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A Wide Bandwidth Folded V-Shaped Patch Antenna with Stable High Gain and Low Cross-Polarization Characteristics

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Abstract—A wide bandwidth folded V-shaped patch antenna with high gain and low cross polarization is presented. The proposed antenna is composed of a folded V-shaped patch, an H-shaped coupling slot cut in the ground plane and a feed line with a stub printed on the bottom layer of the grounded substrate. By folding the V-shaped metallic patch, the proposed antenna can achieve a low profile structure and good performance in radiation patterns. The antenna element and the antenna array operating at 2 GHz were fabricated and tested. The prototypes with the single element can achieve a -10 dB return loss bandwidth of 28.5% (1.65 to 2.2 GHz) and a stable gain of 8.6 dBi, while the 1×2 array exhibits a bandwidth of 34.1% (1.58 to 2.23 GHz) and a stable gain of 11.5 dBi.

1. INTRODUCTION

Recently, with the rapid modern wireless communication development, new base station antennas have become one of the most important research focuses in contemporary antenna engineering [1]. In this concept, patch antennas have been widely used in constructing base station antennas for modern wireless communication systems. However, patch antennas suffer from the disadvantage of narrow bandwidth [2, 3]. Many techniques have been proposed to enhance the bandwidth of patch antennas. Among of these techniques, patch antennas with probe feed structure which can improve the impedance bandwidth were proposed in [4–7]. Increasing substrate thickness can enhance patch antenna bandwidth [8, 9]. By embedding a U-slot or V-slot in a suspended rectangular patch [10–12], good impedance matching over a wideband can be obtained. M-shaped meandering probe was used to feed the patch antenna in [13] to increase the bandwidth. However, all these proposed antennas have high cross-polarization levels. The aperture-stack patch antenna [14, 15], which utilizes several layers and impedance matching techniques are used in the design of a feed network, can provide a very wide bandwidth, but with high cost and difficult fabrication. To achieve higher antenna gain and good shaped radiation patterns, antenna array is widely used in industry, especially for base station applications. In [16], a wide-band aperture coupled dual-polarized 2×4 patch antenna array suitable for base station antenna in personal communication services (PCS) and international mobile telecommunications-2000 (IMT-2000) bands. The array can achieve a 10 dB return loss bandwidth of 19.84% and 28.25% for each port. In [17], a single-layer microstrip line fed U-slot 2×2 patch antenna array was proposed. The array exhibited an impedance bandwidth (VSWR < 2) of 18% ranging from 5.65 to 6.78 GHz. An aperture stacked patch antenna array with a novel dual-layered feeding structure was introduced in [18]. This 1×4 array was designed for mobile communication (GSM), digital communication system (DCS) and universal mobile communication system (UMTS).

In this paper, a wideband folded V-shaped patch antenna with a simple aperture-coupled feed structure is presented. The folded V-shaped patch is composed of two horizontal parts and a V-shaped

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part. Simulated and measured results show that the proposed antenna element and two-element array are suitable for the base station antenna that is required to cover the working bandwidth of DCS, PCS and 3G mobile communication systems. Details of the proposed antenna are described, and obtained experimental results are presented and discussed.

The reminder of this paper is organized as follows. In Section 2, the configuration of the proposed antenna element is presented, and the antenna performances, including simulated and measured results, are compared and discussed. Antenna array based on the proposed element is presented in Section 3. Finally, conclusions are given in Section 4.

2. ANTENNA ELEMENT

2.1. Antenna Configuration

The configuration of the proposed antenna element is shown in Fig. 1. The antenna consists of a folded V-shaped patch, a metal frame, a 1.6 mm-thick FR4 substrate with the dielectric constant of 3.38 and loss tangent of 0.02, and an H-shaped coupling slot with a width of 1 mm. In order to make the antenna more practical, a metal frame with a certain structure [see Fig. 1(d)] is proposed. The folded V-shaped patch is composed of two horizontal parts and a V-shaped part. The tuning angle of the V-shaped patch is 90°. The folded V-shaped patch is supported and fixed to the surface of the metal frame by four cylinder posts made of Teflon with dielectric permittivity of 2.08. The top layer of the substrate is covered by silver. The substrate is embedded in the metal frame. A microstrip feed line is printed on the bottom layer of the substrate. Electromagnetic energy is coupled through an H-shaped slot cut in the ground plane. An H-shaped slot can offer more design freedom than a rectangular slot. Good impedance matching can be achieved by varying the length and width of the coupling slot. To improve

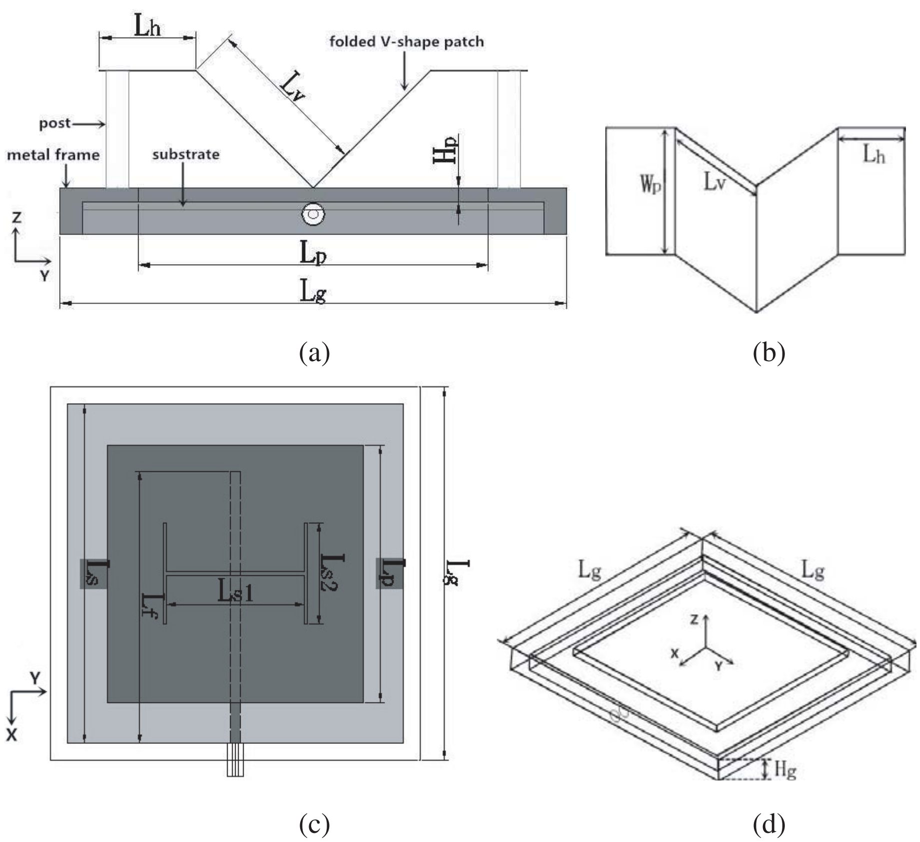


Figure 1. Geometry of the proposed element. (a) Side view. (b) Folded V-shaped patch. (c) Top view. (d) Metal frame.

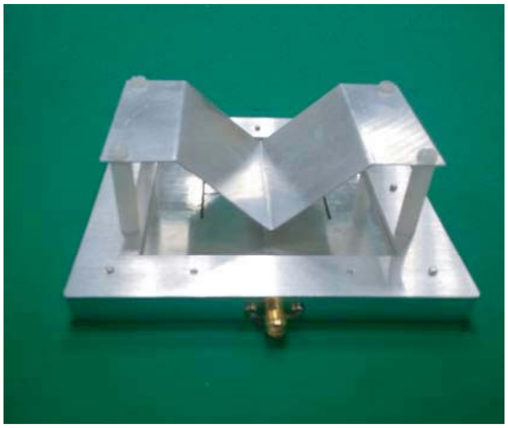


Figure 2. Photograph of the proposed element.

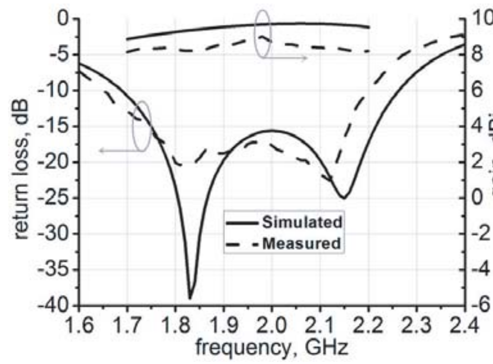


Figure 3. Return loss and gains for proposed element. $L_g = 110\,\text{mm}$, $L_p = 76\,\text{mm}$, $W_p = 57\,\text{mm}$, $L_s = 100\,\text{mm}$, $L_v = 36\,\text{mm}$, $L_h = 21\,\text{mm}$, $L_f = 80.2\,\text{mm}$, $L_{s1} = 41\,\text{mm}$, $L_{s2} = 30\,\text{mm}$, $H_p = 3\,\text{mm}$, $H_g = 10\,\text{mm}$.

the coupling efficiency, the central line of the folded V-shaped patch is located close to the coupling aperture, while the two horizontal edges of the patch can be a large distance away from the ground plane, which makes the excitation of wideband operating modes possible. The central lines of the folded V-shaped patch and H-shaped slot are separated by a small gap of 3 mm. A prototype of the proposed antenna constructed according to the final optimized parameters is shown in Fig. 2.

2.2. Results and Discussions

Figure 3 illustrates the simulated and measured return losses and gains for the designed antenna. The measured $-10\,\text{dB}$ return loss bandwidth of 28.5% is obtained from 1.65 to 2.2 GHz and can fulfill the required working frequency band for the existing DCS, PCS and 3G mobile communication systems. Within 1.7–2.2-GHz frequency band, the measured antenna gains are about 8.2 and 9 dBi while the simulated gains vary from 8.9 to 9.7 dBi.

The measured E- and H-plane radiation patterns at the frequencies of 1.75, 1.94, 2 and 2.13 GHz for the proposed antenna element are plotted in Fig. 4. It can be seen that the proposed antenna radiates a maximum power towards the broadside z-direction. Over the working frequency band, the measured front-to-back ratios are more than 6 dB, but the front-to-back ratios become higher at lower frequencies. The measured cross-polarization levels are below $-25\,\text{dB}$ in the E- and H-planes.

Radiation patterns in the E- and H-planes are almost equal in the working frequency band. In the H-plane, stable broadside radiation patterns are obtained over the working band. In the E-plane, the broadside radiation patterns are symmetric and stable at lower frequencies. However, the main beam becomes narrower at higher frequencies.

The performance of the proposed antenna is compared with those of other patch antennas in Table 1. The comparison gives performances including bandwidth, gain, and cross-polarization of the patch antennas. It can be seen that the proposed folded V-shaped patch antenna has improved gain due to bigger aperture area when the length of the horizontal patch increases. The cross-polarization is suppressed due to the symmetrical feeding structure. As the centre line of the patch is close to the coupling aperture, coupling efficiency is supposed to be improved. For impedance bandwidth, as the two horizontal edges of the patch have a large distance away from the ground plane, dual-resonance performance was achieved, which results in a broadband response.

To obtain more understanding on the usefulness of folding the V-shaped patch antenna, a parametric study has been performed using HFSS. Throughout the study, the total length of the folded V-shaped patch is kept constant as 114 mm (i.e., $2 * L_h + 2 * L_v = 114\,\text{mm}$). With increasing the length of the horizontal patch, the length of the V-shaped patch will decrease. As a result, the height of the

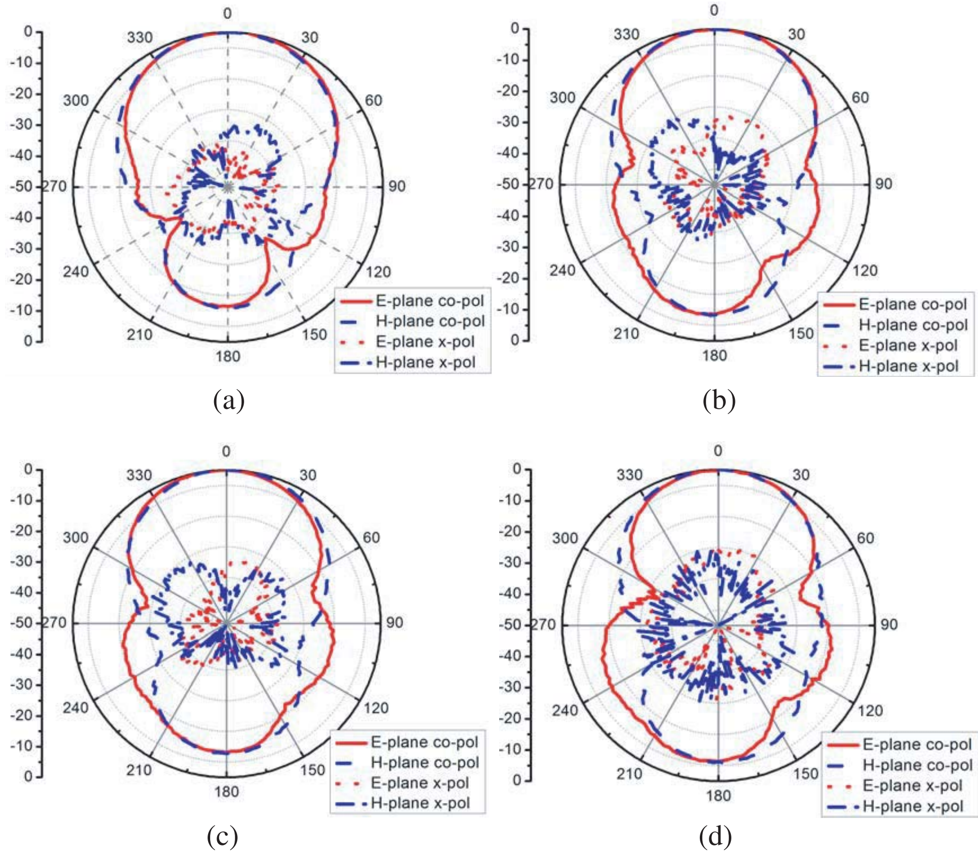


Figure 4. Measured radiation patterns for the proposed element. (a) 1.75 GHz. (b) 1.94 GHz. (c) 2 GHz. (b) 2.13 GHz.

Table 1. Comparison of the patch antennas.

Antennas	Bandwidth %	Peak gain dBi	X-pol dB
[7]	15	6	-10
[11]	11.8	7.92	-15
[12]	19.3	8	-12
[13]	26	10	-18
Proposed element	28.5	9	-25

proposed antenna will be reduced.

In Fig. 5, a comparison of return losses and antenna gains between the antennas with case 1 (i.e., $L_h = 21\,\text{mm}$, $L_v = 36\,\text{mm}$), case 2 (i.e., $L_h = 10.5\,\text{mm}$, $L_v = 46.5\,\text{mm}$), and case 3 (i.e., $L_h = 0\,\text{mm}$, $L_v = 57\,\text{mm}$) is presented. It is shown that the impedance matching and antenna gain can be improved by using the proposed folded V-shaped patch (i.e., case 1) compared to the V-shaped patch antenna (i.e., case 3). Comparing case 1 with case 2, it can be seen that the impedance matching is slightly changed, but the gains of the antenna proposed in case 2 are lower than that of the proposed antenna in case 1 in the operating frequency band. Furthermore, among the three antennas, the height of the proposed antenna in case 1 is the smallest.

Current distributions on the surface of the folded V-shaped patch at different times are shown in Fig. 6. The electric dipole mode of the V-shaped patch is excited at time $t = 0$ and $t = T/2$, where T

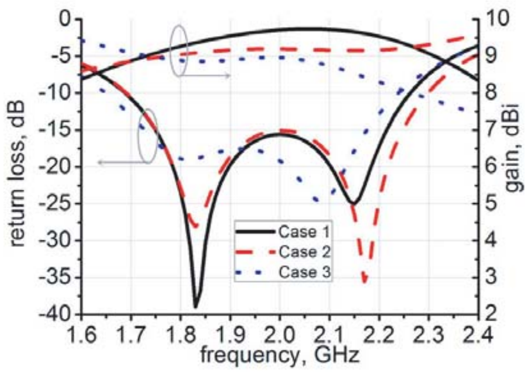
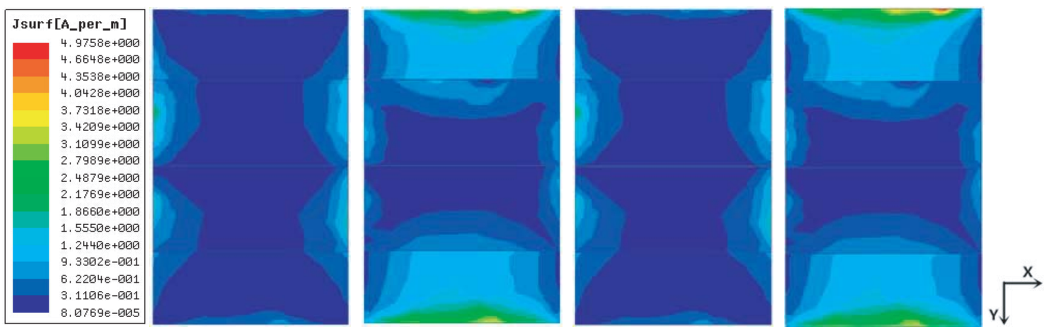


Figure 5. Comparison of return loss and gains between the antennas with case 1 ($L_h = 21$ mm, $L_v = 36$ mm), case 2 ($L_h = 10.5$ mm, $L_v = 46.5$ mm), and case 3 ($L_h = 0$ mm, $L_v = 57$ mm).



(a) (b) (c) (d)

Figure 6. Simulated current distribution of the proposed folded V-shaped patch at different times. (a) $t = 0$. (b) $t = T/4$. (c) $t = T/2$. (d) $t = 3T/4$.

is a period of oscillation, whereas the electric dipole mode of the horizontal patch is strongly excited at time $t = T/4$ and $3T/4$. The results show that the power mainly radiates from the edges of the horizontal patch. Therefore, the edges of horizontal patches represent an essential attribute for the radiations characteristics.

3. ANTENNA ARRAY

For base station applications, a higher antenna gain and good shaped radiation patterns are required for mobile communications. Therefore, it is necessary to employ a certain number of elements in an antenna array combination. In this section, a two-element linear array is proposed for potential applications in mobile communication base station.

3.1. Array Geometry

The geometry of the two-element array based on the mentioned element antenna is shown in Fig. 7. The distance between array elements is chosen as 120 mm. The height from the feeding network to the rectangular reflector of size 121 mm $\times$ 345 $\times$ 2 mm is $H = 30$ mm. A 1.6 mm-thick FR4 substrate, with a dielectric constant of 3.38 and loss tangent of 0.02, is embedded in the metal frame with a thickness of 4.6 mm. The folded V-shaped patch is supported and fixed to the surface of the metal frame by eight cylinder posts made of Teflon with dielectric permittivity of 2.08. A prototype of the proposed antenna array constructed according to the final optimized parameters is shown in Fig. 8.

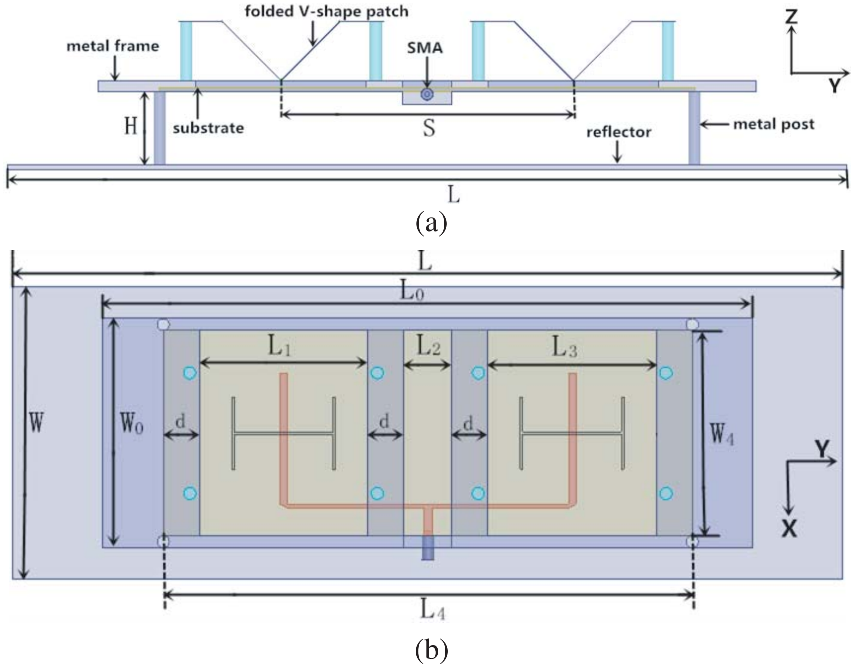


Figure 7. Geometry of the proposed array. (a) Side view. (b) Top view.

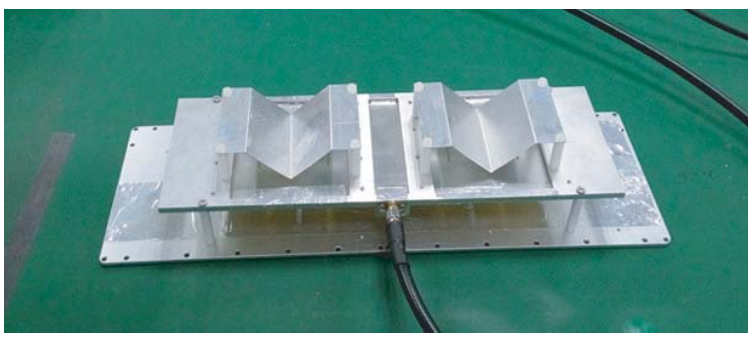


Figure 8. Photograph of the proposed array.

The top layer of the substrate is covered by silver. The feeding network is printed on the bottom layer of the substrate of size 85 mm × 220 mm. The feed line is excited by a 50 ohm SMA connector. For a two-element array, there are two elements with 50 ohm input impedances. One port should be a 50 ohm line and divided into two 100 ohm branches. Theoretically, both of the 100 ohm branches must be matched to elements with 50 ohm input impedances. However, due to the effect of the mutual coupling between the elements and the reflector on the impedance matching for the array, an optimized width of the feed line shown in Fig. 9 has been adopted to match the array.

3.2. Results

Figure 10 shows the simulated and measured return losses and antenna gains of the two-element array. The bandwidth for −10 dB return loss is about 34.1% (1.58–2.23 GHz). The measured gain of the array varies from 11.1 to 12.3 dBi over the working frequency range of 1.7–2.2 GHz as illustrated in Fig. 10.

Figure 11 shows the simulated radiation patterns of the two-element array in the E-and H-planes at the frequencies of 1.71, 2, 2.2 and 2.37 GHz. The antenna array exhibits good unidirectional radiation patterns. Within the operation frequency band, the simulated front-to-back ratios of the proposed

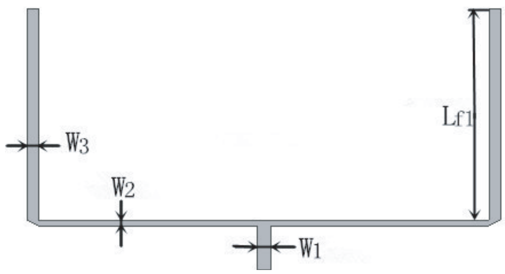


Figure 9. Geometry of the feed network.

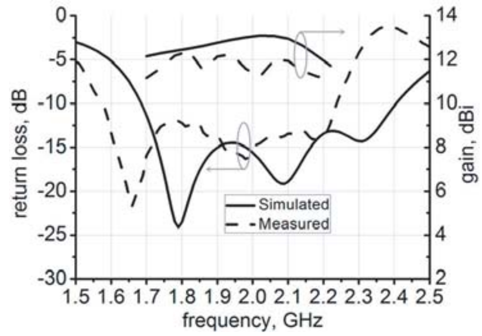


Figure 10. Return loss and gains for the proposed antenna array. $L = 345\,\text{mm}$, $W = 121\,\text{mm}$, $H = 30\,\text{mm}$, $S = 120\,\text{mm}$, $L_0 = 270\,\text{mm}$, $W_0 = 95\,\text{mm}$, $L_1 = 70\,\text{mm}$, $L_2 = 20\,\text{mm}$, $L_3 = 70\,\text{mm}$, $L_4 = 220\,\text{mm}$, $W_1 = 3.6\,\text{mm}$, $W_2 = 1.5\,\text{mm}$, $W_3 = 3\,\text{mm}$, $W_4 = 85\,\text{mm}$, $L_{f1} = 54.5\,\text{mm}$, $d = 15\,\text{mm}$.

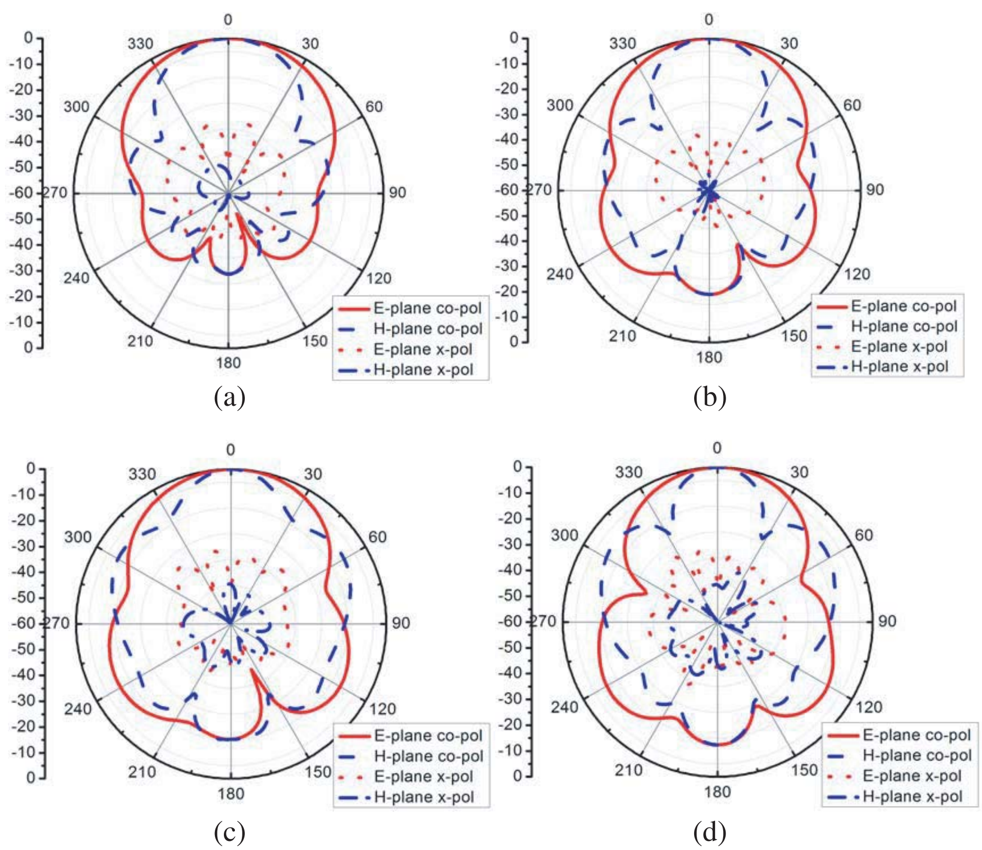


Figure 11. Simulated radiation patterns for proposed array. (a) 1.71 GHz. (b) 2 GHz. (c) 2.2 GHz. (d) 2.37 GHz.

array are more than 12.3 dB. Moreover, the front-to-back ratios are more than 20 dB at low frequencies, and the simulated cross polarization levels in the E- and H-planes are less than -31 and -45 dB, respectively. However, the main beams in the E- and H-planes at higher frequencies are narrower than those at lower frequencies.

4. CONCLUSION

A wide bandwidth folded V-shaped patch antenna has been proposed and investigated. Prototypes with center frequency of 2 GHz are designed, fabricated and tested. The prototypes with a single element can achieve a -10 dB return loss bandwidth of 28.5% (1.65–2.2 GHz) and an average gain of 8.6 dBi, while the two-element antenna array exhibits a bandwidth of 34.1% (1.58–2.23 GHz) and an average gain of 11.5 dBi. Unidirectional radiation patterns with low cross polarization, and high antenna gains are demonstrated. Moreover, the antenna structure is simple and easy to fabricate.

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REFERENCES

1. Balanis, C. A., *Antenna Theory: Analysis and Design*, Wiley, New York, 2005.
2. Montero-de-Paz, J., E. Ugarte-Muñoz, F. J. Herraiz-Martínez, V. González-Posadas, L. E. García-Muñoz, and D. Segovia-Vargas, "Multifrequency self-diplexed single patch antennas loaded with split ring resonators," *Progress In Electromagnetics Research*, Vol. 113, 47–66, 2011.
3. Monavar, F. M. and N. Komjani, "Bandwidth enhancement of microstrip patch antenna using Jerusalem cross-shaped frequency selective surfaces by invasive weed optimization approach," *Progress In Electromagnetics Research*, Vol. 121, 103–120, 2011.
4. Masa-Campos, J.-L. and F. Gonzálea-Fernández, "Dual linear/circular polarized plannar antenna with low profile double-layer polarizer of 45° tilted metallic strips for WiMAX applications," *Progress In Electromagnetics Research*, Vol. 98, 221–231, 2009.
5. Huang, K.-C. and H.-F. Li, "A novel single-layer single-patch wide-band probe-feed crescent like-shaped microstrip antenna," *Journal of Electromagnetic Waves and Applications*, Vol. 23, Nos. 2–3, 279–287, 2009.
6. Liu, C., J.-L. Guo, Y.-H. Huang, and L.-Y. Zhou, "A novel dual polarized antenna with high isolation and low cross polarization for wireless communication," *Progress In Electromagnetics Research Letters*, Vol. 32, 129–136, 2012.
7. Xie, J.-J., Y.-Z. Yin, J. Ren, and T. Wang, "A wideband dual-polarized patch antenna with electric probe and magnetic loop feeds," *Progress In Electromagnetics Research*, Vol. 132, 499–515, 2012.
8. Mak, C. L., H. Wong, and K. M. Luk, "High-gain and wide-band single-layer patch antenna for wireless communications," *IEEE Trans. Vehucular Tech.*, Vol. 54, No. 1, 33–40, Jan. 2005.
9. Liu, Y.-T., "Probe-fed patch antenna with an inclined patch for on-wall WLAN access point," *Progress In Electromagnetics Research Letters*, Vol. 18, 85–95, 2010.
10. Weigand, S., G. H. Huff, K. H. Pan, and J. T. Bernhard, "Analysis and design of broadband single-layer rectangular U-slot microstrip patch antennas," *IEEE Trans. Antennas Propagat.*, Vol. 51, No. 3, 457–468, Mar. 2003.
11. Khidre, A., K. F. Lee, A. Elsherbeni, and F. Yang, "Wide band dual-beam U-slot microstrip antenna," *IEEE Trans. Antenna Propagat.*, Vol. 61, No. 3, 1415–1418, Mar. 2013.
12. Deshmukh, A. A. and G. Kumar, "Broadband compact V-slot loaded RMSAs," *Electron. Lett.*, Vol. 42, No. 17, 951–952, 2006.
13. Lai, H. W. and K. M. Luk, "Dual polarized patch antenna fed by meandering probes," *IEEE Trans. Antenna Propagat.*, Vol. 55, No. 9, 2625–2627, Sep. 2007.
14. Barba, M., "A high-isolation, wideband and dual-linear polarization patch antenna," *IEEE Trans. Antenna Propagat.*, Vol. 56, No. 5, 1472–1476, May 2008.
15. Serra, A. A., P. Nepa, G. Manara, G. Tribellini, and S. Cioci, "Wide band dual-polarized stacked patch antenna," *IEEE Antenna Wireless Propagat. Lett.*, Vol. 6, 141–143, Apr. 2007.

16. Yun, W. and Y.-J. Yoon, "A wide-band aperture coupled microstrip array antenna using inverted feeding structures," *IEEE Trans. Antennas Propagat.*, Vol. 53, No. 2, 861–862, Feb. 2005.
17. Wang, H., X. B. Huang, and D. G. Fang, "A single layer wideband U-slot microstrip patch antenna array," *IEEE Antennas Wireless Propagat. Lett.*, Vol. 7, 9–12, 2008.
18. Moradi, K. and S. Nikmehr, "A dual-band dual-polarized microstrip array antenna for base stations," *Progress In Electromagnetics Research*, Vol. 123, 527–541, 2012.