Microwave Review
July 2025, Vol. 31, No. 1, pp. 3-7
DOI: 10.18485/mtts_mr.2025.31.1.1

Design and Performance Analysis of a Wideband Microstrip Antenna for C. R. Applications

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Abstract – **This paper presents a microstrip antenna design and performance analysis tailored for cognitive radio (CR) applications operating over a wide frequency range from 4.1 GHz to 8.1 GHz. The antenna demonstrates excellent resonance characteristics, particularly at 7.9 GHz, and achieves a gain of 2.93 dBi. The antenna maintains a positive gain across the entire operational bandwidth, with an efficiency exceeding 75%. This high efficiency and positive gain ensure robust and reliable performance, which is essential for dynamic frequency sensing communication in CR systems. The simulated and measured results correlate with each other.**

Keywords – **CR, Sensing Antenna, Communication antenna, Spectrum, Wireless communication.**

I. Introduction

CR is an advanced wireless communication system designed to dynamically detect unused spectrum channels and adapt its transmission parameters accordingly [1]. This technology aims to enhance spectrum efficiency and minimize interference with licensed users, optimizing the use of the limited radio spectrum. Central to this system is the sensing antenna, which scans the spectrum environment to detect the presence of primary users (licensed users) and identify unoccupied channels. These antennas are characterized by their frequency agility, allowing them to operate across various frequency ranges and high sensitivity, enabling the detection of weak signals [1-2]. Depending on the requirement, sensing antennas can be either directional for focused detection or omnidirectional for a broader sensing area. Additionally, they are designed with low noise levels to minimize internal noise, reduce false detections, and improve accuracy in identifying vacant spectrum.

Once the sensing antenna has identified an available channel, the narrowband communication antenna comes into play. This antenna is designed to operate within a narrow frequency range, facilitating efficient and reliable data transmission over the identified vacant channels [3]. It is optimized for performance within this narrow range, leading to minimized interference and enhanced communication quality. Narrowband communication antennas provide high gain, ensuring good signal strength within the specified band, and are designed for limited bandwidth, making them suitable for stable, focused connections. Often, they engineered with specific radiation patterns to enhance signal directionality and reduce interference from other sources [7-9].

Together, these components enable cognitive radios to manage and optimize spectrum usage dynamically, thereby improving spectrum efficiency and meeting the increasing demand for wireless connectivity.

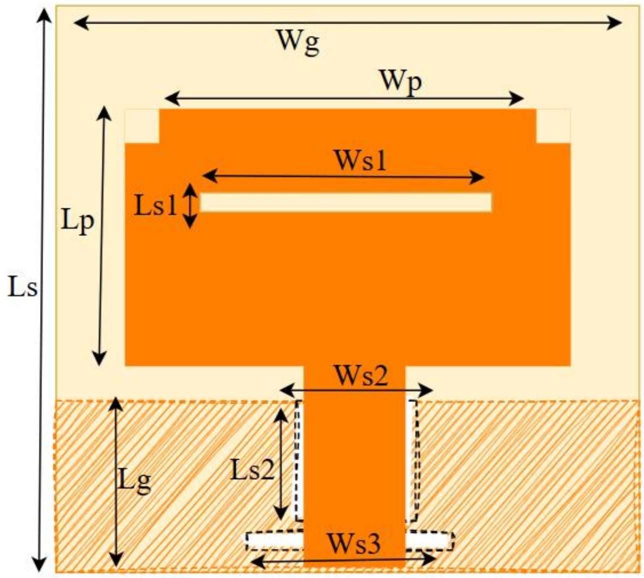

Fig. 1. Proposed sensing antenna front view Wg= 28mm, Ls=29mm, Wp=12mm, Lp=10.5mm, Lg=9.2mm , Ws1=9.6mm, Ls1=0.8mm, Ws2=3.47mm , Ls2=5.7mm, Ws3=6.25mm

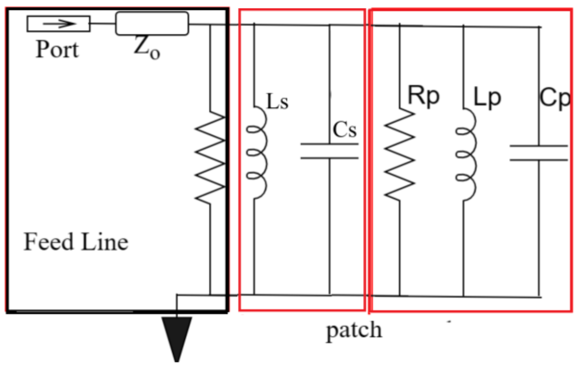

Fig. 2. Equivalent circuit models of proposed antenna

The paper introduces [4] a reconfigurable uniplanar antenna for CR applications, operating in wideband (3.4 to 8.0 GHz) for spectrum sensing. It features an open annular slot with orthogonal feedlines and high inter-port isolation via a ground plane strip. Slot resonator-based filters enable WB/NB mode switching. The antenna ensures over 15 dB isolation and a low envelope correlation coefficient (<0.1). Its CPW-fed structure

Article history: Received July 23, 2024; Accepted April 02, 2025

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simplifies fabrication and reduces costs, making it effective for CR spectrum sensing. In [5], a frequency-reconfigurable antenna for CR applications can switch between a wide operating band (2.63–3.7 GHz) and four sub-bands. The antenna features an inverted U radiating element fed by a microstrip line and horizontal slots with integrated p-i-n diode switches in the ground plane act as reconfigurable filters. This design allows the antenna to sense the entire band and select the appropriate sub-band for communication, reducing hardware complexity. The antenna demonstrates good agreement between simulated and measured results, validating its effectiveness for CR spectrum sensing. [6] Presents a frequency-reconfigurable planar monopole antenna with a wide tuning range for cognitive radio applications. The antenna consists of two sections connected by a PIN diode, enabling switching between high (2.69–3.0 GHz) and low (2.39–2.62 GHz) frequency bands. A varactor in Section I allows continuous tuning within these bands. The compact design (11.5 x 8.4 mm²) employs simple DC bias circuits for the varactor and PIN diode. Simulations and measurements confirm the antenna's performance, though discrepancies arise due to the feeding cable in measurements. The antenna demonstrates omnidirectional radiation patterns and efficient frequency tuning, making it suitable for dynamic spectrum management in cognitive radio systems.

Fig. 3. Proposed sensing antenna prototype for experimental verification: (a): upper patch, (b) lower patch, (c) & (d) setup model

The work introduces in [8] demonstrate compact, frequency-reconfigurable planar antenna system for cognitive radio (CR) applications, addressing the demand for improved wireless system performance. The antenna realized on a single substrate board, utilizes PIN and varactor diodes for frequency tuning across multiple bands from 0.7 to 3 GHz. Three reconfigurable modes enable versatile operation, achieved by activating/deactivating PIN diodes and adjusting varactor diode capacitance. Simulated and measured results demonstrate efficient tuning and omnidirectional radiation patterns, validating the antenna's performance. Planar MIMO antenna system, focusing on the sensing antenna for cognitive radio (CR), offers a pioneering solution in IoT and wireless communication technology [13]. By effectively covering a wide frequency band, including resonating frequencies below 1 GHz and RFID bands, the antenna enables spectrum agility crucial for CR applications. Through innovative design features such as slot insertion to minimize current localization, the antenna achieves enhanced performance, providing a versatile solution for spectrum management and IoT connectivity. This manuscript introduces a simple and compact UWB slot antenna designed for CR applications. The UWB sensing antenna features stepped slots that resonate at three different frequencies within the UWB spectrum. The communication frequency bands are achieved through various switching states of five p-i-n diodes. The proposed antenna can switch between four states: 2.8−10.7 GHz in UWB mode, 3.2−4.5 GHz, 4.3−7.8 GHz, and 7.9−11.2 GHz in communication mode, providing tunability across the entire UWB spectrum. Compared to other antennas reported in the literature, this reconfigurable UWB slot antenna is the simplest and smallest.

Proposed manuscript introduces a simple and compact UWB slot antenna designed for CR applications. The UWB sensing antenna features stepped slots that resonate at 7.7 GHz frequency within the UWB spectrum. The bandwidth of the proposed antenna is from 4.1 GHz to 8.7 GHz. It has a VSWR value of 1.3, which is reliable gain and efficient. The simulated and fabricated results match each other. Proposed antenna has smaller physical dimension and good sensing antenna frequency range as illustrated in Table 1 where comparison of the proposed work with state of art reported.

TABLE 1
COMPARISON OF THE PROPOSED WORK WITH STATE OF ART WORK REPORTED PAGE LAYOUT

Ref. No	Physical dimensions (mm^3)	Sensing antenna range (GHz)	Substrate	Max gain
[4]	(63 x 63 x 1.52)	(3.4-8)	Rogers RT/Duro-id 6035 HTC	……
[5]	(68 x 51 x 1.6)	(2.6-3.7)	FR4-epoxy	…….
[6]	(11.5x8.4x1.6)	(2-3)	Rogers RO 4350	1.83 dBi
[8]	(65 x 120 x 1.6)	(0.7-3)	Rogers 4003	1.77 dBi
[9]	(120 x 65 x 1.6)	(0.67-4.6)	FR-4	4.90 dBi
Propo-sed work	(28 x 29 x 1.5)	(4.1- 8.7)	FR-4	2.93 dBi

II. ANTENNA DESIGN METHODOLOGY

The planar antenna designed for Sensing antenna for CR applications is constructed on an FR4 substrate, known for its relative permittivity of 4.4 and a thickness of 1.5 mm. FR4 is chosen for its cost-effectiveness along with ease of fabrication, and mechanical stability, making it ideal for prototyping and low-cost applications. Despite of its higher dielectric constant value and loss tangent, design optimizations mitigate size and attenuation issues. It is suitable for moderate-performance requirements and integrates well with reconfigurable switching elements like PIN diodes. This balance makes FR4 a practical choice. To achieve the desired antenna characteristics, basic electromagnetic formulas and a microwave calculator were utilized to approximate [9-13] the essential dimensions, such as the width (*W*) and length (*L*) of the substrate, the planar patch, and the microstrip line. The antenna's design is meticulously detailed in Fig. 1 with its equivalent circuit in Fig. 2. *Rp*, *Lp* and *Cp* represents the value of resistance inductance and capacitance value of the outer patch whereas the *Zo* is the input impedance and Cs and Ls are the capacitive and inductive slot effect of the antenna. The partial ground plane of the antenna measures 29 mm in width (*Wg*) and 28 mm in length (*Lg*). These dimensions are crucial as they affect the antenna's grounding effectiveness and overall radiation pattern. The microstrip line, which serves as the feeding structure, is designed with a width of 11.5 mm and a length of 3.47 mm. The width of the rectangular patch is given by:

$$w = \frac{c}{2f_0}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

The length of the rectangular patch is given by:

$$L = L_{eff} - 2\Delta L \tag{2}$$

Feed length and feed width are given by

$$L_f = \frac{\lambda}{4\sqrt{\varepsilon_r}} \tag{3}$$

These measurements are critical for ensuring proper impedance matching and efficient signal transmission. The radiating patch, a vital antenna component, has a length of 14 mm. This patch is responsible for emitting electromagnetic waves, and its dimensions directly impact the resonant frequency and bandwidth of the antenna. The substrate, which supports the entire antenna structure, has overall dimensions of 46 mm in width and 52 mm in length. These dimensions provide a stable platform for the antenna components and influence the overall electromagnetic behaviour. The slot gap is a critical design parameter that affects the antenna's performance, including its resonant frequency and radiation efficiency. By carefully selecting these dimensions and utilizing the substrate, the designed planar antenna achieves a compact and efficient layout, making it suitable for sensing antenna for CR applications [13-19]. Figure 3 illustrates the fabricated prototype and setup model of the proposed antenna. The antenna's structure ensures optimal performance, providing reliable and tunable operation across the desired frequency bands, which is crucial for dynamic and efficient spectrum utilization in CR systems.

III. Results and Discussions

The designed microstrip antenna exhibits a broad operational bandwidth from 4.1 GHz to 8.7 GHz, making it ideal for the sensing antenna in CR. It demonstrates excellent resonance within this range, particularly at 7.9 GHz, with a return loss (S11) of -30 dB demonstrated in Fig. 4, indicating outstanding impedance matching and minimal signal reflection. The surface current distribution in Fig. 5 at 7.9 GHz provides crucial insights into the proposed antenna's performance by illustrating how current flows across the structure. High current density regions indicate strong radiating areas, directly impacting gain, efficiency, and impedance matching. The slot plays a key role in modifying current paths, optimizing resonance, and enhancing bandwidth. This distribution validates the design choices, ensuring effective energy transfer. The wide bandwidth shown in Fig. 4 allows the CR system to effectively sense and adapt to the electromagnetic environment, ensuring optimal frequency usage and avoiding interference. Minimal variations in group delay and phase delay ensure high efficiency, signal integrity, and accurate transmission in antenna.

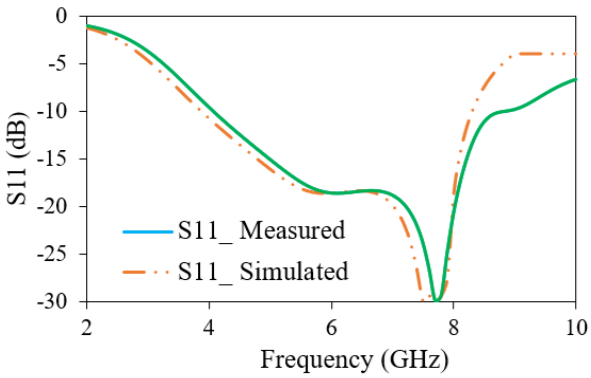

Fig. 4. Graphical representation of simulated and measured reflection coefficient of the antenna

The antenna's ability to cover a broad spectrum and its strong performance at critical frequencies make it a crucial component for dynamic and efficient CR systems. The designed microstrip antenna has a gain of 2.93 dBi at the resonant frequency of 7.9 GHz. This gain indicates how well the antenna converts input power into radio waves in a specified direction compared to an isotropic radiator, which radiates power uniformly in all directions.

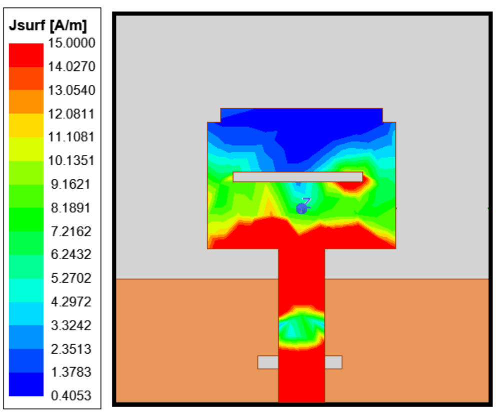

Fig. 5. The simulated current distribution of the antenna at 7.9 GHz

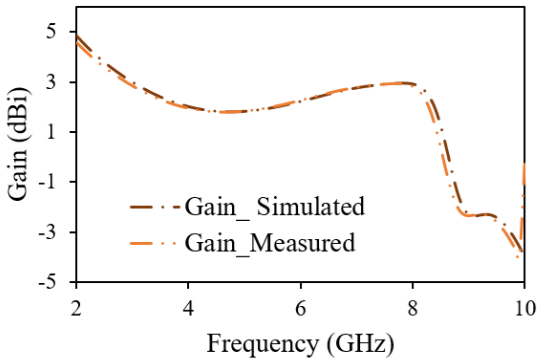

Fig. 6. Graphical representation of simulated and measured gain of the proposed antenna

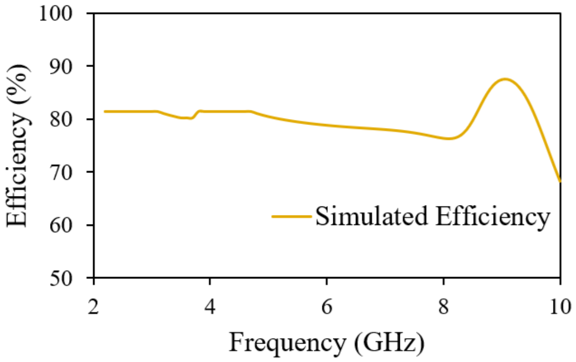

Fig. 7. Simulate efficiency of the proposed antenna

With an entire bandwidth of 4.1 GHz to 8.7 GHz, the antenna maintains a positive gain illustrated in Fig. 6 with consistent efficiency. Positive gain across this wide frequency range signifies that the antenna performs effectively, enhancing the signal strength over the entire operational spectrum. Figure 7 demonstrates efficiency greater than 75%, meaning that the antenna converts most of the input power into radiated energy with minimal losses. This high efficiency is essential for cognitive radio applications, as it ensures that the system can dynamically sense and utilize available frequency bands with optimal performance, minimizing power wastage and maximizing communication reliability. The radiation patterns of the antenna in both the E-plane and the H-plane are analysed to evaluate its performance. The E-plane represents the electric field distribution, indicating the primary polarization and directional characteristics of the antenna. The H-plane, orthogonal to the E-plane, illustrates the magnetic field distribution and provides insights into the antenna's directionality in the azimuth plane.

The simulated and measured co-pol and cross-pol radiation pattern of the proposed antenna for both plane are illustrated in Fig. 8, demonstrating a bidirectional characteristic in the E-plane. This bidirectionality indicates that the antenna radiates effectively in two opposite directions, which benefits applications requiring broad coverage and enhanced communication reliability. In the E-plane, the radiation pattern exhibits almost a symmetrical lobe with main lobes pointing in opposite directions, ensuring consistent signal strength across the desired coverage area with good corelation between the co and cross pol.

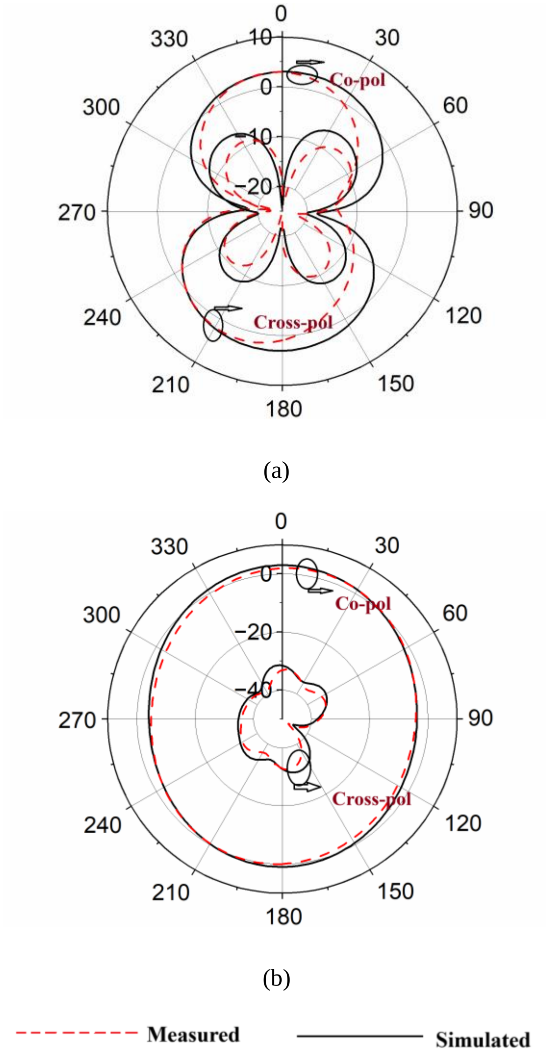

Fig. 8. Graphical representation of the measured and simulated radiation pattern of the proposed antenna at 7.9 GHz: (a) E plane, (b) H plane

Similarly, the H-plane pattern shows a comparable nature, reinforcing the uniformity and stability of the radiation characteristics. This performance is advantageous for CR applications, where reliable and flexible communication is essential for dynamic spectrum access and utilization. The consistency of the bidirectional radiation pattern across E planes underscores the antenna's suitability for other advanced wireless communication along with CR systems.

IV. Conclusion

The designed microstrip antenna, with its wideband capability from 4.1 GHz to 8.1 GHz and peak gain of 2.93 dBi at 7.9 GHz, coupled with efficiency exceeding 75% across the band, proves highly effective for cognitive radio applications. Its strong resonance characteristics and efficient signal transmission capabilities enable reliable spectrum sensing and adaptive communication, which are essential for enhancing cognitive radio networks' performance and flexibility. Future work will optimise the antenna design for improved performance and integration into practical CR sensing and communicating systems.

ACKNOWLEDGEMENT

The authors are also deeply thankful to the anonymous reviewers for their constructive comments and suggestions, which significantly improved the quality of the article.

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