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# Implementation of Double Stage Detector using NI USRP 2920

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## ABSTRACT

*Cognitive Radio is widely expected technology to provide solutions for the next generation wireless communication. This technology provides a path for efficient utilization of spectrum by using various sensing methods. Using this concept, Secondary Users (unlicensed users) can access the spectrum of Primary Users (licensed users) under sublease method. Due to its uniqueness, it will provide solutions to many design challenges in the area of wireless communication. To utilize this technology efficiently, the primary function is to sense the unused spectrum continuously and utilize it properly. Therefore, spectrum sensing becomes the key function in Cognitive Radio to do it. In this paper, a system is proposed with two different sensing algorithms in double stages and with a switching concept. The switching concept helps to choose suitable detector among the two different sensing algorithms based on Signal to Noise Ratio.*

***Keywords***

***Spectrum Sensing, Cognitive Radio, Energy detector, Eigenvalue based detector, Switching concept and Double stage detector***

## 1. INTRODUCTION

With emerging wireless systems, the demand for radio spectrum keep on increasing and the scarcity of this resource is becoming obvious. To address the scarcity of radio spectrum, the Federal Communications Commission (FCC) published a report in which certain bands are crowded while others are fewer used. Secondary Users are temporarily allowed to use the unused licensed spectrum based on sublease basis. In any case, it is difficult to reclaim and release spectrum bands already licensed. This forms the basis for Cognitive Radio Technology. Cognitive Radio (CR) has a great potential in telecommunications systems and extensive research is being carried out for its use in 5G. It helps to sense the unused spectrum to facilitate communication and to avoid interferences with others users like primary users. Due to its significant capabilities, CR can improve the spectrum access in an ultimate way.

CR is a fully re-configurable radio device that can cognitively adapt itself to both user's needs as well as its local environment [1]. CR is viewed as a novel approach for improving the utilization of a precious natural resource. The software-defined radio (SDR) becomes the base for CR and it is defined as an intelligent wireless communication system that is aware, learn and adapt to its environment for two primary objectives in mind (i.e.) highly reliable communication whenever and wherever needed and an efficient utilization of the radio spectrum [2].Spectrum sensing becomes the primary function of CR. Through spectrum sensing and analysis, CR can detect the white space (i.e.) a portion of the frequency band that is not being used by the primary users (PUs) and Secondary Users (SUs) can utilize those unused spectrum. On the other hand, when primary users came back to the licensed spectrum again, CR can switch to some other spectrum through sensing. It, in turn, helps to reduce interference generated due to secondary users (SUs) transmission. Many spectrum sensing algorithms from Narrowband spectrum sensing till wideband spectrum sensing have been proposed [4]. However there are many open research challenges in spectrum sensing and design issues [3].

The main contribution of this paper is to address two different spectrum sensing algorithms, first stage is based on Energy Detector(ED) and later on Eigenvalue based Double threshold detection (EVDT) is used as a second stage and a switch between these two stages is to choose any one sensing method at a time based on SNR value. This will overcome the drawback of ED and EVDT and through this the unused spectrum can be sensed in an efficient way. The remaining section of this paper is organized as follows: In section II, the conventional methods are described in detail with its merits and demerits. In Section III, the proposed system is described in detail with mathematical equations. In section IV, Simulation analysis and hardware implementation of the proposed system is described with results. Finally, the conclusion follows in Section V.

## 2. CONVENTIONAL METHODS

### 2.1 Maximum Eigenvalue Approximation for Spectrum sensing

In this paper, covariance matrix based Eigenvalue detection algorithm is proposed. The Energy Detection method requires noise power. However, calculating accurate noise power is very difficult. But, Eigenvalue based detection no prior information regarding the received signal is needed. Random Matrix Theory (RMT) quantifies threshold value using Eigenvalues [12].At low SNR, the performance is very sensitive to threshold. There are various other techniques based on Eigenvalue based detection namely Energy with Minimum Eigenvalue (EME) and Maximum Minimum Eigenvalue detection (MME) are analyzed. The result indicates that the sensing duration for MME is higher than that of EME. This creates a lead to use EVDT under noise uncertainty conditions.

### 2.2 Eigenvalue Based Double Threshold Detection under Noise Uncertainty

In this paper, a new scheme with double thresholds based on Eigenvalues of the statistical covariance matrix is proposed. The ratio of maximum to minimum Eigenvalue is quantified by Random Matrix Theory and used as a test statistics to detect the presence and absence of Primary Users (PUs). Based on RMT, two threshold equations are proposed for better sensing than the single threshold method. The Eigenvalue method generally exploits the correlation between the PU signal which is absent in the case of a noise [16].Under noise uncertainty region, single stage detector shows poor performance due to continuous re-sensing. Whereas, in the case of EVDT technique, a clear decision is made based on double threshold instead of single threshold. Performance is better even for less number of samples and also it provides better result than Eigen value based single threshold detector.

### 2.3 Double Stage Detector

In this paper, a double stage detector consisting of a coarse and a fine stage is proposed. The Energy Detector is proposed for coarse sensing and a rather more accurate high performance detector, Covariance Absolute Value Detector is proposed for fine sensing. In coarse sensing stage, the possible empty channels among the total available channels are located. The fine sensing is however activated only when a correct decision has to be taken whether the channel is confidently empty or Primary Users (PUs) is present. This paper concentrates on the performance characteristics and detection time requirement of the double stage detector is studied. The sensing time for other double stage detectors are the sum of sensing time of individual detectors. This is a drawback in the conventional double stage detector. The novel high speed detector reduces the sensing duration while maintaining the Probability of false alarm ($P_{fa}$) and Probability of detection ($P_d$) of CR devices. The concept of theoretical SNR [10] is introduced in this paper. The SNR is measured for the received signal and it is compared with the theoretical SNR and if and only if the SNR is lesser than the theoretical value, the second stage of the detector is activated. Thus, the sensing time is reduced in this manner. The ED works well for low SNR regions, whereas the second stage works well in high SNR. But, Complexity is very high.

## 3. PROPOSED SYSTEM

Literature survey concludes that, the Single stage technique has poor performance because of noise uncertainty and double stage detector becomes complex due to coarse sensing and fine sensing. Therefore , to increase the probability of detection ($P_d$) and to reduce in Probability of false($P_{fa}$) a system with double stages to perform linearly at various SNR a system with an Energy Detector(ED) followed by Eigenvalue based

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double threshold detection(EVDT) with a switching concept is proposed. The proposed system is designed and simulated using LabVIEW and implemented in USRP and results are analyzed.

### 3.1 Block Diagram of Proposed System

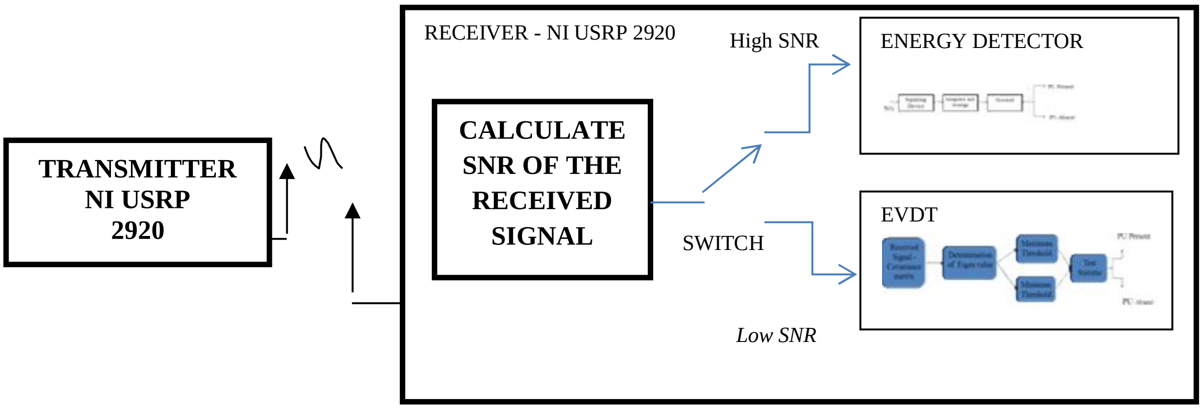


***Figure.1 Block diagram of proposed system***

The proposed system consists of Transmitter and a Receiver. It consists of double stage detectors namely, Energy detector(ED) and an Eigenvalue based double threshold detection (EVDT). ED calculates average energy of the received signal and compares it with threshold to decide the presence of PUs. If the energy is less than threshold then the second stage SNR is computed. Estimated SNR of Energy Detector is compared with theoretical SNR ($\lambda_c$) [8].If the SNR is lesser than $\lambda_c$, sensing is terminated else second stage EVDT is activated. It shows that ED does not work well for low SNR. There was a dilemma to terminate the sensing or to re-sense once again. This will lead to increase in sensing time. In this condition, calculate the SNR of the received at the initial stage and apply a switch to choose either ED or EVDT based on SNR calculated. If the estimated threshold ($\lambda$) is lesser than theoretical SNR ($\lambda_c$) then choose EVDT and when estimated threshold ($\lambda$) exceeds the theoretical SNR ($\lambda_c$) then choose ED. Due to this switching concept, proper sensing method can be chosen to reduce sensing time.

### 3.2 Energy Detector (ED)

The first step of spectrum sensing is using energy detector in which the average energy of received samples is calculated. The computed energy is then compared with the threshold value to decide whether the primary user is present or absent.

***Test hypothesis***

$$H0: y[n] = w[n] \tag{1}$$

$$H1: y[n] = s[n] + w[n] \tag{2}$$

Where $y[n]$ is the complex signal observed by the sensing receiver, $s[n]$ is the PU information signal, $w[n]$ is the noise of the channel. [17]

Energy computation of received samples given by

$$T_{ED} = \frac{1}{N_S}\sum_{n=0}^{N-1}|y(n)|^2 \tag{3}$$

Where, $T_{ED}$ denotes Test Statistic for the Energy Detector, Ns is the Number of samples obtained.

Threshold, Probability of false alarm and Probability of detection are computed using the formula given below

$$a_{ED} = \pm_{W}^{2}\,(1+Q^{-1}(P_{fa})/\sqrt{N}\,) \tag{4}$$

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$$P_{fa} = Q((\lambda/\sigma_n^2 - 1) * \sqrt{N_S/2}) \quad (5)$$

$$P_d = Q((\lambda/\sigma_n^2 - \gamma - 1) * \sqrt{N_S/4\gamma + 2}) \quad (6)$$

$P_{fa}$ - Probability of false alarm, $P_d$- Probability of detection, $\lambda_{ED}$ - Threshold for the energy detector and $Q^{-1}(x)$ is the Complementary Q function of x

Decision is based on,

$T_{ED} < \lambda$ (Primary user absent)

$T_{ED} > \lambda$ (Primary user present)

### 3.3 Eigenvalue Based Double Threshold Detector(EVDT)

The second stage of system is Eigenvalue based Double Threshold method [17].

Obtain the covariance matrix for received signal,

$$R_{cov}(N_s) = \begin{bmatrix} f(0) & f(1) & \cdots & f^*(L-1) \\ \vdots & & \ddots & \vdots \\ f^*(l-1) & & \cdots & f(0) \end{bmatrix} \quad (7)$$

$$f(l) = \frac{1}{N_s} \sum_{m=0}^{N_S-1} x(m) * x(m-l) \quad (8)$$

Where, l = 0, 1, 2….L-1, L denotes the smoothing factor Determine Eigenvalues ‘λ’ from the obtained Covariance matrix. By solving it, find the maximum ($\lambda_{max}$) and minimum Eigenvalues ($\lambda_{min}$). The Ratio of maximum and minimum Eigenvalues gives Test statistic as $T_{EVDT}$,

$$T_{EVDT} = \frac{\lambda_{max}}{\lambda_{min}} \quad (9)$$

Upper and lower thresholds are computed using the formula given below [17],

Upper Threshold as,

$$\gamma_2 = \frac{(\sqrt{N_S}+\sqrt{L})^2}{(\sqrt{N_S}-\sqrt{L})^2} * \left(1 + \frac{(\sqrt{N_S}+\sqrt{L})^{-2/3}}{(N_S L)^{1/6}} F_1^{-1}(1-P_{fa})\right) \quad (10)$$

Lower Threshold as,

$$\gamma_1 = \frac{(\sqrt{N_S}+\sqrt{L})^2}{(\sqrt{N_S}-\sqrt{L})^2} * \left(1 + \frac{(\sqrt{N_S}+\sqrt{L})^{-2/3}}{(N_S L)^{1/6}} F_1^{-1}(1-P_m)\right) \quad (11)$$

Decision is based on,

$$D = \begin{cases} 0, & T(N_S) < \gamma_1 \\ Resense, & \gamma_2 < T(N_S) < \gamma_1 \\ 1, & T(N_S) > \gamma_2 \end{cases} \quad (12)$$

### 3.4 SNR COMPUTATION

The Theoretical SNR is calculated using the formula given below [8],

$$\lambda_c = \frac{\sqrt{2\left(Q^{-1}(P_{fa}) - Q^{-1}(P_d)\right)}}{\sqrt{N_s}} \quad (13)$$

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Where, $P_{fa}$ - Probability of false alarm, $P_d$- Probability of detection and $N_s$- No. of samples

Once theoretical SNR ($\lambda_c$) is calculated, it gets compared with Estimated SNR ($\lambda$) and chooses the sensing algorithm either ED or EVDT

## 4. IMPLEMENTATION ENVIRONMENT

In order to do spectrum sensing in cognitive radio, National Instruments have developed a kit called NI USRP. Universal Software Radio Peripheral (USRP) is used as CR test bed. This hardware gets configures through software called Laboratory Virtual Instrument Engineering Workbench (LabVIEW). In this project one USRP device acts as SU and it is used as receiver to detect signals that are transmitted by another USRP device which acts as PU.

**TABLE I. SPECIFICATIONS OF USRP 2920 AND SIMULATION PARAMETERES**

| PARAMETERS | RANGE |
|---|---|
| Frequency range | 50MHz – 2.2GHz |
| Frequency Accuracy | 2.5ppm |
| Max. Output power | 50mw to 100mw |
| Real time bandwidth | 20MHz – 40MHz |
| Max. IQ rate | 25MS/s - 50MS/s |
| Prob. of false alarm ( $P_{fa}$) | 0.001-0.1 |

## 4.1 RESULTS AND DISCUSSIONS

### *4.1.1. Transmitter Without Noise*

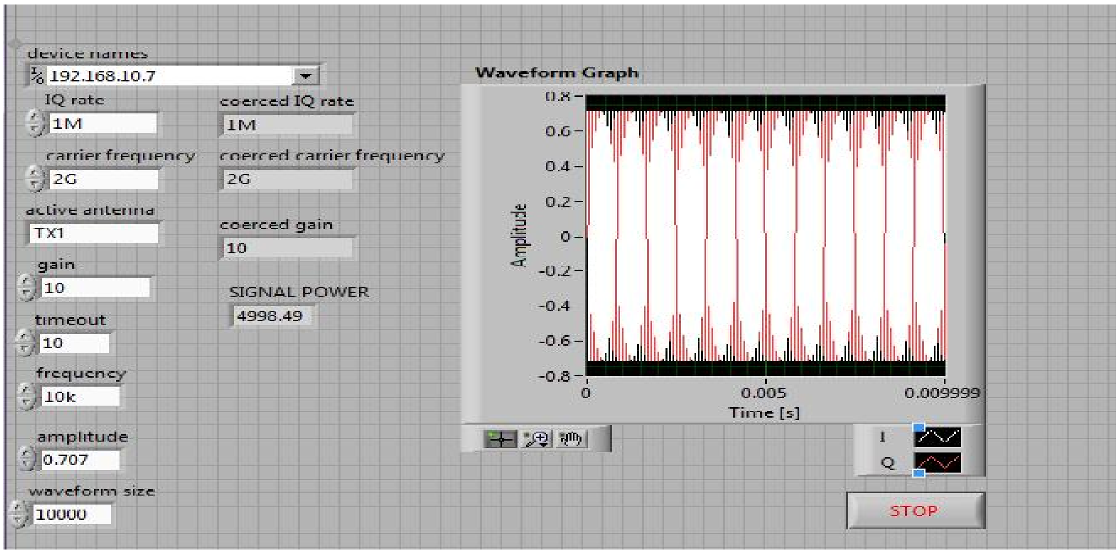


***Figure.2 Transmitter without Noise - Front Panel***

*Figure.2 shows the front panel of the test bed USRP which transmits a signal with a carrier frequency of 2GHz and an amplitude of 5V with an IQ rate of 1M and gain as10*

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### *4.1.2. Receiver Without Noise*

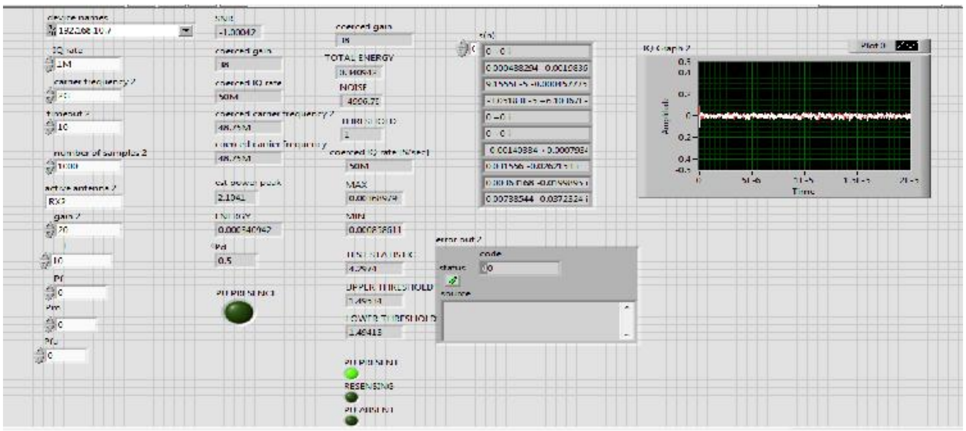

***Figure.3 Receiver without Noise - Front Panel***

*Figure.3 shows the front panel of the test bed USRP which receives a signal with a carrier frequency of 2GHz and amplitude of 5V with an IQ rate of 1M and gain as 20. It shows that PU is present*

### *4.1.3. Transmitter With Noise*

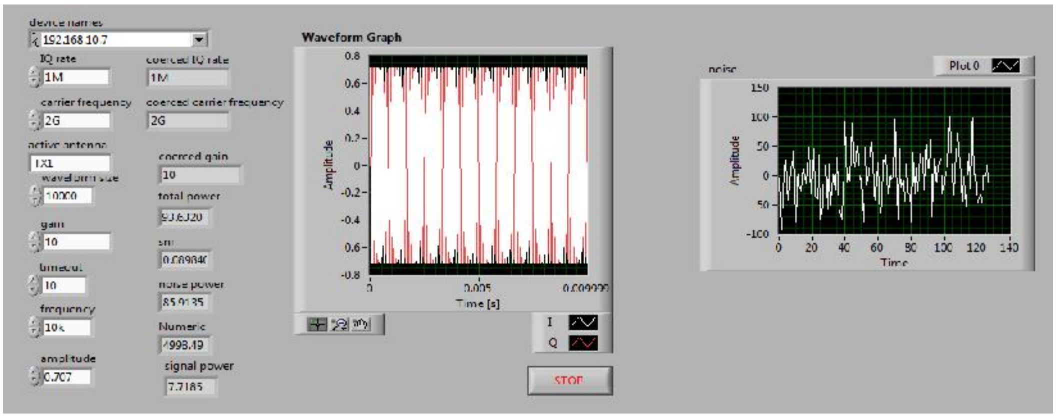


***Figure.4 Transmitter with Noise - Front Panel***

*Figure.4 shows the front panel of the test bed USRP which transmits a signal with a carrier frequency of 2GHz and amplitude of 1V with an IQ rate of 1M and gain as10*

### *4.1.4. Receiver With Noise*

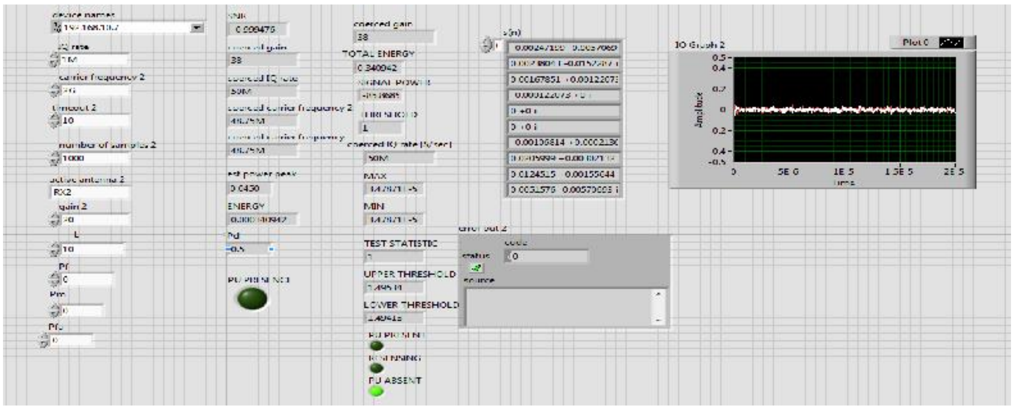

***Figure.5 Receiver with Noise - Front Panel***

*Figure.5 shows the front panel of the test bed USRP which receives a signal with SNR as -0.99 and Pd as 0.5 with a smoothing factor of 10. At low SNR then it shows that PU is absent*

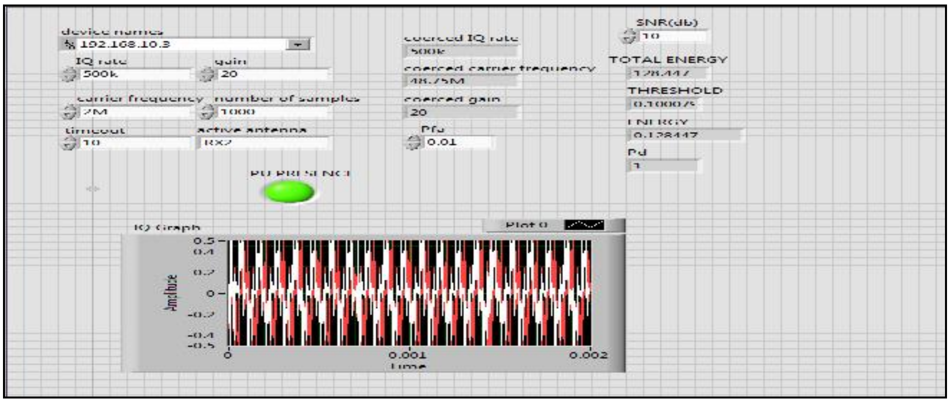


***Figure.6 Energy Detector-Front Panel***

*Figure. 6 shows the front panel of the test bed USRP which detects the Signal when SNR as 10 dB, Prob. of False alarm, $P_{fa}$ as 0.01and Prob. of detection, $P_d$ as 1 and non glowing green light indicates PU is present . It proofs that ED  perform well for high SNR*

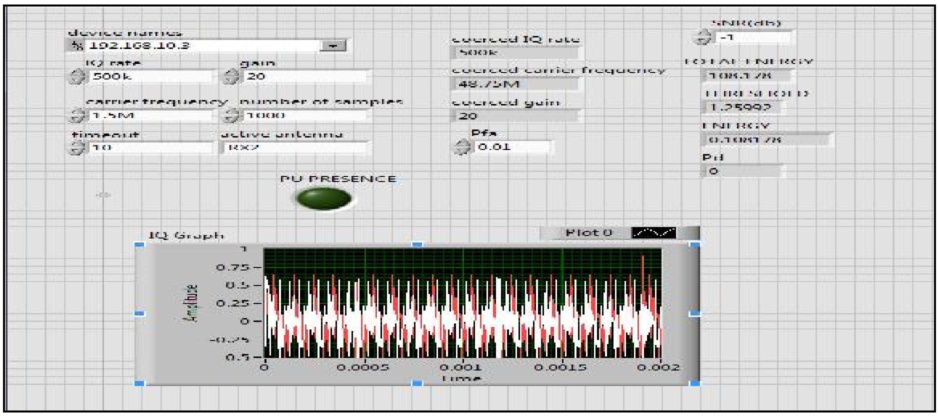


***Figure.7 Energy Detector-Front Panel***

*Figure. 7 shows the front panel of the test bed USRP which detects the Signal when SNR as 10 dB, Prob. of False alarm, $P_{fa}$ as 0.01and Prob. of detection, $P_d$ as 1 and non glowing green light indicates PU I absent even though the PU is present . It proofs that ED  does not perform well for low SNR. At this time, the switch has to be connected to EVDT to show that the PU is present*

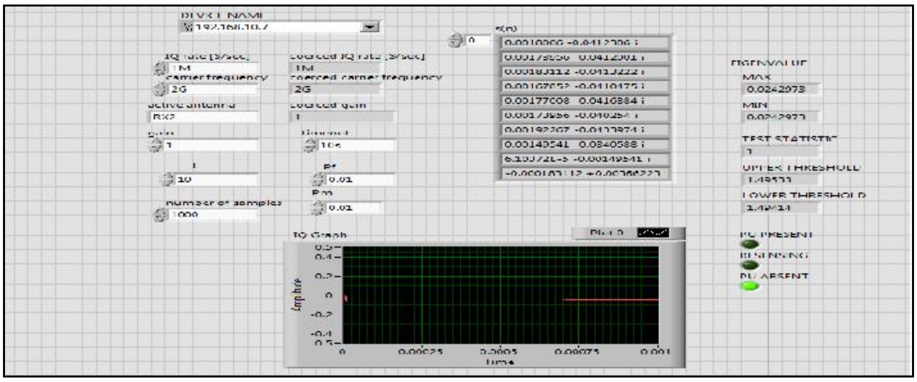

***Figure.8 EVDT-Front panel***

*Figure.8 shows the front panel of the test bed USRP which detects the Signal with a carrier frequency of 2GHz, Smoothing factor, L as 10, Prob. of False alarm, $P_{fa}$ as 0.01 and Prob. of Miss detection, $P_m$ as 0.01 with a Max. Eigen value as 0.0242, Min. Eigen value as 0.0242 and computes the Test Statistics as 1. Due to this, Green light indicates the absence of PU when there is no transmission of PU signal*

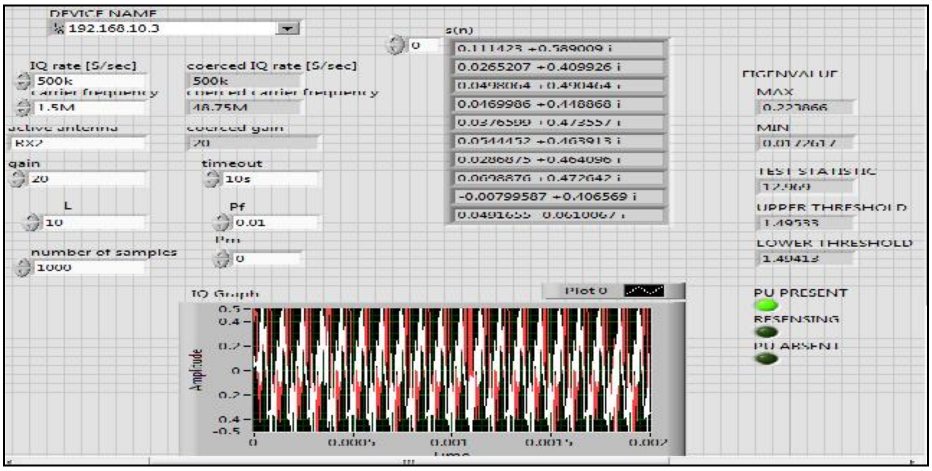


***Figure.9 EVDT-Front panel***

*Figure.9 shows the front panel of the test bed USRP which detects the Signal with a carrier frequency of 1.5MHz, Smoothing factor, L as 10, Prob. of False alarm, $P_{fa}$ as* 0.01 *and Prob. of Miss detection, $P_m$ as 0 with a Max. Eigen value as 0.0223, Min Eigen value as 0.0172 computes the Test Statistics as 12.96.It gets compared with Upper and lower thresholds. It exceeds the threshold. Therefore, Green light indicates the presence of PU when there is PU signal gets transmitted*

**PERFORMANCE ANALYSIS**

**TABLE. II PERFORMANCE ANALYSIS**

| DETECTORS | SNR -5 dB | SNR -1 dB | SNR 1 dB | SNR 5 dB | SNR 10 dB |
|---|---|---|---|---|---|
| ED | *PU Absent* | *PU Absent* | *PU Present* | *PU Present* | *PU Present* |
| EVDT | *PU Present* | *PU Present* | *PU Present* | *PU Present* | *PU present* |
| Double stage Detector with switch | *PU Present* | *PU Present* | *PU Present* | *PU present* | *PU Present* |

This table shows the detection performance of the individual detectors when PU is present. The transmitter block shows the carrier frequency and other information of the PU signal being detected. The EVDT technique might seem optimal since it detects perfectly for all the conditions, but actually its sensing duration is higher compared to ED. Hence, best among them at a particular condition SNR can be chosen by switching concept after calculating the SNR of the received signal at the initial stage.

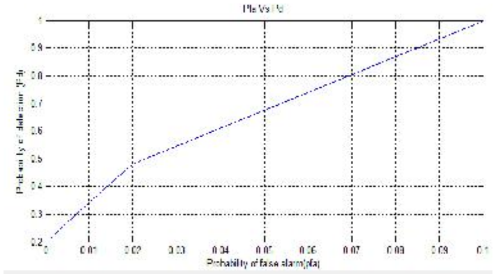

***Figure.10. Plot of Probability of false alarm($P_{fa}$) Vs Probability of Detection( $P_d$ )***

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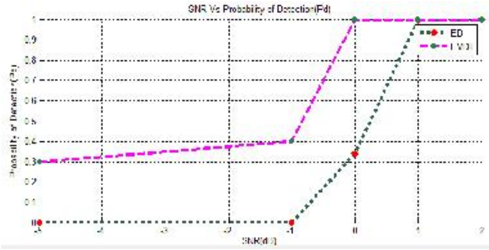


***Figure.11. Plot of Probability of Detection( $P_d$ ) Vs SNR***

*Figure.11. ED performs well above the SNR of -1dB with a $P_d$ of 0.35but for EVDT has the value of $P_d$ as 0.4.Also EVDT starts detection at SNR of -5dB. This shows that EVDT performs well than ED even low SNR and also under noise uncertainty*

## CONCLUSION

In this paper, a double stage detector is designed using switching concept. This was implemented using USRP 2920 and results are also analyzed for various parameters such as Probability of false alarm, Probability of Detection and various values of SNR. The obtained result shows that the Energy Detector(ED) performs well for high SNR region, whereas it failed to sense properly under low SNR region. On the other hand, the Eigenvalue based Double Threshold Detector (EVDT) performs well for both the cases. Therefore, when the SNR of the received signal gets computed at the initial stage then an appropriate spectrum sensing method can be chosen to proceed with a considerable sensing time. This shows that the unused spectrum can be detected effectively and the same being used efficiently. In near future, the performance of the double stage detector for various conditions such as smoothing factor, probabilities of false alarms and SNR can be observed and performance analysis can be done.

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