Antenna Designs for Cognitive Radio Application in the TV Band

M. Y. Abou-Shahine, M. Al-Husseini, A.H. Ramadan, K. Y. Kabalan and Y. Nasser

Abstract— This paper presents three antenna designs suitable for cognitive radio applications in the TV band. Two printed microstrip miniaturized monopole antennas and one Planar Inverted F Antenna (PIFA) are proposed. The microstrip antennas are designed on a Rogers RO3203 substrate fed by a microstrip line over a small partial ground plane. The PIFA antenna consists of a patch above a ground plane with feeding and grounding strips connecting them. These antennas, designed for transmission of cognitive radios in the TV band, operate in the upper part of the UHF band (700-900 MHz) with approximately 2.5 dB transmission gains and omnidirectional patterns.

Index Terms — Cognitive Radio, Monopole Antennas, Miniaturized Antenna, PIFA, TV band.

1 Introduction

THE development of communication systems and the need for higher data rates have led to the scarcity of the radio frequency (RF) spectrum. This is due to the static frequency allocation which has caused a large portion of the spectrum to be underutilized. With the increasing demand for efficient operation of radio frequency devices with limited resources, such as energy and frequency spectrum, cognitive radio [1]-[3] is thought to be a drastic solution. Cognitive radio (CR) is one of the most promising techniques to efficiently utilize the spectrum and intelligently improve communication efficiency. In a CR network, unlicensed users (secondary users) are allowed to access spectrum bands licensed to primary users, while avoiding interference with them. This intelligent radio permits the secondary user to sense the spectrum, locate the free portions or the ones with reduced primary activity, and transmit on the best available channel [4].

A crucial step towards efficient spectrum utilization is based on a secondary opportunistic access as proposed by FCC after the digital switchover [5], in which CR Secondary Users (SU) could access the unused portions of the TV licensed spectrum, called TV white spaces (TVWS). These unused TV white spaces are an attractive target for cognitive radio applications, since they operate at an easy to use frequency, and have good propagation characteristics, improved communication quality, better building penetration, and lower energy consumption.

In cognitive radio networks, two types of antennas are needed: sensing and communicating antennas. The sensing antenna, which is usually an Ultra Wide Band (UWB) antenna, is used to sense the spectrum and find the spectrum holes, and the communicating antenna is used to transmit at the frequencies of these holes.

The fact that this CR system can be utilized in portable devices leads to an important challenge especially at the TV band [6]. Indeed, the size of the antenna must be small so that the antenna can be mounted in these portable devices. Hence, a practical solution is to design miniaturized antennas of compact sizes that can be installed in portable devices and can operate on the frequencies of the TV band. Moreover, there is a need to have an omnidirectional radiation pattern antenna, so that users can sense and identify the spectrum holes in wireless environment, transmit and receive independently of their direction.

Different techniques have been used to design antennas transmitting and receiving in TVWSs. The UWB antenna designed for cognitive radio in the UHF TV band reported in [7] presents a wide bandwidth covering the whole TV band. A pair of slot lines is adopted in order to minimize the antenna size, and this can accomplish good impedance matching at the UHF band. The compact broadband monopole slot antenna described in [8] exhibits a wide bandwidth (460 – 1000 MHz) using a feed-in space and a straight gap. In [9], a coplanar printed monopole antenna for digital television (DTV) in the UHF band (470-862 MHz) application is designed. The meander loop monopole and step-shaped ground plane are printed on the same side of a substrate with an area of 15 x 170 mm. A compact simple folded dipole antenna for digital television (DTV) signal reception in the TV band is proposed in [10]. The proposed antenna can provide the way of the controlling the required bandwidth and impedance matching over the DTV frequency band using narrow rectangular radiating patches and coupling gap. The asymmetric fork-like monopole antenna for digital video broadcasting-terrestrial (DVB-T) signal reception for application in the UHF band is presented in [11]. It consists of two two-branch strip monopoles on a rectangular ground plane with a concave which results in a wide bandwidth of 461 MHz (451–912 MHz). In [12], a novel grating monopole antenna built through a grating patch and a rectangular ground plane with a concave used for digital video broadcasting-terrestrial application is presented. This antenna exhibits a wideband operating bandwidth which is attained by

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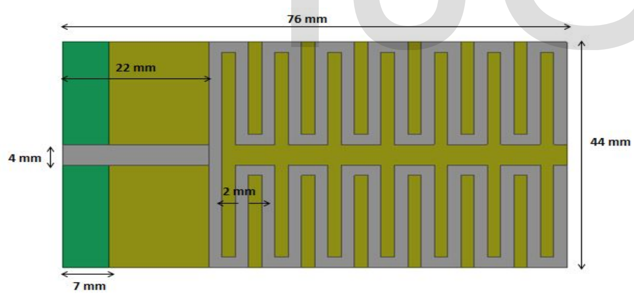
cutting a notch at the ground pattern opposite to the microstrip line.

In this paper, three antenna designs for transmission of cognitive radios in the TV band are proposed. More precisely, we propose two microstrip miniaturized antennas and one PIFA antenna. A meander structure is used to reduce the size of the antennas for lower band operation. The designed antennas having reduced dimensions operate in the band 700-900 MHz which is suitable for cognitive radio applications in the TV band. The target behind this band is that it would be highly recommended for mobile broadband access. The geometry, the design guidelines, and the experimental results of the proposed antennas are presented in Section 3. In Section 4, a brief conclusion is given. The characteristics of the designed antenna are investigated via HFSS and experimentally verified.

2 Design, Simulation, and Results

2.1 Miniaturized Printed Monopole Antenna

The configuration of this proposed antenna is shown in Fig. 1. A miniaturized printed monopole antenna is designed on a 76 mm x 44 mm Rogers RO3203 substrate with dielectric constant εr = 3.02 and thickness h = 1.6 mm. The antenna is fed by a 4 mm width microstrip line over a small partial ground plane of 7 mm. The size of the miniaturized structure is 54 mm x 44 mm with a width of 2 mm and a gap of 2 mm between the spirals as shown in Fig. 1.



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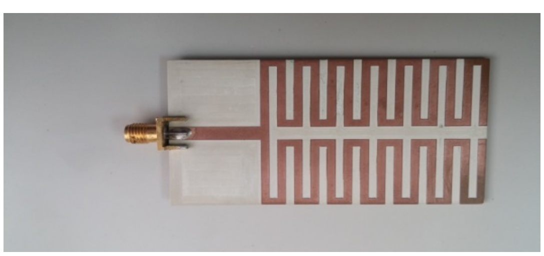

(b)

Fig. 1. (a): Configuration and dimensions of the miniaturized monopole antenna, (b): Photo of the fabricated prototype

The size of this antenna is very small compared to antennas operating in the UHF band. This small size allows this antenna to be utilized in portable devices such as mobile phones, tablets and notebooks.

In this antenna, the meander wire is used as a radiating element, and this is done to reduce the size of the antenna. Globally, the meander line is widely employed as a miniaturized radiating element. However, in the literature, the radiation power and the transmission gain are reduced since the direction of the current on the meander line is usually opposite for neighboring wire, therefore the antenna gain will be very low. To overcome this problem in our proposed design, the current in the meander wire follows the same direction, thus the transmission gain and the radiation efficiency are enhanced. The antenna is designed and simulated using Ansoft HFSS.

The fabricated prototype has undergone the needed measurements. The simulated and the measured reflection coefficient plots of the proposed antenna are given in Fig. 2. It is observed that the simulation results and the measurements results are similar with little difference due to some fabrication issues. As stated in [13], antennas used for DVB transmission in the TV band can operate on frequencies having the reflection coefficients below -6 dB. This antenna can operate in the band 785-855 MHz, thus it can be suitable for transmission in cognitive radio applications in the TV band.

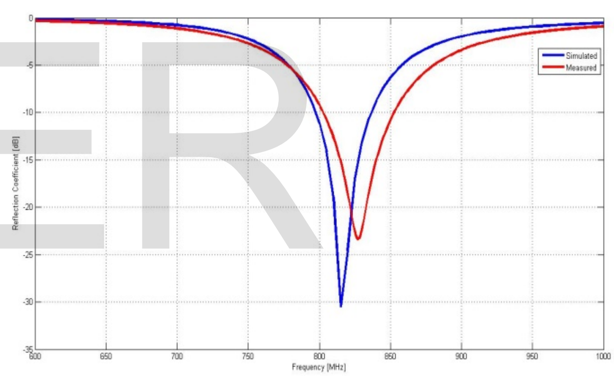

Fig 2. Simulated and measured reflection coefficient plots of the miniaturized monopole antenna

Fig. 3 shows the simulated and the measured radiation patterns of the miniaturized printed monopole antenna. It is observed that the radiation patterns are omni-directional over its band of operation, with almost equal radiation in the H-plane, and radiation with the shape of digit 8 in the E-plane.

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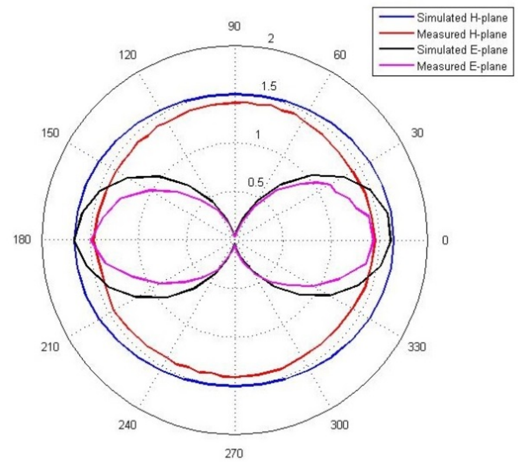


Fig. 3. Simulated and measured radiation patterns of the miniaturized monopole antenna

Fig. 4 shows the simulated and the measured gains for the miniaturized printed monopole antenna in the operating frequency range. It is observed that the peak gain is about 2.25 dBi, and it is located at the resonance frequency of the antenna. The simulation results and the measurements results are similar with little difference due to some measurements issues. This gain can be considered a good gain given the small size of this antenna.

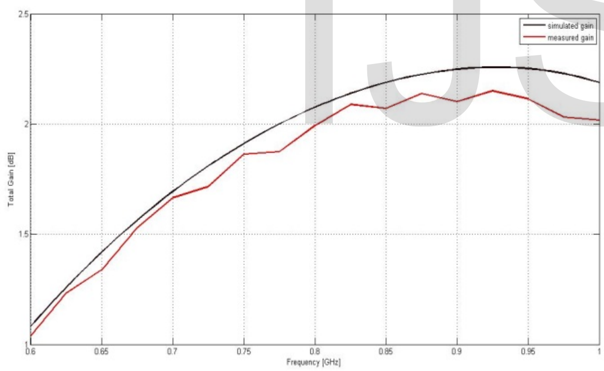
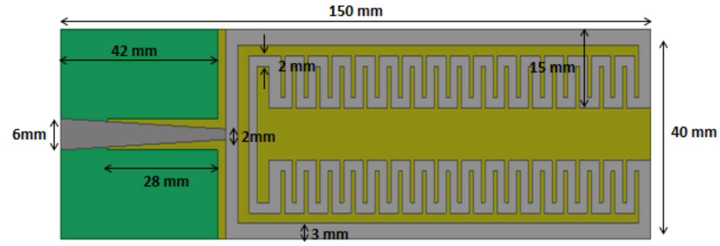


Fig. 4. Simulated and measured gain of the miniaturized monopole antenna

2.2 Meander Loop Monopole Antenna

The configuration of the proposed microstrip monopole antenna is shown in Fig. 5. A meander loop monopole antenna is designed on a 150 mm x 40 mm Rogers RO3203 substrate with dielectric constant of 3.02 and thickness h = 1.6 mm. The antenna is fed by microstrip line which starts with a width of 6mm at the port of the antenna and ends with a width of 2 mm at the patch as shown in Fig. 5. This shape of the feed line is designed in order to maintain perfect matching of the antenna. The antenna is designed over a partial ground plane with a slot in it. The antenna consists of a meander structure with two straight strip lines with a width of 3 mm.



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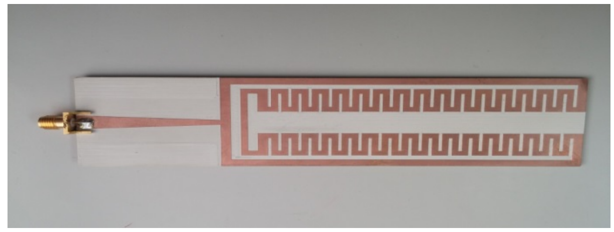


(b)

Fig. 5. Configuration and dimensions of the meander loop monopole antenna, (b): Photo of the fabricated prototype

The size of this antenna makes it appropriated for applications in tablets and notebooks. The meander structure is used as a radiating element. The notch in the ground plane serves as an effective way for the gap between the radiating element and the ground plane, and consequently is responsible for the wide operation. The antenna is designed and simulated using Ansoft HFSS.

The fabricated prototype of the meander loop monopole antenna has undergone the needed measurements. The simulated and the measured reflection coefficient plots of the proposed antenna are given in Fig. 6. It is observed that the simulation results and the measurements results follow the same pattern with little difference due to some fabrication issues. This antenna can operate in the band 700-900 MHz, thus it can be suitable for transmission in cognitive radio applications in the TV band.

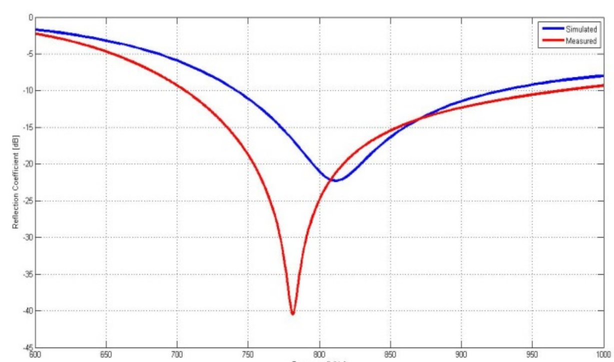


Fig. 6. Simulated and measured reflection coefficient plots of the meander loop monopole antenna

Fig. 7 shows the simulated and the measured radiation patterns of the meander loop monopole antenna. It is observed that the radiation patterns are omni-directional over its band of operation, with almost equal radiation in the H-plane, and radiation with the shape of digit 8 in the E-plane.

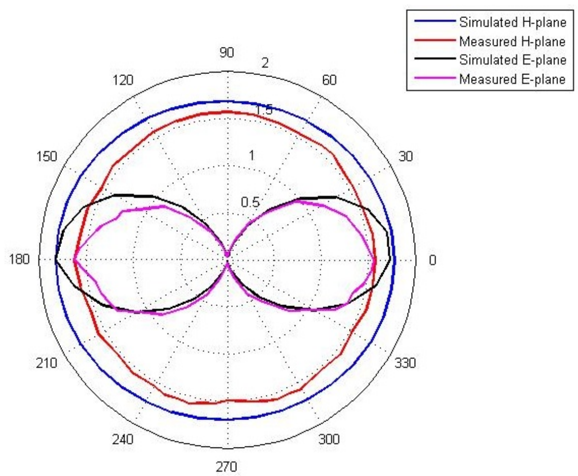


Fig. 7. Simulated and measured radiation patterns of the meander loop monopole antenna

Fig. 8 shows the simulated and the measured gains for the meander loop monopole antenna in the operating frequency range. It is observed that the peak gain is about 2.5 dBi, and the gain pattern is approximately flat in the operating frequency band of the antenna. The simulation results and the measurements results are similar with little difference due to some fabrication and measurements issues, with an acceptable gain value.

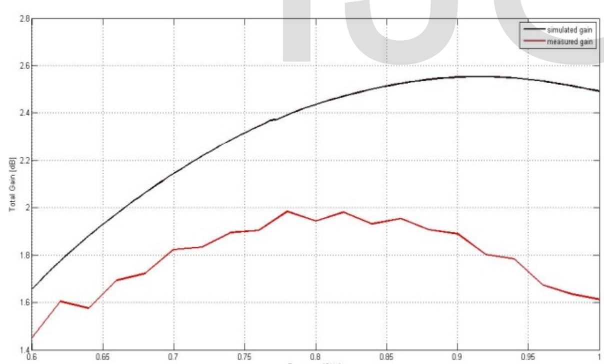
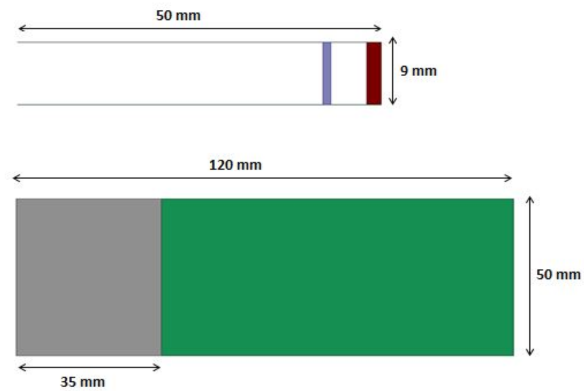


Fig. 8. Simulated and measured gain of the meander loop monopole antenna

This meander loop monopole antenna has a greater size than the previous mentioned miniaturized printed monopole antenna. However, its resonance bandwidth which is about 200 MHz is much larger than the resonance bandwidth of the first antenna which is about 70 MHz. Therefore, there is a trade-off between the size and the bandwidth, and one can use one of these two antennas according to the type of applications and the number of channels used in the cognitive radio design.

2.3 PIFA Antenna

A PIFA antenna is also proposed in this paper, and its configuration is shown in Fig. 9. A simple 50 mm x 35 mm patch is designed over a full ground plane of dimensions 120 mm x 50 mm. These two planes are connected through a feeding strip and a grounding strip. In order to attain optimum results, the dimensions are optimized. The width of the feeding strip is 1 mm and that of the grounding strip is 2 mm, and the distance between them is 5 mm.



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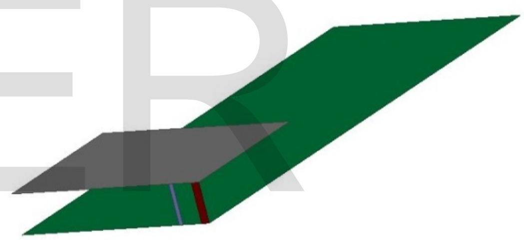

(b)

Fig. 9. Configuration and dimensions of the proposed PIFA antenna – (a): Side view and front view, (b): Panoramic view

PIFA antennas are popular for portable wireless devices because of their low profile, small size, built-in structure, and omnidirectional patterns, and they are almost used in mobile phone market. In mobile phones, there is a single large ground plane that can be placed at the bottom layer of the phone, and the patch which is of much reduced dimensions can be placed on the opposite layer of the phone. Since the radiation is from the patch away from the ground plane, the energy is directed away from the head giving low values of absorption rates.

The simulated reflection coefficient plots of the proposed PIFA antenna are given in Fig. 10. The antenna is simulated via HFSS and CST microwave studio. It is observed that the simulation results of the two software tools follow the same pattern with little difference as the two softwares follow two different methodologies (frequency versus time). This antenna can operate in the band 730-870 MHz, and also can be suitable for transmission in cognitive radio applications in the TV band.

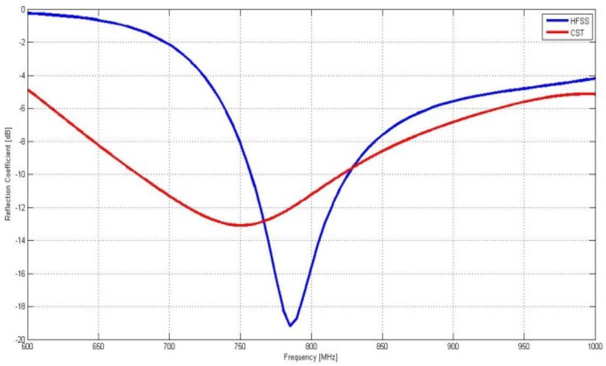

Fig. 10. Simulated (HFSS and CST) reflection coefficient plots of the PIFA antenna

Fig. 11 shows the HFSS and the CST simulated radiation patterns of the PIFA antenna. It is observed that the radiation patterns are omni-directional over its band of operation, with almost equal radiation in the H-plane, and radiation with the shape of digit 8 in the E-plane.

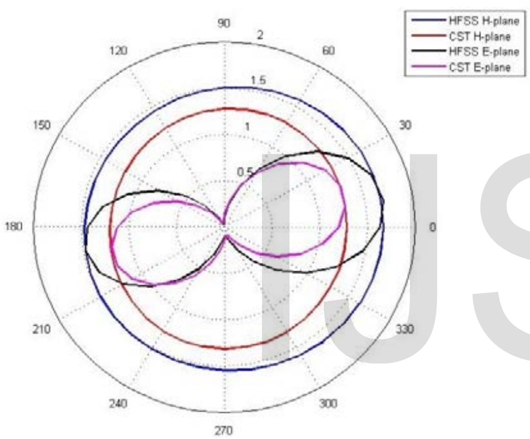

Fig. 11. Simulated (HFSS and CST) radiation patterns of the PIFA antenna.

Fig. 12 shows the HFSS and the CST simulated gains for the PIFA antenna in the operating frequency range. It is observed that the peak gain is about 2.5 dBi, and the gain pattern is approximately flat in the operating frequency band of the antenna. The simulation results of the two softwares are also similar with an acceptable gain given the antenna's dimensions.

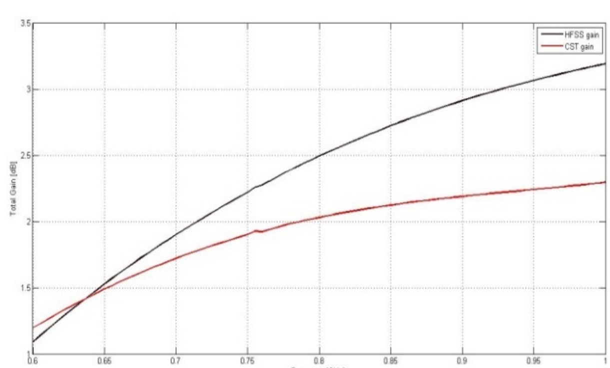

Fig. 12. Simulated (HFSS and CST) gain of the PIFA antenna

The main advantages of this PIFA antenna in comparison with the two mentioned microstrip antennas are the simple structure and the small size of the patch. These properties allow the PIFA antenna to be fabricated inside handsets and portable devices with low manufacturing cost. However, the PIFA antenna is not printed, and this demands a very high accuracy in fabrication. In addition to that, this PIFA's bandwidth is higher than the bandwidth of the microstrip antennas since a thick air substrate is used.

3 Conclusion

A miniaturized printed monopole antenna, a meander loop monopole antenna and a planar inverted F antenna (PIFA) suitable for cognitive radio applications in the TV band are proposed in this paper. These antennas are printed with small dimensions and can operate in the frequency band 700 – 900 MHz, with omni-directional patterns and an acceptable gain of about 2.5 dB. The bandwidth and the size of these antennas make them suitable for portable devices such as notebooks, tablets and mobile phones.

Acknowledgment

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