Spectrum Sensing Ultra Wideband Antenna for Cognitive Radio Applications

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Abstract.
This paper presents the design, testing and validation of an Ultra Wide Band microstrip antenna for spectrum sensing requirements in Cognitive Radio applications. A circular microstrip patch antenna is first designed at 5.8 GHz frequency, and then the size of the ground plane is reduced to increase the bandwidth. For better return loss a cut is made in the ground plane below the feed line. The antenna is simulated using HFSS EM simulation tool. The radiating patch is fabricated on FR4 substrate of thickness 1.6 mm and dielectric constant 4.6. The fabricated antenna is tested using a VNA in anechoic chamber. VSWR and return loss obtained in simulation are well below 2 and -10 dB respectively between 3.6 GHz to 10.1 GHz. Similar results were obtained when practically tested. Measured VSWR, return loss and radiation patterns are presented. The fabricated antenna is then connected to Amitec software defined radio for transmission and reception using narrow band FM modulation in GNU Radio. The photographs of results are presented.

Keywords: UWB Antenna, Cognitive Radio, Software Defined Radio, Spectrum Sensing.
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Introduction

With the rapid development of wireless communication systems, technologies that provide unique solutions or add-ons to existing wireless technologies have been the subject of extensive research for decades, and ultra-wideband (UWB) systems provide a similar solution. The Federal Communications Commission (FCC) allocated 7.5 GHz bandwidth from 3.1 to 10.6 GHz with an effective isotropic radiated power (EIRP) of 41.3dBm/MHz in February 2002, making UWB systems possible [1].An antenna is a device that can send and receive signals. As a result, the speed of this sending and receiving process is a challenging interest, especially given the rapid advancement of communication technologies. On the other hand, the rapid development of communication systems, both fixed and portable, prompted a high data rate transfer to cover a larger area due to network user growth. As a result, they required a wide bandwidth (BW) to cover mobile and all wireless services. This is possible by using low-profile ultra-wideband (UWB) antennas to reduce complexity and fabrication costs [2].

The UWB standards in various countries are unlicensed and the usage of frequency bands in UWB [3] are not restricted which are presented in Table 1. Many UWB antennas were presented in [4] and their design procedure, techniques, findings, and performances were examined. Use of monopole antenna is an easiest method to obtain UWB characteristics. Monopole antennas of various shapes are reported in literature such as circular [5,6], rectangular [7], elliptical and semi-elliptical [8,9,10], complex structures such as cactus shape [11]. The other popular methods used to achieve UWB antennas is altering the ground structure and radiating patch to control the surface current distribution [12].

For applications in compact and wireless devices, antenna sizes are to be small with UWB performance. To fulfill small size in UWB antennas is very tedious task. One can find a variety of compact UWB antennas reporting in literature including [13].MIMO antennas are reported in [14] and use of meander lines in ground plane to increase the current path to increase bandwidth can be found in [15].UWB antennas on flexible substrates are found in [16-18]. Fang et al. developed a graphene-assembled film based low-profile and compact UWB structure in the frequency range 4.1–8.0 GHz for wearable applications [17].

Table 1. UWB Standards as in [2]

Country	Frequency Bands
Europe	3.1-4.8 GHz, avoid restrictions 6-8.5 GHz, no restrictions
Japan	3.4-4.8 GHz, detect-and-avoid (DAA)restrictions 7.2-10.2 GHz, no restrictions
Singapore	6-9 GHz, no limitations 3.4-4.2 GHz, DAA limitations
America, Canada	3.1 to 10.6 GHz, license free
Korea	3.1-4.8 GHz, DAA restrictions 7.2-10.2 GHz, no restrictions

Numerous gain enhancement techniques for UWB antennas have been proposed, like introduction of electromagnetic band gap (EBG) [19], differential feeding [20], Frequency Selective Surface (FSS) below the parasitic radiating patch [21]. Bunch of review articles on UWB antennas are reported in literature for spectrum sensing in Cognitive Radio namely [22,23].

Antenna Design

A microstrip patch antenna is simple, low profile, compact, economical, light weight, flexible to flat and non-flat surfaces and appropriate with Monolithic Microwave Integrated Circuits (MMIC) designs [24]. First a rectangular patch antenna is designed at 5.15 GHz frequency using the relation referring Eq. 1 to Eq. 5. The effective relative dielectric constant is [35],

$$\text{for} \quad W/h > 1$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \tag{1}$$

where, 'L' is length of the radiating patch, 'W' is width, 'h' is substrate height, and 'ε_r' is substrate relative dielectric constant. The effective relative dielectric constant is a constant value for lower frequencies. But as the frequency increases, its value increases and reaches the actual value of ε_r for further increase in frequency.

Fringing effect makes the patch electrically greater than its physical dimensions. Therefore an approximate normalized extensions of the patch length is [26],

$$\frac{\Delta L}{h} = 0.412\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{2}$$

Therefore, the total length considering length extension on both side of the patch by ΔL, is expressed as,

$$L_{eff} = L + 2\Delta L \quad (3)$$

For good radiation efficiencies, the practical width of the patch is given by [26],

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{1+\varepsilon_r}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{1+\varepsilon_r}} \quad (4)$$

where, v_0 is equal to speed of light in vacuum and the actual length of the patch is, for frequency of resonance f_r,1

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L \quad (5)$$

The dimensions obtained for the rectangular patch are length, *L* = 13.04 mm, width, *W* = 17.39 mm. But later the rectangular patch is converted to a circular one using the Eq. 6, to determine the radius of the circular patch [27].

$$(((H+(1.5*Dh))*(W+(1.5*Dh)))^{1/2}) / 2 = Radius \quad (6)$$

The calculated radius of the circular patch is 18.25 mm. The development of the antenna is presented in Figure 1. And Figure 2 shows the actual antenna structure with optimized dimensions.

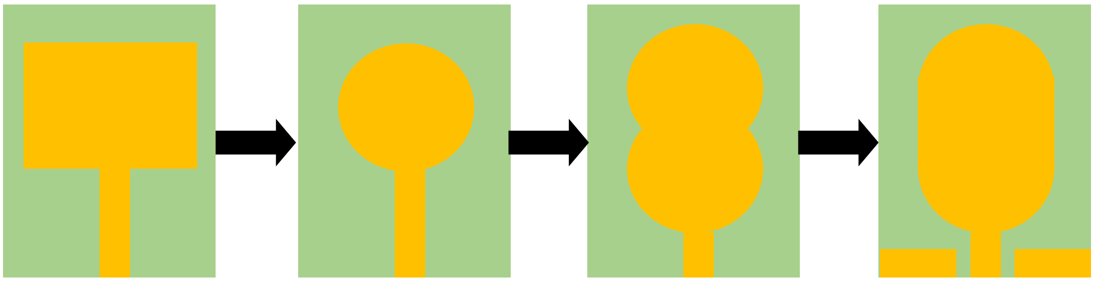
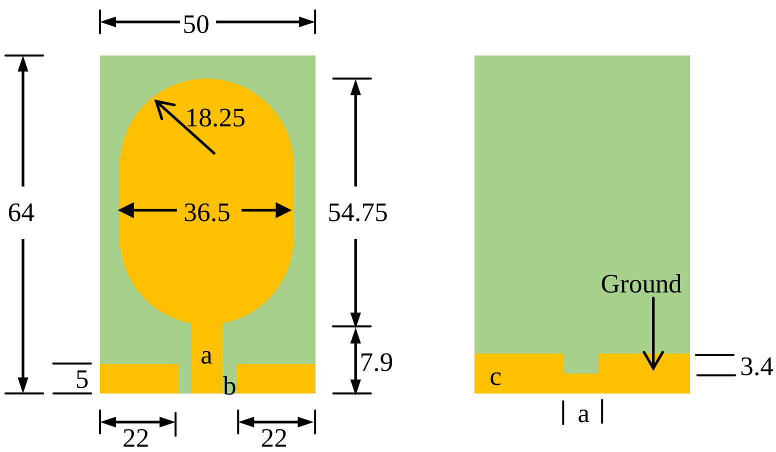


Figure 1. Development of the proposed antenna structure.



(a) (b)

Figure2. Antenna Structure and Dimensions (a) Top View, a = 3.06, b = 1.47 abd (b) Bottom View, c = 7.7 vertical distance (all dimensions in mm).

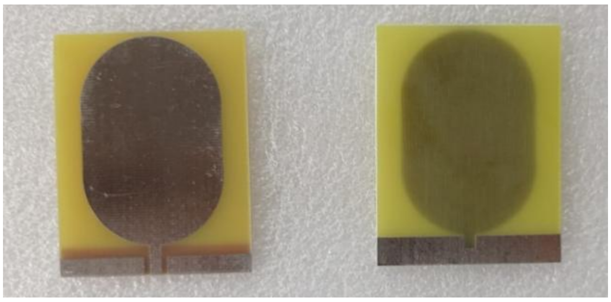


Figure 3. Fabricated Antenna (a) Top View and (b) Bottom View.

The antenna is fabricated on FR4 substrate material which is economical and easy to handle while fabricating. The thickness of the substrate is 1.6 mm and dielectric constant ε_r = 4.6.

Results and Discussions

The fabricated antenna is first connected to Vector Network Analyzer to measure VSWR and return loss as shown in Figure 4. The measured VSWR is below 2 dB from 6.3 GHz to 10.1 GHz and the return loss is less than -10 dB the same range. These results obey the UWB standards.

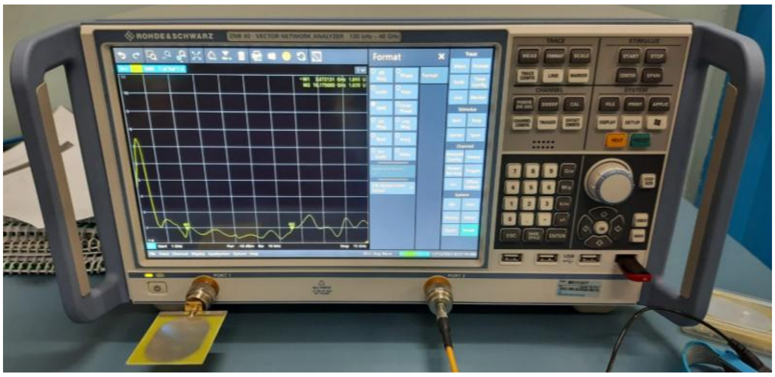


Figure 4. Proposed UWB Antenna connected to Vector Network Analyzer to measure VSWR and Return Loss

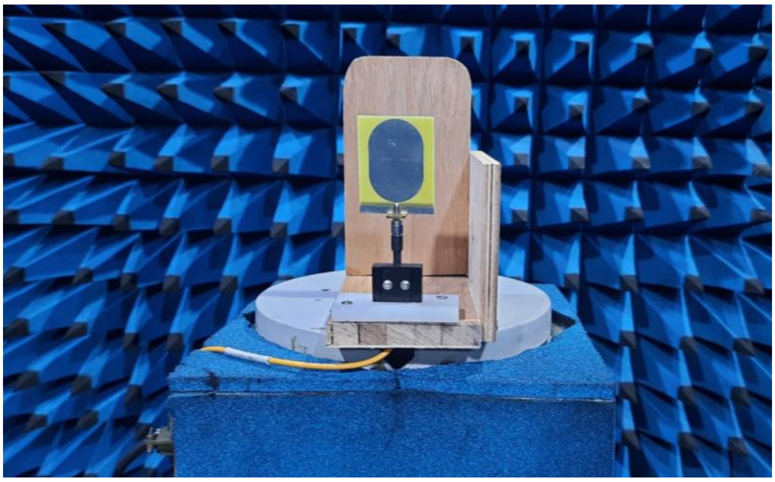


Figure 5. Proposed UWB Antenna connected in Anechoic Chamber to measure Radiation Pattern

Then the fabricated antenna is connected in an Anechoic Chamber for field measurements to obtain the radiation pattern as presented in Figure 5. The measured VSWR and return loss are presented in Figure 6 and Figure 7 respectively. And Figure 8 shows the simulated and measured E-Field radiation pattern at frequency 5.15 GHz. The maximum gain obtained is 4.6 dB.

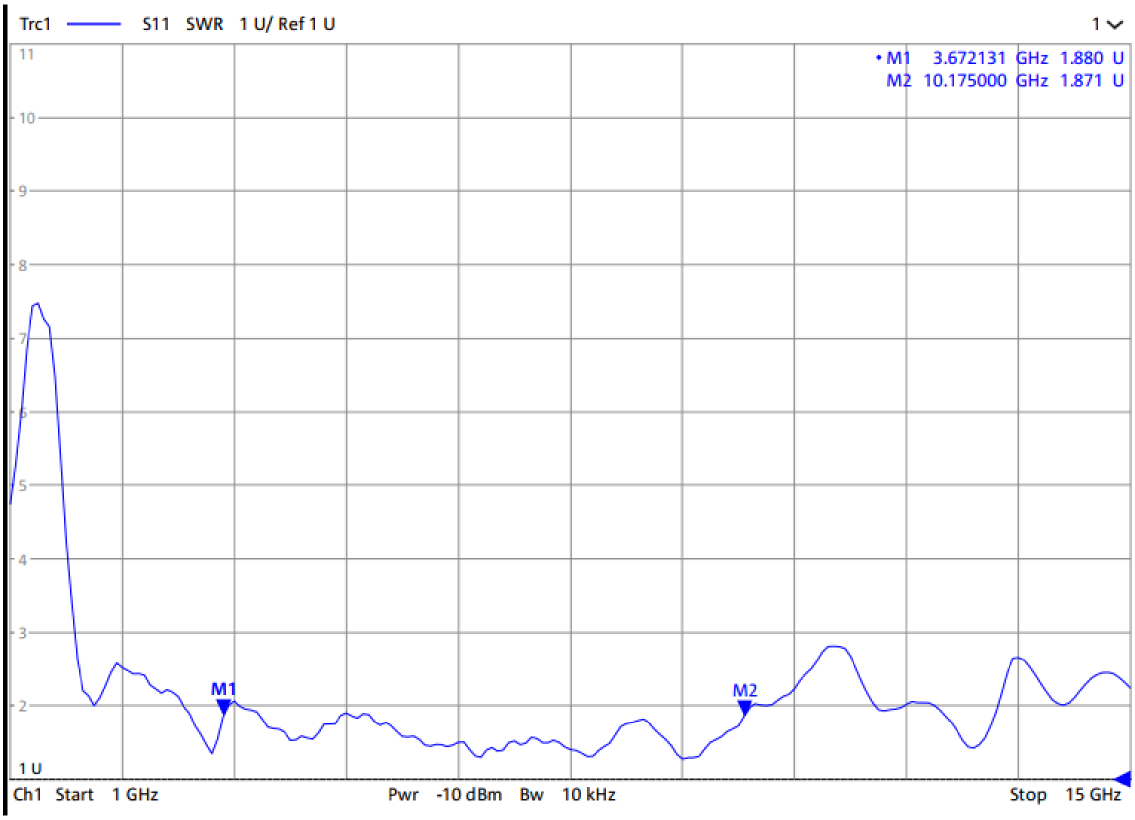


Figure 6. Measured VSWR

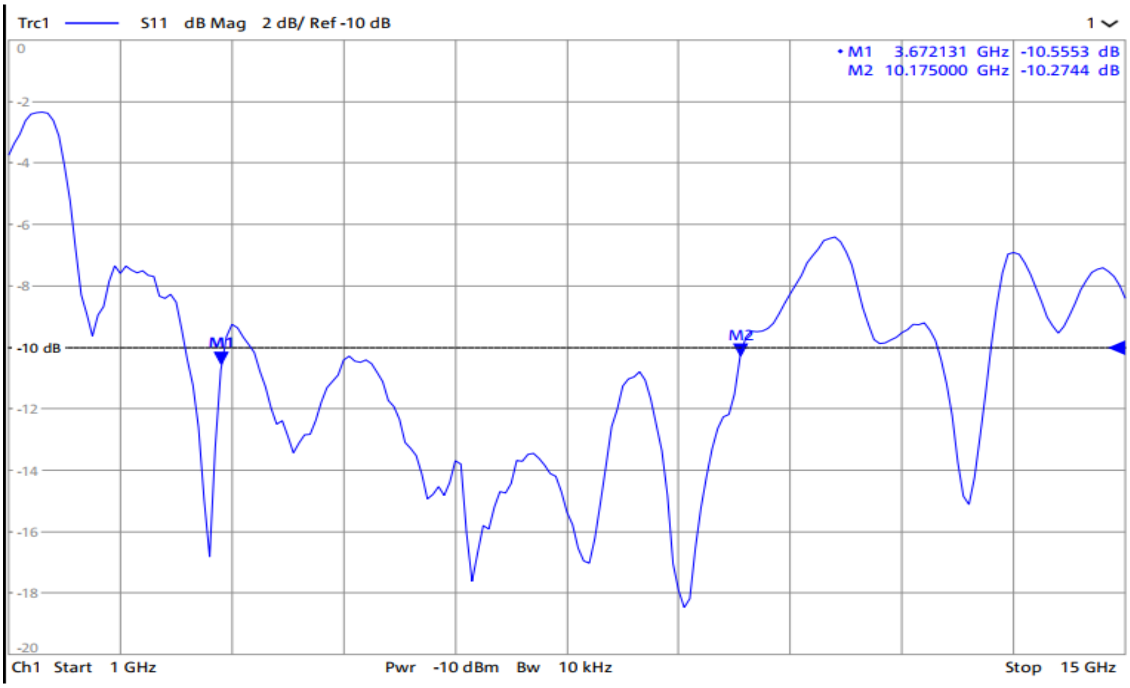


Figure 7. Measure Return Loss

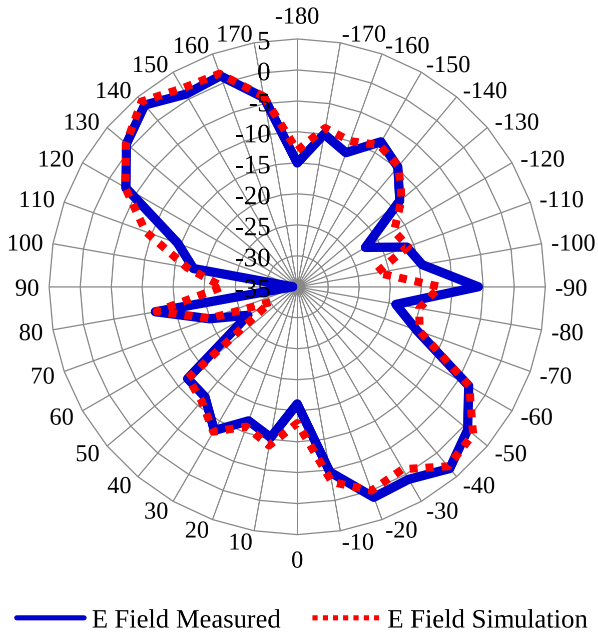


Figure 8. Simulated and Measured E Filed

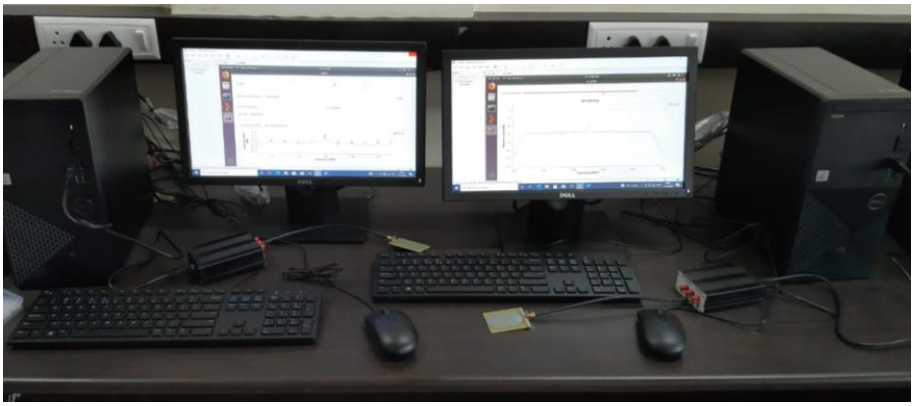


Figure 9. Proposed Antenna is connected to Amitec SDR as a transmitting and receiving antenna.

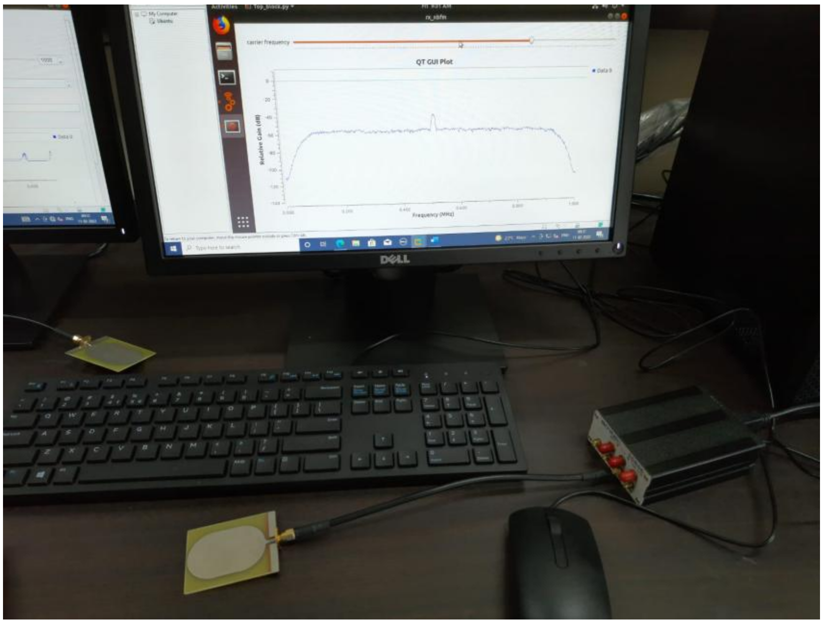


Figure 10.Narrow band FM signal sensing representing presence of user

Next the antenna is connected to Amitec Software Defined Radio (SDR). A program is built in GNU radio to sense the spectrum to validate the proposed antenna for applications in CR. Narrow band FM modulation scheme is chosen to transmit a signal and the same is received by the receiving antenna. Figure 9 shows the antenna connected to SDR, one as transmitting antenna and the other as receiving antenna. Figure 10 shows the received narrow band FM signal representing the presence of a user. The threshold value used for presence of a user or to decide absence of user in a particular frequency band is chosen to be different for various applications including indoor or outdoor environments etc. We have chosen -95 dBm as the threshold level for user detection. With the experiments conducted and results presented we can conclude that the proposed antenna is suitable to use in CR environments.

Summary

A UWB circular antenna is developed for the purpose of spectrum sensing in CR environment. The approach used is novel and the results obtained are obeying the UWB standards. The proposed antenna is tested in anechoic chamber for field measurements and also connected to VNA for return loss and VSWR readings. The maximum gain obtained is 4.6 dB. To validate the antenna for CR applications, it is connected to SDR and tested for transmission and reception of a narrowband FM signal. Spectrum can be sensed from 3.6 GHz to 10.1 GHz frequency range. This antenna agree to the UWB as well as the CR standards.

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