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Design and Analysis of Wideband Cross Dipole Antenna with Bent Arms for Base Station Applications

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ABSTRACT: This paper presents a wideband dual slant polarized cross dipole antenna designed to serve 2G/3G/4G/5G frequency bands. The proposed antenna model comprises two linearly-polarized bent cross-dipole antennas, a cross-shaped director, and a metal reflector with walls arranged in an open box configuration. Bent dipole arms are etched on PCB to make the element compact. These cross dipoles are fed by hook-shaped wideband baluns, and a cross director is strategically placed atop the cross dipole structure to achieve wideband impedance matching. The linearly polarized dipoles are placed orthogonally to achieve $\pm 45^\circ$ slant polarization. Two orthogonal polarizations were realized by exciting two input ports separately. A prototype has been fabricated, and measurements are carried out to validate the antenna performance. The measured results show that the antenna is well matched over the wide bandwidth, and the impedance bandwidth is ranging from 617 MHz to 990 MHz for VSWR < 2, which is about 48%. The measured isolation between two orthogonal ports of the antenna was observed to be better than 33 dB. The radiation characteristics of the proposed model were stable, and the realized gain is in the range of 8.1 ± 0.5 dBi. The values of the cross-polarization discrimination (XPD) are better than 20 dB at the boresight and 8 dB within $\pm 60^\circ$ directions. The proposed antenna model has advantages like wide impedance bandwidth, wide pattern bandwidth, stable radiation performance, simple structure, and a small overall size of $350\,\mathrm{mm} \times 350\,\mathrm{mm} \times 100\,\mathrm{mm}$.

1. INTRODUCTION

In general, new generation base station wireless communication systems require low profile antennas which can support wide bandwidth and have very good unidirectional radiation performance. The need for polarization diversity is another crucial aspect for modern base stations, enabling improved isolation between antenna ports. To meet these requirements and enhance data transmission quality, reliability, and stability, dual slant-polarized antenna elements are employed, providing two communication channels and polarization diversity. Dual-slant-polarized antennas have become widely adopted in base stations for mobile communications. In particular, base station antennas operating in frequency bands such as LTE 700, GSM 850, and GSM 900 require simple and compact structures to facilitate space savings and easy installation. The use of compact antenna elements covering the full 617–960 MHz band allows for the service of the mentioned sub-bands, contributing to a reduction in the number of antennas on the tower.

Due to the demand for increase in the channel capacity of communication system and signal fading reduction in multi-path scenarios, dual slant polarized antennas have gained a crucial role in modern wireless communication systems [14]. The use of polarization diversity techniques is increased and becomes more popular in mobile communications. Because of this increase in popularity, dual slant-polarized radiators have attracted much attention and are used in new generation multifunction base station communication systems. The use of dual polarized elements in base station antenna arrays can increase the channel capacity and reduce installation costs significantly. Dual slant-polarized antenna elements find extensive applications in diverse mobile communication systems, including WLAN, WiMAX, and LTE base stations [5–8]. To effectively cover these mentioned frequency bands, it is essential to use dual-polarized antennas that exhibit excellent radiation properties and optimal matching characteristics across the wide bandwidth. Moreover, good isolation between orthogonal polarized ports over the widebandwidth is one more crucial parameter for base station antennas, which is a measure of coupling between the antenna ports. Antennas demonstrating improved port-to-port isolation typically manifest low cross-polarization levels [6].

Recent research on base station antennas has presented a variety of dual-slant-polarized wideband antennas designed for base stations, documented in the literature [2–15]. However, certain antennas [9–13] may not be optimal choices for low-band spectrum of base station applications (617–960 MHz) due to their substantial dimensions [11–15]. Many of the dual-slant-polarized antennas proposed for base station use are intricate and large, and some fail to meet wide-bandwidth requirements. Notably, a few antennas with good RF performance [12] are unsuitable for multi-band environments due to their size.

In this study, we present the design and analysis of a simple wideband dual-slant-polarized printed cross-dipole with bent arms. While printed cross-dipole antennas commonly fulfill the requirements for base station antennas, theoretical calculations indicate that their antenna element profile tends to be large in the low-band (617–960 MHz). Optimizing the size of the an-

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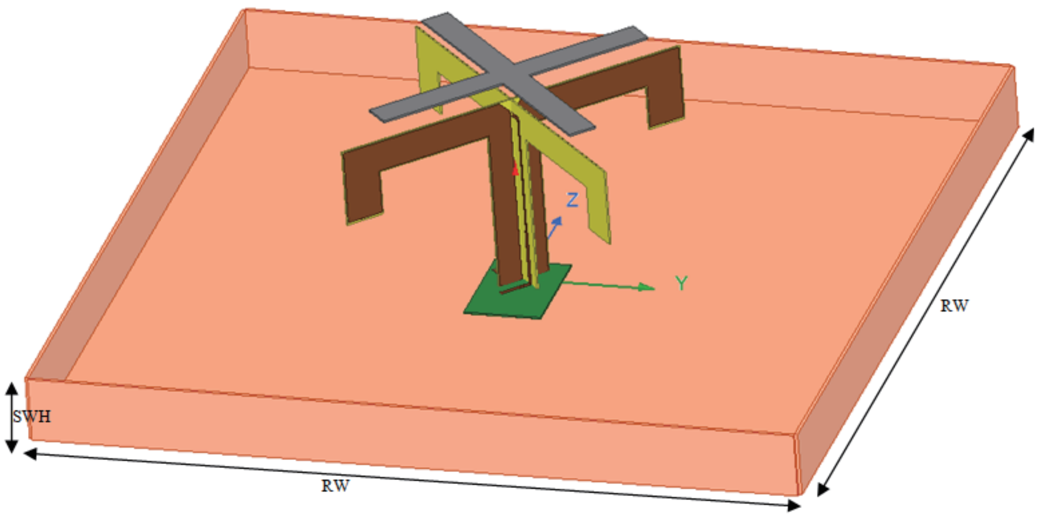

FIGURE 1. Basic 3D geometry of proposed antenna.

tenna element is crucial for its application in multi-band, multifunctional base station antenna arrays. Achieving impedance matching over a wide bandwidth becomes challenging when the antenna structure is compact. Additionally, maintaining a stable radiation pattern throughout the frequency range poses another significant challenge.

The primary focus of the proposed design work is to achieve a compact structure without compromising antenna performance. To achieve compactness, straight dipole arms have been transformed into bent arms, and the antenna feeding baluns are adjusted for improved impedance matching. Additionally, a cross-shaped director is strategically positioned above the cross-dipole at a specific height. This placement of director facilitates the attainment of a second resonance at the higher end of the full band, contributing to better matching across a wide frequency range.

In the following sections, we explore the intricacies of the antenna design and provide a comparison of results obtained from both simulations and measurements. The proposed antenna model offers several advantages, featuring a simple structure, broad impedance bandwidth, minimal cross-polarization discrimination, consistent symmetrical radiation pattern performance in both planes, and an impressive front-to-back ratio. Across the operating frequency band, the variations in gain and beamwidth remain within acceptable limits, with these parameters exhibiting nearly constant values.

2. ANTENNA DESIGN AND PRINCIPLE OF OPERATION

Figure 1 shows the proposed wideband $\pm 45°$ dual-polarized crossed-dipole antenna geometry. The proposed antenna configuration comprises two orthogonally placed dipoles, each equipped with 50-ohm feed lines, a cross-shaped director, and a box-shaped reflector. Bend-shaped dipoles are etched on one side of the printed circuit board (PCB), while corresponding hook-shaped baluns are etched on the opposite side. These two dipoles are arranged in a cross shape to form a cross dipole. The 50-ohm feed lines, etched on the feed PCB, feed the baluns. To achieve a second resonance and consequently widen the bandwidth, a cross-shaped director is positioned atop the cross dipole. The entire structure is integrated on an open box-shaped Aluminium reflector to attain the required unidirectional radiation pattern.

The detailed dipole model geometry and balun dimensions of the proposed novel dual-polarized antenna [4–8] are shown in Fig. 2 and Fig. 3, and the antenna dimensions are provided in Table 1. Fig.4 shows the director used in proposed model.

Figure 1 illustrates the fundamental configuration of the proposed printed bent cross-dipole antenna [15], designed for compactness and ease of manufacturing. The antenna comprises two printed bent dipoles, each excited by a hook-shaped wideband balun [4], and a cross-shaped director etched on one side of the Arlon AD300C substrate [16]. In Fig. 2, the dipole (brown part) is printed on a substrate (yellow part) of Arlon AD300C (with a relative permittivity of 2.97 and a loss tangent of 0.002), having a thickness of 0.8 mm. The balun is printed on the opposite side of the same substrate. Fig. 3 demonstrates that the hook-shaped wideband balun (brown part) is formed by a slot line coupling with a microstrip line.

Figure 3 presents the dimensions of the Balun feed. The Balun is strategically designed to transform the 50-ohm feed impedance to match the input impedance of the dipole. The Balun dimensions are optimized using an electromagnetic (EM) simulation tool to ensure excellent matching across the specified bandwidth. In the design, one section of the horizontal part of the slot line of the Balun, aligned with the $-45°$ direction, has been slightly bent downward for the dipole, while the corresponding section on the other dipole remains straight. This arrangement allows the two printed dipoles to be nested together, perpendicularly crossing over each other to achieve 45° dual polarizations. To achieve directional radiation patterns, a square box-shaped reflector measuring 350 mm × 350 mm ×

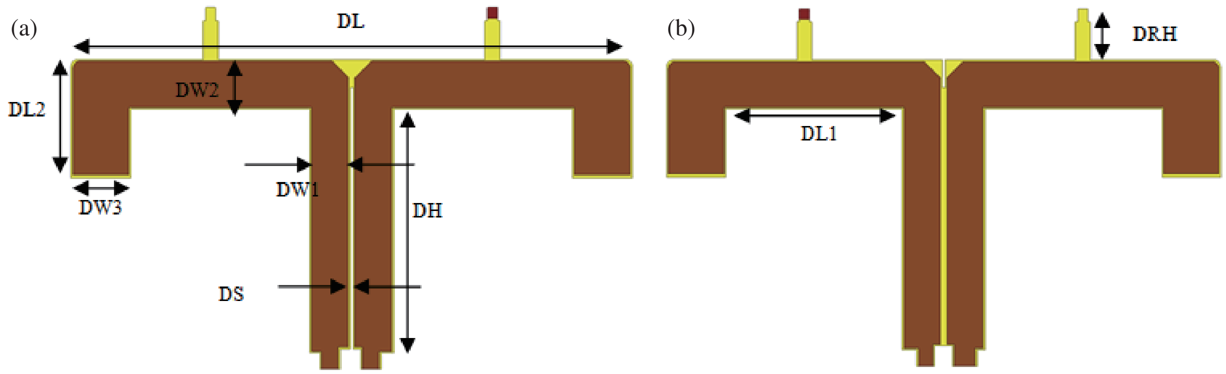

FIGURE 2. (a) Dipole 1 and (b) Dipole 2.

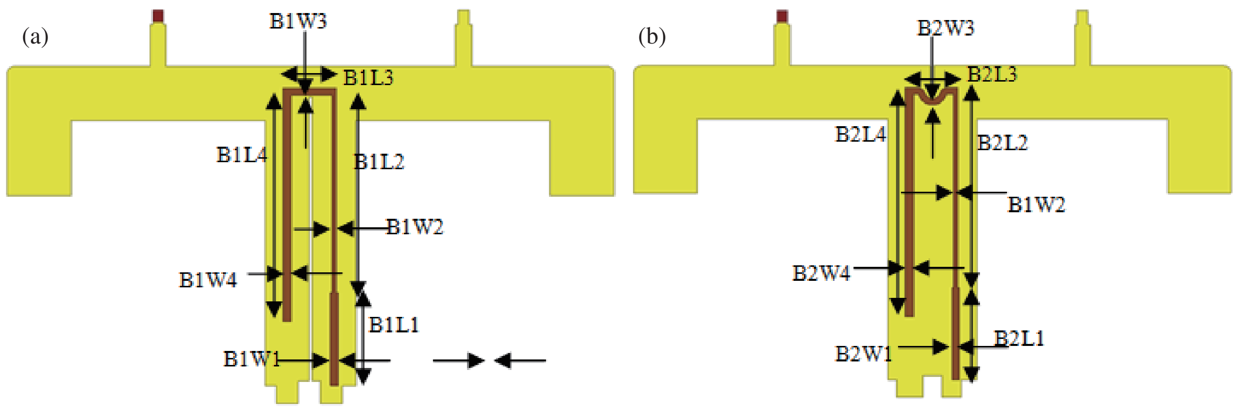

FIGURE 3. (a) Dipole 1 Balun and (b) Dipole 2 Balun.

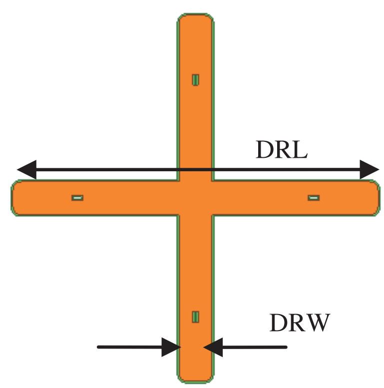

FIGURE 4. Cross shaped director.

25 mm is employed to support the proposed dual-polarized printed bent cross-dipole antenna. Fig. 4 depicts the geometry of a cross-shaped director, which is strategically placed on top of the dipole at a distance director height (DRH), contributing to wide impedance matching. A cross dipole designed [2] to operate within the 617–990 MHz frequency band is proposed. The length of each dipole, considered half-wavelength, is approximately 188 mm at the center frequency of 804 MHz. To enhance compactness, the antenna dipole arms are bent. Two of these dipoles are arranged in a 45° cross-section, forming a dual-polarized antenna. One dipole provides P45 (+45 polarization), while the other provides M45 (−45 polarization).

After numerous iterations, it has been determined that the gap between the orthogonal dipoles needs careful optimization to achieve improved matching and isolation. The hook-shaped microstrip lines on the baluns are meticulously optimized to ensure better matching. The widths (B1W1-B1W4 and B2W1-B2W4) and lengths (B1L1-B1L4 and B2L1-B2L4) of the balun feed lines are also optimized to match the input impedance of

TABLE 1. Dimensions of proposed antenna.

Parameters	RW	SWH	DL	DL1	DL2
Values (mm)	350	25	170	65	34.5
Parameters	DS	DH	DRH	DRL	DRW
Values (mm)	1.9	74	11.5	132	12
Parameters	DW1	DW2	DW3	B1L1	B1L2
Values (mm)	11.25	14	17	26	57
Parameters	B1L3	B1L4	B1W1	B1W2	B1W3
Values (mm)	14.9	65	2.3	1.1	1.9
Parameters	B1W4	B2L1	B2L2	B2L3	B2L4
Values (mm)	2.4	26	57	14.9	65
Parameters	B2W1	B2W2	B2W3	B2W4	
Values (mm)	2.3	1.1	1.9	2.4	

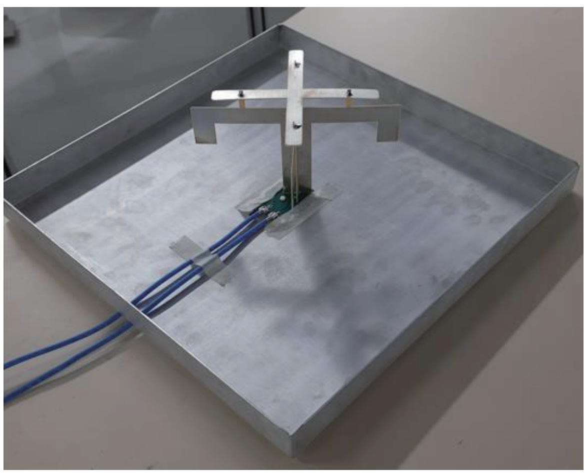

FIGURE 5. Photograph of the fabricated antenna.

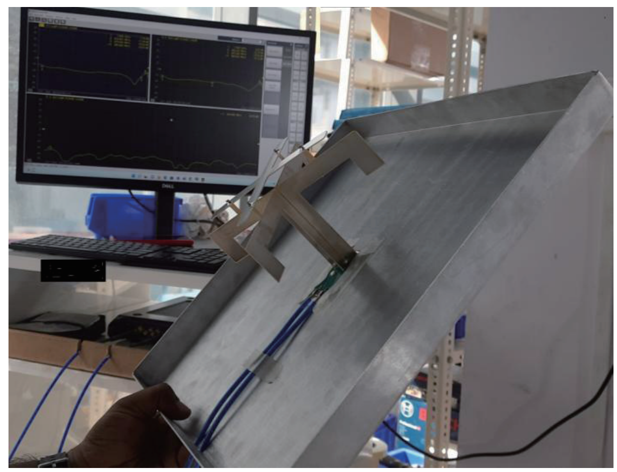

FIGURE 6. Measurement setup of the fabricated antenna.

the dipole. The optimal length and width values are selected to attain the required performance.

3. ANTENNA ANALYSIS

The proposed dual-polarized cross-dipole antenna underwent simulation using Ansys HFSS EM simulation software [17], employing the geometric parameters detailed in Table 1. The validity of the proposed antenna design and its performance were further confirmed through the fabrication and testing of a prototype unit. A visual representation of the fabricated prototype unit is presented in Fig. 5.

The dimensions of the dipole are detailed in Table 1. Through multiple iterations, it has been determined that both the length of the microstrip line and the width of the slotline exert considerable influence on the input impedance of each dipole. Optimal values for length and width are selected to attain the required performance. The hook-shaped balun is employed to excite the dipole, and its dimensions are carefully optimized to achieve good impedance matching.

Two resonances, observed at frequencies around 0.64 GHz and 0.95 GHz, are notable in the antenna performance. The lower resonance primarily emanates from the dipole structure, while the higher resonance is influenced by the antenna's height and the dimensions of the cross-shaped director. The height and dimensions of the cross-shaped director are carefully optimized to achieve better matching at the second resonance. It is important to note that while a higher antenna height may result in improved impedance matching, it can lead to lower antenna gain due to increased fringing fields.

The results of this antenna are discussed in the next section. Experimental measurements on the proposed printed bent crossed-dipole antenna have been carried out. Fig. 6 displays the measurement setup of the proposed antenna.

4. RESULTS

Figure 7 presents a comparison between the measured S-parameters and simulated results for the wideband dual-polarized printed bent cross-dipole antenna. The bandwidth for $|S11|$ (or $|S22|$) < -10 dB is approximately 48% (0.61–

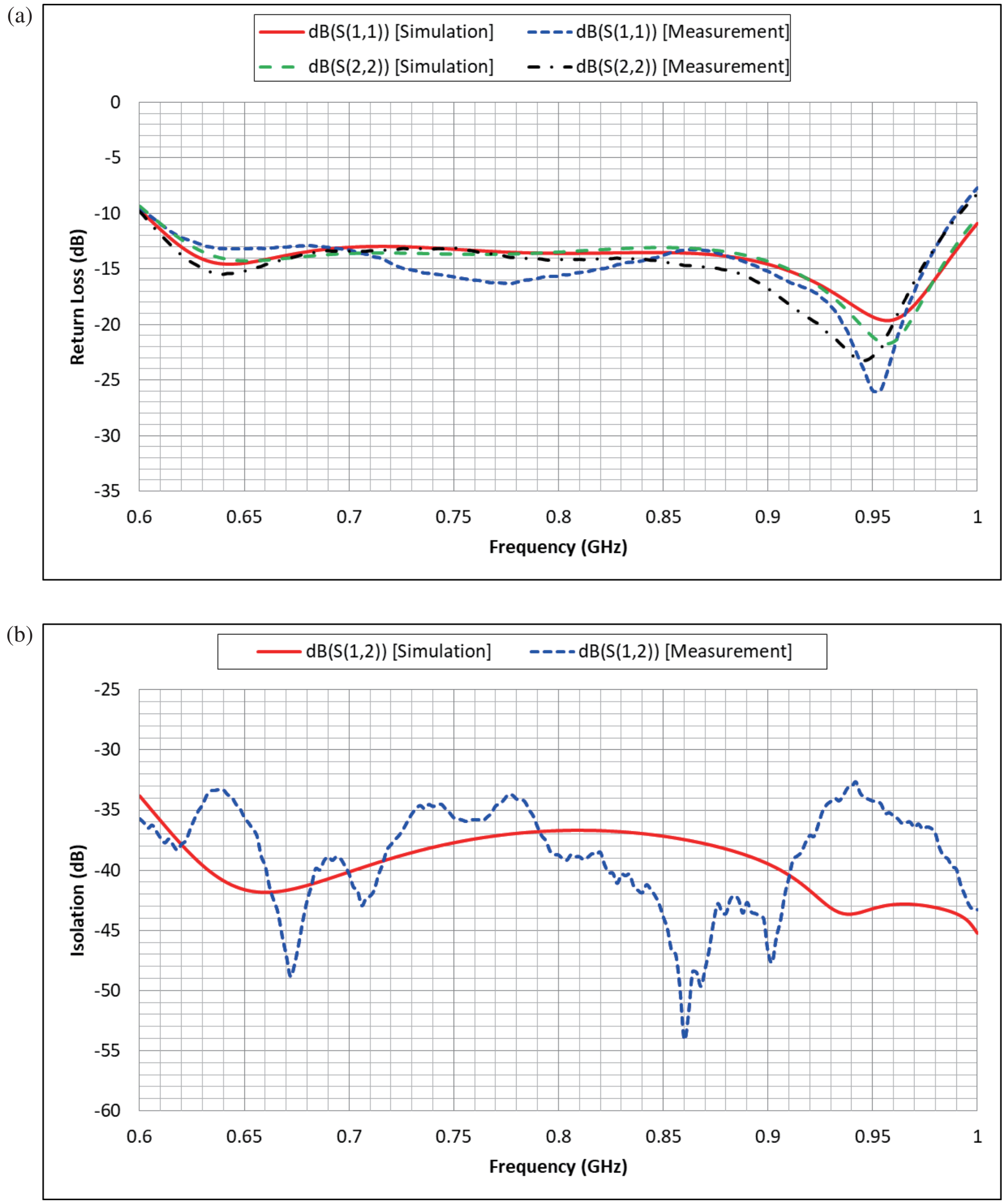

FIGURE 7. (a) Return loss and (b) Isolation of the proposed antenna.

0.99 GHz). Given that the proposed antenna is a dual-polarized element, the isolation between ports becomes a crucial parameter. In Fig. 7(b), the isolation between the slant-polarized ports is observed to be more than 33 dB across the entire band.

The measured results closely align with the simulated data, demonstrating good agreement. The obtained impedance bandwidths are sufficient to cover applications such as LTE700/GSM850/GSM900, making the proposed antenna well suited for base station antenna requirements.

The dual-polarized printed bent cross-dipole antenna demonstrates stable radiation patterns, maintaining a half-power beamwidth (HPBW) within $69.5 \pm 3^\circ$ in the horizontal plane (i.e., the x-y plane). Figs. 8–13 display the measured versus simulated radiation patterns for two orthogonal ports in both azimuth and elevation planes at 617 MHz, 817 MHz, and 990 MHz. The simulated half-power beamwidth of the proposed antenna closely matches the measured value. No significant changes are observed over the frequency range of 610–990 MHz.

The patterns include co-polarized and cross-polarized graphs. Due to the symmetrical characteristic of the proposed antenna, there is minimal difference between the radiation patterns of the two ports. In both azimuth and elevation planes, the broadside radiation patterns remain stable and symmetric across the operating band. Low cross-polar discrimination and a good front-to-back ratio are consistently achieved across the

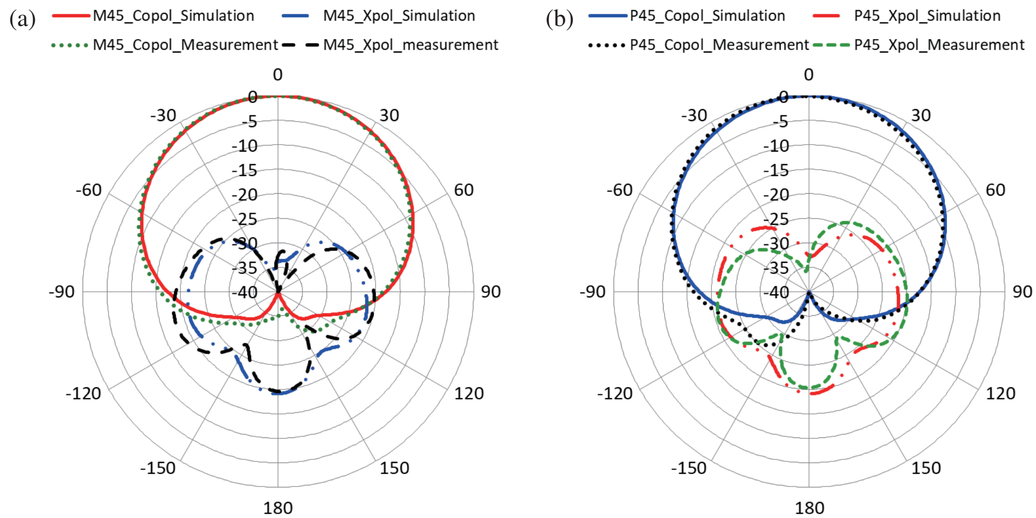

FIGURE 8. Azimuth Radiation pattern for (a) M45 Port and (b) P45 Port at frequency 617 MHz.

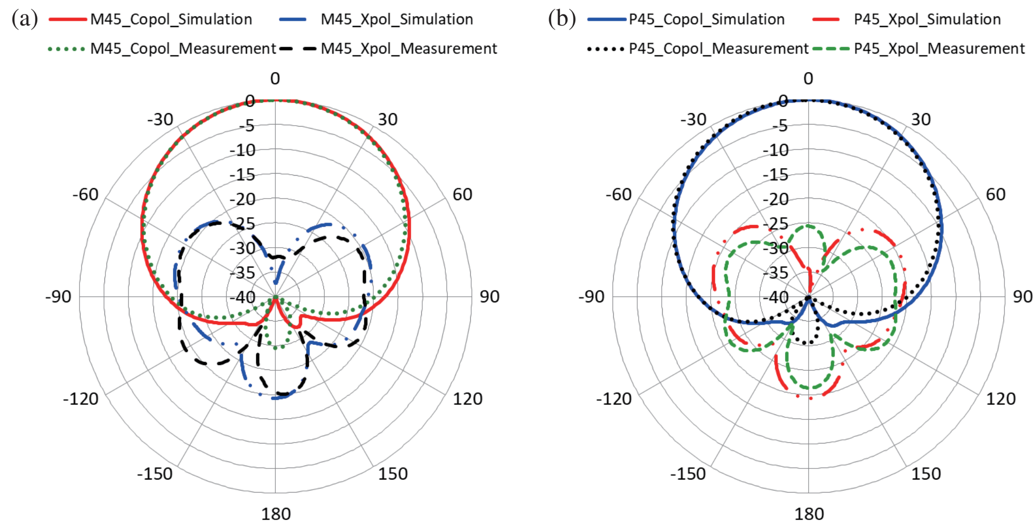

FIGURE 9. Azimuth Radiation pattern for (a) M45 Port and (b) P45 Port at frequency 817 MHz.

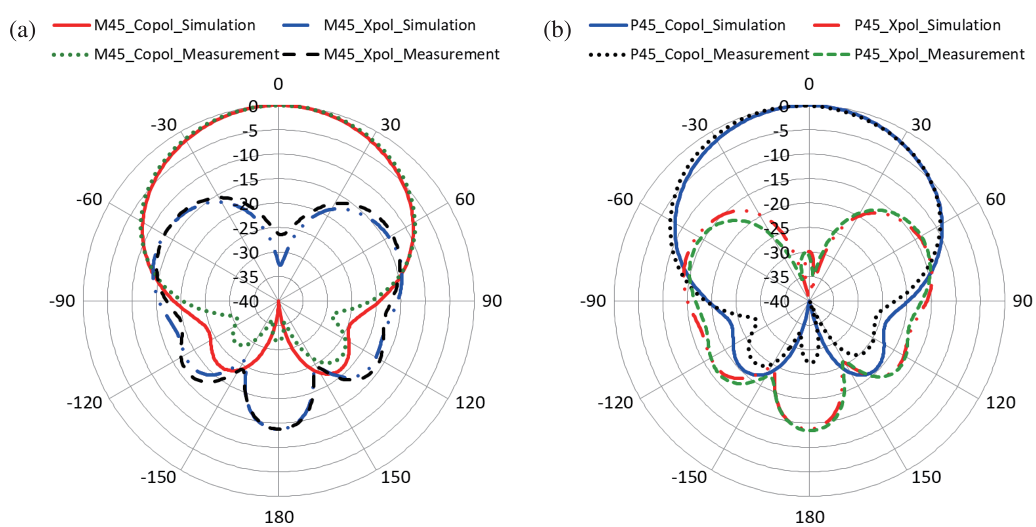

FIGURE 10. Azimuth Radiation pattern for (a) M45 Port and (b) P45 Port at frequency 990 MHz.

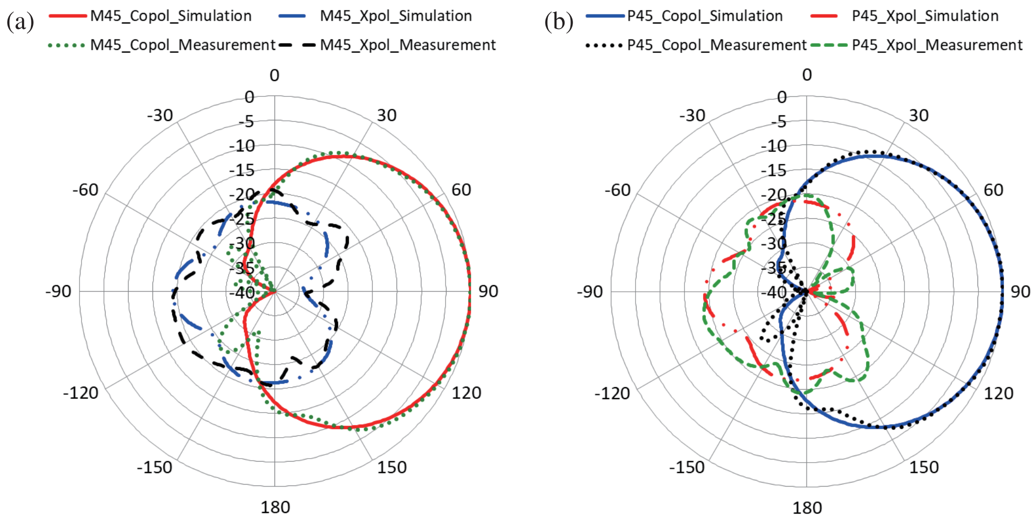

FIGURE 11. Elevation radiation pattern for (a) M45 Port and (b) P45 Port at frequency 617 MHz.

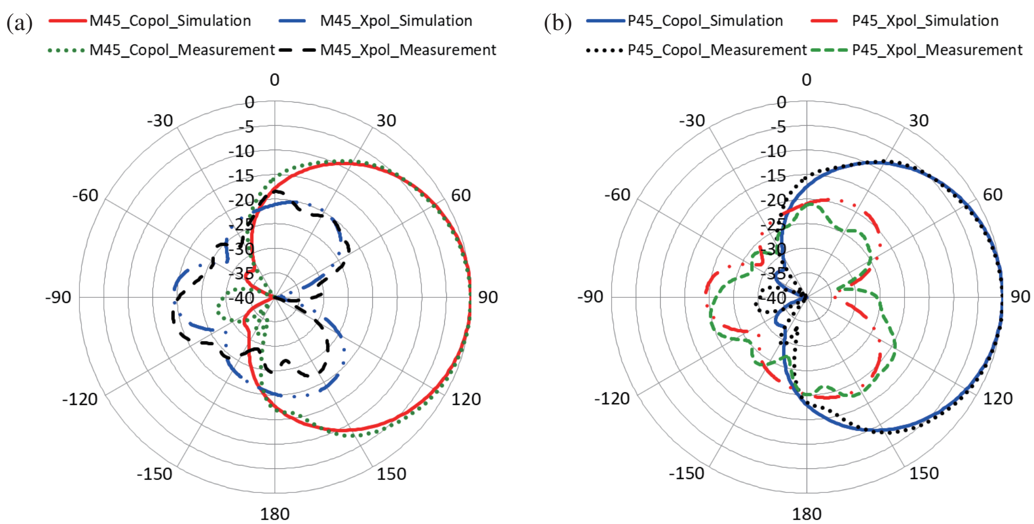

FIGURE 12. Elevation Radiation pattern for (a) M45 Port and (b) P45 Port at frequency 817 MHz.

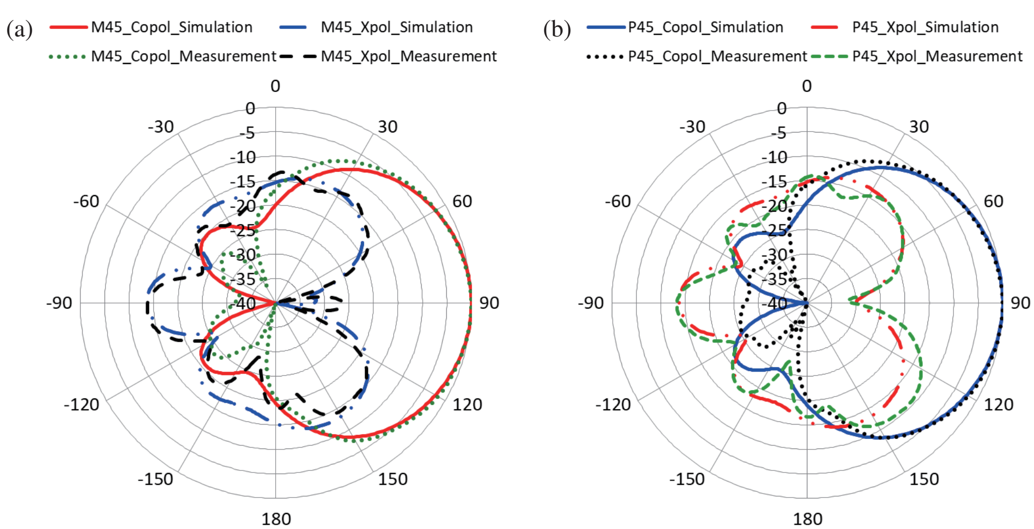

FIGURE 13. Elevation Radiation pattern for (a) M45 Port and (b) P45 Port at frequency 990 MHz.

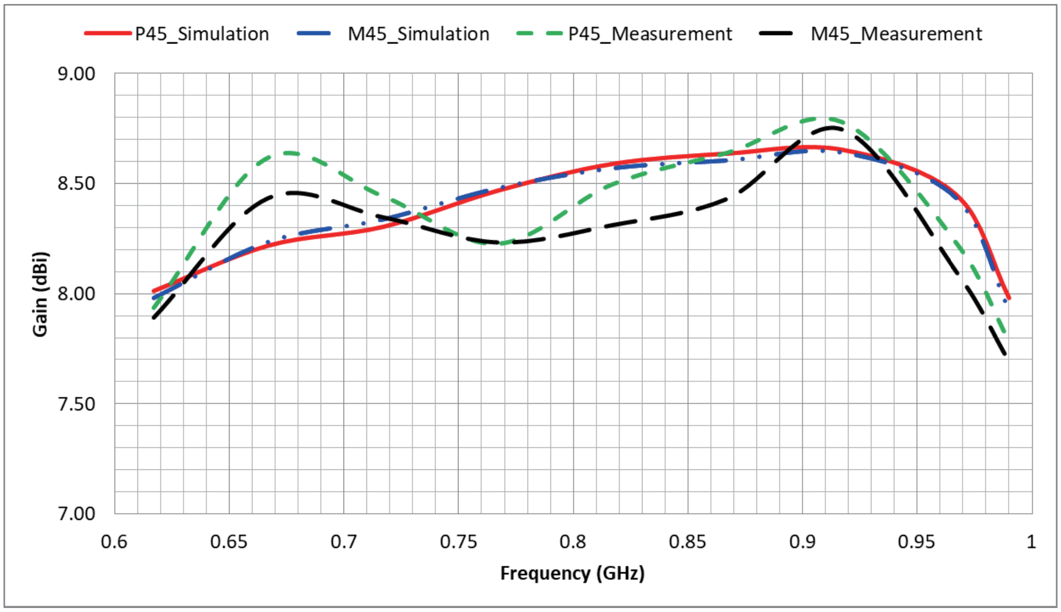

FIGURE 14. Simulated and measured gain of the proposed antenna.

TABLE 2. Comparison of the proposed antenna with published literatures.

Ref.	Size (mm^3)	VSWR/RL (dB)	BW (%)	Isolation (dB)	HPBW	Gain (dBi)
[13]	$384 \times 384 \times 117$	$1.5/-15$	37	-30	$65 \pm 3^\circ$	8
[12]	$326 \times 326 \times 90$	$1.5/-15$	37.5	-40	$61.7 \pm 1.5^\circ$	9.25
[11]	$250 \times 250 \times 69$	$1.5/-15$	19.4	-26	$65 \pm 2.5^\circ$	9.9
[9]	Not Given	$1.5/-15$	31.6	-25	$90 \pm 5^\circ$	NG
Proposed	$350 \times 350 \times 100$	$2/-10$	48	-33	$69.5 \pm 3^\circ$	8.4

entire operating frequency band. Cross-polarization levels, as observed from the radiation patterns, are approximately 20 dB lower than the maximum radiation in the antenna boresight and close to 8 dB at 120° sector edges.

The proposed cross-dipole antenna achieves an average antenna gain of approximately 8.4 dBi, as depicted in Fig. 14. The figure illustrates both simulated and measured gain curves of the antenna across the frequency range. The measured and simulated gain values closely align, indicating good agreement. While the achieved gain is slightly less than the antennas referenced in Table 2, potential enhancements can be achieved by narrowing the azimuth beamwidth further and improving matching.

The comparison of the proposed antenna with published literature is tabulated in Table 2. Some dipoles in the references exhibit higher gain, as these models feature distinct dipole geometries and principles of operation. Notably, those designs are tailored for narrowband applications with superior matching performance.

5. CONCLUSION

A wideband dual-polarized bent cross-dipole antenna designed for modern base station communication applications consists of a pair of linearly orthogonally-polarized dipole antennas, a cross-shaped director, and a metal reflector surrounded by side fences in an open box configuration. The dipoles are placed orthogonally to achieve $\pm 45^\circ$ slant dual polarizations. Both the simulated and measured results demonstrate that the antenna exhibits favorable electrical and radiation characteristics. Key features of this proposed antenna model include a stable radiation pattern with low cross-polarization levels at boresight and sector edges, low back lobe radiation, identical E- and H-plane patterns, and stable antenna gain across the entire operating frequency range. The design offers advantages in terms of size, weight, cost, and ease of manufacturing. It is suitable for the use in multiband multifunction base station arrays and can be advantageous in indoor applications requiring increased bandwidth and coverage. By forming a linear antenna array with this element, narrow beamwidths and higher gain in the elevation plane can be achieved. The proposed antenna holds wide-ranging potential applications in modern wireless base station communications.

REFERENCES

[1] Lindmark, B. and M. Nilsson, "On the available diversity gain from different dual-polarized antennas," *IEEE Journal on Selected Areas in Communications*, Vol. 19, No. 2, 287–294, Feb. 2001.

[2] Luk, K.-M. and H. Wong, "A new wideband unidirectional antenna element," *Int. J. Microw. Opt. Technol.*, Vol. 1, No. 1, 35–44, 2006.

[3] Wong, H., K.-M. Mak, and K.-M. Luk, "Directional wideband shorted bowtie antenna," *Microwave and Optical Technology Letters*, Vol. 48, No. 8, 1670–1672, Aug. 2006.

[4] Cui, Y. H., R. L. Li, and P. Wang, "A novel broadband planar antenna for 2G/3G/LTE base stations," *IEEE Transactions on Antennas and Propagation*, Vol. 61, No. 5, 2767–2774, 2013.

[5] Liu, Y., H. Yi, F.-W. Wang, and S.-X. Gong, "A novel miniaturized broadband dual-polarized dipole antenna for base station," *IEEE Antennas and Wireless Propagation Letters*, Vol. 12, 1335–1338, 2013.

[6] Cui, Y. H., R. L. Li, and H. Z. Fu, "A broadband dual-polarized planar antenna for 2G/3G/LTE base stations," *IEEE Transactions on Antennas and Propagation*, Vol. 62, No. 9, 4836–4840, Sep. 2014.

[7] Gou, Y., S. Yang, J. Li, and Z. Nie, "A compact dual-polarized printed dipole antenna with high isolation for wideband base station applications," *IEEE Transactions on Antennas and Propagation*, Vol. 62, No. 8, 4392–4395, Aug. 2014.

[8] Mak, K. M., X. Gao, and H. W. Lai, "Low cost dual polarized base station element for long term evolution," *IEEE Transactions on Antennas and Propagation*, Vol. 62, No. 11, 5861–5865, Nov. 2014.

[9] Samb, D., Z. Wu, M. Liu, and H. B. Jie, "Development of ultra-broadband base station antenna for all mainstream LTE 700/800/900 MHz frequency bands," *International Journal of Antennas and Propagation*, Vol. 2014, 2014.

[10] Liu, Q. and L. Shi, "Wideband dual polarized radiating element and antenna," *Chinese Patent Cn103094668a*, 2013.

[11] He, Y. and W. Tian, "A broadband dual-polarized base station antenna element for european digital dividend, CDMA800 and GSM900 applications," in *2017 13th International Wireless Communications and Mobile Computing Conference (IWCMC)*, 659–663, Valencia, Spain, Jun. 2017.

[12] Wu, R. and Q.-X. Chu, "A wideband dual-polarized antenna for LTE700/GSM850/GSM900 applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 16, 2098–2101, 2017.

[13] Yang, Z., X. Mo, Y. Cui, and R. Li, "A wideband crossed-dipole antenna for LTE700/GSM850/GSM900 base stations," in *Proceedings of The 2019 9th IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (IEEE APWC'19)*, 30–33, Granada, Spain, Sep. 2019.

[14] Pollayi, L., R. K. Dasari, and V. M. Pandharipande, "Design and development of wide band dual-polarized magneto electric dipole antenna for mobile communications," *International Journal of Microwave and Wireless Technologies*, Vol. 11, No. 2, 175–181, Mar. 2019.

[15] Yang, Z., X. Mo, Y. Cui, and R. Li, "A wideband crossed-dipole antenna for lTE700/GSM850/GSM900 base stations," in *Proceedings of The 2019 9th IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (IEEE APW'19)*, 30–33, Granada, Spain, Sep. 2019.

[16] https://imageserv11.team-logic.com/mediaLibrary/303/AD300C.pdf.

[17] https://www.ansys.com/en-in/products/electronics/ansys-hfss.