Frequency reconfigurable for Ultra wideband planar Antenna Based Cognitive Radio Test Bed

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Abstract – *Cognitive radio is one of the most promising techniques to efficiently utilize the radio frequency (RF) spectrum. As the Digital Video Broadcasting – Handheld (DVB-H) band is targeted (470-862 MHz), the size of the antenna becomes challenging. Metamaterial concept is used as a miniaturization technique. Two antennas are designed, fabricated and measured. The first one achieved multiband operation by loading it with a metamaterial unit cell. These bands are controlled by engineering the dispersion relation of the unit cell. The design of a four switch radiating structure, integrating wide and narrow band antennas for cognitive radio applications, is presented. It consists of a UWB antenna for spectrum sensing and two narrowband antennas for wireless communication integrated on the same substrate.*

Keywords: *Reconfigurable antennas, cognitive radio, UWB*

I. Introduction

As per the need for higher data rates is increasing as a result of the transition from voice-only communications to multimedia type applications. The current static frequency allocation has led to a shortage in the radio frequency (RF) spectrum, and hence, the need of dynamic spectrum access (DSA) became a must. Cognitive radio (CR) is considered one of the most promising and innovative DSA techniques due to its two unique properties: cognitive capability and reconfigurability. An antenna is defined by the IEEE Standard Definitions [1] as “a means for radiating or receiving radio waves”. It transforms the electric energy to electromagnetic energy and vice versa.

Newly, with the development of novel communication systems, frequency reconfigurable antennas have gained a lot of attention, by adapting their properties to achieve selectivity in frequency, polarization, bandwidth, and gain (Pazin and Leviatan, 2013). A reconfigurable antenna is an antenna capable of modifying dynamically its frequency and radiation properties in a controlled and reversible manner (Bernhard, 2007). In order to provide a dynamical response, reconfigurable antennas integrate an inner mechanism (such as RF switches, varactors, mechanical actuators or tunable materials) that enable the intentional redistribution of the RF currents over the antenna surface and produce reversible modifications over its properties. Reconfigurable antennas differ from smart antennas because the reconfiguration mechanism lies inside the antenna rather than in an external beam forming network. The reconfiguration capability of reconfigurable antennas is used to maximize the antenna performance in a changing scenario or to satisfy changing operating requirements. Reconfigurable antennas apply various techniques and methods to achieve the required change in one or more of its operation parameters.

The most common technique is based on using switches such as PIN diodes, Gallium Arsenide Field Effect Transistors (GaAs FETs) or Micro-Electro Mechanical System (MEMS) switches. Other techniques include the use of optical switches or mechanical structure alteration to achieve the necessary change in the antenna configuration and these are promising methods to overcome the enormous biasing problems of the electronic switches.

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I.1. Types of antenna reconfiguration

Reconfigurable antennas can be classified according to the antenna parameter that is dynamically adjusted, typically the frequency of operation, radiation pattern or polarization. In antenna, reconfigurability is the capacity to change the fundamental operating characteristics of a radiator through electrical, mechanical or other means. Reconfigurable antennas can be placed in four groups based on the properties of the reconfiguration. These are shown in Figure 1.

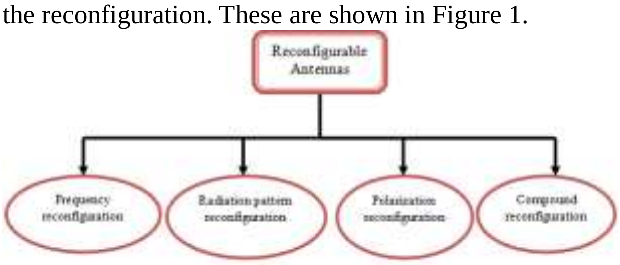

Fig.1 Different categories of reconfigurable antennas

II. Advantages and Disadvantages of reconfigurable antenna

The advantages are significant:

- Have a multiband antenna in a single terminal for various applications.

- Easy to integrate with switching devices and control circuit.
- Small in size.

However, the design of reconfigurable antenna are typically driven by the balance of trade-offs. Compared with fixed-tuned antenna, due to its short developing time, there are still some disadvantages waiting to be solved:

- The technology of reconfigurable relies largely on RF switch technology, which is not mature enough yet.
- Increased complexity and cost to the mobile phone.
- Reduced Efficiency.

III. Antenna

An antenna can be defined as a usually metallic device which radiates and receives electromagnetic waves (EM waves), more specifically,(Kraus and Marhefka, 2003). Another explanation says that an antenna is the transition between a guided EM wave and a free-space EM wave (Balanis, 2005) and vice-versa. This process is explained by a general communication between a transmitting antenna and a receiving antenna. As shown below, for both antennas, the transmission line has the form of a coaxial line or a waveguide. The latter, when a transmitting antenna is considered, is connected to a transmitter that generates radio-frequency (RF) energy that is guided through the uniform part of the line as a plane. Transverse Electromagnetic (TEM) wave with little loss, transformed into a signal that is amplified, modulated and applied to the antenna; otherwise, when a receiving antenna is considered, the transmission line is connected to a receiver which collects the alternating currents that resulted from the transformation process of the received radio waves by the antenna.

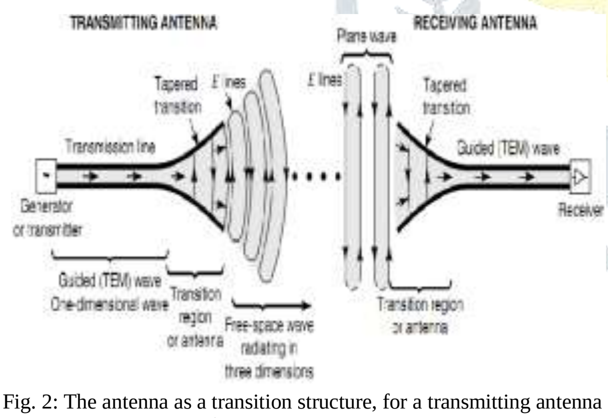

Fig. 2: The antenna as a transition structure, for a transmitting antenna and for a receiving antenna

Antenna characteristics concerning to radiation are basically the same regardless of its type. Therefore, if a time-changing current or an acceleration (or deceleration) of charge occurs, the radiation will be created in a certain length of current element. This can be described by

$$l.\frac{dl}{dt} = l.qi.\frac{dv}{dt}\left(A.\frac{m}{s}\right) \quad (1)$$

Where:
l - Length of the current element in meters (m);
di/dt Time-changing current in ampere per second (A/s).
qi Charge per unit length (coulombs/m).
Note that q = I. t = 1.602×10-19 Q.
Furthermore, the radiation is always perpendicular to the acceleration and its power is proportional to the square of both parts of the equation (1). It is important to refer that the spacing between the two wires of the transition line is just a small part of a wavelength; therefore, the more the transition curve of the antenna opens out the more the order of a wavelength or more is reached; consequently, the more the wave tends to be radiated and launched into the free-space(Kraus and Marhefka, 2003).

Looking at the antenna structure as a whole, the transition region of the antenna is like a radiation resistance (Rr) to the transmission line point of view, which represents the radiation that the antenna emits, analyzing it as a circuit. Figure 3 shows the complete circuit of an antenna; where the source is an ideal generator with a tension V_g (or V_s) and with an impedance Z_g (or Z_s); the transmission line is a line with characteristic impedance Z_c (or Z_o), and the antenna itself is represented by a load impedance ZA [*ZA= (RL+ Rr) + jXA*] connected to the transmission line. The load resistance *RL* is used to represent the conduction and dielectric losses associated with the antenna structure while *Rr*, referred to as the radiation resistance, is used to represent radiation by the antenna.

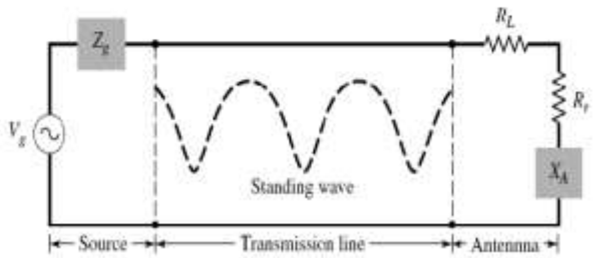

Fig.3: Circuit representing antenna as whole structure

The reactance *XA* is used to represent the imaginary part of the impedance associated with radiation by the antenna. Therefore, if ideal conditions are applied, the radiation resistance Rr, which is used to represent radiation by the antenna, will get all the energy that is generated by the transmitter.

IV. Dynamic spectrum access and cognitive radio

The increasing demand for wireless connectivity and current crowding of licensed and unlicensed spectra necessitate a new communication paradigm to exploit the existing spectrum in better ways. The current approach for spectrum allocation is based on assigning a specific band to a particular service. The FCC Spectrum Policy Task Force [12] reported vast temporal and geographic variations in the usage of allocated spectrum with utilization ranging from 15 to 85% in the bands below 3 GHz. In the frequency range above 3 GHz the bands are even more poorly utilized. In other words, a large portion of the assigned spectrum is used sporadically, leading to an under utilization of a significant amount of spectrum.

This inefficiency arises from the inflexibility of the regulatory and licensing process, which typically assigns the complete rights to a frequency band to a primary user. This approach makes it extremely difficult to recycle these bands once they are allocated, even if these users poorly utilize this valuable resource. A solution to this inefficiency, which has been highly successful in the ISM (2.4 GHz), the U-NII (5–6 GHz), and microwave (57–64 GHz) bands, is to make spectra available on an unlicensed basis. However, in order to obtain spectra for unlicensed operation, new sharing concepts have been introduced to allow use by secondary users under the requirement that they limit their interference to pre-existing primary users.

IV.1. Cognitive radio

Cognitive radio (CR) technology is key enabling technology which provides the capability to share the wireless channel with the licensed users in an opportunistic way. CRs are foreseen to be able to provide the high bandwidth to mobile users via heterogeneous wireless architectures and dynamic spectrum access techniques.

In order to share the spectrum with licensed users without interfering with them, and meet the diverse quality of service requirements of applications, each CR user in a CR network must [2]:

• Determine the portion of spectrum that is available, which is known as Spectrum sensing.

• Select the best available channel, which is called Spectrum decision.

• Coordinate access to this channel with other users, which are known as Spectrum sharing.

• Vacate the channel when a licensed user is detected, which is referred as Spectrum mobility.

To fulfill these functions of spectrum sensing, spectrum decision, spectrum sharing and spectrum mobility, a CR has to be cognitive, reconfigurable and self-organized. An example of the cognitive capability is the CR's ability to sense the spectrum and detect spectrum holes (also called white spaces), which are those frequency bands not used by the licensed users. The reconfigurable capability can be summarized by the ability to dynamically.

V. Spectrum Sensing and Allocation

In order to identify the spectrum holes in OSA model, CR systems need to scan the spectrum and spot the vacant or idle parts of the spectrum which is known as spectrum sensing. Based on the information CR knows about its own internal state and surrounding environment, it then determines the optimum frequency band and subsequently starts the communication. This procedure is referred to as communication. Two main approaches for spectrum sensing and communication are as follow:

A. The continuous spectrum sensing is carried out in a process in parallel to the communication link as shown in Fig. 4.

B. A single channel is used for both spectrum sensing and communication as shown in Fig. 5.

A two antenna system is proposed for approach (A) [8]. One antenna is wideband and Omni-directional, feeding a receiver capable of both coarse and fine spectrum sensing over a broad bandwidth. The second antenna is directional and feeds a frequency agile front end that can be tuned to the selected band. A single wideband antenna feeding both spectrum sensing module and the frequency agile front end can also be a solution for approach (A) [9].

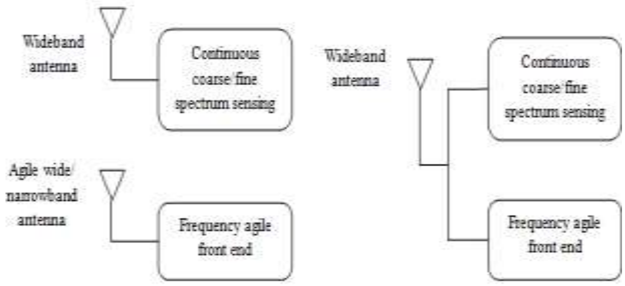

Fig. 4 Cognitive radio architecture with parallel sensing and communications

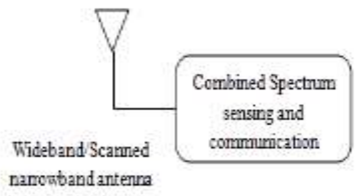

Fig. 5 Cognitive radio architecture with combined sensing and communications

In approach (B), spectrum sensing and radio reconfiguration are performed when the communication link quality falls below defined thresholds. In [10], two thresholds are used. Link quality falling below the first threshold triggers spectrum sensing, so that a better system configuration can be identified that will meet the link quality requirements. When the quality degrades below a second lower threshold, the system is reconfigured.

Considering the system requirements discussed above a potential antenna solution for CR might be an antenna with multiple functionalities. The potential system might include an antenna with wideband frequency response and Omni-directional radiation pattern for spectrum sensing together with reconfigurable narrowband functionality. Narrowband functionality can be achieved by supplementary filtering in the RF stage; however, this might add to the complexity of the RF front end circuitry. Filtering and reconfiguration can be included into the antenna in order to reduce the complexity of the filtering circuits in RF stage.

VI. Results

In this section, discuss the proposed three-port antenna system composed of a UWB and two NB antennas integrated on the same substrate. The patch antenna design was carried out using a high frequency structure simulator (CST 2017) based on finite difference time domain method. The gaps between the two rectangular parasitic elements and the main patch is carefully optimized to enhance the bandwidth of the main patch by coupling multiple resonances at different frequencies. The antenna is designed to exhibit a relative bandwidth of 31.3% ranging from 2 to 6 GHz. The antenna frequency reconfigurability was achieved by implementing four switches as follow: all switch is connect with base design architecture as show in figure.

Here design four switch s1,s2,s3,s4,based antenna architecture as show on figure 6 In proposed architecture design The antenna frequency response is reconfigured by altering its current path through the use of three switches (named S1, S2,S3 and S4 respectively). The three switches are used to connector disconnect the metallic patches etched on the FR4 substrate, rectangular parasitic elements and the main patch. This architecture is design with the help CST EDA tool . After analysis, it is found that elliptical notch parameters are critically affected the impedance BW of the antenna. USB exhibits the impedance BW of 24 % from 2 GHz to 10 GHz for |S_11 |<-10 dB. This antenna showsthe resonance behavior at resonating frequencies (measured) 1.1, 2.81, 3.83, 4.94, 5.72 and 7.2 GHz. The series of the equation has been developed after inspecting the vector current distribution at resonating frequencies. The lower edge frequency of this antenna depends on the major axis radius of the elliptical patch. It has been found that the higher order modes are generated at the higher frequency. Due to higher order modes, the distorted pattern has observed at frequency 3.83 GHz. In the second part of this chapter CWSA with tuning element has been analyzed. In evolution of this antenna, it has been examined that the slots and notch critically affect the impedance matching in entire frequency span.

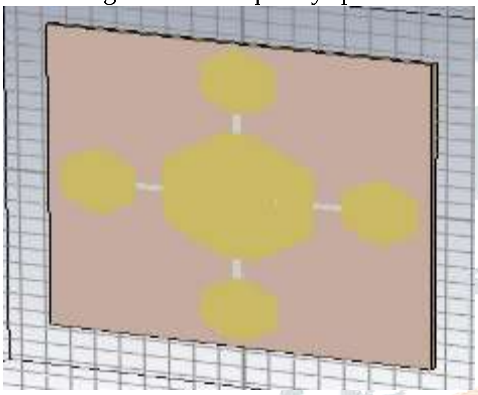

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Figure:6 Base Module without without switch

Initially it is design without switch then connect pin diode as a switch. We connect switch in all four side of base architecture. After the design we analysis different scenario of operation ,operate switch on and off cases and analysis operation and frequency of the antenna . First connect s1 switch on and rest of switch will off and test get result 30.1% BW used. In this scenario we get 2.1 to 5 GHz. frequency range.

After this we on switch S1 and S2 and get the result that our spectrum band is 2 to 9 GHz. and bandwidth optimization is 30.1% and 26%. as show on table 1 .

Below architecture is final architecture of our proposed Reconfigurable USB antenna which is generate best output of multi frequency band and optimized bandwidth. This is design multi switch based architecture and operate different scenario for multifunction operation.

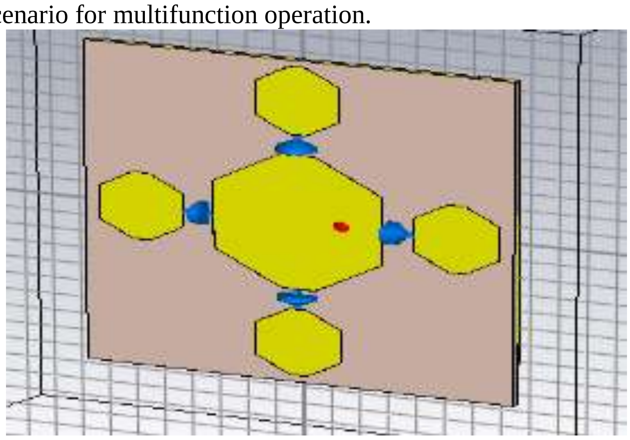

Figure:7 Proposed Reconfigurable USB with Four switch

In figure 7 is shows time frequency graph which is generate by our proposed system architecture, shows utility of signal with respect to time.

In figure 8 is show basic s parameter result when all switch is off (S1,S2,S3,and S4). In this figure we get different frequency band between 1 to 6 GHz frequency and BW requirement of this architecture 31.3%. We also test this circuit in different scenario based on switch operation.

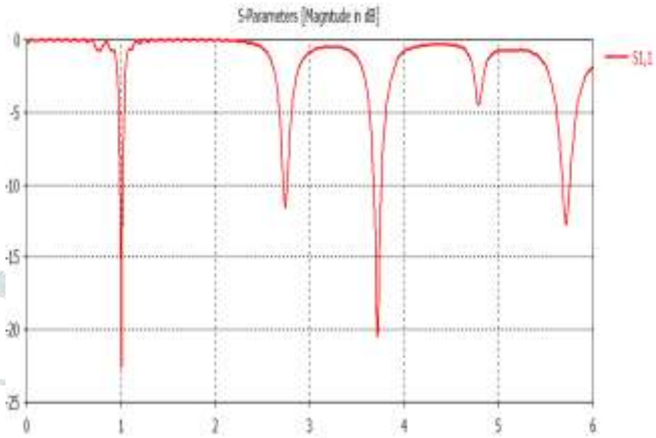

Figure:8 S- parameter without use on switch

Table 1 Compare Previous and proposed design

	Base		Proposed	
The Switch State (S1,S2,S 3 & S4)	Frequency Range	Relative Bandwidth %	Frequency Range	Relative Bandwidth %
Off Off Off Off	5 to 7 Ghz.	33.8%	2 to 6 Ghz	31.3%
Off Off Off ON	4.3 to 6 Ghz & 7 to 9 Ghz	33.4% & 25.2%	2 to 6 Ghz & 7 to 9 Ghz	30.1% & 26%
	4 to 5.1 Ghz & 7 to 9 Ghz	26% & 25.2%	2 to 9 Ghz	24%

Conclusion

To accomplish the research aim, the detailed analysis, design and fabrication of cognitive radio system, here present compact reconfigurable UWB patch antenna. To observe the behavior of the antenna the parametric study of both antennas has been carried out. After analysis, it is found that elliptical notch parameters are critically affected the impedance BW of the antenna. Proposed design of the proposed compact reconfigurable patch antenna. Four switches are used to reflect a better UWB case . The series of the equation has been developed after inspecting the vector current distribution at resonating frequencies. The lower edge frequency of this antenna depends on the major axis radius of the elliptical patch. It has been found that the higher order modes are generated at the higher frequency. The frequency domain parameters of these antennas have been perceived in terms of VSWR, S11 parameter, input impedance and radiation pattern. USB exhibits the impedance BW of 24 % from 2 GHz to 10 GHz for |S_11 |<-10 dB. This antenna shows the resonance behavior at resonating frequencies (measured) 1.1, 2.81, 3.83, 4.94, 5.72 and 7.2 GHz.

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