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A Literature Review on Multifunctional Integrated Antenna Systems for Cognitive Radio Applications

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Abstract- This study presents a thorough report on the development, design concept, and actual realization of multifunctional antennas (MFA). Originally developed as a clever way to counteract poor spectrum utilization through opportunistic spectrum allocation policies, MFAs are now an essential part of many contemporary wireless applications, including software-defined radio (SDR) environments and multi-standard radios (CR). Multiple radiating components on a shared substrate are used in traditional MFA realizations, which increases design constraints related to mitigating/reducing parasitic coupling and spurious impacts of the rotational arrangements needed for actuating diverse radiating elements. This study reports on a recent research contribution on the design of MFAs using a single UWB radiating element.

This paper provides comparative Analysis of antennas system for Time and Frequency Division Spectrum Sensing Frameworks in Cognitive Radio Network application. In Time Division Spectrum Sensing Frameworks (TDSSF), it would consist of only one antenna that performs both sensing & communication functions. In TDSSF technique, there is discontinuity and interruption in data transmission due to sensing period in the frame. Reconfigurable antennas or Tunable antenna are used in TDSSF technique. Frequency Division Spectrum Sensing Frameworks (FDSSF) allows simultaneous spectrum sensing and data transmission over the complete spectrum for full frame duration. Multi-port antennas are used in FDSSF Technique. In FDSSF technique, one UWB antenna is used for continuously sensing and other NB antennas are used for data transmission. Theses antennas system 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, Reconfigurable antenna, UWB antenna, NB Antenna, TDSSF, FDSSF*

INTRODUCTION

In recent years, demand for the spectrum continues to increase with the advent of various wireless communication applications. So, in 2002 FCC has proposed several solutions to enhance the spectrum utilization efficiency when the spectrum channels are unused[1,2,5]. In the wireless communication, we employ cognitive radio technology to utilize unused or free licensed channels. Cognitive radio (CR) is an adaptive, intelligent radio and network technology that can automatically detect available licensed channels in a wireless spectrum called “white Space ” and use it for secondary communication purpose. A generic cognitive radio workflow diagram is given in Figure 1. Some experts have suggested that UWB antenna should be used for sensing operation. The sensing antenna communicates with the “spectrum sensing” module of the CR engine which continuously searches for unused frequency channels within the operating band of the sensing antenna. The information obtained by the “spectrum sensing” module is passed on to the “spectrum decision” module which determines the appropriate frequency band for communication. The switch controller then tunes the operating frequency of the reconfigurable antenna. The antennas used for CR networks are omnidirectional antennas with gains of 0dBi of higher. The word cognitive radio was coined by Joseph Mitola in 1998 and published in an article by Mitola and Gerald Q. Maguire, Jr. in 1999. In this model, the licensed spectrum is assumed to be owned by the primary users, who do not fully utilize their channels. Hence, the secondary users utilize these free channels until the primary users demand them.

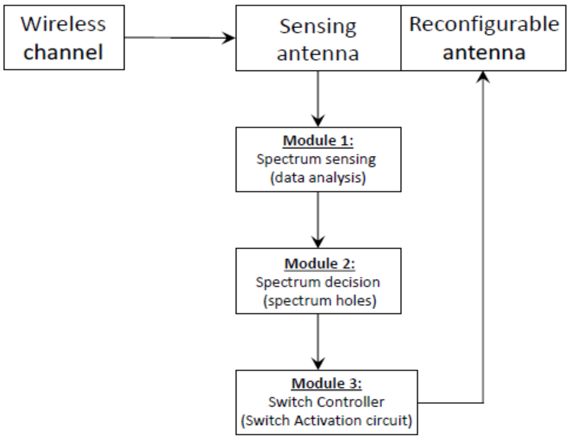


Figure 1- A generic cognitive radio workflow diagram

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.

Antennas system 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.

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.

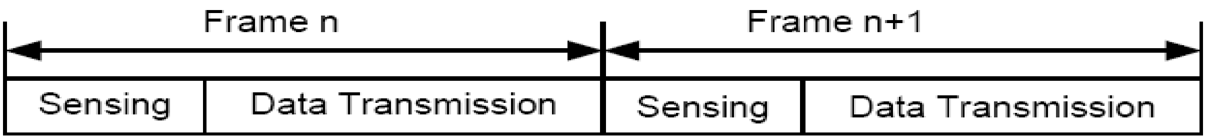


Figure 2- Time division based spectrum sensing framework

Reconfigurable antennas or Tunable antenna are used in TDSSF technique. A reconfigurable antenna is an antenna capable of modifying its frequency and radiation properties dynamically, in a controlled and reversible manner. Reconfigurable antennas, with the ability to radiate more than one pattern at different frequencies and polarizations, are necessary in modern Telecommunication systems. Reconfigurable antenna applies various techniques or methods to achieve the required change in one or more of its operation parameters. Six major type of reconfiguration techniques are used to implement reconfigurable antennas, as shown in Figure 3.

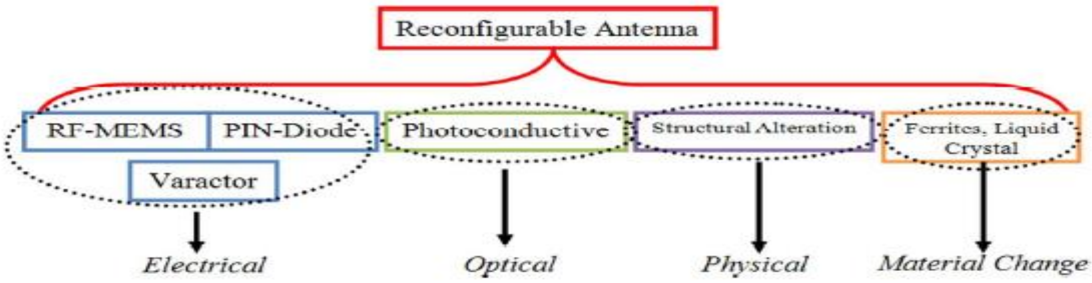


Figure 3 - Various techniques adopted to achieve reconfigurable antenna

An electrically reconfigurable antenna relies on electronic switching components (RF-MEMS, PIN diodes, or varactors) to redistribute the surface currents, and alter the antenna radiating structure topology and/or radiating edges.Antennas that rely on photoconductive switching elements are called optically reconfigurable antennas. Physically reconfigurable antennas can be achieved by altering the structure of the antenna. Reconfigurable antennas can be implemented through the use of smart materials such as ferrites and liquid crystals.
The activation of such switches requires biasing lines that may negatively affect the antenna radiation pattern and add more losses. The incorporation of switches increases the complexity of the antenna structure due to the need for additional bypass capacitors and inductors which will increase the power consumption of the whole system. These systems are able to perform only one operation at a time. Sometimes, the reconfiguration mechanisms employ motors to achieve the required reconfigurability. In TDSSF technique there is discontinuity and interruption in data transmission due to sensing period. To address the limitation of TDSSF . a frequency division spectrum sensing framework may be used which supports simultaneous spectrum sensing and data transmission.

(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 4. 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 antenna is shown in Figure 5

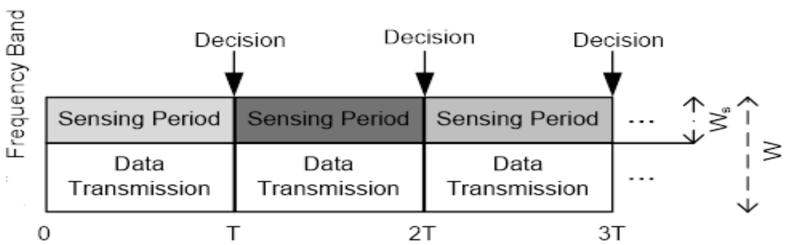


Figure 4- Frequency division spectrum sensing framework

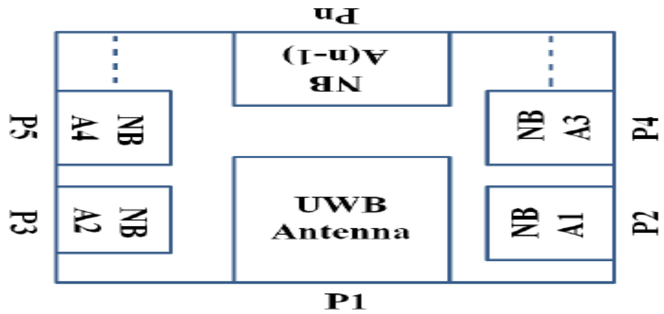


Figure 5- Basic model of multi-port system

A key component of wireless communication is the antenna. Compared to large sized antennas, microstrip patch antennas are employed for a variety of applications. Various types of antennas are designed according to the requirements of a specific application. Reconfigurable and UWB antennas are two of the types of antennas used in cognitive functions. UWB, sometimes referred to as ultraband or ultra wide band antenna, is a radio technology that employs a low energy level to communicate over short distances with a wide radio spectrum at a broad bandwidth. Applications include target detection, data collection, precise location, and tracking make use of it. It has a bandwidth of roughly 500 MHz. Given that it serves as a detecting antenna, it has a large bandwidth. Antennas that can be reconfigured are utilised for adaption. It can dynamically change its characteristics with the use of switches such as PIN, varactor diode, and MEMS. By altering a few parameters to meet shifting operating needs, it optimises the antenna's performance. There are three different kinds of reconfiguration strategies used: pattern reconfiguration, frequency reconfiguration, and pattern reconfiguration. There are two categories of users for cognitive radio: primary and secondary. Secondary users are not licensed, although primary users are. When the primary user is not using this channel, cognitive radio switches to the secondary user to use the licensed channel. Cognitive radio senses the spectrum. It uses dynamic spectrum access to be used to traffic, military, and rescue applications. This research examines several approaches to antenna design for cognitive radio applications. When the environment changes, cognitive radio can adapt its spectrum usage. The primary function of reconfigurable and UWB antennas in cognitive radio is spectrum sensing and reconfiguration. The unprecedented growth of the wireless market and industry, primarily due to consumer demand for high-speed, high-data-rate services, continuously pushes wireless and electromagnetic engineers to investigate next-generation technologies and improve the ultrawide band (UWB) system more effectively. The effective and opportunistic use of the UWB spectrum is one of the main strategies that has been tried in recent years to increase the potential of UWB systems even more. The discovery that i) several of the spectrum's frequency bands are essentially empty the majority of the time and ii) some of them are partially occupied is what gave rise to the idea of efficiently utilizing the UWB spectrum. Cognitive radiography (CR) is a method that looks for One great way to effectively employ UWB spectrum is to make the primary user's unused spectrum available and assign it to the secondary user. Compatible antenna systems are necessary for this kind of spectrum search and the subsequent dynamic allocation of the idle spectrum to the secondary user. For these kinds of applications, the antenna design is highly complex since several antennas must be installed on a single platform. The antenna or antennae in question should be able to communicate concurrently over a constrained bandwidth in a reconfigurable manner and perform wideband "scanning" to monitor the idle spectrum, also referred to as "white" space. Therefore, multifunctional antenna modules are required for cognitive radio applications. This study addresses the creation and design of MFAs that can multiple antenna features, specifically: i) assigning the idle spectrum (white space) to the secondary user and ii) recognising the primary user's unused spectrum, also known as "spectrum sensing".

LITERATURE REVIEW

Harish Rajagopalan etal., (2014) Proposed a E shaped reconfigurable patch antenna for Cognitive application[14]. It uses MEMS switches for frequency reconfiguration. Nature inspired optimization and particle swarm optimization techniques are used for channel sensing, based on sensing results MEMS switches turn into ON and OFF state. When it is ON state secondary user will uses the licensed channel otherwise it will uses its own channel. Operating frequency of this design is 2 to 3.2 GHz. Rogger substrate with coaxial feed is used for antenna design. Antenna is operated from 2to 2.7 GHz when switch is in OFF state, in ON state 2.7 to 3.2 GHz frequency.

Y. Tawk etal., (2009) proposes a antenna for cognitive radio application. This design has two structures which are implemented into the same substrate[16]. Ultra wideband (UWB) antenna is used for channel sensing to cover the spectrum from 3.1–11 GHz. Triangular-shaped antennas is used for frequency reconfiguration. Reconfigurability is done by rotational motion of an antenna. Cognitive radio systems needs sensing antenna to senses the spectrum and reconfigurable antenna for adaptation and communication.

Antenna design proposed in this paper fulfilled the needs of cognitive radio. For antenna design Roger substrate and coax feed is used with 1.6 mm substrate height. Reconfigurable antenna is rotated into two positions at position 2 it covers 3–5 GHz and at position 1 it covers 5– 9 GHz frequency band. Antenna produces different results when it is rotated into two different positions. In future FPGA is used to control the rotating motion of an antenna which in turn increases the bandwidth from 700MHz to 11GHz.

H. F. AbuTarboush etal., proposes double C-Slot Reconfigurable microstrip patch antenna[15]. The frequency is tuned based on switching states of an antenna. The antenna is operated from 5 to 7 GHz frequency. Two switches are connected each patch of the feed. FR-4 substrate with 4.4 of dielectric constant is used for antenna design. PIN diode is used as switch. Three switching states are obtained from two switches such as both switches in ON state, switch 1 alone in ON state and Switch 2 alone is ON state. This antenna is produce cross polarized radiation pattern which achieves 5 to 8 dBi as gain and 80%.

Y. Tawk etal., (2011), proposes an antenna design which also has a UWB antenna and reconfigurable antenna[17] Frequency reconfiguration is done with help of rotating motion of an antenna. Rotating motion of motor is done by stepper motor which is controlled by LABVIEW software. Operating frequency of this antenna is from 3 to 11 GHz. Printed monopole antennas as UWB antenna and circular rotating section as reconfigurable antenna. CPW feed is used for antenna design which produces coupling loss as less than 10dB.

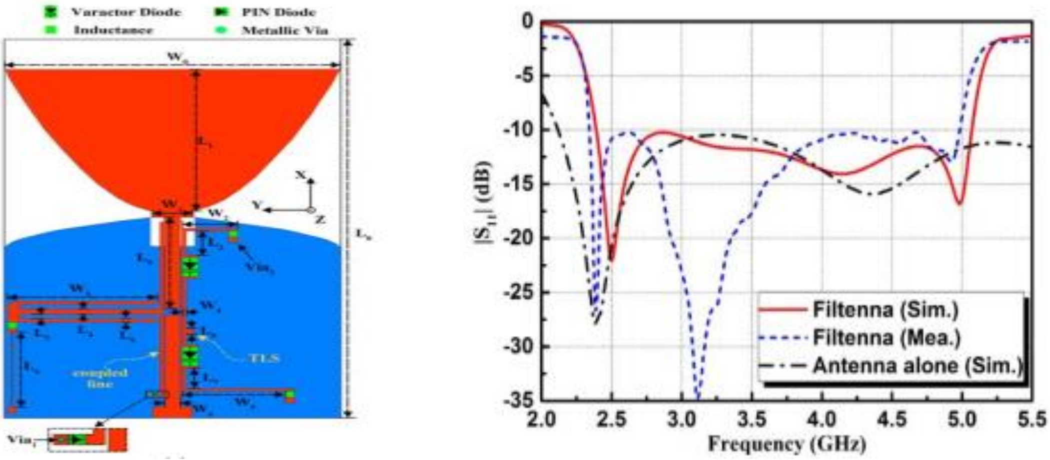
Terence Wu etal., (2010) proposes a quad-band antenna which has a directional radiation pattern[19]. It is operates with four frequency bands, (800–900 MHz), (1.7–2.5 GHz), (3.3–3.6 GHz), and (5.1–5.9 GHz). This design is used for various wireless applications since it is operated with four different bands. This design produces a gain about 9-11 dBi. Two element arrays is introduced to increase the gain of the antenna. It is suitable for the cognitive radio base station radio systems.

Elham Ebrahimi etal., (2011) proposes a multi-standard antennas[10]. Wide band and narrow band of antennas are used which should isolated from each other. In top substrate antenna is printed which act as ground plane to bottom layer small antenna. UWB antenna is integrated with CPW feed. Monopole type printed patch antenna or planar inverted F antenna is used as UWB antenna. Hour glass shape antenna with one side of printed patch substrate is used. External tuning circuits are introduced for reconfiguration of an antenna which may be either L network or Pi network. L type network covers the frequency from 4 to 10 GHz and Pi network covers frequency at 8 GHz. Capacitors and resistors are used for switching operations. If capacitor is connected parallel to patch then it acts as open circuit similarly resistor is for short circuit this in turn kept the switching states ON and OFF.

Joseph Mitola (1999) discusses about a survey of cognitive radio networks[1,2,3]. SDR (Software Defined Radio) is used to implement many high performance devices. Cognitive radio is programmed by SDR to perform dynamic operations. Cognition cycle involves four stages orient, plan, decide and act. When any comment came from an external world, then it communicates with orient stage. In this stage analysis is done based on priority or urgency of communication and then based on analysis, plan is done for communication. Then decision is made and resources are allocated for communication. In an act stage action is taken to complete within allotted time. Cognitive radio observes the environment, makes plans and measures alternatives since it is mainly used for rescue applications and traffic management.

A compact, frequency-reconfigurable filtenna with sharp out-of-band rejection in both its wideband and continuously tunable narrowband states is presented[20]. It is intended for use in cognitive radio applications. The wideband state is the sensing state and operationally covers 2.35–4.98 GHz. The narrowband states are intended to cover communications within the 3.05–4.39 GHz range, which completely covers the Worldwide Interoperability for Microwave Access (WiMAX) band and the satellite communications C-band. A p-i-n diode is employed to switch between these wide and narrowband operational states. Two varactor diodes are used to shift the operational frequencies continuously among the narrowband states. The frequency-reconfigurable filtenna is attained by integrating the compact composite filter into a wideband funnel shape monopole antenna . The geometry of the structure shown in Figure 6 (a) & The corresponding simulation and measured S-parameter results for this wideband state of the filtenna are depicted in Figure 6(b).

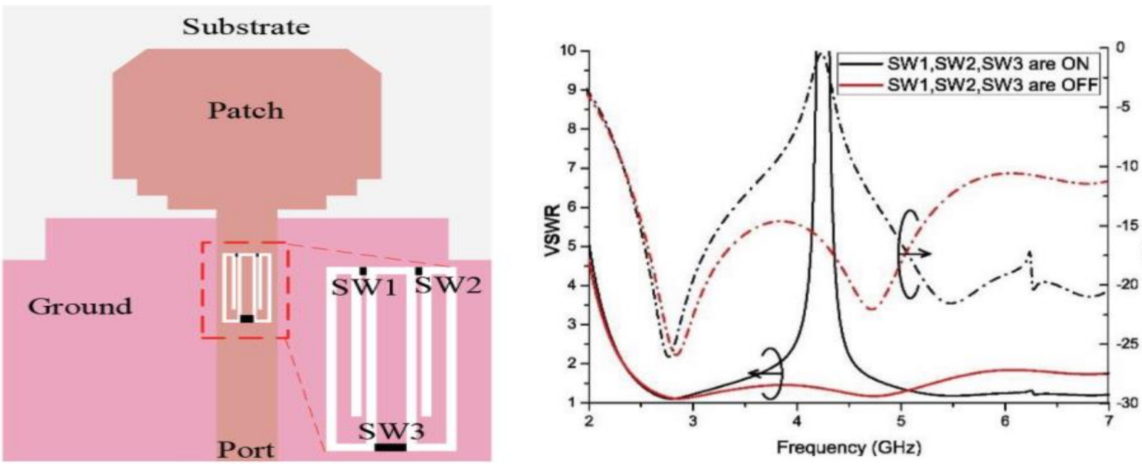
In Frequency reconfigurable Filtenna, p-i-n and varactor diodes are employed, respectively, to switch between the wideband and the narrowband states, and to realize continuous tuning amongst the various narrowband state.



(a) (b)

Figure 6 - (a) Frequency-reconfigurable filtenna , (b) Reflection coefficients of the filtenna

A printed reconfigurable ultra-wideband (UWB) monopole antenna with triple narrow band-notched characteristics is proposed for cognitive radio applications[21] . The triple narrow band-notched frequencies are obtained using a defected microstrip structure (DMS) band stop filter (BSF) embedded in the microstrip feed line and an inverted π-shaped slot etched in the rectangular radiation patch, respectively. Reconfigurable characteristics of the proposed cognitive radio antenna (CRA) are achieved by means of four ideal switches integrated on the DMS-BSF and the inverted π-shaped slot. The proposed UWB CRA can work at eight modes by controlling switches ON and OFF. Moreover, impedance bandwidth, design procedures, and radiation patterns are presented for analysis and explanation of this antenna. The designed antenna operates over the frequency band between 3.1 GHz and 14 GHz (bandwidth of 127.5%), with three notched bands from 4.2 GHz to 6.2 GHz (38.5%), 6.6 GHz to 7.0 GHz (6%), and 12.2 GHz to 14 GHz (13.7%). CR-UWB antenna may change the modes between the band-notched UWB and UWB communication systems, three switches, namely, switch-1 (SW1), switch-2 (SW2) and switch-3 (SW3), are incorporated into the band-notched UWB antenna to make the antenna reconfigurable as shown in Figure 7.



(a) (b)

Figure 7 - Reconfigurable UWB antenna. (a) Reconfigurable UWB antenna. (b) Behaviour of the antenna

The reconfigurable switching mechanisms are having various defects like biasing line affects, non-linear affects of switches, additional hardware, and power consumption. Sometimes, the reconfigurable antennas require additional biasing circuitry or motors to achieve the required reconfigurability. In CR applications, the important objectives of adopting the reconfigurable antennas are to reduce cost, space and for fast tuning. But, all the existing reconfigurable mechanisms make the planar antennas bulky and complex, which limit all the benefits of printed antennas. Also, the implementation of reconfigurable mechanisms is very difficult in practice. Moreover, these systems are able to perform only one communication operation at a time. So, to overcome the obstacles of these reconfigurable mechanisms and to preserve all the advantages of planar antennas multi-port integrated UWB and NB antennas systems can be adopted[22].

MULTI- PORT ANTENNAS SYSTEM

These systems compose of one UWB antenna and multiple NB antennas integrated on a single substrate. Multiple NB antennas are utilized to conquer the drawbacks of reconfigurable antennas and to perform multiple communication operations simultaneously when the UWB antenna senses multiple spectrum holes, which match with the NB antennas operating frequencies. This mechanism further improves the spectrum utilization efficiency, which is the main motive of cognitive radio technology. In fact, in these systems also reconfigurable switching is performed among the NB antennas such that only required antennas are operated at a time. The selection of particular NB antennas depends upon the sensed spectrum holes in the frequency spectrum to which they match. The required NB antennas are switched ON by exciting with a source signal. The remaining NB antennas go on ideal. This new type of switching is termed as excitation switching reconfigurable mechanism. In this type of switching systems any number of NB antennas can be considered depending upon available space, required isolation, bandwidth, number of parallel communication links, and cost. As the number of NB antennas increases the integrated antennas system dimensions may increase slightly but, this drawback can be neglected when comparing with the disadvantages of existing reconfigurable switching mechanisms. The other advantages of the proposed systems are that the NB antennas can also be used for RF energy harvesting when the corresponding spectrum is utilized by the primary user. The NB antenna designs can be modified so as to use the system in cognitive radio MIMO applications. Moreover, the existing reconfigurable mechanisms can also be incorporated in these types of reconfigurable switching systems. The main challenges in these designs are isolation, proper antenna switching and size reduction.

In the regard of multi-port integrated UWB and NB antenna systems, in this paper, in [22]we reported a Four-port integrated wide and narrow band antennas system design. It consists of one UWB antenna and three NB antennas integrated on top surface of a FR-4 substrate having dimensions 30mm ×50mm × 1.6 mm as shown in Figure 8. The suggested antenna construction is shown in Figure 1. This Funnel shaped UWB monopole antenna is attached to Port-1. Three narrow band slotted rectangular antenna are attached with Port-2 ,Port-3 and Port-4.

(i) UWB Sensing Antenna- We took into consideration a funnel shaped monopole with consideration for the ground plane reusability. 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.

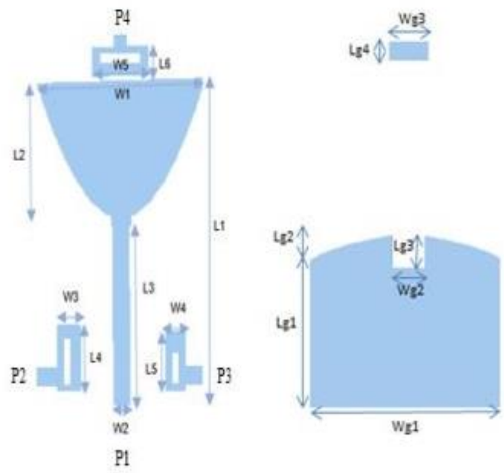


Figure 8- Proposed CR antenna system, (a) front view, (b) bottom view

An UWB monopole's effectiveness is mainly determined by its ground plane width, feed-gap, and effective radius. Beyond a certain length, it is independent of the ground plane's length. Bandwidth and impedance matching are impacted by the CPW ground's breadth. We first set the size of the ground plane to a reasonable amount. Its effect on the impedance values was observed. We added a half-pentagon to the top of the circular monopole, as seen in Figure 2, to enhance the impedance performance. This supports the finding in that bandwidth (BW) performance is enhanced by vertex reduction in the feed section. The lower circular part is similar to trimming along several vertex points. The bottom circular component increases bandwidth, while the pentagon part enhances impedance performance because of its uniform current distribution. It is well known that a circular monopole has a higher BW than other forms. We were able to accomplish UWB while minimising the size of the ground plane. 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 2 GHz - 11 GHz with VSWR ≤ 2, thus includes complete UWB spectrum from 3.1 GHz - 10.6 GHz which is approved by FCC in 2002. The 50Ω microstrip feed line is connected to the base of the funnel.

(ii) Rectangular Slotted NB Antennas- Slotted rectangular 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 NB antenna coupled 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.

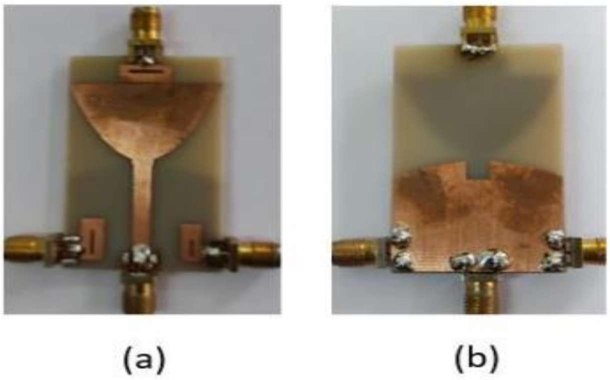


Figure 9- Fabricated antenna prototype, (a) top and (b) bottom view

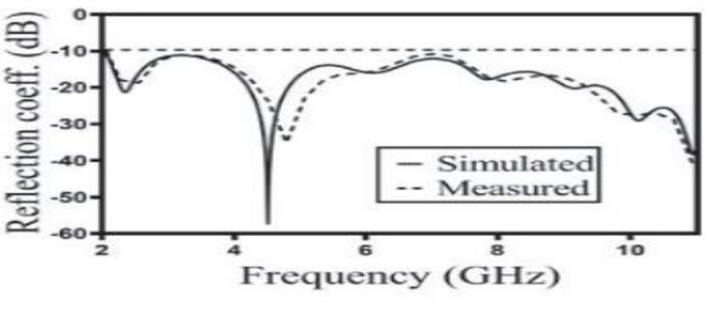


Figure 10 - Comparison of simulated and measured reflection coefficients of the UWB monopole

MULTIFUNCTIONAL ANTENNA DESIGN

MFAs, requiring UWB, narrow band and or notched UWB response in a common platform, can be designed by (i) employing multiple radiating elements on a common substrate and (ii) improvised design of the radiator/feed-line and combinatorial loading of switches and parasitic elements, on a single radiator.

(i) MFAs with Multiple Radiating Elements- In MFA realization with multiple radiators, one of the radiators is designed as UWB antenna for spectrum sensing while other radiator/radiators act as the 'communicating antenna' with frequency reconfigurable features. Rotation mechanism of a portion of the substrate sequentially brings the radiating elements in contact with the feeding line and thereby excites different narrowband configurations. Another useful technique of designing communicating antenna stage of the CR antenna system is to employ reconfigurable filtennas. In this technique, a tunable bandpass or band stop section loaded in the feed line of the communicating antenna along with an UWB antenna together forms an excellent CR antenna for spectrum underlay and spectrum interweave models. While designing MFA system comprising multiple radiating elements on a common substrate, ensuring minimal mutual-coupling is an important design criteria along impedance and radiation characteristics of the antenna.

(ii) MFAs with Single Radiating Elements- Since here the same antenna contributes to multiple antenna functionalities (UWB, notched UWB and/or narrow band) response, this technique employs an UWB radiator as the basic element. Figure 4 shows conceptual block diagram of a MFA, realized with a single radiating UWB antenna. When the Feed section of this basic UWB radiator is loaded with band-notch and or band-pass filter sections, the same antenna contributes to multiple antenna responses. Mechanical or electrical switching of the feed section to toggle around all-pass, band-notched and band-pass response with a sufficient speed is the key in practical realization of such multiple antenna response. In addition, sufficient care should be taken to ensure minimal impact of the switching and tuning elements on the radiator. Key advantages of this technique of MFA design is:

(a) minimum antenna foot-print as only one radiator is enough to achieve multiple antenna response

(b) no isolation enhancing elements are needed like the MFA design with multiple radiators.

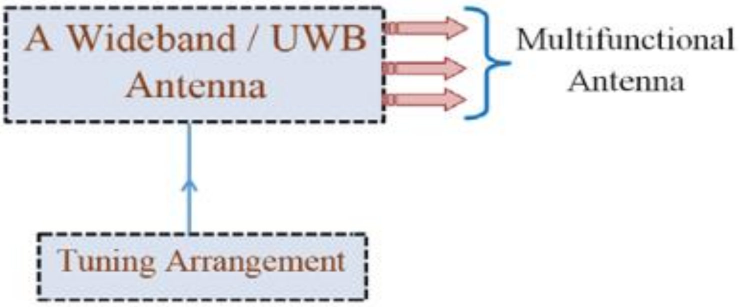


Figure 11-Conceptual block diagram of a MFA

CONCLUSION

A small, low-profile multi-port CR antenna system was reported in this study. In this paper, a four-port antenna system composed with one funnel shaped UWB antenna and three 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 one or more than one frequency bands to cover ultrawide band spectrum for direct communication purpose. This antenna system is able to perform sensing as well as communication task simultaneously and improve the spectrum utilization, which is the main objective of cognitive radio technology. The suggested antenna system satisfies the radiation characteristics such as pattern, efficiency, gain, etc. needed for the CR system. 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.

This paper presents an extensive overview of various multifunctional antennas for cognitive radio applications, including application scenarios and different schemes to realise these antennas. Research and development on MFA are still in their early stages, and antenna researchers must devote their full attention to realising such antennas with improved efficiency and performance.

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