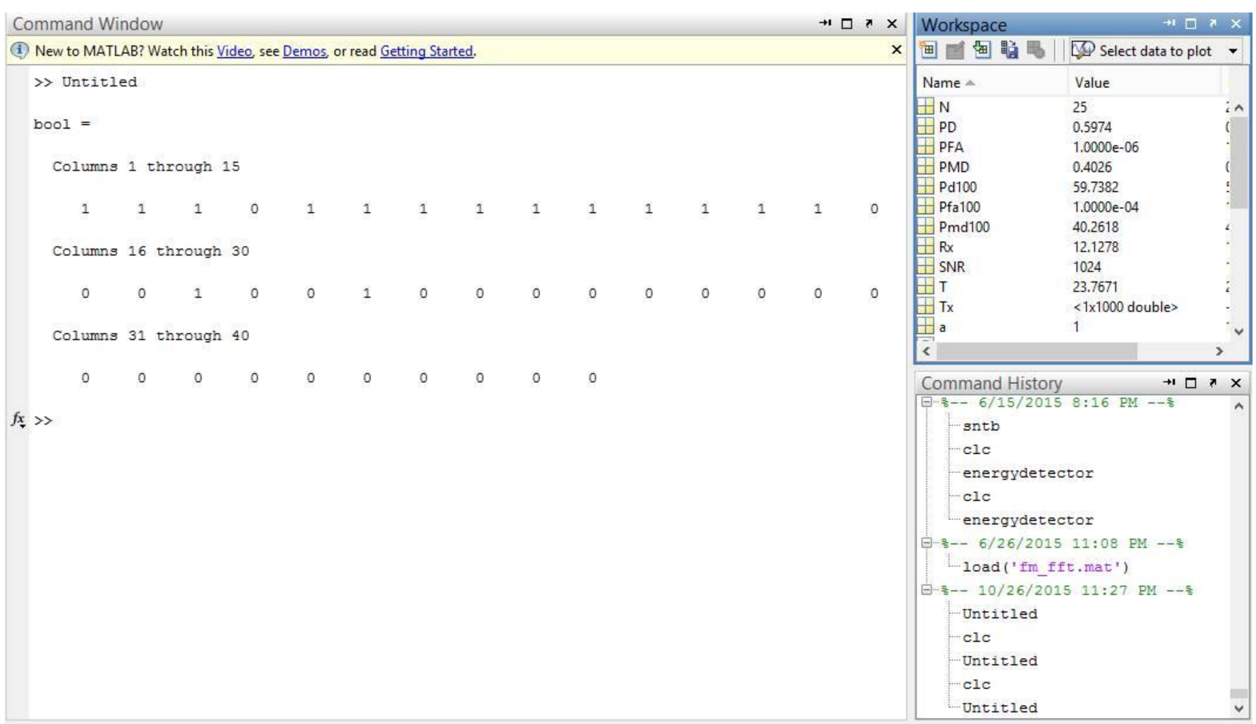


Fig. 2.3 Detection result of Matlab Simulation

CHAPTER 3

Real Time Implementation on FM

In this chapter we will discuss our experiments of FM transmission and reception simulated in GNU environment, their making, testing, simulations and results. Furthermore we will discuss about using Energy Detector in FM to achieve spectrum sensing of live FM, its results which were tested using our previously described Neyman Pearson rule disclosing of achieved results.

3.1 Frequency Modulation

FM is defined as encoding of useful information within a carrier wave by changing frequency of the wave. FM can commonly be seen in environment in applications like radars, radio, seismic monitoring.

It is mainly used for broadcasting speech transmissions. It can also be employed to cancel naturally occurring noise in radio system that is it have better SNR then AM at certain parameters and bands.

Commonly known formula of FM is

$$Xc(t) = Ac \cos(2*pi*Fc*t)$$

3.2 FM Transmission

3.2.1 Introduction

FM transmitter is commonly known as an electronic device which sends radio waves of frequency modulated signal. FM transmitters are most commonly employed for audio devices or car radio which doesn't contain "AUX" input. They can also be used for broadcasting at minimal level for a small amount of users in nearby area. FM transmitter have a range of 100-300 feet, this range generally depends on receiver's quality, height and obstruction to reception end. Generally FM is broadcasted on frequency ranging from 87.5 to 108 MHz in most of the world.

3.2.2 FM Transmitter

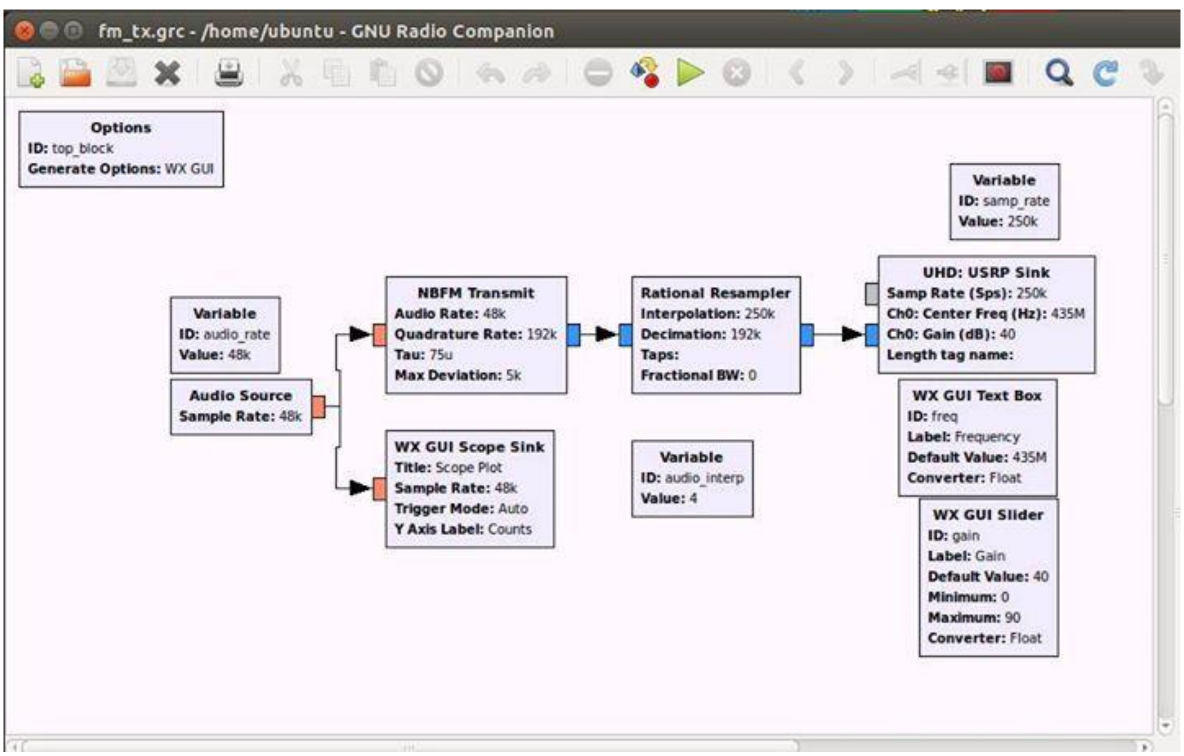


Fig. 3.1 Flow Graph of FM Transmitter

3.2.3 Description

GNU platform on LINUX is utilized for performing the above task (figure 3.1). The audio rate is set to 48k and audio source from library of GNU is used to play through FM Transmitter. Narrow Band FM Transmitter (NBFM) is placed here to conserve the use of additional bandwidth; it is commonly used for voice communication as well. Scope sink provide the constellation of input audio. Rational resampler is a combined version of decimator and interpolator. It perform an essential task of converting sample rate according to need of receiver. USRP sink is used to visualize output of FM transmitter. GUI text box is sued to assign frequency and GUI slider is placed to adjust gain with respect to need.

3.3 FM Reception

3.3.1 Introduction

A receiver is a device that catches signal and convert it into useful information in a medium understandable by humans. A receiver provides output in form of video, Audio or even data.

3.3.2 FM Receiver

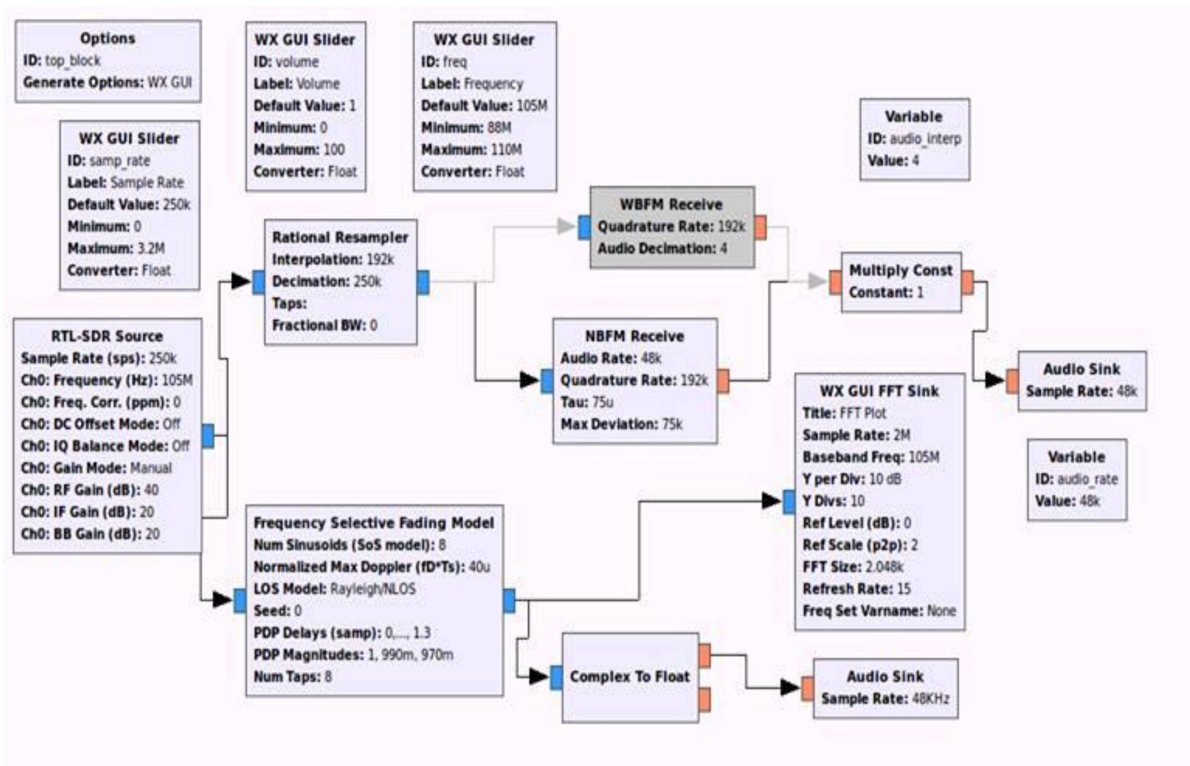


Fig. 3.2 Flow Graph of FM Receiver

3.3.3 Description

As shown in fig 3.2, to receive FM signal we use RTL-SDR as FM reception hook that connects to rational resampler that perform synchronization of sample rate of incoming signal in accordance to receiver need. Both Narrow Band FM and Wide Band FM are connected so we can inspect output of both in GNU environment. Audio sink provide saves or play incoming signals, we also use frequency selective fading model to achieve near to original signal at reception, as most of the time signal get interfered by noise or other distortions resulting in path difference (shortening or lengthening).[10] Frequency selective fading model is connected to complex to float converter, this block convert complex signal in float form so it can be seen at scope as scope need float readings. FFT sink is used to convert signal from time domain to frequency domain for graphical representation an output.

3.4 Spectrum Sensing

3.4.1 Collection of Data

After performing transmission and reception of FM in GNU we use USB Dongle to receive live FM signal of several bands and play it via our FM receiver. Moreover we make use of command “terminal” from built in library of GNU, we were able to take statistical data of live FM in Linux. To perform necessary steps on it and to get some useful outcome from live reception we convert data using terminal from Linux and import it to MS Excel as shown in figure 3.3.

	A	B	C	D	E	F	G	H	I	J
1	linux;	GNU	C++	version	4.8.2;	Boost_105400;	UHD_003.007.003-0-ge10df19c			
2										
3	Using	Volk	machine:	sse4_2_64						
4	gain	=	24.8							
5	2015-06-14	20:22:22.09	center_freq	104093750	freq	104000000	power_db	3.220363568	noise_floor_db	-76.059621
6	2015-06-14	20:22:22.09	center_freq	104093750	freq	104006250	power_db	3.513898489	noise_floor_db	-76.059621
7	2015-06-14	20:22:22.09	center_freq	104093750	freq	104012500	power_db	1.940796921	noise_floor_db	-76.059621
8	2015-06-14	20:22:22.09	center_freq	104093750	freq	104018750	power_db	1.80983574	noise_floor_db	-76.059621
9	2015-06-14	20:22:22.09	center_freq	104093750	freq	104025000	power_db	2.166061119	noise_floor_db	-76.059621
10	2015-06-14	20:22:22.09	center_freq	104093750	freq	104031250	power_db	2.999883713	noise_floor_db	-76.059621
11	2015-06-14	20:22:22.09	center_freq	104093750	freq	104037500	power_db	3.326645785	noise_floor_db	-76.059621
12	2015-06-14	20:22:22.09	center_freq	104093750	freq	104043750	power_db	3.067487093	noise_floor_db	-76.059621
13	2015-06-14	20:22:22.09	center_freq	104093750	freq	104050000	power_db	1.399435384	noise_floor_db	-76.059621
14	2015-06-14	20:22:22.09	center_freq	104093750	freq	104056250	power_db	3.084065731	noise_floor_db	-76.059621
15	2015-06-14	20:22:22.09	center_freq	104093750	freq	104062500	power_db	2.926836492	noise_floor_db	-76.059621
16	2015-06-14	20:22:22.09	center_freq	104093750	freq	104068750	power_db	4.200423467	noise_floor_db	-76.059621
17	2015-06-14	20:22:22.09	center_freq	104093750	freq	104075000	power_db	3.803366249	noise_floor_db	-76.059621
18	2015-06-14	20:22:22.09	center_freq	104093750	freq	104081250	power_db	2.377576802	noise_floor_db	-76.059621
19	2015-06-14	20:22:22.09	center_freq	104093750	freq	104087500	power_db	2.290610615	noise_floor_db	-76.059621
20	2015-06-14	20:22:22.09	center_freq	104093750	freq	104093750	power_db	2.892177737	noise_floor_db	-76.059621
21	2015-06-14	20:22:22.09	center_freq	104093750	freq	104100000	power_db	4.846375714	noise_floor_db	-76.059621
22	2015-06-14	20:22:22.09	center_freq	104093750	freq	104106250	power_db	5.28191183	noise_floor_db	-76.059621
23	2015-06-14	20:22:22.09	center_freq	104093750	freq	104112500	power_db	3.980748693	noise_floor_db	-76.059621
24	2015-06-14	20:22:22.09	center_freq	104093750	freq	104118750	power_db	6.115904322	noise_floor_db	-76.059621
25	2015-06-14	20:22:22.09	center_freq	104093750	freq	104125000	power_db	7.523809986	noise_floor_db	-76.059621
26	2015-06-14	20:22:22.09	center_freq	104093750	freq	104131250	power_db	9.071072843	noise_floor_db	-76.059621
27	2015-06-14	20:22:22.09	center_freq	104093750	freq	104137500	power_db	8.999748537	noise_floor_db	-76.059621
28	2015-06-14	20:22:22.09	center_freq	104093750	freq	104143750	power_db	9.840038549	noise_floor_db	-76.059621
29	2015-06-14	20:22:22.09	center_freq	104093750	freq	104150000	power_db	9.703991654	noise_floor_db	-76.059621

Sheet1

Fig. 3.3 Osmocom_spectrum_sense result imported on MS excel

3.4.2 Utilization of code

The Neyman Pearson rule as previously described in detail in chapter 2 is brought to light and above data placed in matrix from in code and following output is achieved. The threshold used this time is arbitrary but the idea was to integrate the simulation code with original spectrum sensing data and generate the detection results.

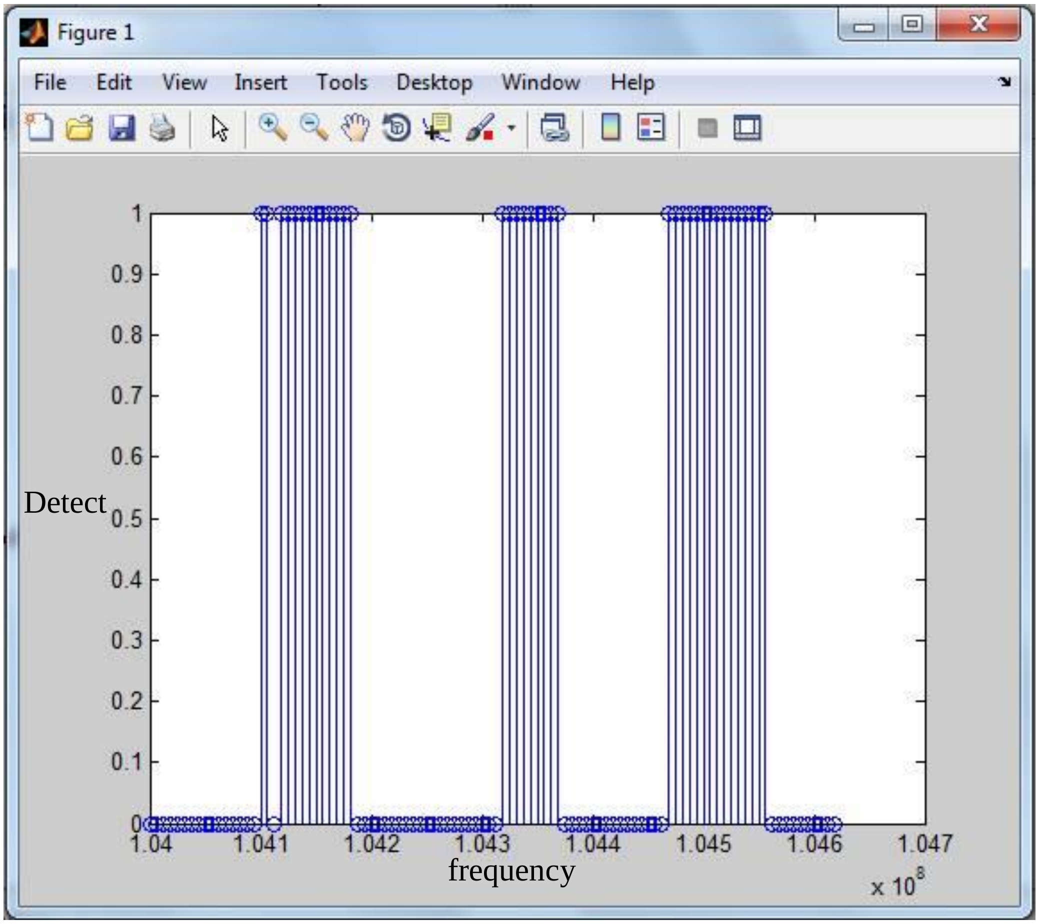


Fig. 3.4 FM detection result on Matlab simulation

3.4.3 Results

In our next step toward spectrum sensing, we achieve spectrum sensed output of live FM showing underutilized or unused (white spaces) and crowded spectrum, providing an inner view of FM spectrum and bringing to light the free spaces in a tested small chunk of spectrum.

3.5 FFT plot of FM

To determine the actual threshold of FM signals FFT plot of the signal is required since it tells the power of the signal at a particular range of frequencies.

3.5.1 Detection using RTL SDR

The flow graph presented below in figure 3.5 gives multiple graphs of received signal namely FFT, scope, waterfall and constellation.

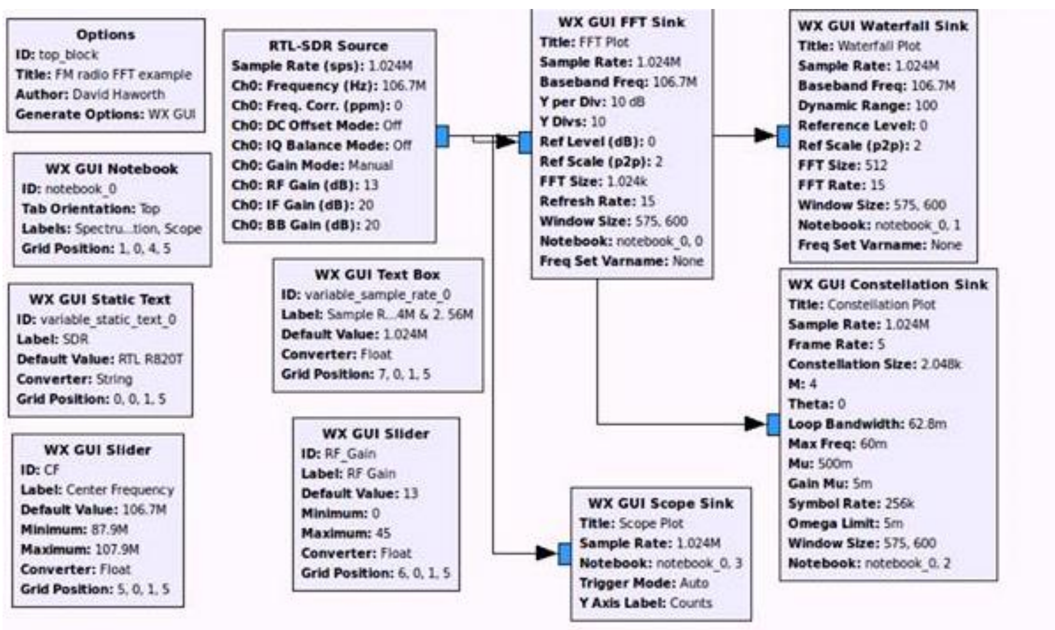


Fig.3.5 Flow graph for FFT graph of FM.

3.5.2 FFT plot

It can be clearly seen in the FFT graph (figure 3.6) that the signal is centered on 105 MHz; since the frequency deviation used by our FM stations is 75 kHz, signal approximately have its amplitude decreased to noise level at 75 kHz on both sides of 105 MHz . The amplitude of noise is no more than -74dB in this plot so corresponding power can be calculated for the power estimation.

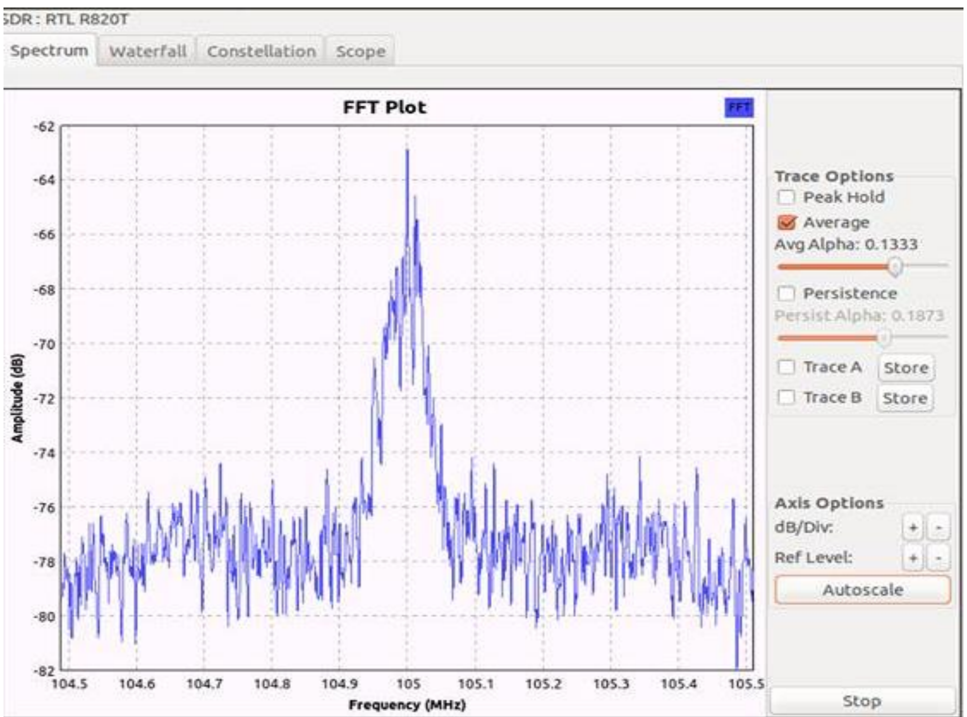


Fig. 3.6 FFT plot of 105 MHz

3.5.3 Waterfall plot

Waterfall plot is another useful tool for spectrum sensing and it tells the 'extent' of presence of a signal in a frequency range. Waterfall plot presented in figure 3.7 illustrates presence of signal in 105 MHz channel (abundance of green color line) in the background noise (green color dots).

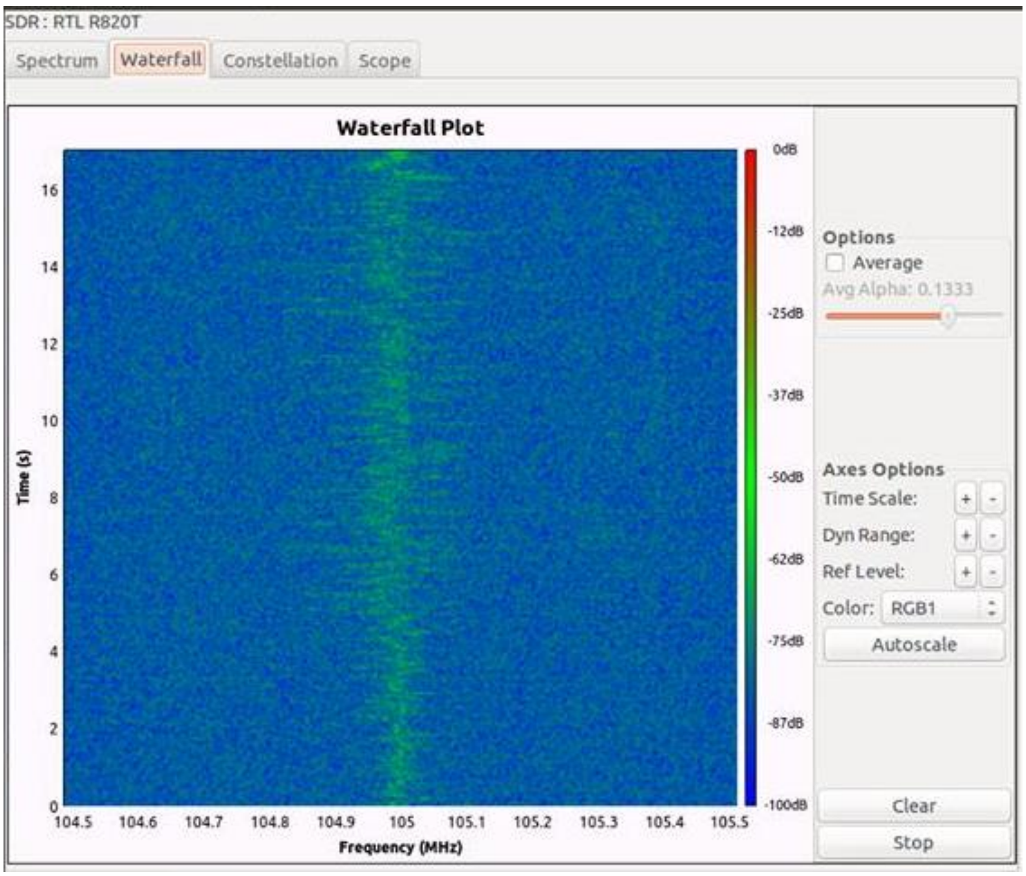


Fig. 3.7 Waterfall plot of 105 MHz

3.6 Energy Detection on FM

3.6.1 Introduction

Energy detection is a novel way of sensing white spaces in spectrum or given frequency bands. The advantage of energy detection over other signal detector is that it doesn't need prior knowledge of signal parameters. It consists of some novel parameters that include sample rate calculation, estimating noise power and detection threshold clearing the path for detection.

Energy detection is done on following hypothesis:

Signal is absent: 0 (H1)

Signal is present: 1 (H2)

This depends on state of primary/license user is either idle or busy, along the noise interference with all the parameters. Secondary user can be modeled on the basis of above hypothesis. Energy detector measures energy of received signal with respect to time duration and bandwidth. This measured value is later compared to threshold weather primary user is present or not.

3.6.2 Energy Detection in GRC

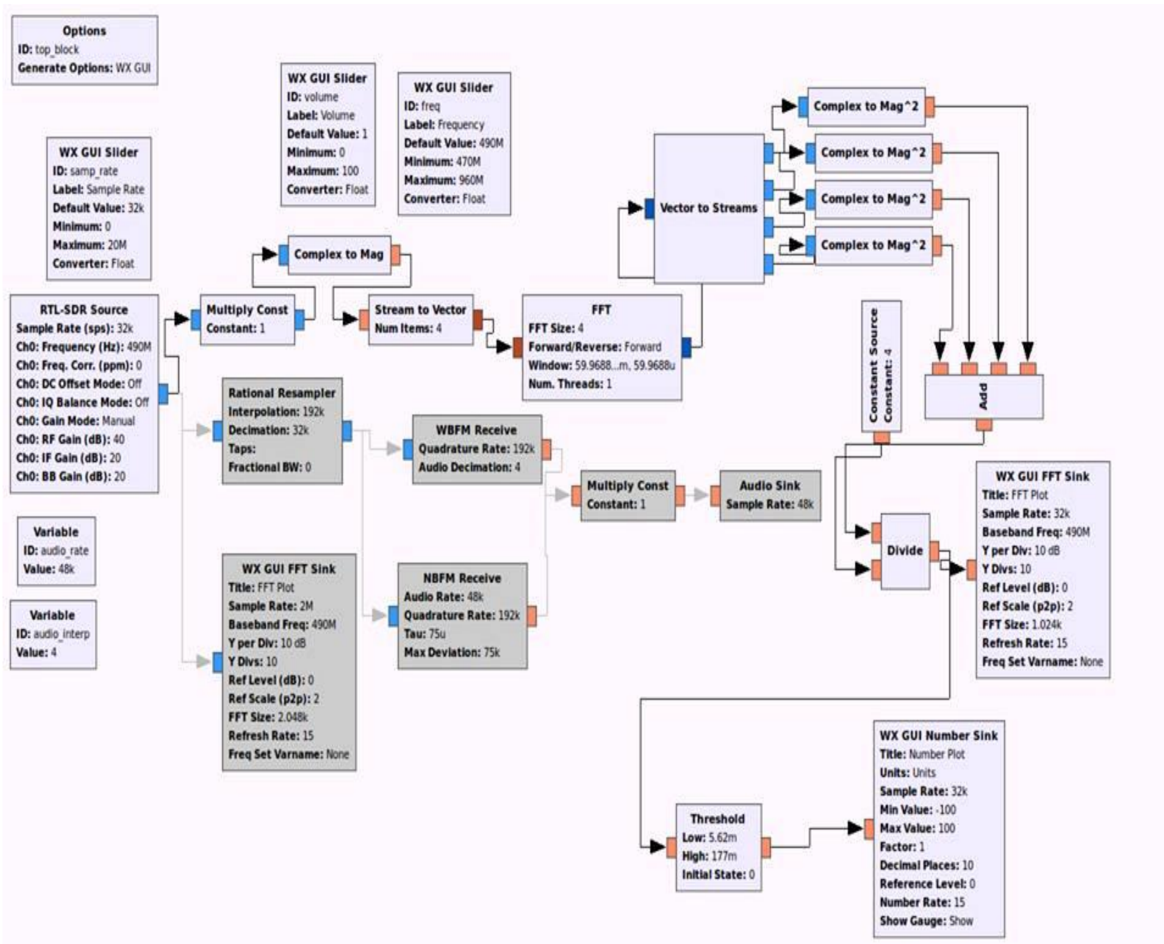


Fig. 3.8 Flow Graph of Energy detection of FM signals

3.6.3 Working

FM energy detection was made to provide two real world simulations one in form of FFT and other to listen and store live FM via audio sink as shown in figure 3.8. Rational resampler, Narrow band FM and Wide band FM are described previously; we will now use another way of energy detection. Here FM band is sensed by energy detector and readings were converted into magnitude from complex form. Now to perform FFT stream of magnitude is converted to vector form, it again converted to stream from vector which later convert complex stream into magnitude, adding all and dividing by equal interval, at this point a probe is added to spectate FFT output and finally the value is compared to threshold which complete energy detector and final output of spectrum sensing can be seen in number sink scope.

3.6.4 Outcome

We achieved spectrum sensed output of FM 105, readings were taken in urban area of Karachi at 105 MHz the spectrum was completely occupied and Energy Detector shows presences of signal, while same testing at 105.4 MHz shows spectrum is empty and can be utilized. Thus spectrum sensing through energy detector provide accurate real world results in figures 3.9.

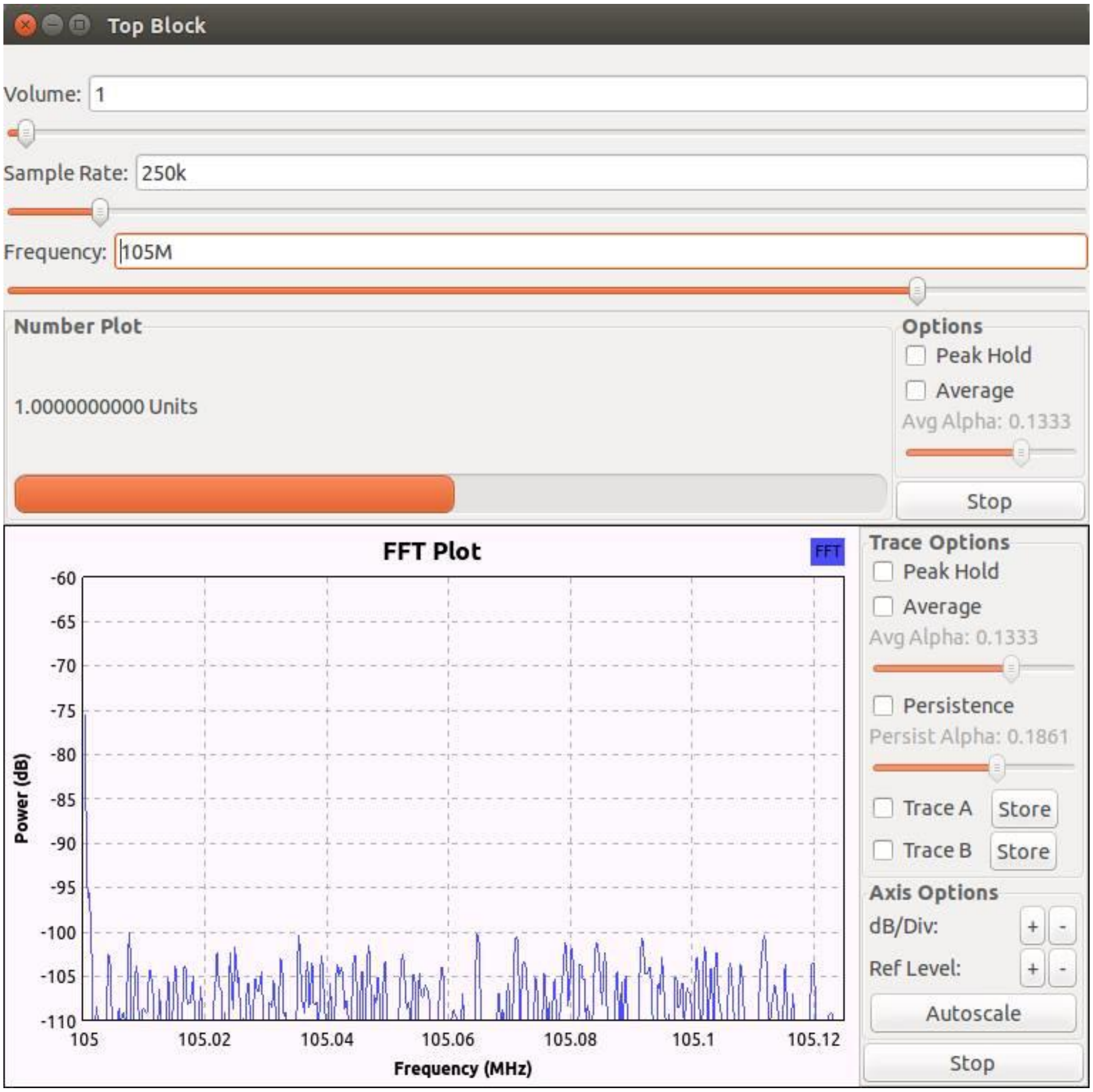


Fig. 3.9a Energy detection result of FM in real world scenario (signal present)

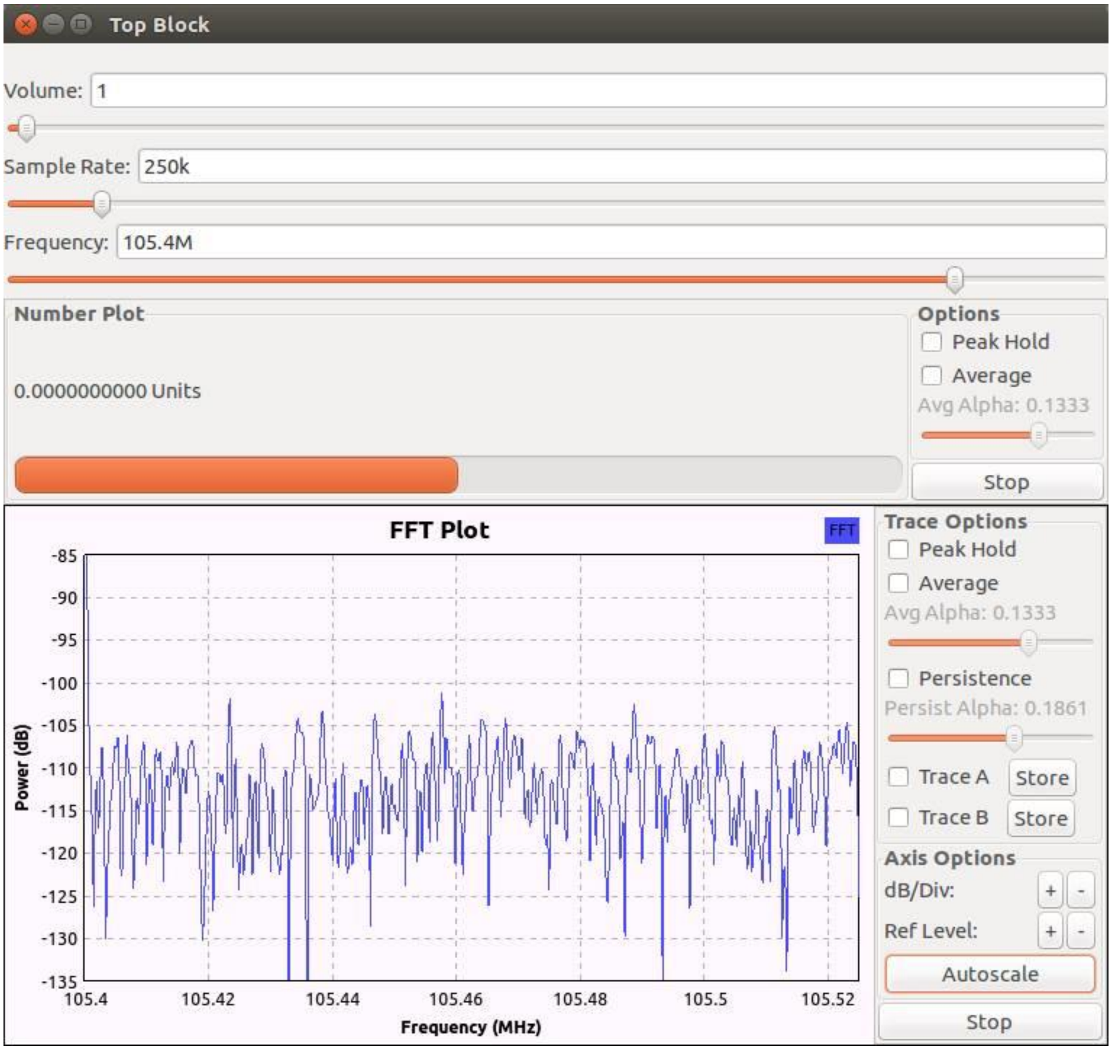


Fig. 3.9b Energy detection result of FM in real world scenario (signal absent)

CHAPTER 4

OFDM Simulation

4.1 Orthogonal Frequency Division Multiplexing

The main focus of this chapter is to implement OFDM system Using GNU radio. It is a special case of MCM multi carrier modulation scheme in which data which is modulated Symbols in parallel or orthogonal subcarrier .the main idea behind OFDM system is to separate high data rate into N parallel low data sub streams that can be modulated on N orthogonal sub carriers[2]. Process of OFDM made in discrete time Domain with N point (IFFT) inverse fast Fourier transform or (IDFT) inverse discrete Fourier transform & finally in sequence resulted signal can be transmitted at receiver end & information can be retrieved by DFT/FFT unit[3].

4.1.1 Advantages of OFDM

- Spectrum can be used efficiently by permission of over lap
- Cyclic prefix removes ISI & IFI
- Maximum likely hood decoding can be used with some complexity.
- It provides protection against the influence of impulsive parasitic noise &co channel interference[3]
- FFT techniques make OFDM more computationally efficient for implementation of modulation and demodulation functions[2].

4.1.2 Disadvantages of OFDM

- Sensitive phase noise & frequency offset
- Significant power loss and Capacity due to guard interval which could have been 20% like in IEEE 802.11a
- Signal- Carrier system compared with the increased (PAPR) peak to average power ratio.

4.1.3 Block Diagram of OFDM

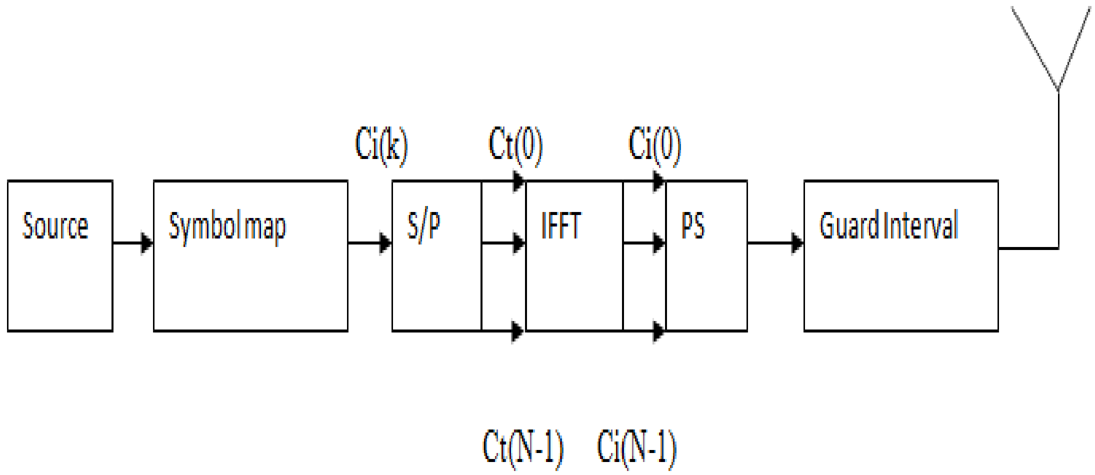


Fig. 4.1a Block Diagram of OFDM transmitter

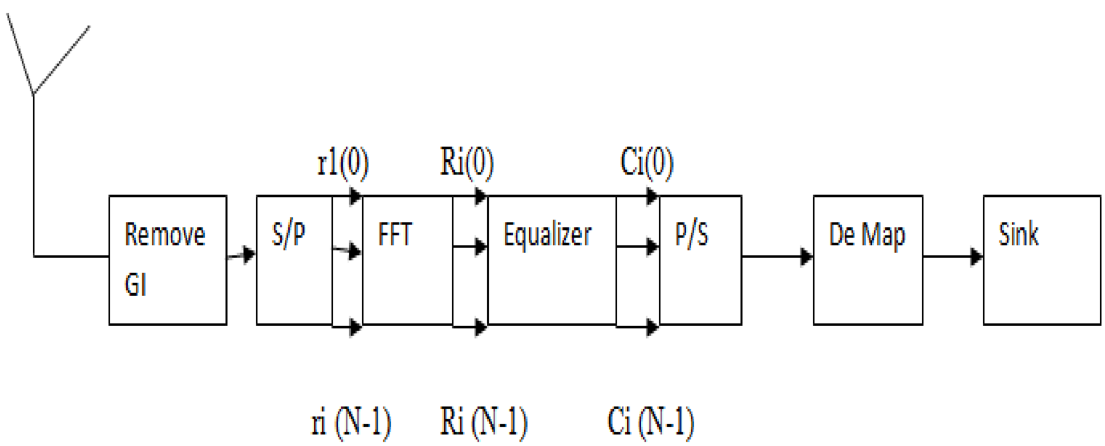


Fig. 4.1b Block Diagram of OFDM receiver

4.1.4 Working of OFDM Transmitter

- From the transmission end bit stream is broken in group of K bits
- The modulated symbol (complex symbol) corresponding to each group of K bits mapped by symbol mapping block[2]
- Complex number will be placed into a vector
- (IFFT) inverse Fourier transform will be computed
- At the end Guard Interval (GI) will be added then results will be fed to the up converter.

4.1.5 Working of OFDM Receiver

- First of all at receiving end signals will be received from down converter & Guard Interval (GI) will be removed.[4]
- Complex signal will be placed into vectors.
- (FFT) Fast Fourier Transform will be computed
- Received Signal which is resulting signal will be fed to equalizer block
- To get original signal it will be passes through De Map Block

4.1.6 Synchronizations in OFDM System

Huge performance degradation in orthogonal property with sub carriers is caused due to error in multi carriers' frequency & timing. Synchronization in frequency & timing is very necessary in building a wireless communication system. Main objectives of synchronization function is to get significant parameters like frequency offset, frame & sampling clock from signal which is received from down converter for reliable transmission. Synchronization objectives can be identified in OFDM System through following.[5]

- **Sampling clock synchronization:**

  When we go through some practical systems we will get little bit difference b/w corresponding frequency which is transmitted & frequency of sampling clock.

- **Timing Synchronization:**

  The main objectives of timing synchronization is detection of start of each received OFDM frame & OFDM symbol

- **Frequency Synchronization:**

  It is used for correction of errors between frequencies which are transmitted through transmitter & receiver frequencies.

4.1.7 Theoretical OFDM Spectrum

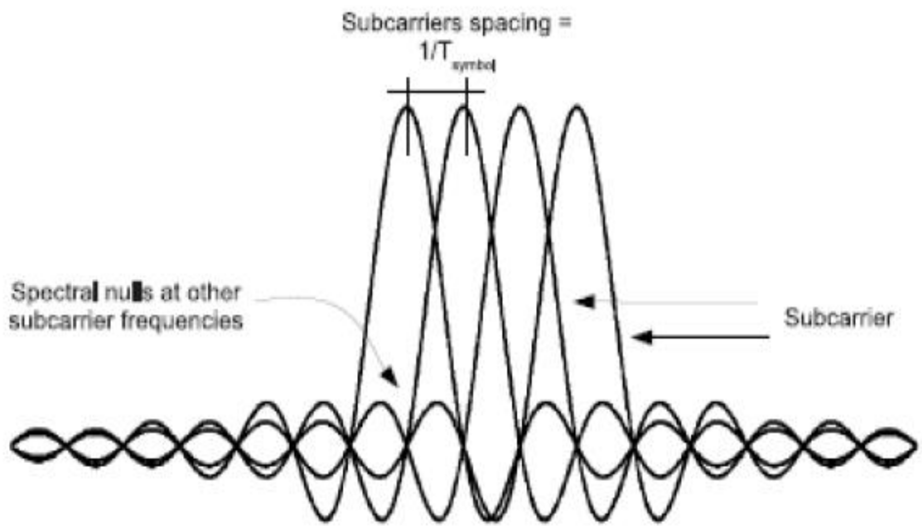


Fig. 4.2 Theoretical OFDM Spectrum

4.1.8 OFDM Systems Performance in different propagation environments

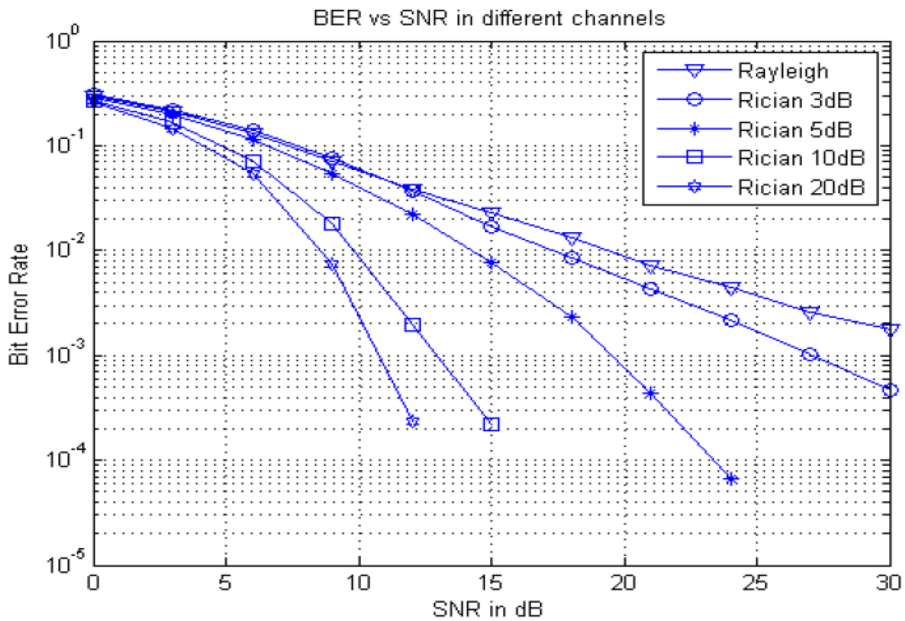


Fig. 4.3 OFDM in different fading environments

4.1.9 Implementation of OFDM in GRC

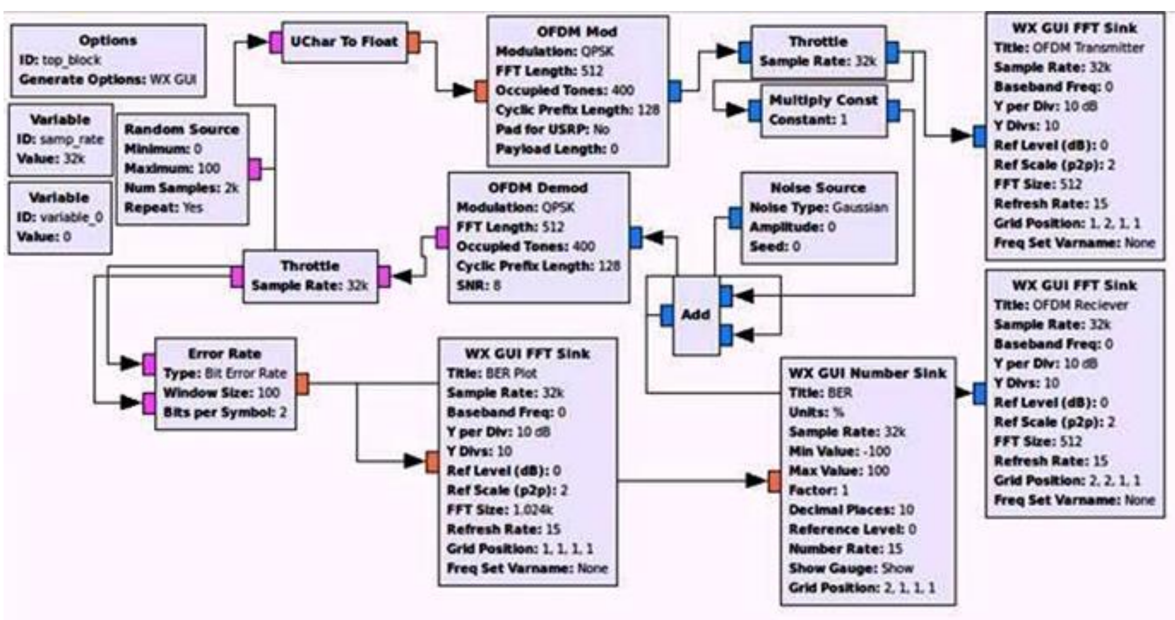


Fig.4.4 OFDM Transmitter & Receiver using GNU Radio Companion

4.1.10 Results

Here we have shown the results obtained using above flow graph. It includes FFT plots of OFDM transmitter and receiver.

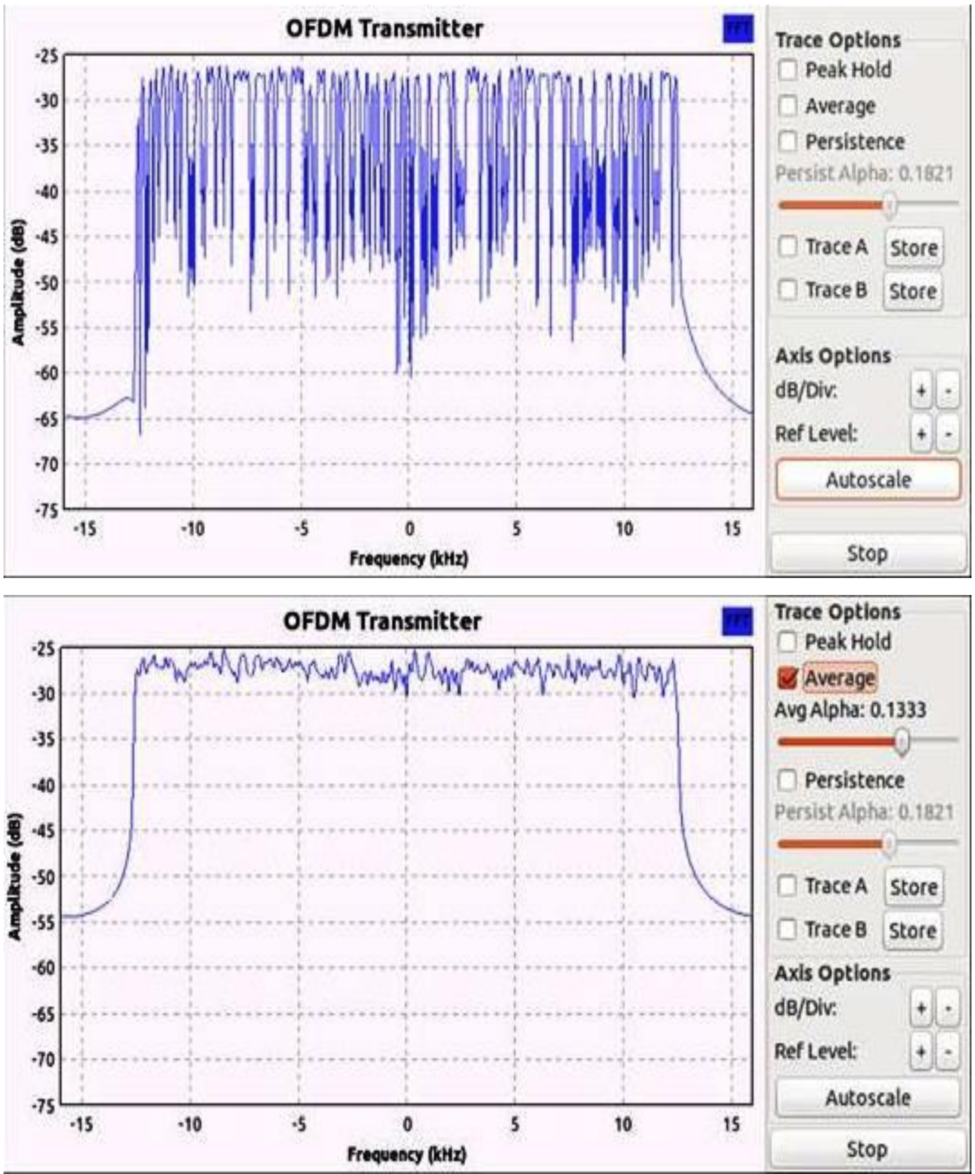
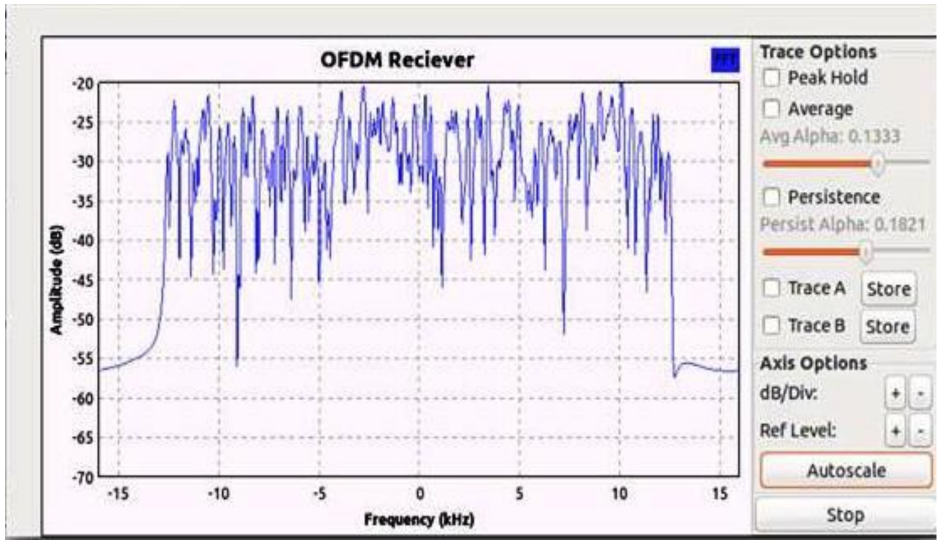


Fig. 4.5a OFDM Transmitter FFT plot



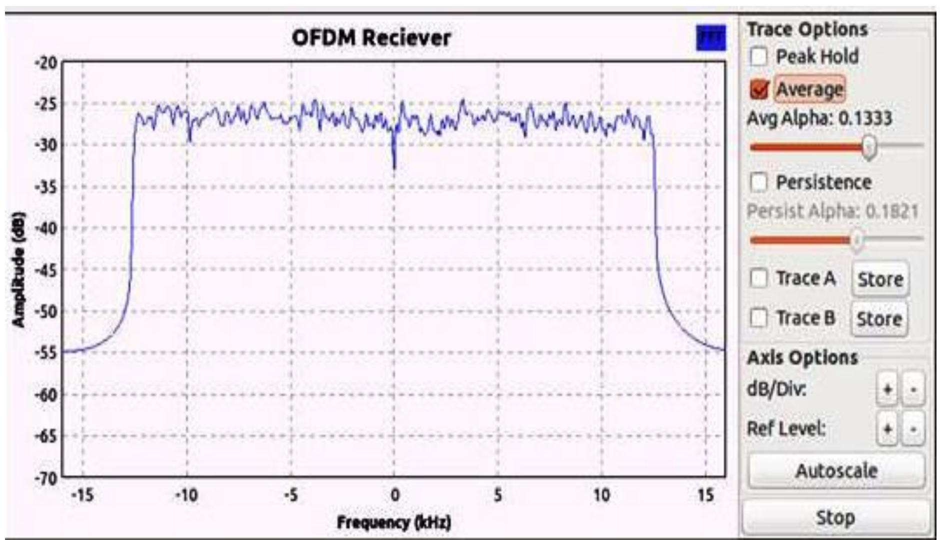


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Fig. 4.5b OFDM Receiver FFT plot

Bit Error Rate (BER) of a transmission system is an important parameter to decide the feasibility of channel and transmission frequency. Above simulation flow graph also calculates the BER of the simualted system. It is represented in the form of instantaneous percentage and a graph BER with respect to time.

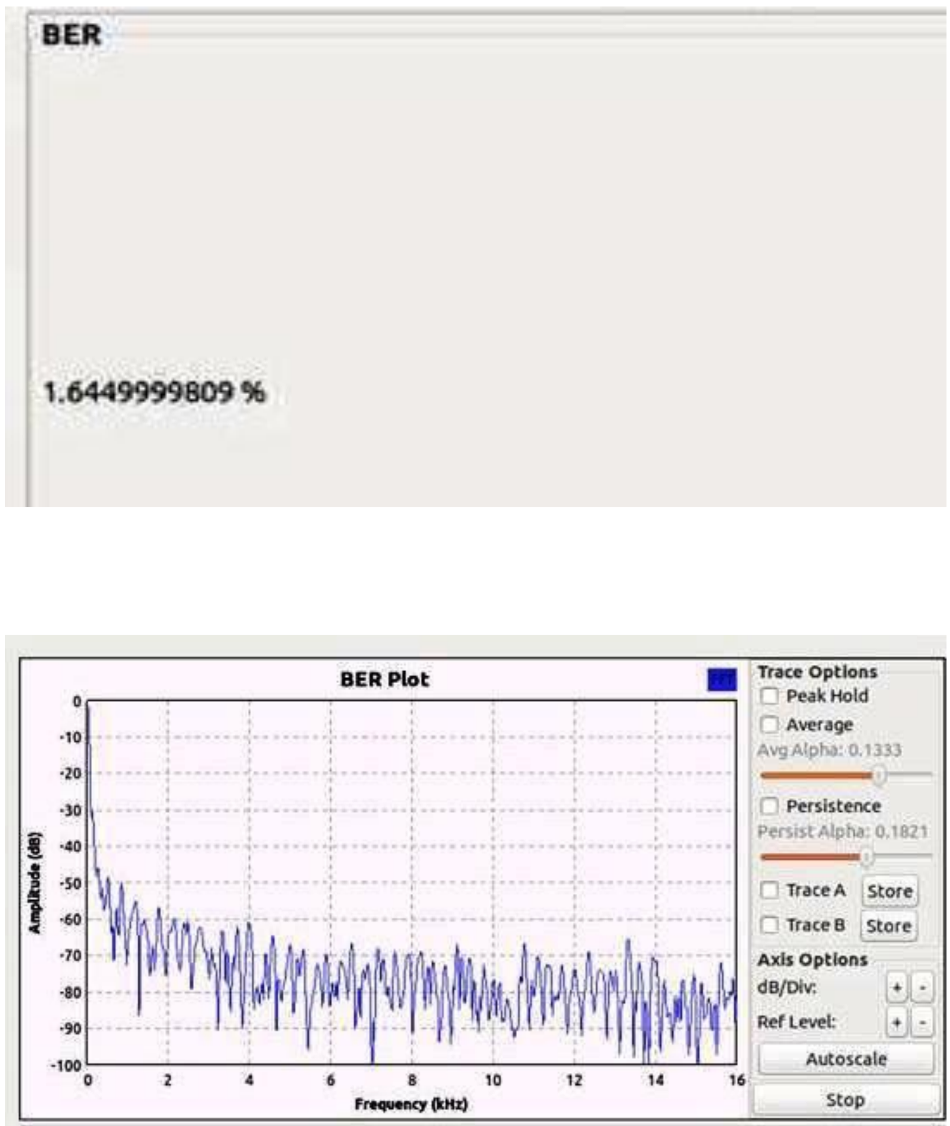


Fig. 4.6 BER calculation of OFDM Simulation

CHAPTER 5

Energy Detection of DVB-T Signal in GRC

5.1 Introduction

In the previous chapter, we discussed about spectrum sensing for the presence of FM signals using Energy Detection technique. We also presented the results of energy detection carried out on FM bands that are currently running in our part of the world.

We now move our attention towards our main objective, which is Energy Detection of the DVB-T signal. But before we go straight into the implementation, it is better to have some knowledge of Digital Video Broadcasting and its various standards.

Digital Video Broadcasting (DVB) is a set of standards for digital television which are internationally acknowledged. These standards are published by the Joint Technical Committee (JTC) of the European Telecommunications Standard Institute (ETSI) and European Broadcasting Union (EBC), and are preserved by the DVB Project which is an international association having more than 270 members.

A number of variations of the DVB standard exist, each having a variety of approaches to distribute data. These variations are as follows:

- **Satellite:** This variation includes three standards which are DVB-S, DVB-S2 and DVB-SH.
- **Cable:** This variation includes standards DVB-C and DVB-C2.

- **Terrestrial:** Standards DVB-T and DVB-T2 form part of the terrestrial variation. DVB-H and DVB-SH are standards for terrestrial television used by handheld devices.
- **Microwave:** The microwave variation uses DVB-MT, DVB-MC and/or DVB-MS

All these variations differ in the modulation schemes and the error correcting codes used due to different technical constraints and to suit their applications.

Now that we are a little familiar with the DVB standard, we will be moving towards the main objective of this chapter. However energy detection of the DVB-T signal is not as easy as that of the FM signal. The reason for this is that there is no terrestrial transmission of the DVB signal in Pakistan.[6] Hence, before we could go ahead with the detection, we have to design a transmitter that could get the DVB-T signal into the air and we also have dig into the DVB-T specifications[7]. Figure 5.1 is the block diagram of the DVB-T transmitter, as specified by ETSI.

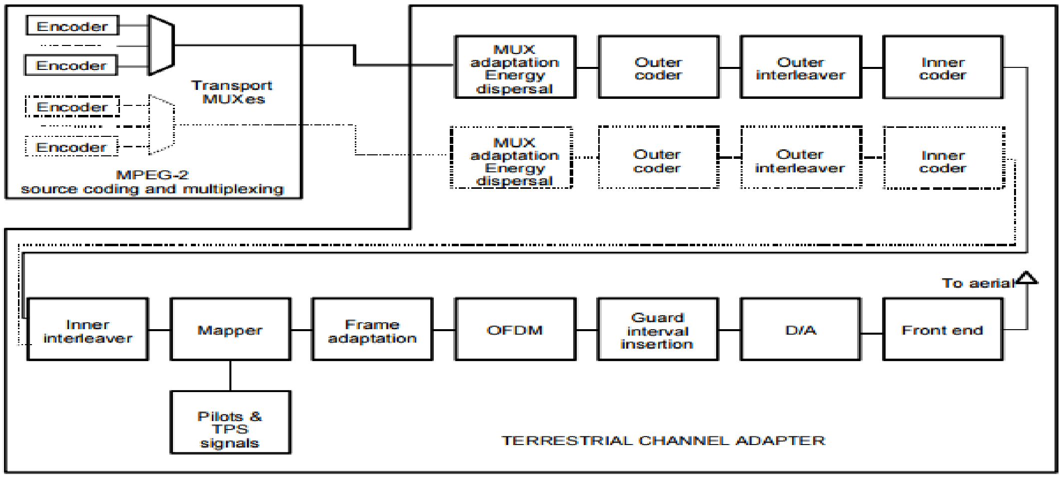


Fig. 5.1 The functional block diagram of the DVB-T system [6]

5.2 DVB-T Transmitter

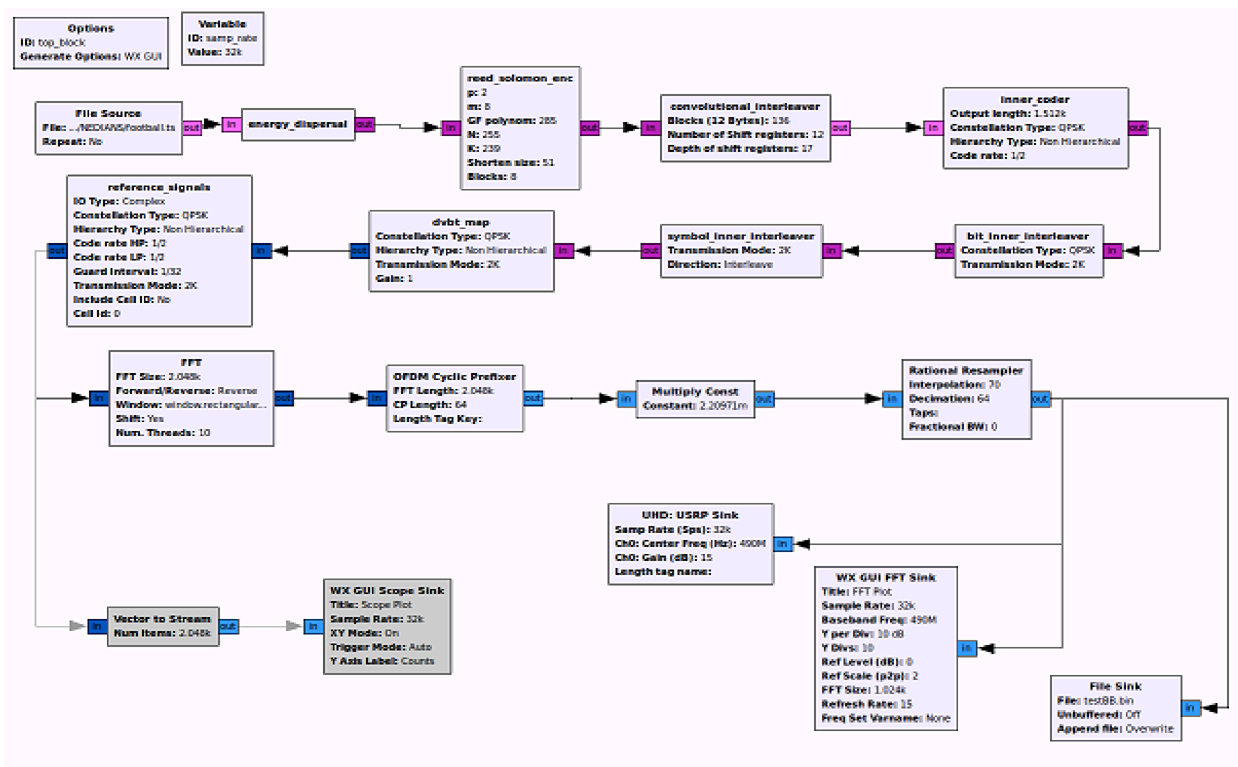


Fig. 5.2 Flow graph of DVB-T transmitter

5.3 Description

5.3.1 Energy Dispersal

The spectrum of the information signal (MPEG-2) is dispersed to reduce interference to other services that are close in frequency. The actual data is XORed with a pseudorandom binary sequence to obtain a dispersed signal. This block also creates MUX frames by multiplexing 8 packets each of 188 bytes.

The generator polynomial of the Pseudo Random Binary Sequence is $1 + X^{14} + X^{15}$

5.3.2 Outer Coder (Reed Solomon Coder)

The error correcting code used is the Reed Solomon Coder, in which the message to be transmitted is divided into blocks of data. It is represented as RS(N,K) where N is the total number of symbols in the codeword, K is the number of message symbols, and N-K is the number of parity symbols added to the message symbol for error correction. The number of symbols in the codeword are defined by the following equation:

$$N \le 2^m - 1 \quad ,$$

where m is the number of bits in the every message symbol. This code can correct upto T errors which is found using the following relation:

$$T = (N-K)/2 \qquad \text{for } (N-K) = \text{even}$$

OR

$$T = (N-K-1)/2 \qquad \text{for } (N-K) = \text{odd}$$

The DVB-T standard uses a RS(255,234; T=8) code. However, this code is shortened to form RS(204,188; T=8) code because a TS packet (MPEG-2 packet) has 188 bytes. This specifies that a 16 parity symbols are added to a 188 byte message symbol to form a codeword of 204 bytes. Such a Reed Solomon Coder can correct upto 8 errors. [6]

5.3.3 Outer Interleaver (Convolutional Interleaver)

Interleaver is a device that takes symbols from an alphabet as the input and returns the identical symbols at the output but in a different sequence. The purpose of interleaving is to disperse the sequence of bits in a bitstream so that burst errors are minimized. The outer interleaver does not provide any error correction but is used to arrange the symbols so as to prepare for error correction of long burst errors. The DVB-T standard uses a convolutional interleaver instead of a block interleaver, because the latter requires more storage capacity and is less sensitive against periodic disturbances. The convolutional interleaver used has an interleaving depth, which represents the number of bytes in each block, of I=12 and base delay, which refers to the minimum separation at the output between two adjacent input symbols, of M=17. (M= N/I). This ensures that adjacent bytes are separated by 204 bytes and the total delay for all symbols is M * (I-1) * I

5.3.4 Inner Coder

The outer interleaver is followed by an inner coder. The purpose of this inner coder is to provide protection at the bit level. A convolution encoder with a code rate of 1/2 is used. Thus, for every input bit two bits are calculated at the output. This results in high redundancy (50%), which is normally reduced by a puncturing mechanism, whereby not all output bits are transmitted. The DVB-T standard specifies code rates of 1/2, 2/3, 3/4, 5/6 and 7/8.[13]

5.3.5 Inner Interleaver

The next block is that of an inner interleaver, which in the case of DVB-T consists of a combination of bit interleaver and symbol interleaver. In the bit interleaver 126 successive bits are combined to form a block, which are then interleaved within this block. On the other hand, the symbol interleaver is a pseudorandom sequence interleaver and changes the temporal order of the symbols. Therefore, in this way, interleaving within every DVB-T symbol is achieved.

The input to the bit interleaver is de-multiplexed into v streams, with v=2 for QPSK, v=4 for 16-QAM and v=6 for 64-QAM, the three modulation schemes compatible with the DVB-T standard. The input stream is divided into v streams when using the non-hierarchical mode. On the contrary, in the hierarchical mode, high priority stream is broken into two streams while the low priority stream is broken into v-2 streams. Since each stream is interleaved by a separate interleaver, there are up to six interleavers (block size of 126 bits), each having a different permutation function. This makes the interleaving process to repeat twelve times per OFDM symbol in the 2K mode and forty eight times in the 8K mode.

The symbol interleaver maps the output of the bit interleaver onto 1512 (2K mode) or 6048 (8K mode) active carriers per OFDM symbol (Block size of 1512 or 6048 respectively). The output vector, hence, contains either twelve or forty eight groups of 126 data words.

5.3.6 Mapper

The DVB-T system uses Orthogonal Frequency Division Multiplex (OFDM) transmission. OFDM is a multicarrier transmission technique that is used to accomplish a high data rate in an environment that exhibits multipath fading. The available spectrum is divided into a number of subcarriers which are made orthogonal (independent) to one another. The subcarriers can, therefore, be arranged close to one another without the need for individual guard band overhead. [9] The individual carriers of the OFDM signal can be modulated by using QPSK, 16-QAM or 64-QAM modulation techniques [8]. This means that two, four or six bits are assigned to each carrier using Gray coding. The parameter α determines the exact proportion of the constellation. A can have values of 1, 2 or 4. Figure 3 shows the constellation diagrams of the three systems for α=1.

The DVB-T system enables the use of hierarchical modulation [7]. This means that two independent data streams can be sent in one signal using different modulation techniques. For example, one data stream (high priority) can be sent using QPSK, while the other data stream (low priority) is sent using 16-QAM. However, the data rate and performance under errors will be different for the two streams. The high priority stream will be transmitted at a low data rate but will be more robust to errors, while the low priority stream will be transmitted faster and will be less robust to errors.

In our project we have used QPSK with non-hierarchical transmission mode.

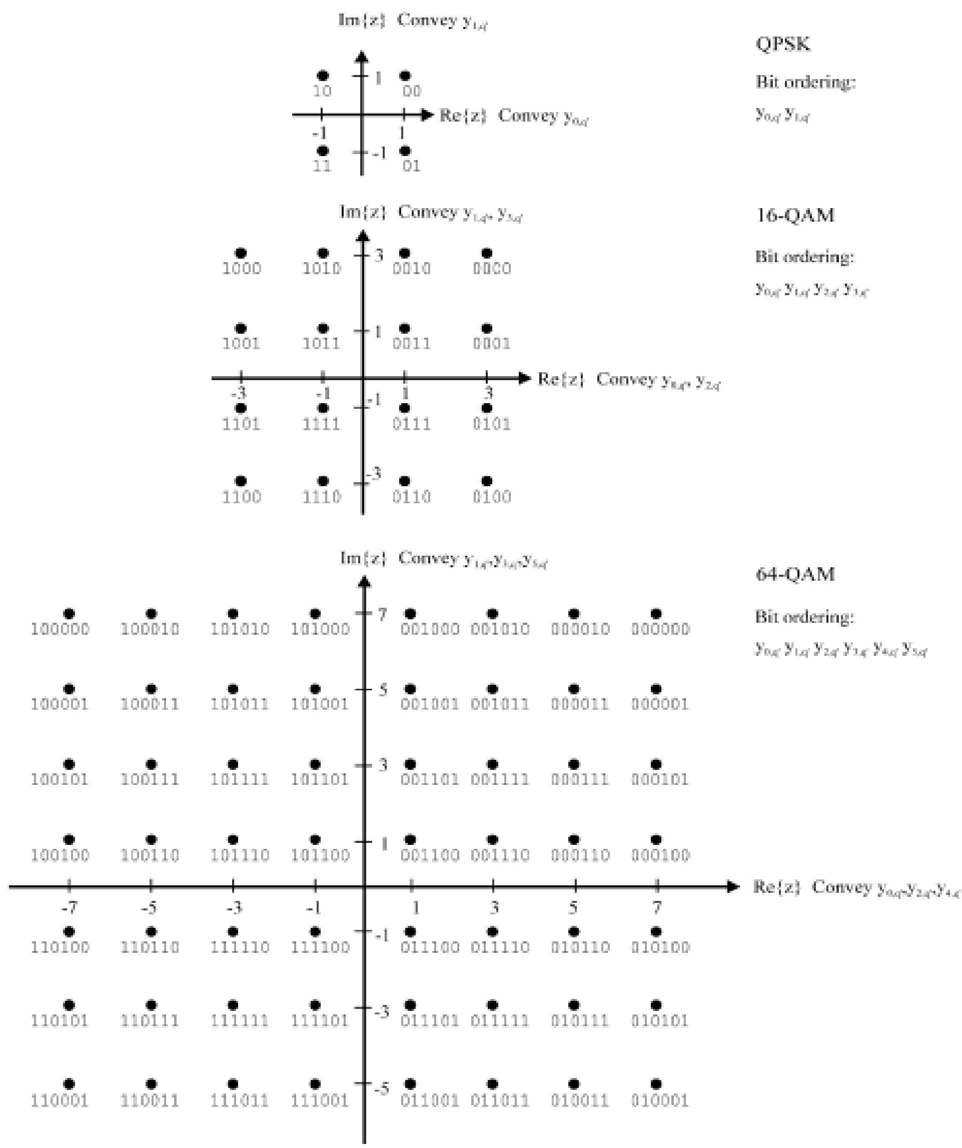


Fig. 5.3 QPSK, 16-QAM and 64-QAM mapping and their bit patterns (for α=1) [6]

5.3.7 OFDM Frame Structure

The signal is then organized into frames, each consisting of 68 symbols. Four consecutive frames make up a super frame. The OFDM symbol consists of either 1705 (2K mode) or 6817 (8K mode) carriers. Each symbol begins with a guard interval which is a cyclic repetition of the symbol. The main reason for using guard interval is to provide protection to the symbol against echoes and reflections. The echoes must be smaller than the guard interval so that the useful symbol is not corrupted, and can easily and accurately be decoded at the receiver. The length of the guard interval relative to the useful symbol can take up values of 1/4, 1/8, 1/16 or 1/32.

5.3.8 Reference Signals Block

The DVB-T standard adds three types of pilots to the OFDM frame to support synchronization and equalization at the receiver: Continual Pilot, Scattered Pilot and Transmission Parameter Signaling (TPS) Pilot. The amplitude of these pilots is kept higher than the data symbols so that they are more immune to transmission errors. The TPS pilots, in particular, tell about the functioning parameters of the system and are modulated by Differential Binary Phase Shift Keying. This means that there is one TPS pilot for every symbol in the frame, thereby making a total of 68 TPS pilots in one OFDM frame. These 68 bits are distributed as : 1 initialization bit, 16 synchronization bits, 37 information bits (of which 31 are used while the remaining 6 are set to zero) and 14 redundancy bits for protection against errors. The TPS data is sent on 17 or 68 carriers for 2K or 8K modes respectively for immunity against frequency selective channel distortions.

The reference signals block used in our project has a guard interval of 1/32.

5.3.9 Inverse Fast Fourier Transform

After the symbols are assigned to each of the subcarriers, the symbol frame formed as a result is in frequency domain. Each of the symbol frames uses an N-point Inverse Fast Fourier Transform (IFFT) to convert the symbol frames into time frames, which then line up to form a digital data stream. This digital data stream is then converted into an analog waveform and transmitted through the antenna. [9] The FFT size can be 2K, 4K or 8K.

Our implementation of the transmission of DVB-T signal uses N-point IFFT with N=2048.

5.3.10 Cyclic Prefixer Block

This block adds a cyclic prefix (CP) to the time domain signal. A cyclic prefix is used to combat against Inter Symbol Interference (ISI) and Inter Carrier Interference in the DVB-T implementations. The last part of the time domain signal is appended to its beginning. Adding a cyclic prefix also aids in synchronizing at the receiver.

5.3.11 Rational Resampler

Conversion from one sample rate to another is done using the rational resampler block. The purpose of using this in our project is to match the sample rate of the USRP N210 (clock of 100MHz) with the DVB-T clock which samples at a rate of 9.1 Msps. The equation relating the input and output sample rate is as follows:

Fs(out) = Fs(in) * Interpolation / Decimation

The value of interpolation for our project is 70 while that for decimation is 64. Hence, the input sample is up-converted to match the sample rate of the USRP N210.

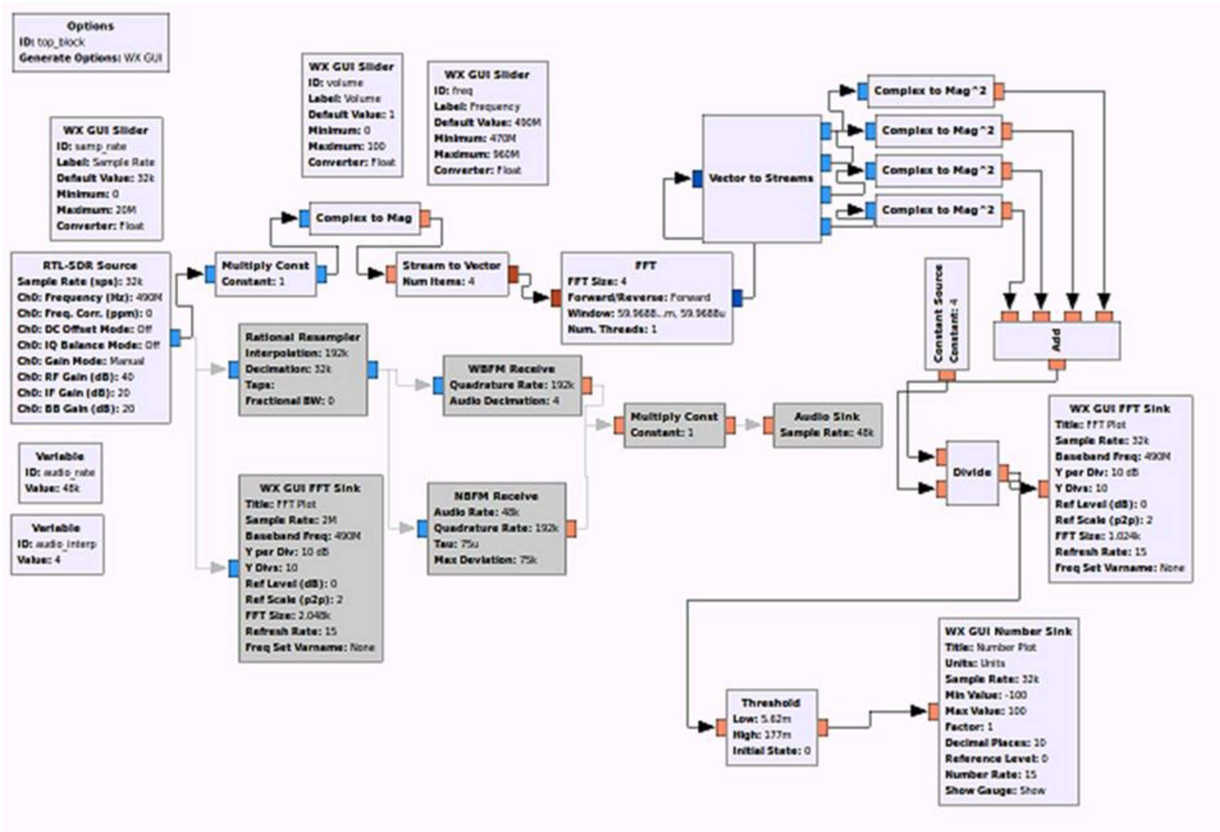
5.3.12 USRP Sink

After all the signal processing blocks, the signal is finally sent to the USRP sink block, where it is analog modulated and transmitted into the air. The center frequency for our transmitter is 490MHz (The USRP has a frequency range of 50MHz – 2.2GHz), which is within the frequency range of the RTL-SDR 820T2 dongle that we are using as the receiver.

5.4 Energy Detection using RTL SDR

The previous section described the transmission of the DVB-T signal, as specified by ETSI. Now that we have accomplished the transmission of the DVB-T signal, we can move towards our main task, that is, to sense the frequency spectrum for the availability of the DVB-T signal using the Energy Detection technique.

The Energy Detector flow graph designed in GNU Radio Companion platform is given in figure 5.4:



5.4.1 RTL SDR Source

The DVB-T signal that was transmitted using the USRP N210 has been received using the RTL SDR dongle. The dongle is tuned at a center frequency of 490 MHz, which is the same as that at which the signal is transmitted. The signal received by the RTL SDR is passed through the Complex to Mag block, which returns the absolute value and converts the data type from complex to floating point. This signal is then converted into a vector which can then be input to the FFT block.

5.4.2 Fast Fourier Transform

The FFT is a faster way of performing the Discrete Fourier Transform (DFT) to a time domain signal. FFT, like DFT transforms the signal into frequency domain which is very important for spectral analysis. However it takes much less time than DFT.

The time domain signal vector is transformed into frequency domain so that spectral analysis steps can be performed on it.

5.4.3 Signal Squaring, Adding and Dividing

The output of the FFT is reconverted into individual streams. These individual streams are squared using the Complex to Mag^2 block, the result is added by the adder and then the output of the adder is divided by the number of individual streams to give a number that forms the decision metric. This decision metric is then compared with the threshold to decide whether the signal is present or not.

5.4.4 Threshold Block

The threshold block checks whether the input to it is within the range specified. The low and high parameters of this block specify the range. The block returns a zero if the signal is not within the specified range and a one when the signal is within the range.

The threshold in our case has been decided by trial and error method. We have conducted tests in different scenarios and have come up with a minimum threshold of -45.0dB. Hence, if the signal level is below this threshold, we conclude that the signal is due to noise only and hypothesis H1 is selected. This also means that the spectrum is empty and a white space exists. On the other hand, when the signal level is above the threshold, the primary signal is actually present (hypothesis H2 is selected) and no white space exists.

5.4.5 FFT Sink

The FFT sink block is used to show the FFT plot of the signal that is received by the RTL-SDR. The FFT plot shows the spectral energy of the signal. In other words, it gives the frequency content of the signal that is received by the RTL SDR dongle.

5.4.6 Number Sink

The output of the threshold is input to the Number Sink block. This block displays the value of the input that is provided to it. Thus, the number sink displays either a 1 or a 0 depending on the output of the threshold block.

5.5 Results

In this section we present the results of the experiments that were carried out. Initially the DVB-T signal was transmitted using the USRP N210. The FFT of the transmitted signal is shown in the following figure.

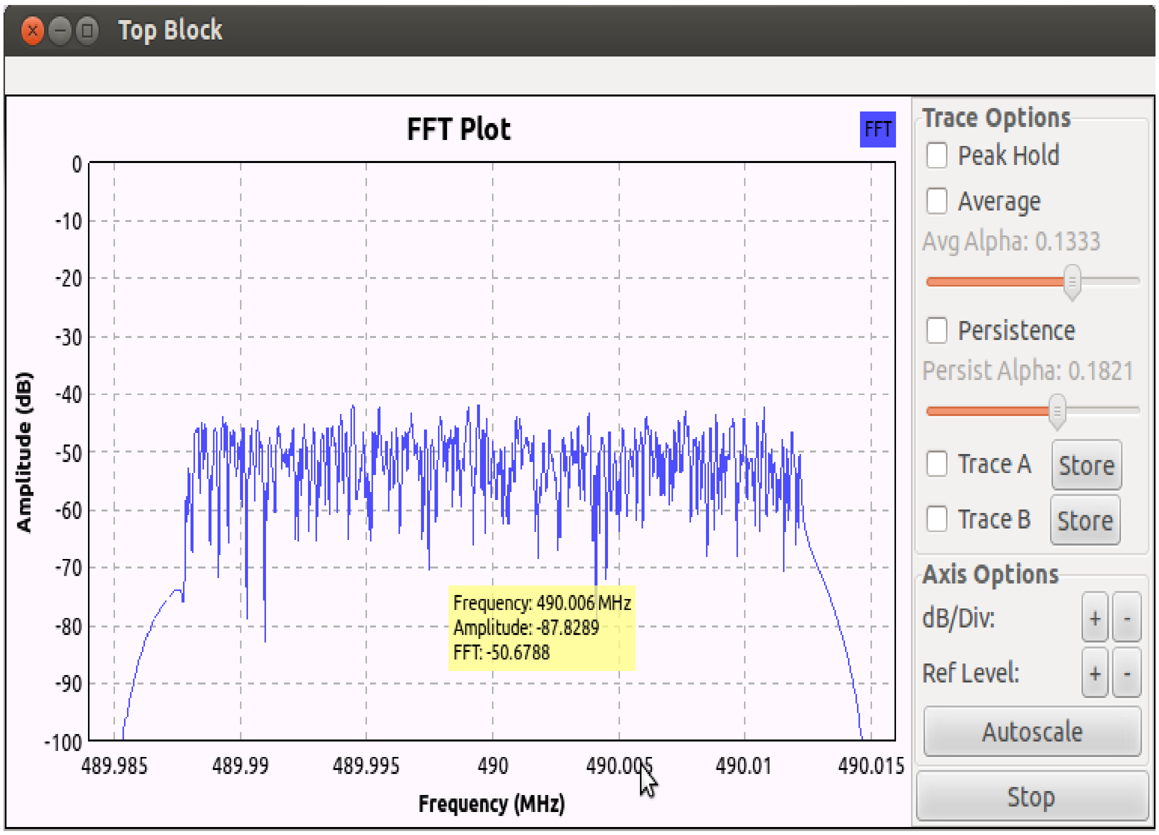


Fig. 5.5 FFT plot of DVB-T signal at 490MHz

The transmitted signal was received by the RTL-SDR dongle and Energy Detection was performed on it. The spectrum was first sensed at 485MHz. The original signal was not transmitted at this frequency which means that the level of the signal should lie below the threshold that was decided as -45.0dB. Figure 5.6 shows this condition.

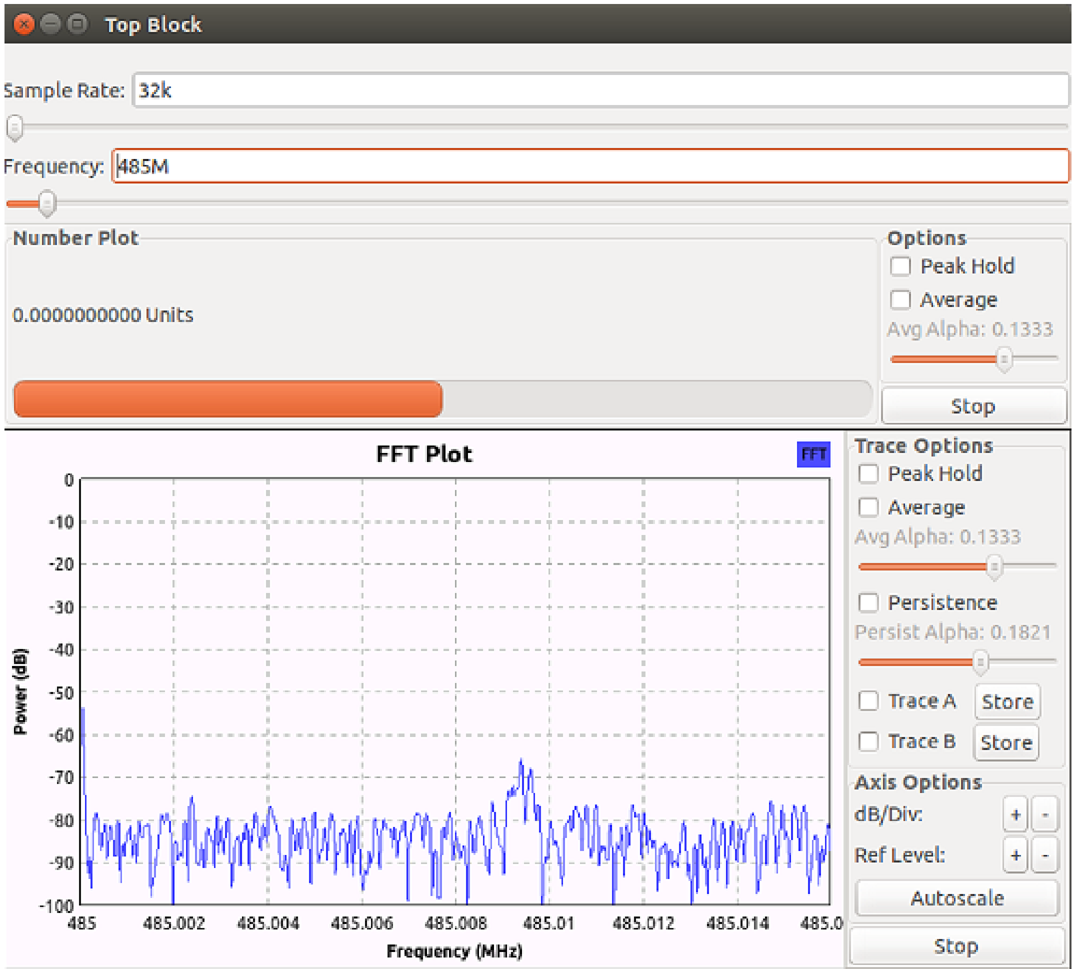


Fig. 5.6 Detection at 485MHz when signal is transmitted at 490MHz

As can be seen, the number sink is showing a value of 0 which means that the signal is not present at this frequency.

We next scanned the 490MHz frequency but this time without transmitting the signal from the USRP. The plot in this case showed that the signal lied below the threshold, which means that the signal was not present. Also the number sink returned a 0, which is consistent with the fact that the signal was absent and a white space existed. The following plot (figure 5.7) confirms our result for this condition.

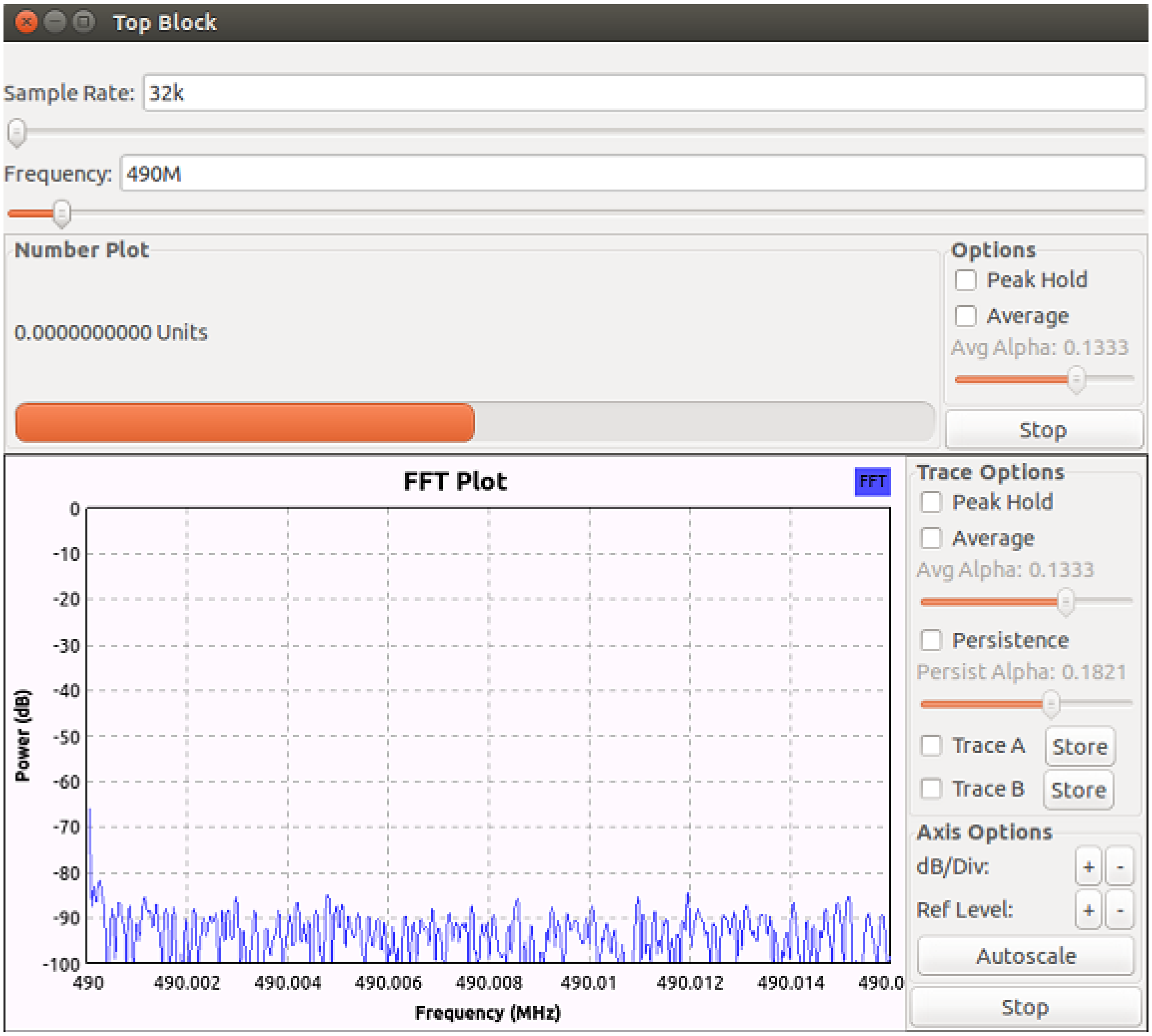


Fig 5.7 Sensing at 490MHz when no signal is transmitted

We then looked for the signal at 490MHz. This time the signal lied above the threshold. The FFT plot and the number sink plot both detected that the signal was present. Hence, in this case Hypothesis 2, which states that the signal and noise is present, was selected. This shows that our detector is working fine. Figure 5.8 illustrates this:

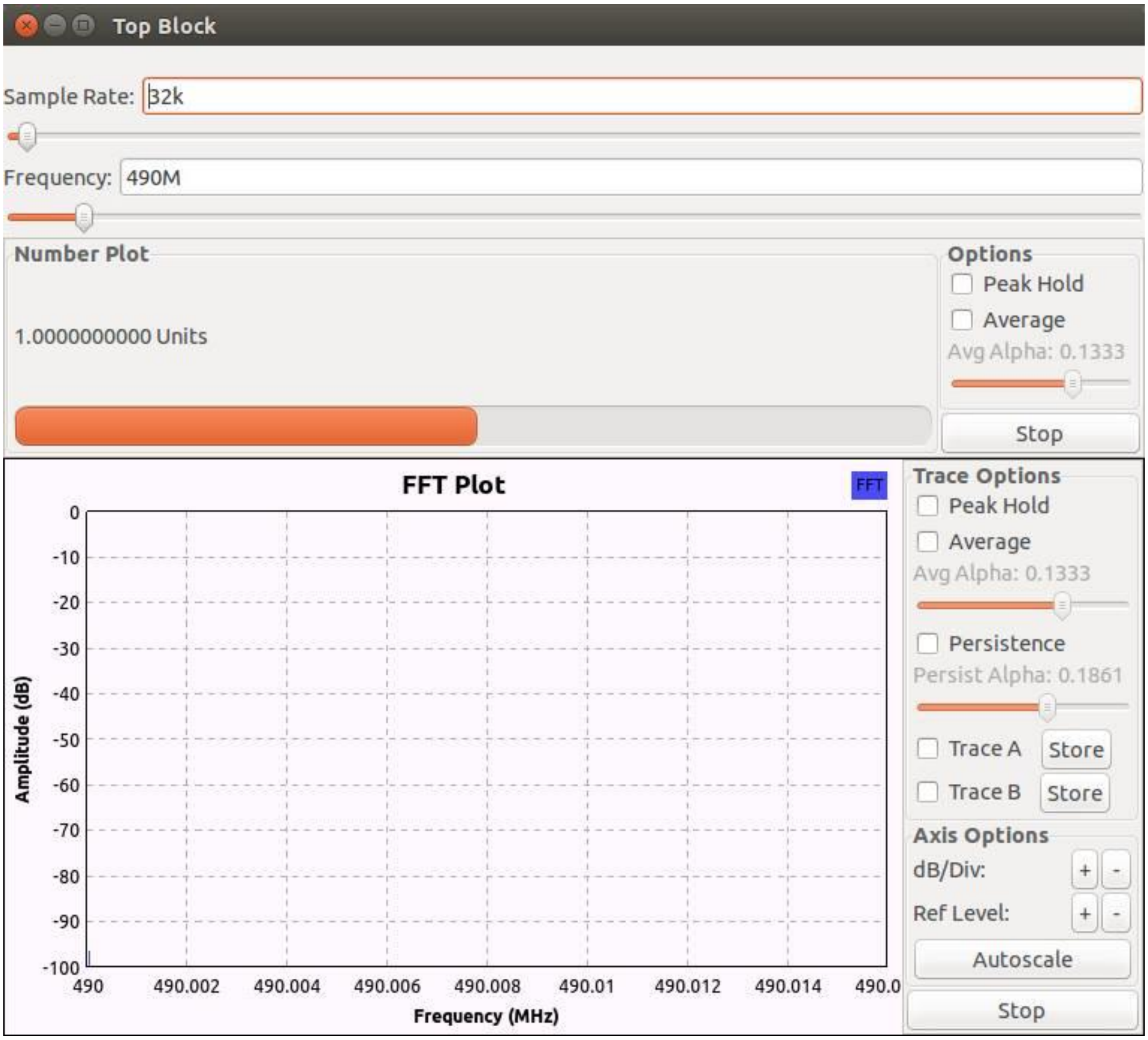


Fig 5.8 Sensing at 490MHz when signal is present.

Throughout this project we moved our direction gradually from simulations to real world problems and became successful in our aims i.e. to detect a TV band signal with help of software defined radio on an SDR platform. Energy detection is presented as a suitable option for spectrum sensing on DVB-T standard and is proved with help of actual detection.

FUTURE RECOMMENDATIONS:

Threshold for Energy detector under different channel conditions such as urban, sub-urban and rural can be determined by creating models for these conditions. This can be regarded as a future work of this project and this task can be accomplished by repeating this method in different scenarios and recording results. Ultimately, models can be formulated by using these observations. Another field of interest is to devise an adaptive threshold selection technique. This technique may be of extreme importance for future cognitive radios. Other detection methods can also be compared with this methods to compare the feasibility of this method with other traditional methods such as matched filtering, cyclostationary detection etc.

REFERENCES

Books:

- Fundamentals of Radar Signal Processing by Mark A. Richards
- Wireless and Cellular Telecommunications (Third Edition) by William C.Y.Lee

Publications:

[1] Duc Toan Nguyen "Implementation of OFDM System Using Gnu radio & USRP" 2013

[2] Le Chung Tran Duc Toan Nguyen ; Safaei, F. ; Vial, P.J. "An experimental study of OFDM in software defined radio systems using GNU platform and USRP2 devices"

[3] Aur09] Dominik Auras. "GNU Radio Implementierungen zur Synchronisierung von OFDM-Systemen." Studienarbeit, RWTH Aachen, 2009.

[4] G. Yamuna, T. Padmavathi, Varghese Thattil "Frequency and Timing Offset Analysis in OFDM using GNU Radio"

[5] Reed-Solomon Error Correction by C.K.P Clarke (British Broadcasting Corporation)

[6] Terrestrial DVB: A Broadcast Technology for Stationary Portable and Mobile Use by UWE LADEBUSCH AND CLAUDIA A. LISS

[7] Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital terrestrial television by European Telecommunications Standard Institute

[8] Maziar Nekovee" A Survey of Cognitive Radio Access to TV White Spaces"

[9] 1. Qing Zhao 2. Brian M. Sadler" A Survey of Dynamic Spectrum Access"

[10] Haiyun Tang" Some Physical Layer Issues of Wide-band Cognitive Radio Systems"

[11] 1.Yonghong Zeng 2. Ying-Chang Liang " Eigenvalue-Based Spectrum Sensing Algorithms for Cognitive Radio"

[12] Stefan Geir Hofer and Lang Tong" Dynamic spectrum access(DSA) in time domain, modeling and exploiting white spaces"

[13] Yanfeng Han, Yijin Wen, Wanbin Tang, Shaoqian Li" Spectrum occupancy measurement : focus on the TV frequencies"

Websites:

http://gnuradio.org/

http://yo3iiu.ro/blog/?p=1220

https://gnuradio.org/doc/doxygen/page_ofdm.html

https://en.wikipedia.org/wiki/GNU_Radio

https://gnuradio.org/redmine/projects/gnuradio/wiki/Guided_Tutorial_Hardware_Considerations