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A Compact Multiport Sensing and Communicating Antenna System for Cognitive Radio Applications

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Efficient utilization of unlicensed radio spectrum is a significant concern in wireless communication. This manuscript proposes an antenna structure system to support secondary user (SU) functionality. The design integrates a sensing UWB antenna (3.1–11) GHz to monitor spectrum utilization by primary users (PU) and four narrow-band (NB) communication antennas, resonating at (9.66, 9.03, 5.72, 7.78, and 10.21) GHz with 75.30 % UWB spectrum utilization. The configuration supports up to four simultaneous communications with acceptable gain & isolation, validated using Ansys-HFSS and experimental results, highlighting its potential for trustworthy Cognitive Radio applications.

Keywords: Antenna, CR, Communication antenna, NB, Sensing antenna, Spectrum, UWB

1 Introduction

In the modern era growing demand for wireless communication has increased the problem of spectrum scarcity, making the effective utilization of available resources provide a critical challenge. One of the most promising approaches to address this critical challenge is Cognitive Radio (CR), an excellent technology that allows to intelligently sense their environment, detect unused spectrum, and adapt their transmission parameters accordingly. This capability not only improves spectrum efficiency but also ensures minimal interference with licensed users. Currently, the idea of CR is becoming an increasingly important issue for SU, which does not have direct access to the spectrum since the government only provides a license to PU within a specified geographical zone [1-4]. This means that CR is becoming an increasingly relevant topic for SU because SU does not have direct access to the spectrum. However, the concept of CR is becoming an increasingly crucial subject for PU, which has direct access to the spectrum. PU can use the spectrum. This is because the government only issues licenses to PU, which means that SU does not have direct access to the spectrum. The reason for this is that the government only provides licenses to public utilities. As a direct result of this, the circumstance is present. SUs is reliant on CR to carry out their responsibilities since they do not have unrestricted access to the spectrum. This makes CR a necessary component. For the SU to be able to carry out its responsibility of ensuring that the CR is operating properly, it must have its very own individual antenna that it can use for detecting and transmitting information about the spectrum. However, delivering a good quality of service (QoS) to the members of its network without interfering with the communication that is going on in the main network is the most challenging issue to overcome[5-12]. When it comes to choosing an antenna for use in a communication system, most of the time, reconfigurable or multiple-input NB antennas are used.

On the other hand, ultra-wideband (UWB) antennas are the ones that are chosen to be used to fulfil the function of scanning antennas. Due to the significant drawbacks of reconfigurable NB antennas, such as the nonlinear influence of the switch, interference, biasing line antagonistic effect, complexity, additional hardware, and the fact that only one communication can take place at a time, the multiport NB antenna has garnered a lot of attention in recent years. This is because it allows for multiple communications to take place at the same time. NB multiport antennas assist in improving the effectiveness of spectrum utilization in several different ways [13]. Making it feasible for a greater number of transmissions to take place at the same

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*Corresponding author: E-mail:vijaynath@bitmesra.ac.in time is one of these approaches. An increased spectral efficiency, wideband operation, MIMO capabilities, spatial diversity, adaptive beamforming, integration of sensing as well as communication functions, interference mitigation, and a compact form factor are some of the benefits that come along with using a Compact Multiport Sensing and Communicating Antenna System (CMSCAS) for CR applications. Other benefits include a wideband operation, MIMO capabilities, spatial diversity, adaptive beamforming, and integration of sensing as well as communication functions[14]. In addition to these advantages, the system also increases its spectral efficiency. CMSCAS is the right option because of the necessity to dynamically access and make use of the readily available spectrum resources in a way that is both efficient and dependable. Because of these attributes, CMSCAS is the ideal solution. This need is a direct consequence of CMSCAS's capabilities, and it has emerged as a direct result of those capabilities. Nevertheless, the most essential qualities for it are that it has a sufficient level of isolation, that it possesses white space, that it possesses many parallel communication channels, that it is inexpensive, and that it is of a small size.

The paper presents[11]a compact five-port integrated UWB and NB antenna system for CR applications. The system comprises a UWB antenna for spectrum sensing, covering the (3.1–10.6) GHz band, and four NB antennas for communication, operating across various single or dual frequency bands. The antennas are printed on a compact FR-4 substrate, achieving a high level of integration while maintaining isolation of less than 16 dB between the ports. Each NB antenna covers different portions of the UWB spectrum, enabling efficient communication across the entire band. The design is cost-effective, simple, and capable of performing up to four simultaneous communication tasks, enhancing spectrum utilization. In author presents a compact four-port coplanar antenna designed for CR applications, featuring a CPW-fed UWB antenna for spectrum sensing and three rectangular loop antennas for communication[15]. The UWB antenna covers the entire UWB spectrum, while the loop antennas operate in distinct low, mid, and high-frequency bands, ensuring full UWB coverage with only three antennas. The design achieves high isolation (>17.3 dB) between the UWB and NB antennas without additional decoupling structures. The antenna supports several operational modes, including spectrum sensing and communication, with realized gains over 2.7 dBi and 1.38 dBi for the UWB and loop antennas, respectively.

The author discussed a reconfigurable antenna that combined a sensing antenna and a communication antenna onto a single substrate[16]. This antenna could be used for both sensing and communication. This antenna was able to be used for CR applications because it was suitable for such use and because it was usable for such purposes. Those are the two reasons why it was possible to be used for CR applications. Rotating the communication antenna counterclockwise in the direction of the clock is one approach to provide a degree of partial reconfigurability. However, finishing the project will be challenging due to the complexity of creating the rotating mechanism and ensuring that the transitions between frequency bands are seamless. This will make the project more difficult to accomplish. These two pursuits demand a large expenditure of one's time as well as one's physical work. One of the possibilities proposed for use by |CR is the utilization of an optically pumped reconfigurable antenna system, also referred to as OPRAS[17]. In this circumstance, optical methods are utilized to dynamically adjust and optimize antenna settings, which ultimately permits more efficient use of radio spectrum resources in CR systems. This is accomplished via the application of optical techniques. Concerns may be raised, however, about the complexity of putting the recommended optical pumping technique into reality as well as the technology's practical applicability in situations that are representative of the real world. This may be seen as something that works against us in the current scenario. The construction's already high level of complexity would be increased if more electrical components were added to it to support the laser diode; not only are there performance constraints that are examined, but compatibility with the CR infrastructure that is already in place is also taken into consideration.

This paper presents a five-element planar antenna system for CR applications, integrating a UWB antenna for spectrum sensing and four NB antennas for communication[18]. Printed on a 50 mm × 50 mm FR-4 substrate, the UWB antenna covers the 3.1–10.6 GHz band, while the NB antennas operate across various frequencies, supporting WiMAX, WLAN, 5G sub-6 GHz, and X-band applications. The system achieves a minimum of 16 dB isolation between antennas, with MIMO performance evaluated through

ECC, DG, and MEG metrics. Its compact, planar design makes it ideal for efficient spectrum utilization in CR-based wireless devices. An antenna with "three-port combined WB and NB antennas" refers to a design where both NB antennas support dual-band operation, covering 22.7% of the UWB spectrum (3.1 to 10.6) GHz [19]. This configuration offers several advantages, including simplicity, cost-effectiveness, and the ability to handle two simultaneous communications. Additionally, it is compact and easy to operate. According to the antenna, it can achieve a maximum gain of up to 3.5 dBi across the entire UWB band[20]. However, achieving a broader bandwidth while maintaining higher gain remains a challenging task in antenna design. The above investigation highlights that both sensing and communication antennas are fabricated on a single substrate, and one of the key findings is the strong correlation between the simulated and measured results, which is a notable achievement. Design successfully integrates multiple functionalities, though combining several antennas on the same substrate poses challenges due to limited space, often resulting in performance compromises. Antenna geometry plays a critical role in determining overall performance, including radiation patterns and other characteristics. The choice of geometry is crucial for optimizing functionality; as different antenna shapes serve specific purposes in various applications. An antenna's geometry is one of the most significant parameters that influences its radiation pattern, gain, bandwidth, and polarization, and it is also one of the most overlooked aspects of antenna design. The resonant behaviour of the antenna is governed by its effective electrical length, which is directly influenced by the geometry and the introduction of slots. By modifying the patch dimensions and slot structure, multiple current paths of different electrical lengths are created. The fundamental patch dimension supports the primary resonance, while the slot perturbations introduce additional resonances. When these resonances overlap, particularly under multiport excitation, they merge to form a wide impedance bandwidth that accounts for the UWB response. At the same time, specific dimensions of other antenna optimized for narrowband operation, demonstrating how the chosen geometry inherently enables both UWB and NB characteristics. Equations (1-2) provide the mathematical expressions that explain the role of geometry, slot loading, and effective length in achieving both UWB and NB resonances. Where, where ccc is the speed of light in free space, L_{eff} and L_{slot} are the effective lengths of the patch and slot, respectively, and ε_{eff} is the effective dielectric constant.

The proposed antenna involves designing, developing, and evaluating a multiport antenna system to support CR, drawing inspiration from the work in [11]. The design incorporates a sensing antenna capable of wideband sensing, working in conjunction with multiple NB antenna. These antennae are tuned to specific frequencies for efficient communication. The system includes a UWB sensing antenna that operates across a specific range, along with four NB communication antennas resonating at predetermined frequencies. Together, these antennas cover approximately 75.3% of the UWB spectrum, providing comprehensive and efficient spectrum utilization. The five-port compact sensing and communication antenna assists up to four simultaneous communications, with potential future expansion to five, optimizing spectrum utilization for maximum efficiency. Because of its flexibility and capacity, this antenna is an excellent choice for use in CR applications. There is a substantial match between the simulated outcomes and the measured results. This may be analyzed from the fact that both sets of data exhibit a pattern that is comparable to one another.

$$f_r = \frac{c}{2L_{eff}} X \frac{1}{\sqrt{\varepsilon_{eff}}} \qquad \dots (1)$$

$$f_{slot} \approx \frac{c}{2L_{slot}} X \frac{1}{\sqrt{\varepsilon_{eff}}} \qquad \dots (2)$$

2 Materials and Methods

2.1 Antenna Geometry and Design

The combined sensing and communication antenna that was exhibited here consists of one UWB antenna and four independent NB antenna configurations. The values for its dielectric constant (ε_o) and loss tangent (δ) are 4.4 and 0.019, respectively. It was designed on a FR-4 substrate that is 1.6 millimeters thick. The overall dimension of the antenna consists of both the UWB and the four NB antennas, having a dimension that is like forty millimeters by thirty-six millimeters. The ground plane for the designs of Antenna 1, Antenna 4, and Antenna 5 is laid out on a plane that has only been partly grounded. For sensing antenna, it is helpful to have a defective ground structure that consists of a circular slit that is 1 mm in diameter. This helps to obtain an extremely high bandwidth, which would not have been possible without it. There is a complete ground plain for antennas 2 and 3, which are both located in the same general area. The four NB antennas should be able to cover 75.30% of the complete UWB sensing spectrum. Additionally, it is possible to carry out up to four transmissions at the same time using the NB antenna; the whole spectrum matches within the resonance frequency of the sensing antenna. This is a good way to make use of the spectrum that is now being used for CR. Figure 1 depicts the overall optimized design of the proposed structure. In this context, using 50-ohm matching connections is the most effective way to terminate all underutilized NB antennas. This is because these connections are highly compatible with each other. The measured data obtained during the prototype's design aligns perfectly with the simulated results, which were carried out by Ansys-HFSS software. However, minor deviations may occur due to factors like measurement techniques, material imperfections, connection losses, or manufacturing errors. Despite the strong overall match, small shifts and variations may arise from these sources.

2.2 Analysis of Sensing UWB Antenna

Port 1, which is connected to the first antenna, can cover the whole of the UWB spectrum, which extends from 3.1 to 11 GHz. The several resonant frequencies that are generated by the system are the result of the design of the arc, which is located on the top patch and offers multiple pathways for the passage of current. Figure 2 depicts the simulated and observed reflection coefficients of the antenna. The figure also illustrates the fabricated structure of the proposed antenna. Figure 3(a) illustrates the block diagram representing the analysis process of the sensing and communicating NB antenna, while Fig. 3(b) shows the experimental setup of the vector network analyzer (VNA) used to evaluate the performance of the proposed antenna. The way this setup is designed allows for a reliable evaluation and validation of the antenna's measurement performance using the simulated results.

2.3 Analysis of the Communicating NB Antenna

Antennas 2, 3, 4, and 5 are responsible for establishing communication links with SU, while the sensing antenna's role is to detect any frequency bands being occupied by the PU. The second antenna, connected to port 2, resonates at 9.66 GHz and covers the spectrum from 9.16 GHz to 9.95 GHz. At its resonant frequency of 9.66 GHz, the antenna achieves

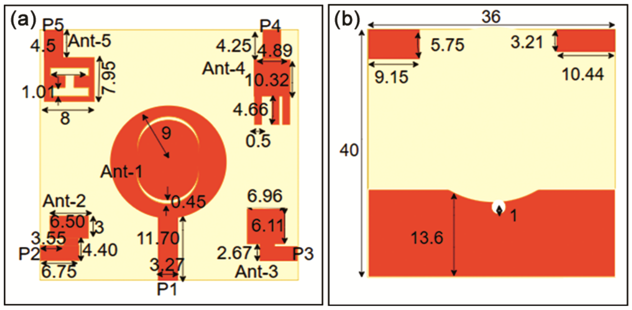

Fig. 1 — Proposed antenna (all dimensions in mm) (a) top view; and (b) bottom view

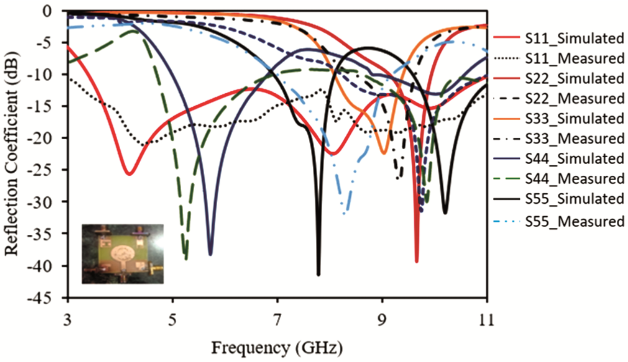

Fig. 2 — Simulated and measured the Reflection coefficient of Sensing and communication antennas

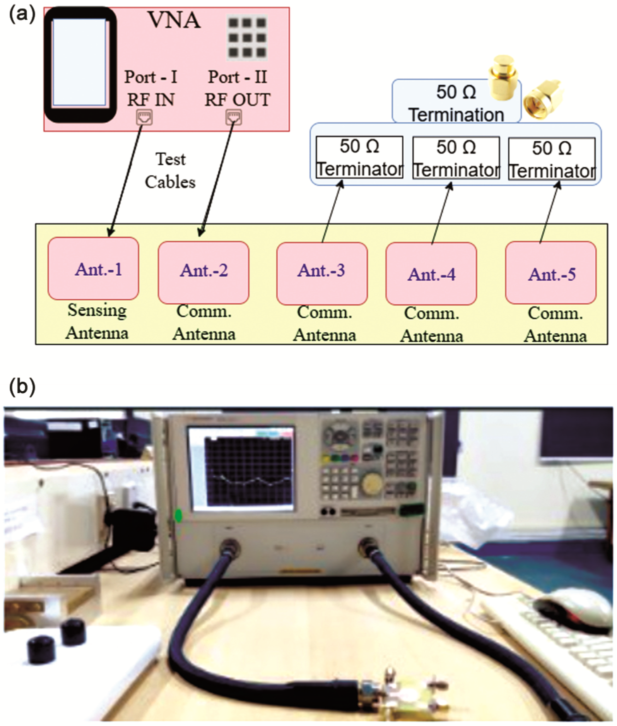

Fig. 3 — (a) Block diagram of the communicating NB antenna analysis process; and (b) Measurement setup of fabricated antennas

a gain of 8.52 dBi and covers approximately 10.66% of the total spectrum that the sensing antenna can monitor. When combined with UWB operation, the antenna provides electrical isolation of less than 19 dB across the entire frequency range.

The third antenna, connected to port 3, operates within the frequency range of (8.1 to 9.4) GHz, with a resonant frequency of 9.03 GHz. This port can handle all frequencies within this range, and the antenna covers 17.33% of the overall spectrum monitored by the sensing antenna. At its resonant frequency of 9.03 GHz, the antenna achieves a remarkable gain of 7.08 dBi. Additionally, it maintains electrical isolation of less than 18 dB across the entire UWB band, ensuring minimal interference.

Figure 4 shows good isolation with some deviations between simulation and measurement, due to fabrication tolerances, substrate property variations, SMA connector losses, and radiation leakage in the measurement environment, which are difficult to perfectly replicate in simulations results. Slight misalignments during soldering of ports also introduce practical differences due to impedance mismatch. While the overall trend remains consistent and validates the design.

This is made possible due to the thoughtful setting up of the arrangement. To aid in comparison, Fig. 5 shows both the simulated and measured gains across the entire frequency band. Whereas Fig. 6 illustrates the surface current distribution of the sensing antenna at 9.66 GHz, 9.03 GHz, 5.72 GHz, 7.78 GHz, and 10.21 GHz. These frequencies are based on the resonating frequencies of all four NB antennas, which will be discussed in more detail later in this study.

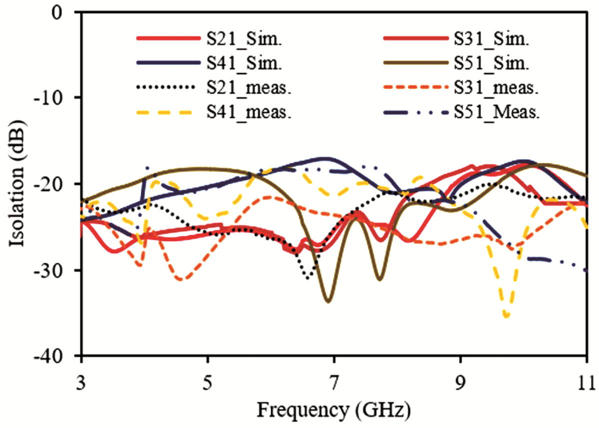

Fig. 4 — Simulated and measured Isolation of Communication antenna with sensing antenna

The fourth antenna, connected to port 4, has a resonant frequency of 5.72 GHz. It covers a bandwidth ranging from 5 GHz to 6.9 GHz, which accounts for 25.33% of the total bandwidth provided by the sensing antenna. To achieve this functionality more efficiently, a patch can be used to combine three strips of the same pattern into a larger piece. This improves the patch's perimeter and the current path, leading to lower resonance and increased bandwidth [21-23]. Despite a gain of only 2.3 dBi, the antenna maintains an isolation of better than 17 dB across the entire band.

The fifth antenna, connected to port 5, operates in two distinct frequency bands: 6.78 GHz to 8.10 GHz and 9.37 GHz to 10.95 GHz. It resonates at 7.78 GHz and 10.21 GHz, respectively. Together, these bands cover 38.66% of the sensing antenna's total

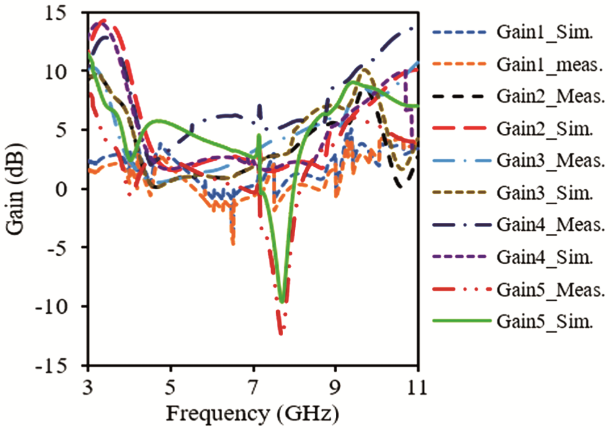

Fig. 5 — Simulated and measured gain of Communication antenna and sensing antenna

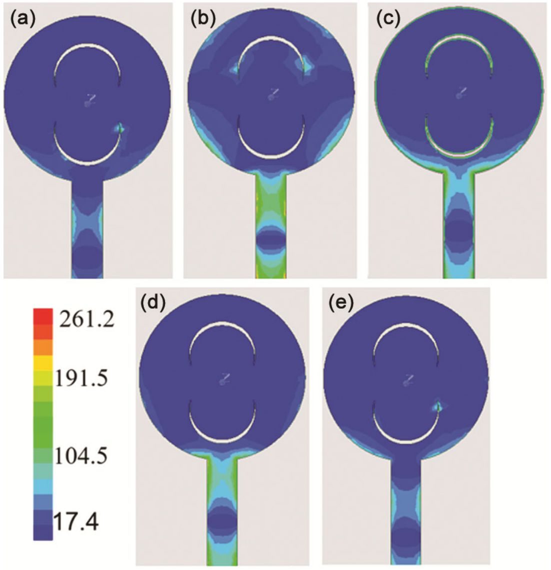

Fig. 6 — Surface current distribution of Sensing antenna (a) 9.66 GHz (b) 9.03 GHz (c) 5.72GHz (d) 7.78GHz, and (e) 10.21GHz

bandwidth. Despite covering a large portion of the spectrum, the antenna maintains satisfactory levels of isolation and gains across both frequency ranges.

The desired result can be achieved by etching an H-shaped slot into the top patch of the antenna v, which alters the current distribution in the patch. This modification leads to the desired improvement of performance. Figures 2, 4, and 5 present the simulated and measured reflection coefficients, the isolation concerning the sensing antenna, and gains of all NB communication[24-27] antennas, respectively. Figure 7 illustrates the current surface distribution of the second and third NB antennas at 9.66 GHz and 9.03 GHz, respectively, the fourth antenna at 5.72 GHz, and the fifth antenna at 7.78 GHz and 10.21 GHz, respectively.

Figure 8 provides a detailed analysis of the radiation characteristics of the proposed antenna at various resonating frequencies in both the E-plane and H-plane. Measurements and analysis of the antenna's radiation patterns were conducted at 9.66 GHz, 9.03 GHz, 5.72 GHz, 7.78 GHz, and 10.21 GHz. The resonance frequency range and key performance parameters of the NB communication antenna were likely considered during the selection process for these resonating frequencies. To evaluate the directional properties of the antenna in different spatial dimensions, the radiation patterns were studied. A comparison between the measured and simulated radiation patterns shows only minor differences, which may be attributed to factors like calibration problems, cable losses, poor connections,

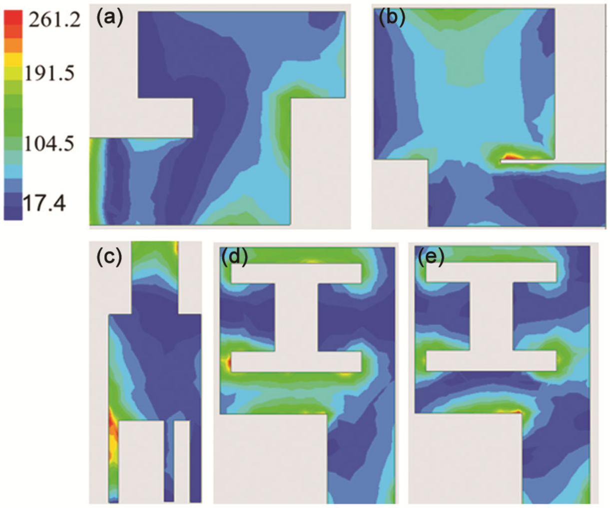

Fig. 7 — Surface current distribution of communication antenna (a) 9.66GHz_2nd antenna (b) 9.03GHz _3rd antenna (c) 5.72 GHz_4th antenna (d)7.78 GHz_5th antenna (e) 10.21 GHz_5th antenna

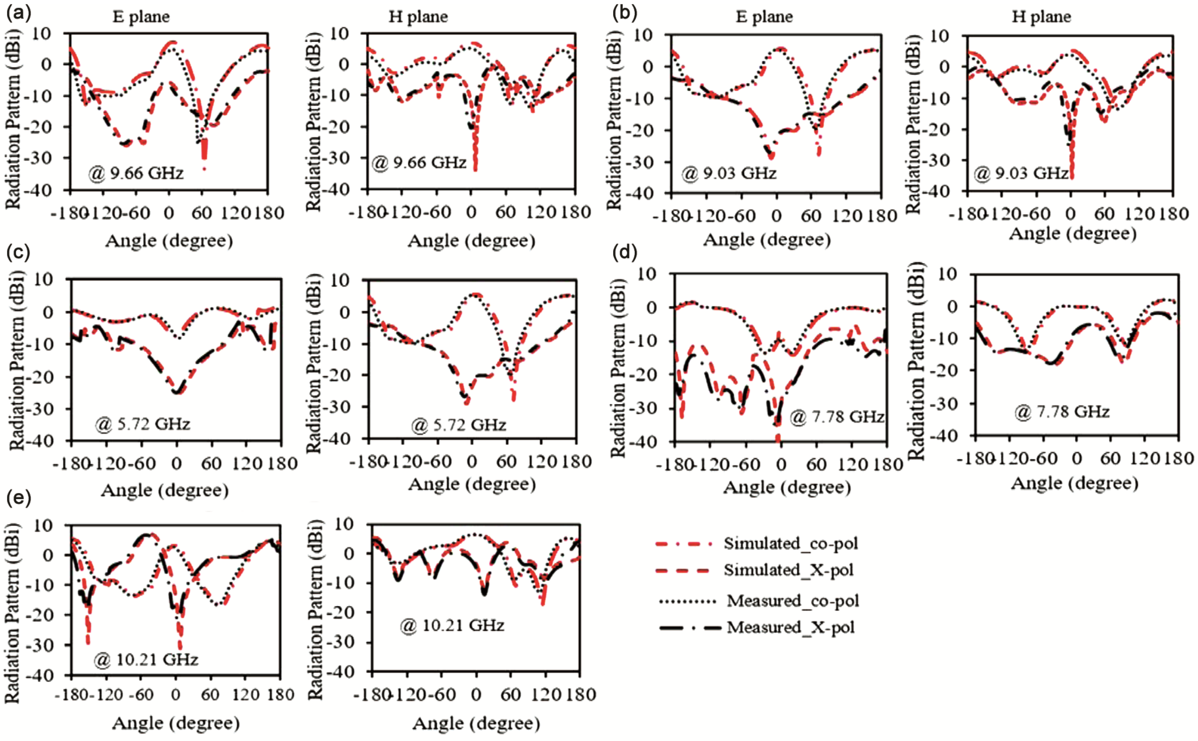

Fig. 8 — Simulated and measured co-pol and X-pol of E plane & H plane (a) 9.66GHz (b) 9.03GHz (c) 5.72GHz (d) 7.78GHz; and (e) 10.21 GHz

Table 1 — Comparison with previously reported antennas for CR application

Ref.	Dimensions (mm$^{3)}$	Sensing antenna range (GHz)	NB Frequencies	Sensing antenna band % covered by NB antenna	Simultaneous communications capacity	FoM ($\frac{\%}{mm^2}$)
[2]	(50×45.5×1.6)	(3.0 – 11.0)	(3.2–4.3) GHz, (4.15-5.1)GHz, (4.8–5.7) GHz.	36.90%	1	0.0161
[3]	(40×38.5×0.5)	(3.0 – 11.0)	(5.8-6.8) GHz, (6.7-7.3) GHz, (7.0-8.4) GHz & (7.9-9.2) GHz.	42.50%	1	0.0276
[4]	(27×21×1.6)	(2.7- 10.7)	(8.2- 9.4) GHz.	15.07%	1	0.0265
[5]	(30×30×1.6)	(3.1 - 10.6)	Four bands in b/w (6 - 10) GHz spectrum	22.40%	2	0.0249
[9]	(58×65.5×1.6)	(3.3 – 11.0)	(3.4 - 4.85) GHz (5.3 - 9.15) GHz	68.83%	1	0.0181
[10]	(40×36×0.662)	(3.0 – 11.0)	Three bands in b/w (5 -6) GHz spectrum	12.50%	1	0.0087
This work	(40x36x1.6)	(3.1 – 11.0)	Five bands in b/w (5 - 11) GHz spectrum	75.3%	4	0.0521

or misalignment. Table 1 presents a comparison of the proposed design with other state-of-the-art works. This design supports up to four simultaneous communications while utilizing 75.30% of the UWB band. The proposed antenna achieves the highest sensing band coverage (75.3%) and supports 4 simultaneous communication bands, which is superior to other reported works. Its figure of merit(FoM) value (0.0521) further confirms its compactness and efficiency compared to the existing state of art. FoM relates sensing band coverage and communication[28-31] capacity to that of antenna size for fair design comparison. Future improvements aim to achieve 100% coverage using five additional NB antennas, allowing for the operation of five simultaneous communications[32-33].

3 Conclusion

This work introduces a refined strategy to optimize spectrum utilization for CR applications using a compact five-port antenna system. The system includes a UWB, sensing antenna (operating from 3.1 GHz to 11 GHz) and multiple NB communication antennas resonating at 9.66 GHz, 9.03 GHz, 5.72 GHz, 7.78 GHz, and 10.21 GHz, covering significant frequency ranges. Together, these antennas provide up to 75.30% coverage of the UWB spectrum and support four simultaneous transmissions, with the potential to expand to up to five in future work.

Detailed analysis of each antenna's design ensures excellent gains and isolation, minimizing interference. By integrating UWB spectrum sensing with multi-band communication, this system significantly improves spectrum efficiency, boosting communication capacity and reliability to a greater extent. It represents a major advancement in the development of an antenna having both sensing and communication antennas on a single substrate for CR application.

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