

DUAL-WIDEBAND SQUARE SLOT ANTENNA WITH A U-SHAPED PRINTED TUNING STUB FOR PERSONAL WIRELESS COMMUNICATION SYSTEMS

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Abstract—A square slot antenna fed by two orthogonal feedlines is designed for dual polarized applications. The presented antenna has not only dual operating band, but also very wide bandwidth. The bandwidth is 18% in the first band and 82% in the second one. It can serve most of wireless communication applications that operate at 0.9, 1.8, 1.9 and 2.4 GHz and require wide band characteristics. The antenna can also produce circular polarization with wideband characteristics. Arrays of this antenna are also designed and presented.

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1. INTRODUCTION

In recent years, personal wireless communications have gained a wide popularity. Presently, the trend is to provide a wireless link to every kind of electronic device. In this framework, Personal Digital Assistants (PDAs), PCMCIA, and cellular phones are becoming constitutive elements of new generation networks. In particular, there

is a specific need for greater capacities and transmission speeds, which, together with a growing demand from users for more complicated services, require the design of higher performance systems. In this context, multi- and wide-band antennas are required [1–4]. Many researchers investigated the design of multi-band antennas to cover different frequency ranges [1–9]. Other researchers investigated techniques to improve the antenna bandwidth [10–14], where a very good bandwidth varying from 57% to 70% is achieved.

This paper presents a new design that can simultaneously support operations of dual wide-band, dual linear and circular polarizations. The return loss, VSWR and far field radiation characteristics of this antenna are presented. Furthermore, two array configurations are presented to satisfy the requirements of different personal wireless applications. The simulation and analysis for the presented antennas are performed using the commercial computer software package, Ansoft HFSS, which is based on the finite element method. Verification for the return loss is performed using the commercial software Momentum of Advanced Design System (ADS) of Agilent Technology, which is based on the method of moments.

2. ANTENNA GEOMETRY AND DIMENSIONS

The proposed antenna is printed on a Rogers RT/Duroid 6010/6010 LM substrate of a dielectric constant of 10.2 and a conductor loss ($\tan \delta$) of 0.0023. The use of high dielectric constant substrate material reduces radiation losses because most of the electromagnetic field is concentrated in the dielectric between the conductive strip and the ground plane. Another benefit of having a high dielectric constant is that the antenna size decreases by the square root of the effective dielectric constant. To minimize conductor loss, the conductor thickness should be greater than 5δ [1], where δ is the skin depth, which is approximately $0.65 \mu\text{m}$ for the copper. The conductor thickness used in this research is $34 \mu\text{m}$. The description of the antenna geometry is introduced in the following section.

The geometry and parameters of the proposed dual-polarized dual-band microstrip-fed printed square slot antenna are shown in Fig. 1. The antenna consists of a wide square slot sandwiched between two identical dielectric substrates, and fed by two orthogonal identical microstrip-fed-two-arm feedlines, as illustrated in Fig. 1. The square slot is printed on a finite ground plane of a $75 \times 75 \text{ mm}^2$ size, and the edge of the square slot is W , where $W = 50 \text{ mm}$. Each substrate has a thickness $h = 50 \text{ mil}$ (1.27 mm). The microstrip-fed-two-arm feedline is placed symmetrically with respect to the centerline of the

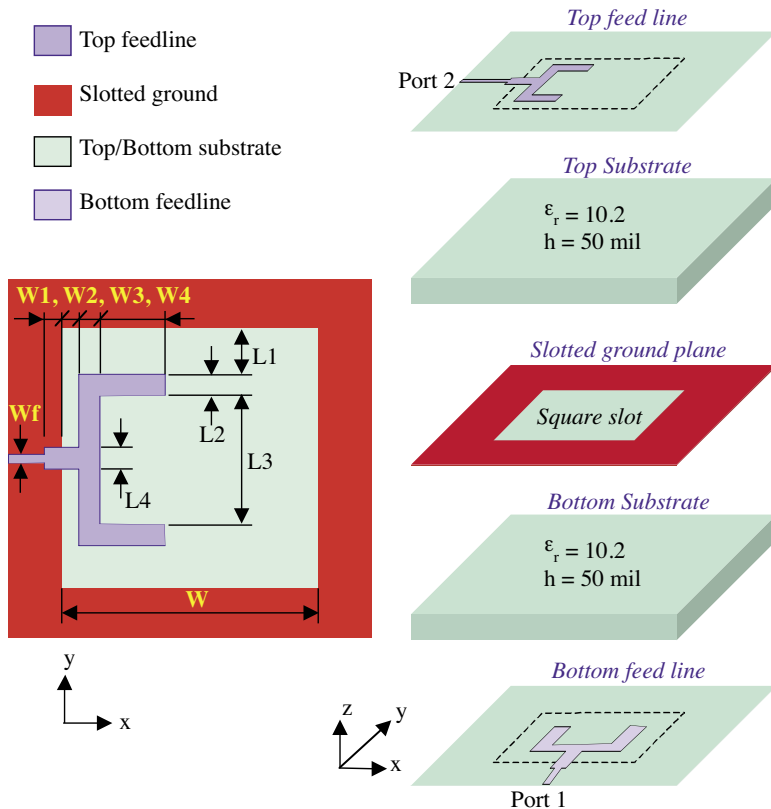


Figure 1. Geometry and parameters of the dual-polarized dual-band microstrip-fed printed square slot antenna.

square slot. The dimensional parameters of the microstrip-fed-two-arm feedline are shown in Fig. 1, where $W1, W2, W3, W4, L1, L3, L3$ and $L4 = 2.5, 2, 3, 12, 8.5, 3, 27$ and 3 mm, respectively, and the width of the microstrip feedline Wf equals 1.18 mm for an approximate characteristic impedance of 50Ω .

3. ONE ELEMENT DESIGN

The proposed antenna is simulated using Ansoft HFSS and ADS Momentum. Figure 2 shows comparisons between the resulting return loss and VSWR for the presented antenna using Ansoft HFSS and ADS Momentum. Very good agreement between the results is obtained, which verifies the results of this antenna. In HFSS, the exact geometry

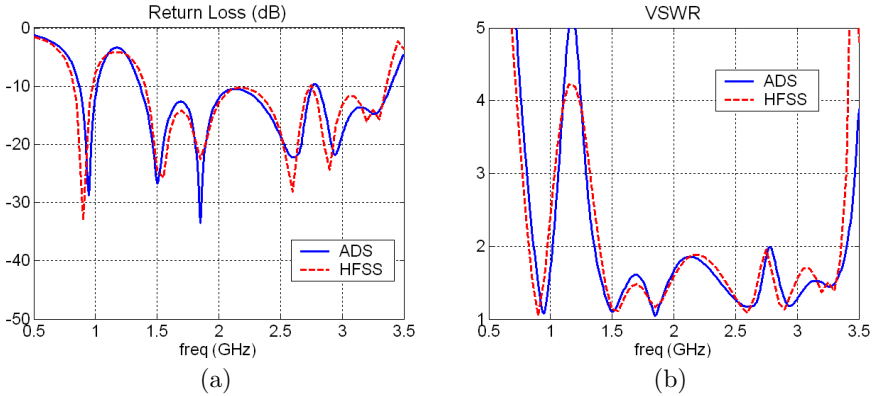


Figure 2. Comparison between the (a) return loss, and (b) VSWR, for the dual-polarized dual-band microstrip-fed square slot antenna, computed by HFSS and ADS.

of the antenna is simulated with a finite substrate and ground plane of a $75 \times 75 \text{ mm}^2$ size. In ADS Momentum, an infinite substrate and ground plane are considered. As shown in Fig. 2, the HFSS results show that the antenna operates in two bands in the range from 0.5 to 3.5 GHz. The first band spans from 0.82 to 0.98 GHz, with a wide bandwidth of 18%, and the second band spans from 1.4 to 3.36 GHz, with a very wide bandwidth of 82%. According to ADS results, the first band spans from 0.87 to 1.02 GHz, with a wide bandwidth of 16%, and the second band spans from 1.36 to 3.4 GHz, with a very wide bandwidth of 86%. One main advantage of this antenna is its multi-resonate capabilities around 0.9, 1.8, 1.9, and 2.45 GHz. The VSWR level at 0.9, 1.8 and 2.6 GHz is less than 1.1, which is less than the required VSWR for personal wireless communication applications.

The 2D radiation patterns for the proposed antenna in the E - and H -planes are computed using Ansoft HFSS, with only Port 1 excited. The radiation patterns computed at 0.9, 1.4, 1.9, 2.4, 2.7, and 3.1 GHz are shown in Fig. 3, and the computed gain is shown in Fig. 4. The lower half of all patterns is cropped because they are almost symmetrical to the top half. The co-polarized field components, E_ϕ in the x - z plane and E_θ in the y - z plane, are almost stable in the operating bands. The cross-polarized fields are disturbed after 2.4 GHz mainly because of the coupled fields between the slot and the upper feed line. The antenna gain spans from 0.45 to 2.15 dB. Placing a ground plane at a quarter wavelength distance from the antenna will suppress the back radiations and enhance the gain. The

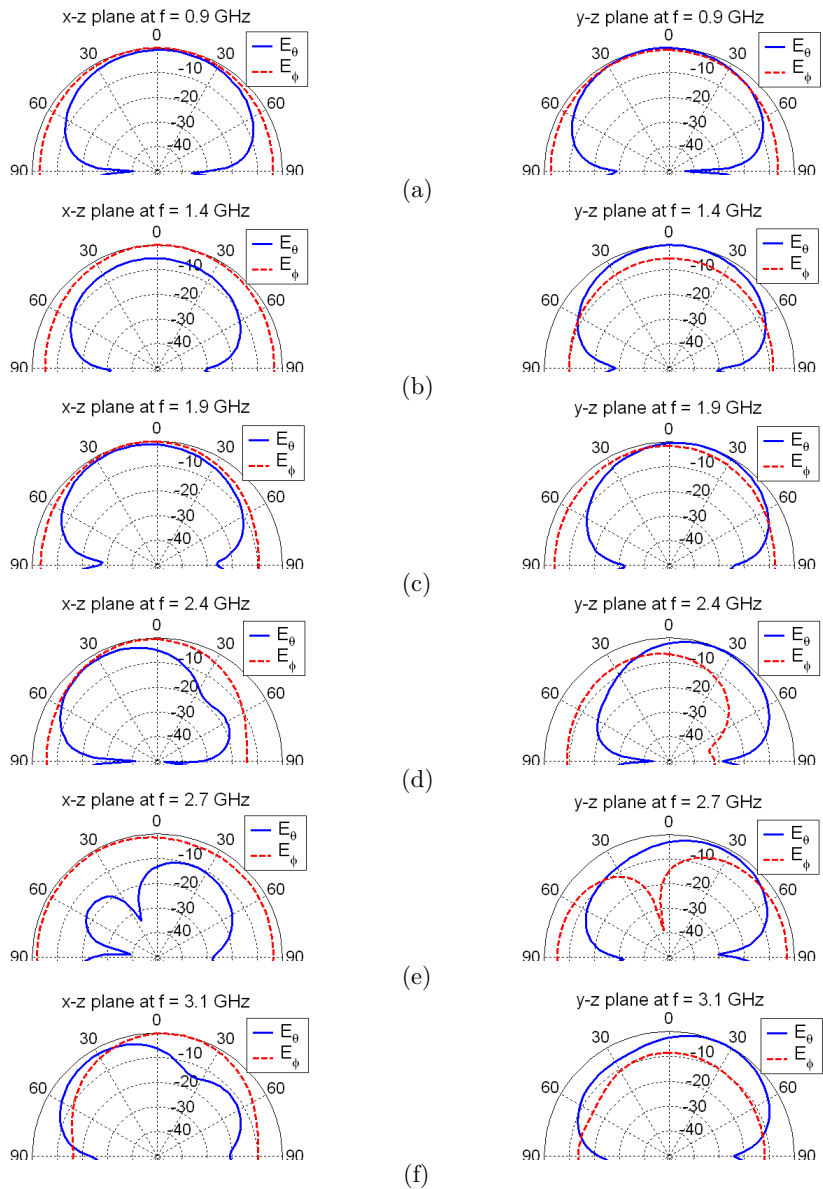


Figure 3. Computed radiation patterns in the H -plane (x - z) and the E -plane (y - z) at (a) 0.9, (b) 1.4, (c) 1.9, (d) 2.4, (e) 2.7, and (f) 3.1 GHz, when only Port 1 excited.

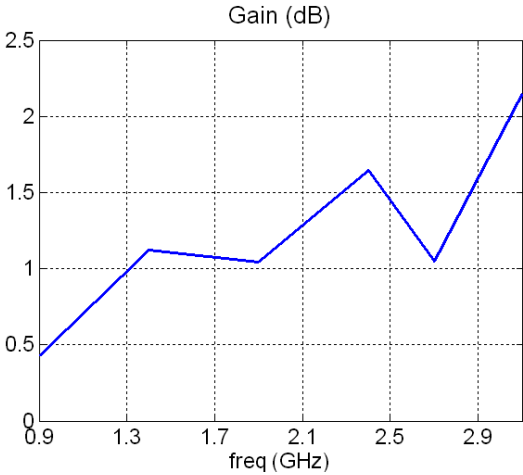


Figure 4. Gain in dB for one-element.

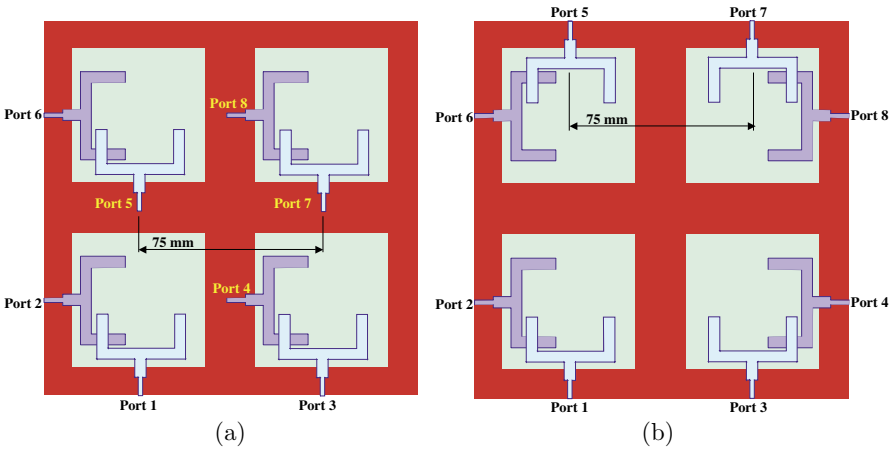


Figure 5. 2D Antenna array configurations: (a) Array 1, and (b) Array 2.

aforementioned results show that the antenna is a very good candidate for modern personal wireless communication applications that require wideband characteristics. Using this antenna gives these systems the ability to serve simultaneously the frequency bands of the GSM 900, GSM 1800 and GSM 1900, and industrial, scientific and medical ISM band around 2.4 GHz, in addition to WLAN and Bluetooth applications operating at 2.4 GHz.

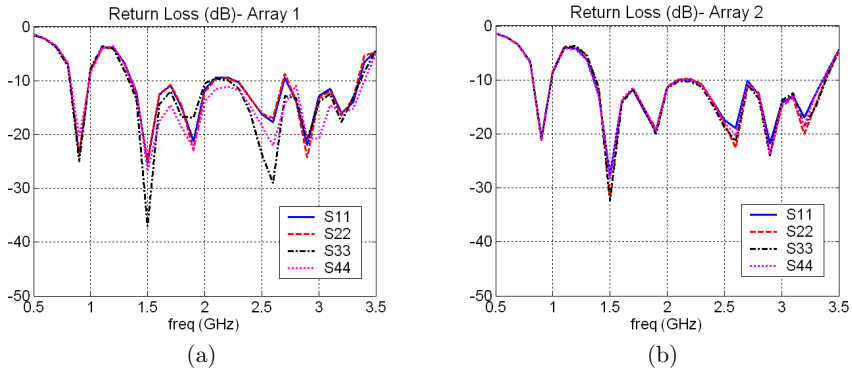


Figure 6. Return loss for (a) Array 1, and (b) Array 2.

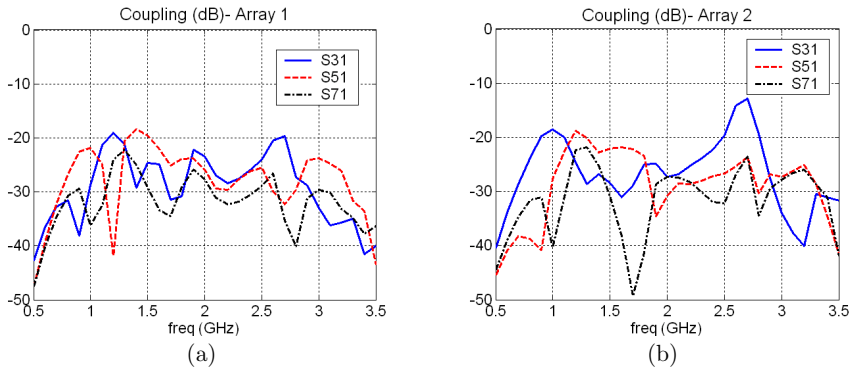


Figure 7. Coupling between the bottom layer ports of (a) Array 1, and (b) Array 2.

4. ANTENNA ARRAYS DESIGN

For the purposes of point-to-point wireless communications, it is desirable for the antenna to have a narrow beamwidth in one direction and a zero in all the other directions. Such a pattern cannot be obtained by using a single element. Therefore, in such applications antenna arrays are mainly required. This section presents the performance of arrays of the dual-polarized dual-band microstrip-fed square slot antenna. Two configurations are proposed for the 2D antenna arrays, Array 1 and Array 2, and they are presented in Fig. 5. Each of these two configurations can be considered a unit cell of larger 2D arrays. Array 1 is a direct arrangement for the 2D array, where

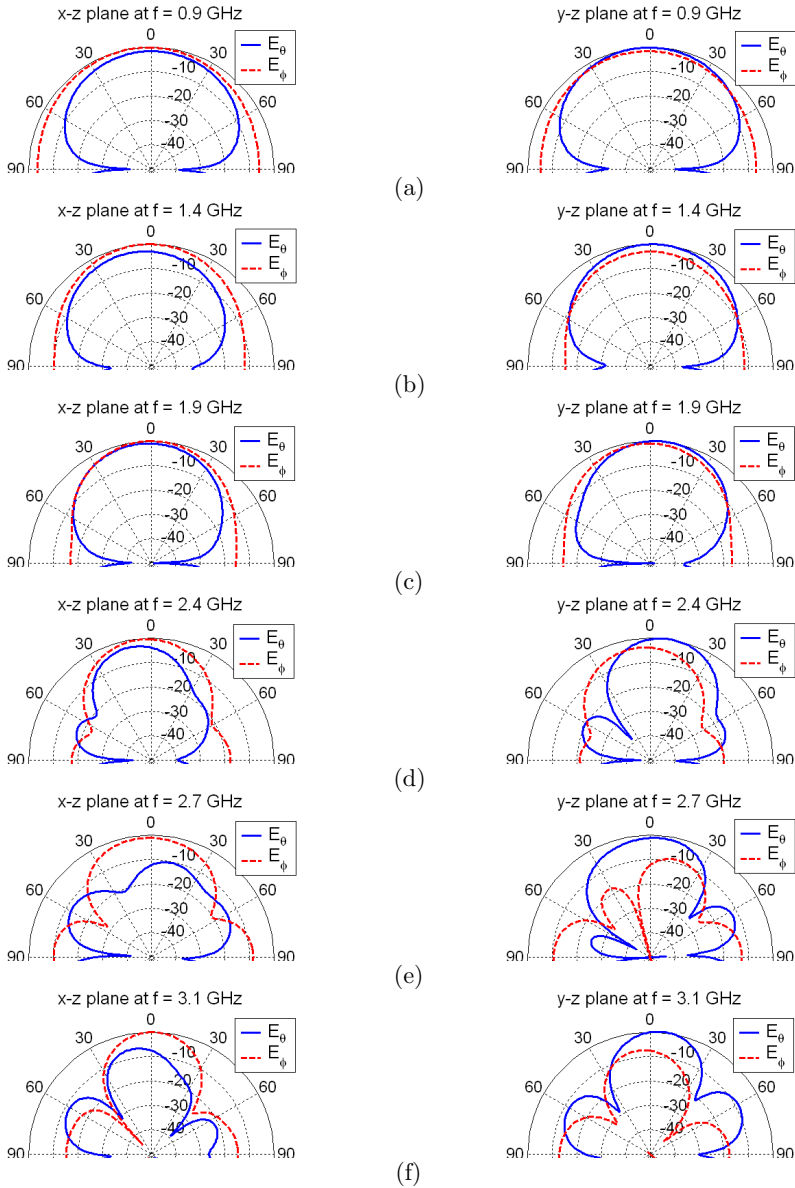


Figure 8. Computed radiation patterns in the H -plane (x - z) and the E -plane (y - z) at (a) 0.9, (b) 1.4, (c) 1.9, (d) 2.4, (e) 2.7, and (f) 3.1 GHz, for Array 1 when Ports 1, 3, 5 and 7 are excited.

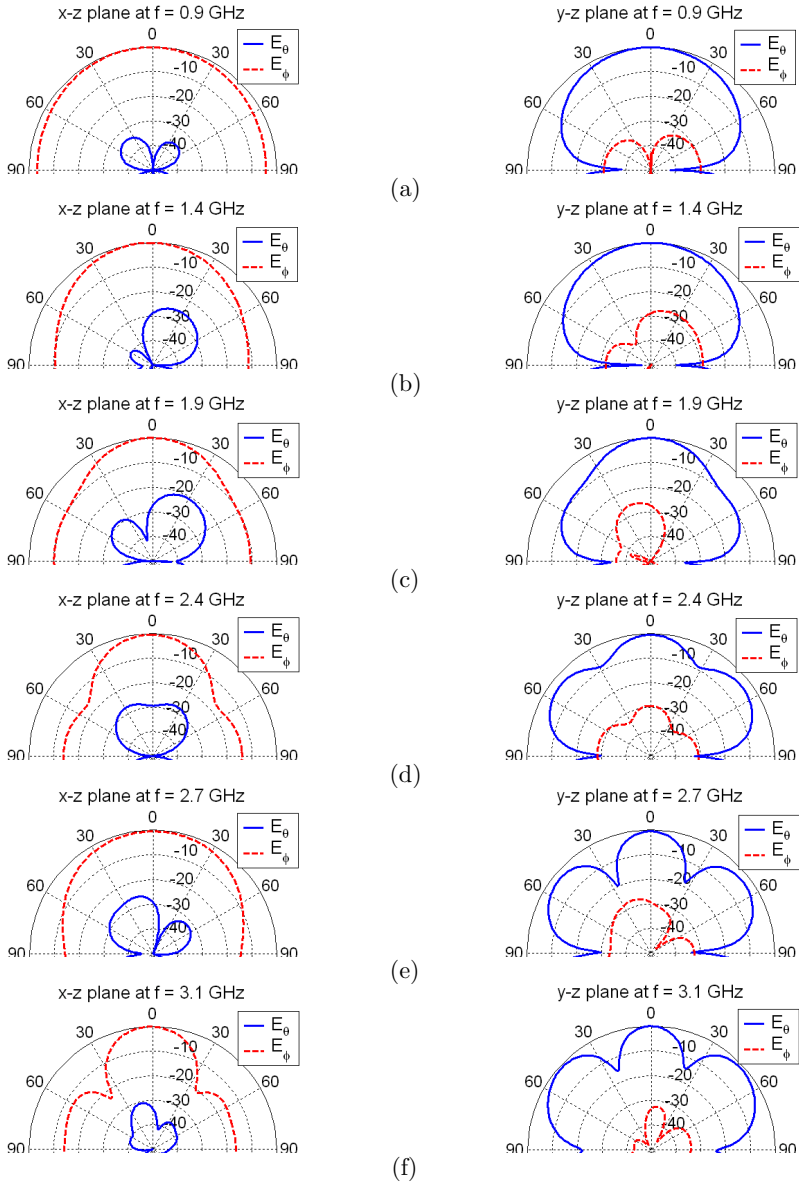


Figure 9. Computed radiation patterns in the H -plane (x - z) and the E -plane (y - z) at (a) 0.9, (b) 1.4, (c) 1.9, (d) 2.4, (e) 2.7, and (f) 3.1 GHz, for Array 2 when Ports 1, 3, 5 and 7 are excited, and Ports 5 and 7 have 180° phase shift.

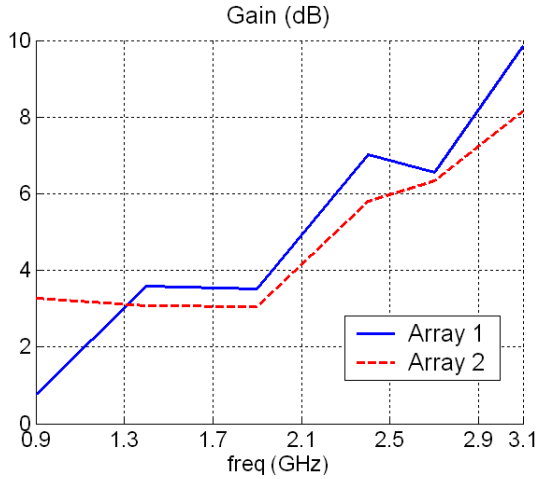


Figure 10. Gain in dB for Array 1 and Array 2 when Ports 1, 3, 5 and 7 are excited.

Ports 1, 3, 5, and 7 are in the bottom layer and Ports 2, 4, 6, and 8 are in the top one. In Array 2, the right elements are rotated by 180° around the y -axis, and the top elements are rotated by 180° around the x -axis. In order to compare these two array configurations, a 180° phase shift is added to Ports 5 and 7 in the bottom layer and to Ports 4 and 8 in the top layer. The vertical and horizontal distances between elements are equal to 75 mm.

The two arrays are simulated using Ansoft HFSS. The return losses at Ports 1, 2, 3, and 4 for Array 1 and Array 2 are presented in Fig. 6, where the two arrays have almost the same bandwidths of the single antenna element. The couplings between the ports in the bottom layer are shown in Fig. 7. Low coupling between elements is noticed in Arrays 1 and 2, where the coupling is -20 dB except in the small range between 2.5 and 2.8 GHz for Array 2.

The 2D radiation patterns for Array 1 and Array 2, in the E -(y - z) and H -(x - z) planes, are computed using Ansoft HFSS, with only Ports 1, 3, 5, and 7 excited, and are shown in Figs. 8 and 9, respectively, where Ports 5 and 7 have 180° phase shift in Array 2. The lower half of all patterns is cropped because they are almost symmetrical to the top half. As shown in Fig. 8, Array 1 is suitable for the applications that require narrow beamwidth and are not sensitive to the cross polarization level. On the other hand, as shown in Fig. 9, Array 2 is more appropriate for the applications that necessitate a low cross polarization level, which is less than -20 dB for this array. Figure

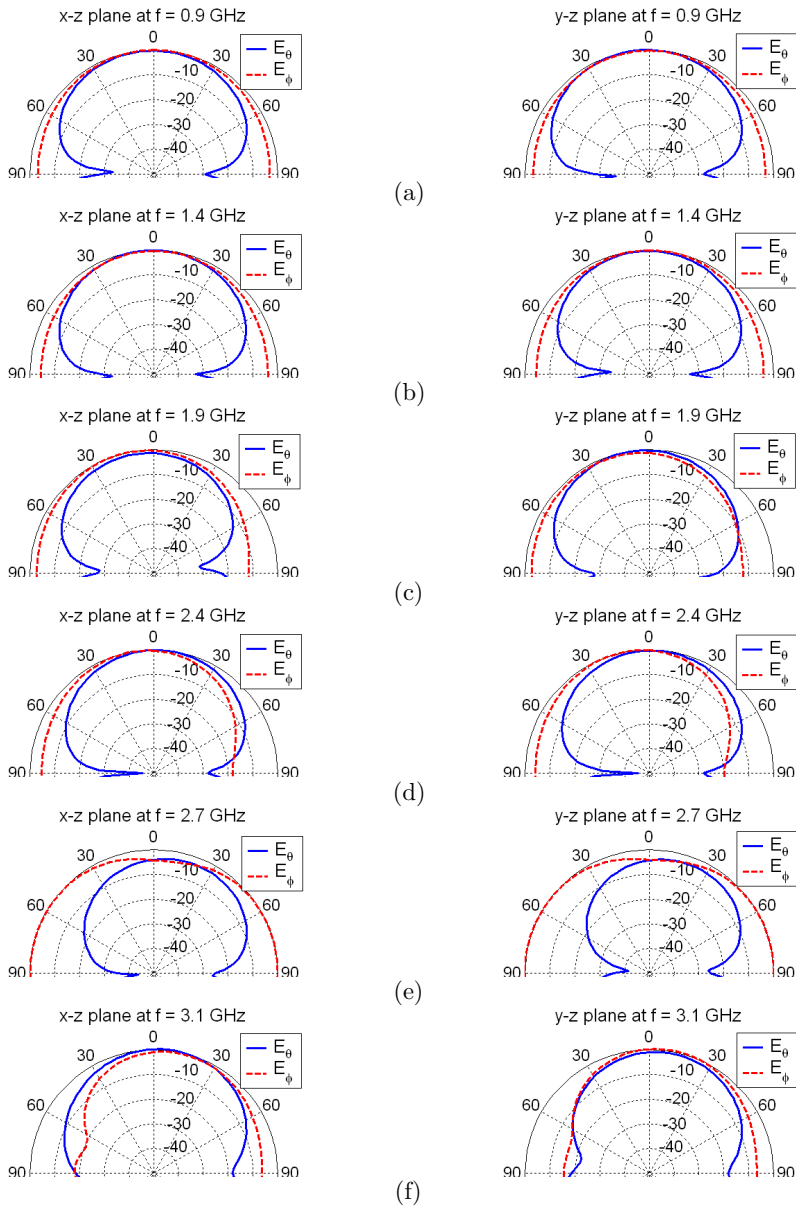


Figure 11. Computed radiation patterns in the $(x-z)$ and $(y-z)$ at (a) 0.9, (b) 1.4, (c) 1.9, (d) 2.4, (e) 2.7, and (f) 3.1 GHz, for the single antenna when Ports 1 and 2 are excited.

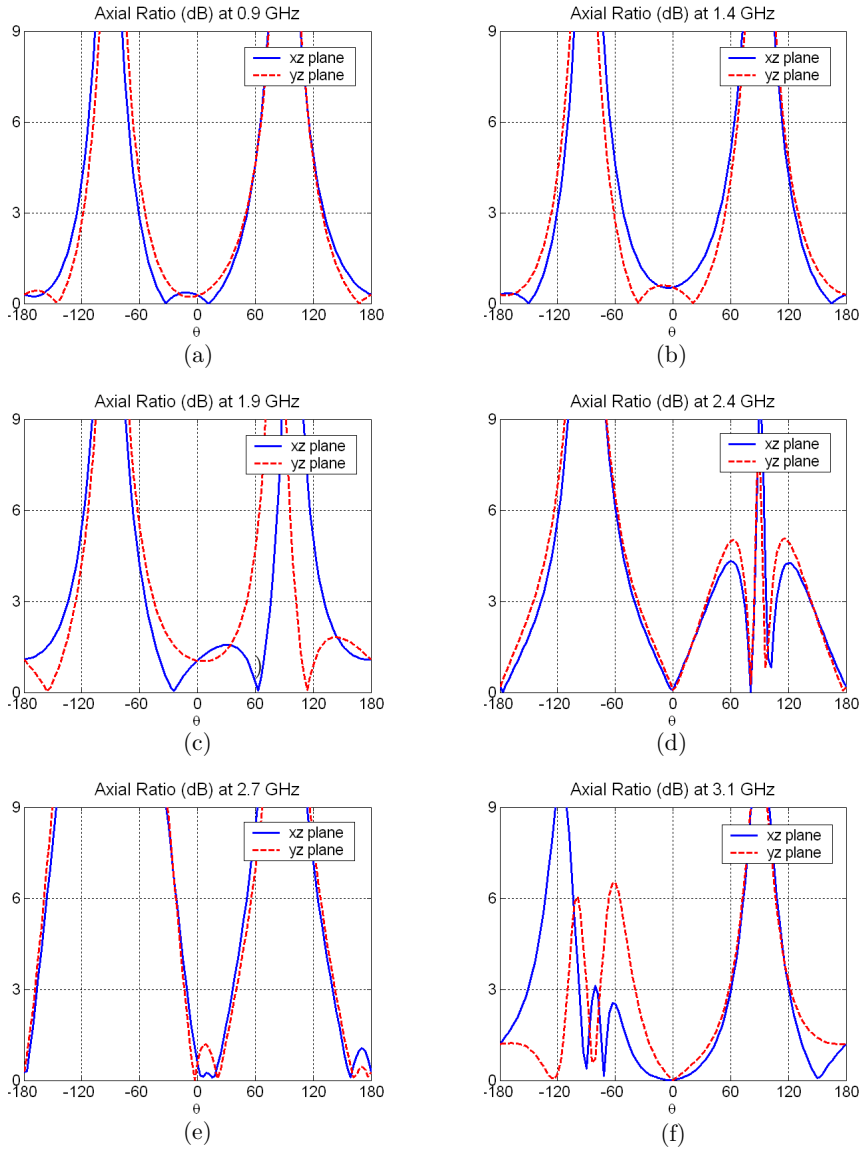


Figure 12. Computed axial ratio in the (x - z) and (y - z) at (a) 0.9, (b) 1.4, (c) 1.9, (d) 2.4, (e) 2.7, and (f) 3.1 GHz, for the antenna when Ports 1 and 2 are excited.

10 shows the gain of Array 1 and Array 2. Although Array 2 provides lower gain in the upper operating band, it improves the gain in the lower operating band.

5. CIRCULARLY POLARIZED ANTENNA CONFIGURATION

In many wireless communication applications, circularly polarized antennas have received increasing attention because of their insensitivity to the orientation between the transmitter and receiver. By exciting simultaneously the two orthogonal ports, Port 1 and Port 2, shown in Fig. 1, a circular polarized pattern can be obtained. To prove that, the radiation patterns and the axial ratios are calculated at 0.9, 1.4, 1.9, 2.4, 2.7, and 3.1 GHz, with both ports of the single element antennas are excited. Figure 11 shows the radiation patterns for the circularly polarized antenna. Equal co-and cross-polarized fields are obtained for wide angles at all frequencies. The axial ratio is shown in Fig. 12, where the antenna has an axial ratio less than 3 dB around the z -axis, which is the main direction of radiation. The beamwidth 3 dB axial ratio ranges from 25° to 140° .

6. CONCLUSION

A wideband dual-polarized dual band antenna is designed and presented for current personal wireless communication applications at 0.9, 1.8, 1.9, and 2.4 GHz. The antenna has a relatively small size and operates over two wide bands with bandwidths of 18% and 82% with a reasonable gain. Two array configurations are presented to show that this antenna can match the requirements of different wireless applications by changing its array arrangement and feeding ports phases. The presented antenna can also provide circular polarization patterns at the proposed frequency bands.

REFERENCES

1. Chen, H. M. and Y. F. Lin, "Printed monopole antenna for 2.4/5.2 GHz dual-band operation," *IEEE Antennas and Prop. Society International Symp.*, Vol. 3, 60–63, Columbus, OH, June 2003.
2. Li, R. L., G. Dejean, M. M. Tendtzeris, and J. Laskar, "Novel multi-band broadband planar wire antenna for wireless communication handheld terminals," *IEEE Antennas and Prop.*

- Society International Symp.*, Vol. 3, 44–47, Columbus, OH, June 2003,
3. Chang, F. S., W. K. Su, and K. L. Wong, “Folded meandered-patch monopole antenna for triple-band operation,” *IEEE Antennas and Prop. Society International Symp.*, Vol. 1, 278–281, Columbus, OH, June 2003.
 4. Nepa, P., A. A. Serra, S. Marsico, and G. Manara, “A dual-band antenna for wireless communication terminals,” *IEEE Antennas and Prop. Society International Symp.*, Vol. 4, 4284–4287, Monterey, CA, June 2004.
 5. Rennings, A., M. Rauf, P. Waldow, and I. Wolff, “A compact single/dual-band inverted-F type antenna structure,” *20th Annual Review of Progress in Applied Computational Electromagnetics ACES 2004*, Syracuse, NY, April 2004.
 6. Angelopoulos, E. S., A. I. Kostaridis, and D. I. Kaklamani, “A novel dual-band *D*-inverted antenna printed on a PCMCIA card,” *Microwave Opt. Tech. Lett.*, Vol. 42, No. 2, 153–156, July 2004.
 7. Eldek, A. A., A. Z. Elsherbeni, C. E. Smith, and K.-F. Lee, “Wideband rectangular slot antenna for personal wireless communication systems,” *IEEE Antennas and Propagat. Magazine*, Vol. 44, No. 5, 146–155, Oct. 2002.
 8. Allen, C. M., A. Z. Elsherbeni, C. E. Smith, C-W P. Huang, and K.-F. Lee, “Tapered meander slot antenna for dual band personal wireless communication systems,” *Microwave Opt. Tech. Lett.*, Vol. 36, No. 5, 381–385, March 2003.
 9. Martinez-Vazquez, M. and O. Litschke, “Design of a multi-standard antenna system for PCMCIA,” *IEEE Antennas and Prop. Society International Symp.*, Vol. 4, 4288–4291, Monterey, CA, June 2004.
 10. Lin, X.-C. and L.-T. Wang, “A broadband CPW-fed loop slot antenna with harmonic control,” *IEEE Trans. Antennas and Wireless Propagat. Lett.*, Vol. 2, 323–325, 2003.
 11. Chiou, J.-Y., J.-Y. Sze, and K.-L. Wong, “A broadband CPW-fed strip-loaded square slot antenna,” *IEEE Trans. Antennas and Propagat.* Vol. 51, No. 4, 719–721, April 2003.
 12. Chen, H.-D., “Broadband CPW-fed square slot antennas with a widened tuning stub,” *IEEE Trans. Antennas and Propagat.*, Vol. 51, No. 8, 1982–1986, Aug. 2003.
 13. Behdad, N. and K. Sarabandi, “A multiresonant single-element wideband slot antenna,” *IEEE Trans. Antennas and Wireless Propagat. Lett.*, Vol. 3, 5–8, 2004.

14. Sze, J.-Y. and K.-L. Wong, "Bandwidth enhancement of a microstrip-line-fed printed wide-slot antenna," *IEEE Trans. Antennas and Propagat.*, Vol. 49, No. 7, 1020–1024, July 2001.

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