

A Novel Design of Multifunctional Compact Four-Port Antennas System for Cognitive Radio Applications

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Abstract – The paper proposes a hybrid, compact, low profile, multi-port antenna system for Cognitive Radio (CR). It consists of three different shaped NB antennas and a Funnel-shaped UWB monopole antenna which is operating between 1.8 and 14.2 GHz. The objective of this article is to design and discuss a four-port antennas system for cognitive radio application. This antenna system consists with one ultra-wide band antenna (UWB) and three different shaped narrow band (NB) antennas. The compact size of this antenna system is $0.18\lambda_L \times 0.30\lambda_L$, where λ_L corresponds to the wavelength at lowest operational frequency. In this antenna system one ultrawide band (UWB) antenna is used for sensing the frequency spectrum and three narrow band antennas are employed for communication purpose. The ultra-wideband antenna sense 1.8 GHz - 14.2 GHz spectrum which cover the ultrawide band frequency range from 3.1 GHz - 10.6 GHz, which is permitted by Federal Communication Commission in year 2002. CST Microwave Studio is used to simulate the system, and a prototype is built to confirm the outcomes. The observed and simulated results accord rather well. The suggested antenna may be used for public safety wireless communication, marine radio navigation, X-band satellite communication, mid-band 5G, ISM/WLAN/Military applications, and C-band operations.

Keywords - Cognitive radio, ultrawide band antenna, narrowband antenna

1. Introduction

The last several decades have seen a surge in the use of wireless communication due to the information age of human civilisation. Beginning with the creation of wireless devices (such as smartphones, Bluetooth, Wi-Fi, Wi-Max, near-field communications, etc.), networks were subsequently established, ranging from first generation (1G) to 5G and beyond. Antennas have been crucial to these advancements and the different protocols that go along with them. In order to accommodate future users and maintain communication speed and dependability, it is necessary to use the spectrum wisely and efficiently as the number of wireless device users grows exponentially. As a result, the cognitive radio (CR) idea was developed, in which the system dynamically assigns particular portions of the users' spectrum according to their behaviours. Users in CR are separated into two groups: principal users (PU) and secondary users (SU). While secondary users are permitted to use the available spectrum that is not taken by primary users, primary users are assigned to a specific frequency spectrum. For effective spectrum distribution amongst users, two modes interweave mode and underlay mode are typically utilised. The CR gadget finds the available frequency spectrum, also referred to as "white space," while in the weave mode and assigns it to the secondary users. On the other hand, up to a predetermined interference threshold, secondary users can coexist with prime users during the overlay mode of operation. The underlay and interweave modes of operation are shown graphically in Figure. 1. Two types of antennas are needed to achieve the interweave mode: a narrowband (NB) frequency reconfigurable antenna and an ultra-wideband (UWB) channel sensing antenna [1,2,3]. While the tunable antenna adjusts its operational frequency

over those accessible spaces to enable secondary users to communicate, the detecting antenna finds the white spaces in between the spectrum that are underutilised by the primary users.

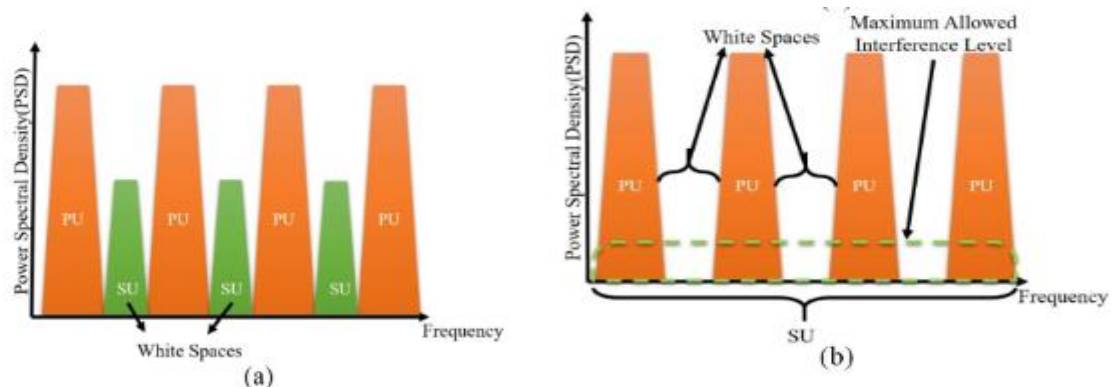


Figure 1- Cognitive radio techniques: (a) interweave mode, (b) underlay mode

In order to allow users to share the spectrum simultaneously, the antenna should broadcast UWB signals with a certain power restriction while in the overlay mode. However, if the principal users demand a greater degree of isolation, the antenna ought to prevent secondary users from sending data at that frequency using a feature of a band stop [5,6]. Therefore, in the underlay CR mode, a UWB antenna with a notch band is preferred for the secondary users. A major development in wireless communication will be the integration of underlay operation and interweave into a single antenna device without sacrificing either reliability or performance.

In recent years, with large development in wireless communication technologies, the available frequency spectrum is becoming more congested. This is due to inefficient utilization of frequency spectrum. Cognitive radio (CR) is effective methods for effective utilization of frequency spectrum [7,8]. A CR technology possesses the ability to sense the frequency spectrum and detect the vacant frequencies for direct communication without impacting the primary users. The multi-port planar antennas comprise with ultra-wide band (UWB) antenna and one or more than one narrowband antenna are popularly used for cognitive radio (CR) technology. In this system one ultrawide band antenna works as sensing state and one reconfigurable narrow band antenna works as communication state [13,14]. The reconfiguration techniques incorporated with single antenna to access more than one resonant frequency holds too many disadvantages [15]-[17], [19,20]. The multi- port antenna system is the effective system to resolve these problems. The multi-port antenna system which consists one UWB antenna and multiple narrowband antennas to access multiple frequencies bands [7]. In recent years, the conventional antennas are not used in wireless communication area because these antennas are not suitable in CR technologies. Therefore, planar monopole antenna is widely used because these antennas are having various advantages like low cost, light weight, compact size any easy fabrication [8]. The proposed system integrated with one funnel shaped ultrawide band antenna and three rectangular shaped narrowband antennas. The funnel shaped ultrawide band antenna performs sensing operation and three rectangular narrowband antennas perform communication or data transmission operation at different frequencies ranges. This antenna system can perform spectrum sensing and communication operation simultaneously. This mechanism is very effective to enhance the efficiency of the spectrum utilization, which is the main aim of CR networks. In this four-port antenna system the funnel shaped ultrawide band antenna and one rectangular narrowband antenna are employed for sensing & Communication respectively, and the two other narrowband antennas remain in idle mode. In each case, switching is performed among three narrow band antennas such that only one narrow band antenna is operated at a time and other remains idle mode. The switching among three NB antennas is termed as excitation switching. The selection of narrowband antenna is depending upon the sensed frequency spectrum to which NB antennas operating frequency matched.

2. Function of Cognitive Radio

The main functions of cognitive radio are as follows:

- Sensing the radio environment continuously for spectrum holes, which is termed as spectrum sensing.
- Identify the best possible channels for data transmission.

Reconfigurable antennas for Cognitive Radio can be classified into two categories.

In the first category, it would consist of one antenna that performs both sensing & communication functions.

Reconfiguration can be achieved by switching device like PIN diode, varactor diode or optical switches.

In the second category, two separate antennas, which include one UWB antenna and one frequency reconfigurable NB antenna, are employed for spectrum sensing and communication, respectively

3. Channel spectrum sensing

(i) **Spectrum Sensing Framework (TDSSF)**- In the TDSSF, Frame is divided into sensing and data transmission time slots [4], as shown in Figure 2. In TDSSF, it would consist of only one antenna that performs both sensing & communication functions. In this technique there is discontinuity and interruption in data transmission due to sensing period in the frame.

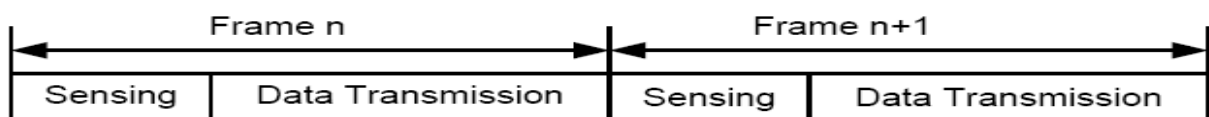


Figure 2- Time division based spectrum sensing framework

(ii) Frequency Division Spectrum Sensing Framework (FDSSF)- FDSSF allows simultaneous spectrum sensing and data transmission over the complete spectrum for full frame duration [4], as shown in Figure 3. Multi-port antennas are used in FDSSF. In this category one UWB antenna is used for continuously sensing and other NB antennas are used for data transmission. The basic model of Multiport antennas system is shown in figure 4

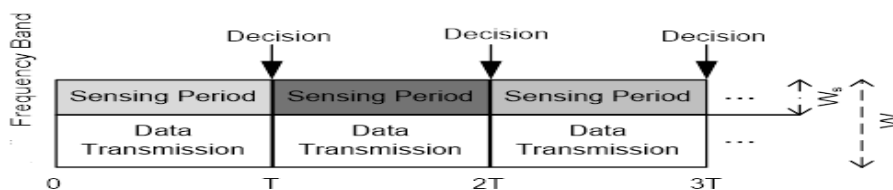


Figure 3- Frequency division spectrum sensing framework

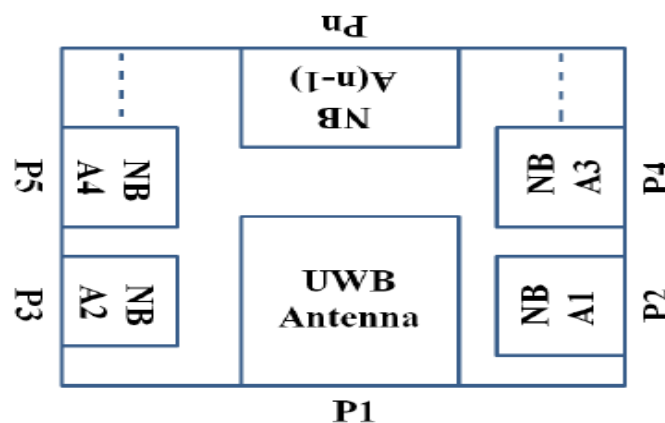


Figure 4- Basic model of multi-port system

4. Proposed Four-Port Antennas System Integrated with One UWB And Different Shaped Three NB Antenna

The frequency spectrum for CR application is attained by four-port system integrating with wideband funnel shape UWB antenna and narrow band antennas. The geometry of the antenna structure and fabricated antennas system is shown in Figure 5 and Figure 6 respectively. In this antenna system four antennas are fabricated on the same substrate. The FR-4 with dielectric constant value 4.3 is used as substrate and a loss tangent value is 0.019. The compact size of this antenna system is $0.18\lambda_L \times 0.30\lambda_L$, where $\lambda_L = C/f_L$ corresponds to the wavelength at lowest frequency f_L of its entire -10 dB operational frequency range.

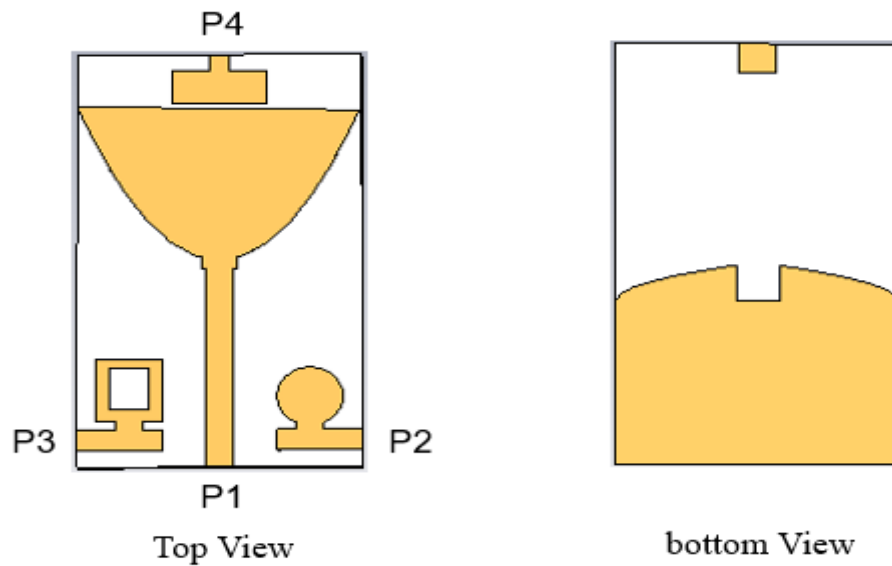


Figure 5 - Proposed four - port Antennas system (a) Top View (b) bottom View



Figure 6 - Photographs of fabricated prototype

The funnel shaped UWB antenna is etched on top of the substrate. The funnel shaped antenna is used for sensing the wide band frequency spectrum from 1.8GHz - 14.2 GHz with $VSWR \leq 2$, thus includes complete UWB spectrum from 3.1 GHz - 10.6 GHz which is approved by FCC in 2002 [9]. The 50Ω microstrip feed line is connected to the base of the funnel [1]. The shape of the funnel is designed by the equation

$$X = a \sin \theta \quad (i)$$

$$Y = b(\cos\theta)^2 \quad (ii)$$

Where a is width of the funnel and b is length of the funnel.

The metallic ground plane is etched on other side of the substrate; its structure shown in Figure 5. the curved edge of the ground plane is designed with equation (i) and (ii), but $a = 8.5\text{mm}$ and $b = 15\text{mm}$. A rectangular slot with dimensions $W \times L = 4.6\text{mm} \times 4.23\text{mm}$ is taken at upper curved edge. This arrangement achieves high impedance matching. The UWB funnel shaped antenna and third NB antenna integrated partial ground obtains ultrahigh impedance bandwidths. This antennas design is simulated in CST Software. The measured results are very closed to the simulated results. However, there are some variations may cause by material impurities, connector losses, faults in fabrication and measurement process.

The UWB funnel shaped antenna allied with port 1(P1) is performed sensing of frequency spectrum and other NB antennas associated with port 2, port 3 and port 3 are used for communication. These three NB antennas develop three communication operations. These three NB antennas generate either single band or dual band to cover maximum UWB frequency spectrum which is sensed by Funnel shaped UWB antenna. This technique improves the spectrum utilization efficiency. This four-port antenna system forms three different operation. In first operation, the funnel shaped UWB antenna associated with port 1 (P1) and one narrowband antenna associated with port 2 perform spectrum sensing and direct communication respectively, where other two NB antennas remained off. In second operation, the funnel shaped ultra-wide band antenna allied with port 1 and one narrow band antenna associated with port 3 are used for spectrum sensing and communication respectively, whereas remaining ports are off. In the third case, the funnel shaped ultra-wide band antenna incorporated with port 1 and narrow band antenna incorporated with port 4 perform continuously spectrum sensing and direct communication respectively, whereas remaining port 2 and port 3 are off. These three operative conditions are discussed in this paper. The funnel shaped ultra-wide band and other narrowband antennas in different operations are shown in Table 1.

Table 1: Comparative analysis of all three operations

Antenna	First operation	Second operation	Third operation
Ultra-wide band	1.8- 14.2 GHz	1.8-14.2 GHz	1.8 -14.2 GHz
Narrow band 1	7.6 – 8.4 GHz	OFF	OFF
Narrow band 2	OFF	8.4 – 9.2 GHz	OFF
Narrow band 3	OFF	OFF	4.2-6.8 GHz and 9.2-11 GHz

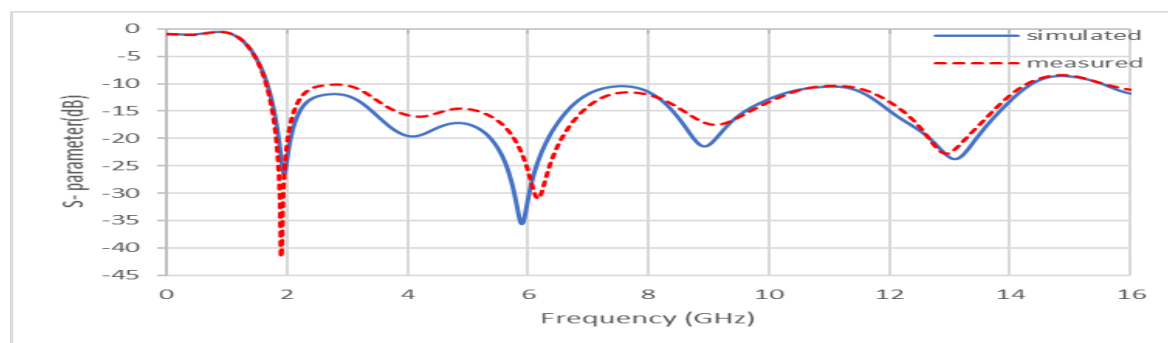


Figure 7 - Simulated and Measured S_{11} Funnel shaped UWB Antenna

The comparison between simulated and measured radiation patterns at frequencies 7.9 GHz, 8.8 GHz, 5.5 GHz and 10.2 GHz are displayed in Figure 9. measured radiation pattern slightly differs from simulated radiation pattern, it may cause of environment surrounding of measuring instruments or measurement and fabrication

error. The simulated gain and frequency graph is displayed in Figure 10. The realized gain varies from 2.2 to 4.2 dBi in operational frequency range.

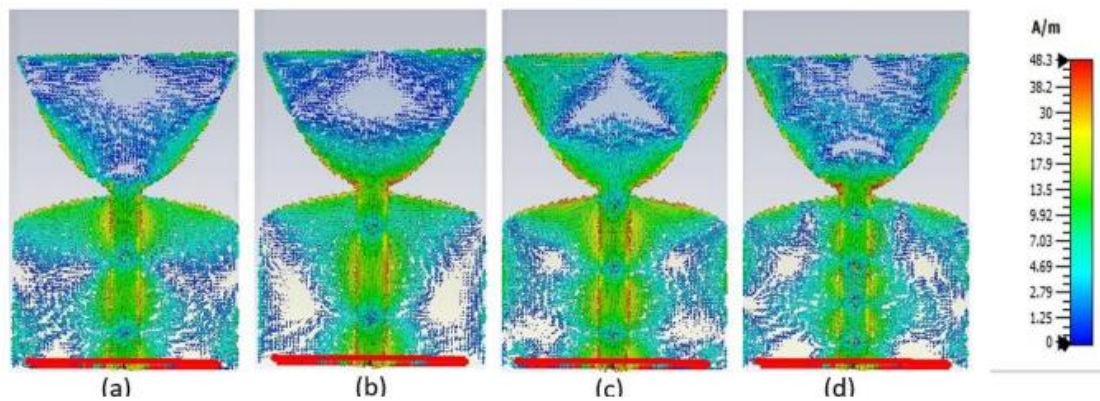


Figure 8- Simulated surface current distribution of Funnel Shaped UWB sensing monopole in standalone configuration at (a) 7.9 GHz, (b) 8.8 GHz, (c) 5.5 GHz, and (d) 10.2 GHz

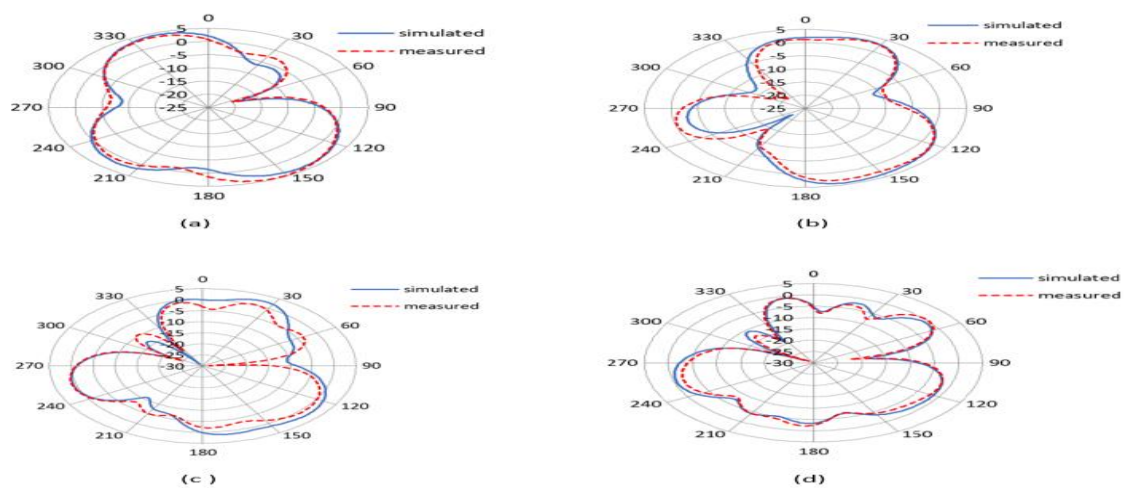


Figure 9 -The radiation pattern of ultra-wide band at (a) 7.9 GHz (b) 8.8 GHz (c) 5.5 GHz (d) 10.2 GHz

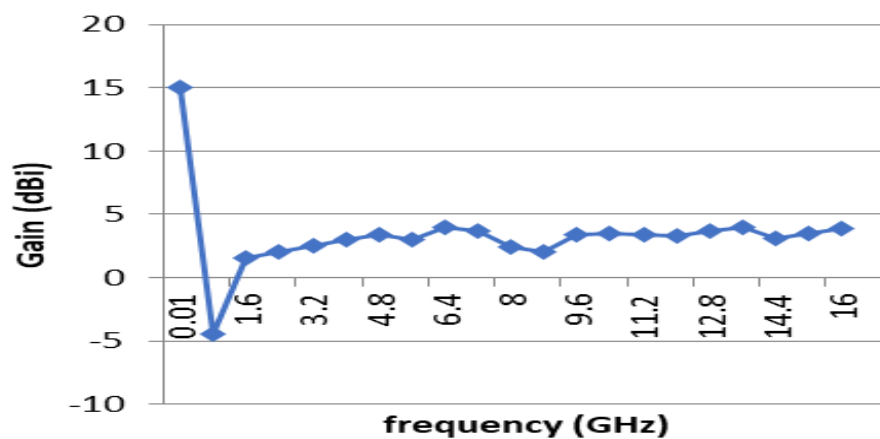


Figure 10 - Gain plot of funnel shaped ultra-wide band antenna

5. First Operative Condition of Proposed Antennas System

In first case, the funnel shaped ultra-wide band antenna incorporated with port 1 perform the spectrum sensing and the narrow band antenna incorporated with port 2 performs communication and remaining port 3 and port 4 are match terminated. The reflection coefficient of UBW antenna is shown in Figure 7.

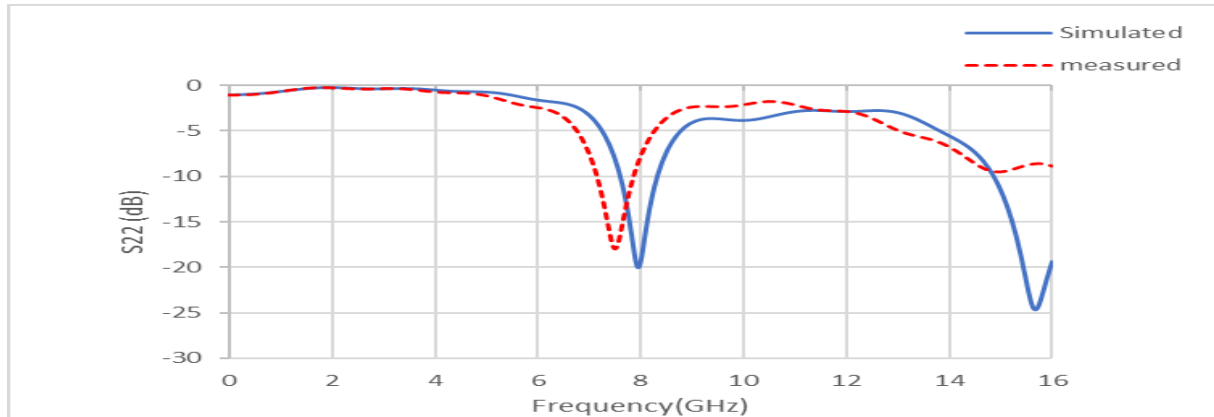


Figure 11 - Simulated and Experimental reflection coefficient of first NB antenna

In this case funnel shaped antenna is covered the frequency spectrum from 1.8 GHz to 14.2 GHz, which includes the unlicensed spectrum 3.1 to 10.6 GHz approved by FCC. The narrow band antenna associated with port2 generates frequency band from 7.6 GHz to 8.4 GHz with resonant at 7.9 GHz as shown in Figure 11. 2-D radiation pattern of first NB antennas at resonant frequency are shown in Figure 12.

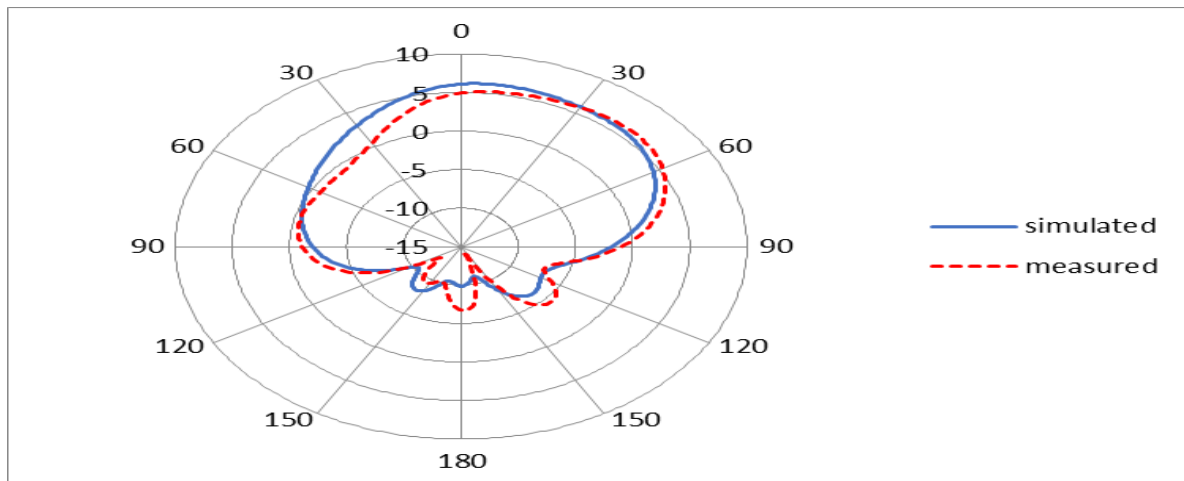


Figure 12 - Radiation pattern of first NB antenna at 7.9 GHz

6. The Second Operative Condition of Proposed Antennas System

In second case, the funnel shaped antenna incorporated with port 1 perform the spectrum sensing and the narrow band antenna incorporated with port 3 performs communication and remaining port 2 and port 4 are match terminated.

In this case funnel shaped antenna is covered the frequency spectrum from 1.8 GHz to 14.2 GHz, which includes the unlicensed spectrum 3.1 to 10.6 GHz approved by FCC. The narrow band antenna associated with port 3 generates frequency band from 8.4 GHz to 9.2 GHz with resonant at 8.8 GHz as shown in Figure 13. 2-D radiation pattern of second NB antenna at resonant frequency are shown in Figure 14.

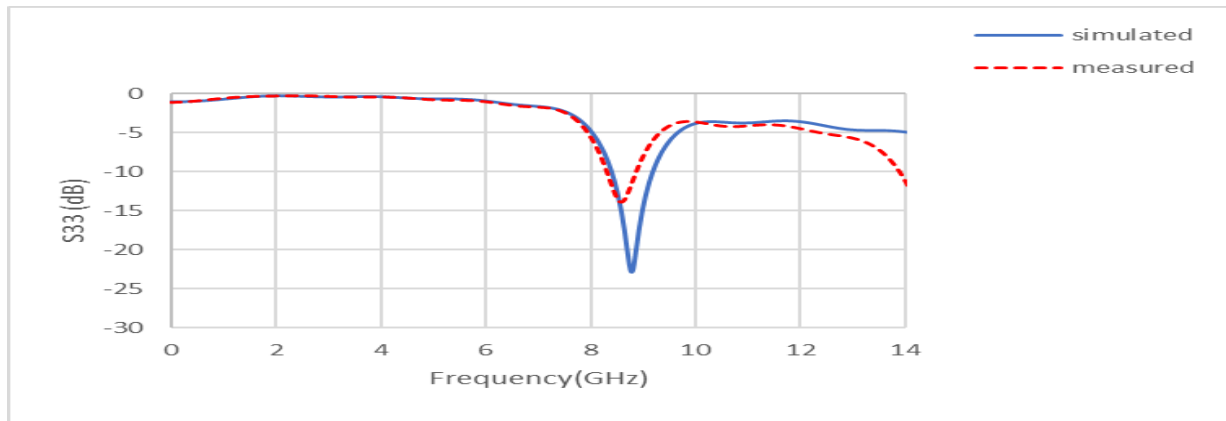


Figure 13 - Simulated and Measured reflection Coefficient of second NB antenna coupled with port 3

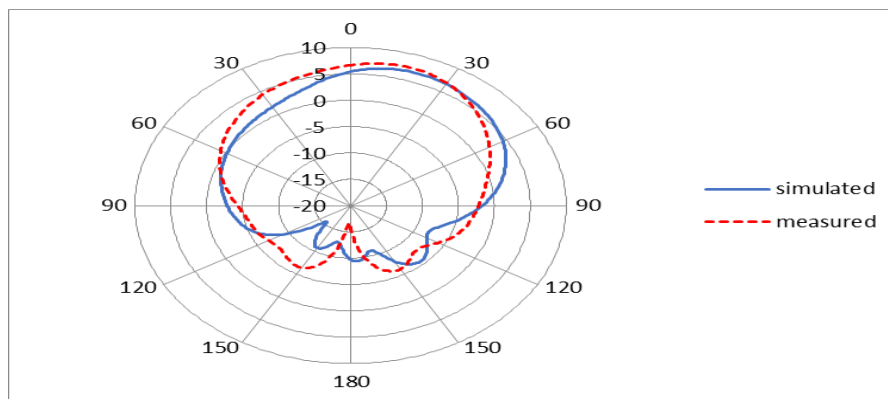


Figure 14 - Radiation pattern of second NB antenna at 8.8 GHz

7. The Third Operative Condition of Proposed Antennas System

In Third case, the funnel shaped antenna incorporated with port 1 perform the spectrum sensing and the narrow band antenna incorporated with port 4 performs communication and remaining port 2 and port 3 are match terminated. In this case funnel shaped antenna is covered the frequency spectrum from 1.8 GHz to 14.2 GHz, which includes the unlicensed spectrum 3.1 to 10.6 GHz approved by FCC. The narrow band antenna associated with port2 generates dual frequency band from 4.2 GHz to 6.8 GHz with resonant frequency 5.5 GHz and from 9.2 GHz to 11 GHz with resonant at 10.2 GHz and as shown in Figure 15. 2-D radiation pattern of third NB antennas at resonant frequencies are shown in Figure 16.

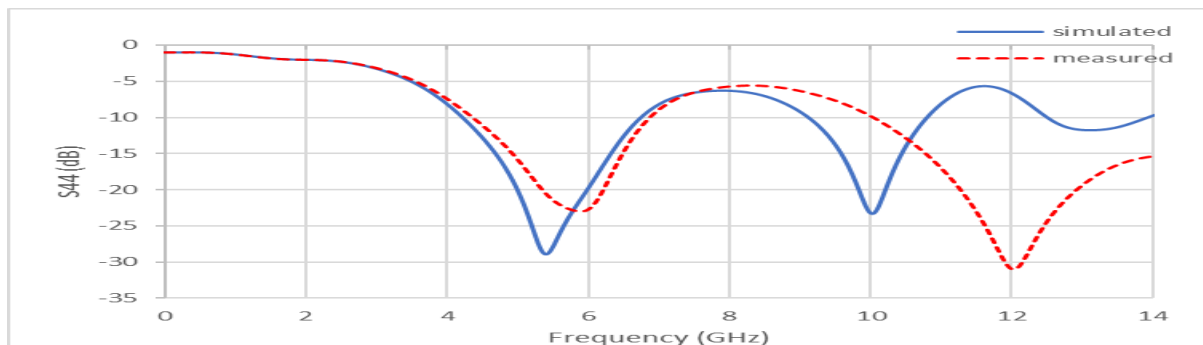


Figure 15 - Simulated and Measured reflection Coefficient of third NB antenna coupled with port 4

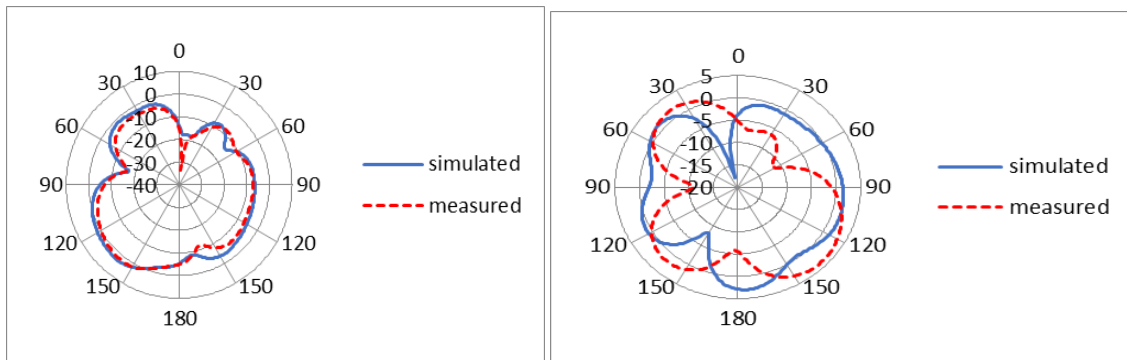


Figure 16 - 2D radiation pattern of third NB antenna at 5.5 GHz and 10.2 GHz respectively

Comparison analysis of different existing CR System with proposed system is shown in Table 2. It is noted that proposed system is compact in design and funnel shaped UWB antenna sensed large frequency range from 1.8 GHz to 14.2 GHz and three narrow band antennas are able to generates four frequencies bands which resonates at different frequencies. These narrow band antennas are covered maximum part of sensed frequency spectrum.

Table 2: Comparison of various antenna structure with UWB and NB antennas ranges

References	Substrates Dimensions	UWB Frequency (GHz) Range	NB Frequency (GHz) Range
[21]	58.5mm×65.5mm×1.6mm	3.3 to 11	3.4 to 4.85 and 5.3 to 9.15
[22]	68mm×54mm×0.79mm	3 to 11	4.9 to 5.35
[23]	37mm×63.6mm×0.254mm	2 to 12	5.7 to 5.9
[24]	70mm×50mm×1.6mm	2 to 10	Five bands within 2 to 10 GHz
[25]	50mm×45.5mm×1.6mm	3 to 11	3.2 to 4.3, 4.15 to 5.1, 4.8 to 5.7
[26]	41mm×25mm×1.14	2.5 to 11	5.1 to 5.5
[27]	38mm×25mm×0.762mm	3.05 to 13.5	5.1 to 5.8
[31]	40mm×36mm×0.662mm	3 to 11	Three bands within 5 to 6 GHz
[32]	27mm×21mm×1.6mm	2.74 to 10.7	8.2 to 9.4 GHz
[34]	30mm×30mm×1.6mm	3.1 to 10.6	Four bands within 6 to 10 GHz
Proposed Antennas System	50mm×30mm×1.6mm	1.8 to 14.2	Four bands within 4.2 to 10.6 GHz

8. Conclusion

In this paper, a four-port antenna system composed with one funnel shaped UWB antenna and three different shaped narrowband antennas are integrated on the same substrate, designed for cognitive radio application, has been presented. The reconfigurable antenna has some drawback and limitation during switching operations, so this antenna system is designed to overcome the drawback of reconfigurable antenna. the three narrow band antennas are able to generate either single frequency band or dual frequency band to cover ultrawide band spectrum for direct communication purpose. This antenna system is able to perform sensing as well as communication task simultaneously and enhance the spectrum utilization efficiency, which is the main objective of cognitive radio technology. The suggested antenna system is suitable for C-band, ISM/WLAN/Military application, mid-band 5G, X-band satellite communication, marine radio navigation, and public safety wireless communication. In order to facilitate 5G communication, the suggested UWB, NB antennas system can be used for CR applications in a variety of wireless devices.

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