A Wideband Matching Technique for Polarization Versatile Applications

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Abstract— A rectangular patch exhibiting polarization diversity throughout a notable bandwidth is designed for operation at the 2.4 GHz WiFi band. A wideband matching technique is implemented, introducing path inequality between specular feeding points, i.e., points giving rise to a specific polarization mode. There are two pairs of such specular feeding points and two sources, offering polarization diversity when excited appropriately. Exploiting these features, linear (horizontal, vertical or diagonal) as well as RH and LH circular polarization can be achieved, over a remarkable bandwidth around the 2.4 GHz frequency band.

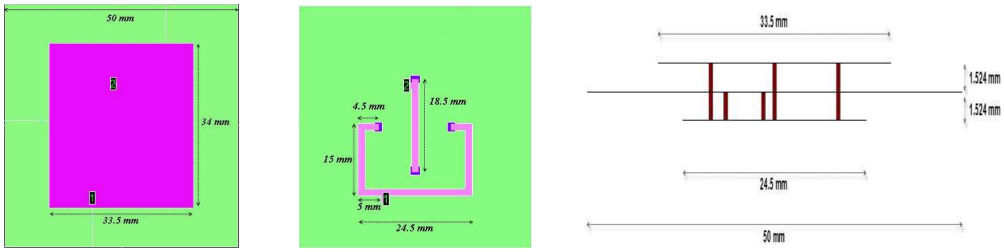
1. INTRODUCTION

As requirements for terminal equipment are getting more and more strict in terms of performance versus size, rectangular patch antennas are a fair solution due to their characteristics, such as ease of design and fabrication, low cost and compensatory behaviour despite their small size [1]. However, patch antennas suffer a substantial drawback, concerning their poor bandwidth performance. Many techniques have been proposed, aiming to overcome this disadvantage. Previous works includes parasitic patch loading [2], chip resistor loading [3], use of lower dielectric constant and thicker substrate [4], as well as other techniques. The technique used herein is a way of wideband matching in the sense described in [5], yet it is applied to a polarization versatile configuration. Also, the proposed configuration is designed for the 2.4 GHz band, commonly known as the WiFi band, which is allocated for Internet access and computer-to-computer communications, according to [6]. The major concept of wideband matching for a specific polarization mode is exciting the patch with a single source, by introducing a path inequality between two specular feeding points. Note that both point excite the same resonant mode (e.g., TM_{10}). This implementation splits the apparent draught at resonance frequency to two separate resonances, speaking in terms of Return Loss. Choosing an appropriate length of inequality, the overall behaviour of the Return Loss parameter follows the envelope of the resonant pair, thus enhancing the antenna bandwidth for the concerning polarization mode. This procedure is analytically described in [5]. Extending this procedure while aiming to acquire polarization diversity performance, a second pair of feeding points, biased by a second source, is introduced orthogonally to the previous pair. Again both point excite the same mode, which is orthogonal to the previous one (e.g., TM_{01}). Concerning the primary configuration, the same results are now expected, but for an orthogonal polarization. As one should guess, also circular polarization is now at hand by a simultaneous excitation of both TM_{10} and TM_{01} modes, while assigning appropriate phase to each source to get 90 degrees difference. A similar technique is described in [7], where it is stated that polarization diversity can be obtained by introducing a 90° phase difference between two adjacent linear resonances, exploiting shorting posts.

2. ANTENNA CONFIGURATION

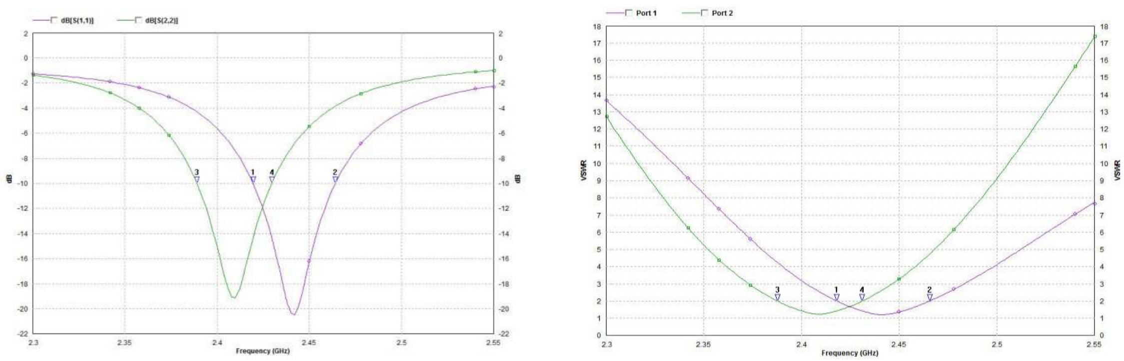
The simulated patch is 33.5 mm long and 34 mm wide, printed on a $50 \times 50 \times 1.524$ mm Rogers dielectric substrate with $\varepsilon_r = 3.4$ and $\tan\delta = 0.002$. The ground plane is printed on the back of the substrate, and a second identical substrate is attached. The feeding network is folded on the backside of the structure, consisting of transmission lines which are 1.5 mm wide. The patch is fed via circular holes in the substrates and the ground plane, which were designed as 1.975 mm rectangular holes for simulation convenience. Downwards, backside and broadside aspects of antenna configuration are depicted in Fig. 2, along with all corresponding dimensions.

Examining the proposed configuration, it becomes obvious that Source 1 excites two points for horizontal polarization, yet a path inequality is introduced between them. The same holds for Source 2, which excites two points placed along the vertical axis. This configuration, as was our primary goal, enables wideband matching for horizontal, vertical and diagonal polarization, as well as polarization diversity including circular polarization, RHCP or LHCP, depending on the relative phase assigned to the sources.



(a) (b) (c)

Figure 1: (a) Downwards, (b) backside and (c) broadside aspects of the proposed configuration.



(a) (b)

Figure 2: (a) Return Loss and (b) VSWR parameters, for horizontal (purple) and vertical (green) polarization. circular polarization modes can be excited. In Table 1 the bandwidth-defining frequency points are summarized.

3. SIMULATION RESULTS

The antenna was simulated using the Zeland IE3D® suite. This first section includes simulation results of parameters that are common to all polarization modes.

3.1. Return Loss and VSWR

It is common to measure Return Loss parameter bandwidth between the frequency points where the $-10\,\text{dB}$ requirement is met. Furthermore, we need $1 \leq \text{VSWR} \leq 2$, in order to obtain good radiation characteristics. Examining Fig. 2 and the corresponding frequency markers, we can assume that the useful bandwidth region is confined from the Return Loss parameter $-10\,\text{dB}$ points, as the corresponding points for VSWR allow a greater bandwidth. It is also noted, that in the region where both the S_{11} and S_{22} curves are below $-10\,\text{dB}$, diagonal and along with rational BW for each polarization mode, and the values that shall be assigned to each source, in order to get the desirable polarization mode.

Table 1: Source voltage, centre frequency and rational bandwidth for each polarization mode.

	Source 1 Mag^{Deg}	Source 2 Mag^{Deg}	f_- [GHz]	f_+ [GHz]	f_{center} [GHz]	BW %
Horizontal	1^0	0	2.41951	2.46402	2.44176	1.82
Vertical	0	1^0	2.38904	2.42958	2.40931	1.68
Diagonal	1^0	1^{90}	2.41951	2.42958	2.42454	0.41
RHCP	1^0	1^0	2.41951	2.42958	2.42454	0.41
LHCP	1^0	1^{180}	2.41951	2.42958	2.42454	0.41

3.2. Horizontal Polarization

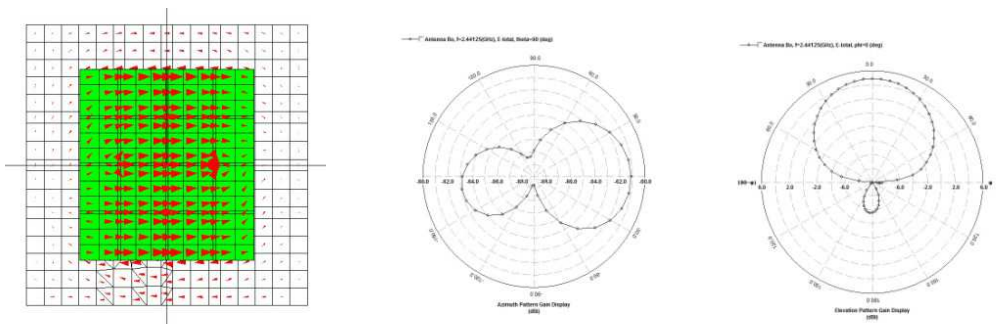
We can obtain horizontal polarization by assigning appropriate values to the voltage sources. According to our simulation results, a fractional bandwidth of 1.82% can be obtained, around the frequency of 2.44176 GHz. Furthermore, the antenna input impedance when operating at this frequency has a magnitude that ripples from 33.1 to 64.7 Ohm, while impedance angle varies from 29.3° to −31.9°. Also, antenna efficiency is above 55% throughout the whole bandwidth, and radiation efficiency varies from 67.8% to 69.4%. Antenna current distribution and power gain patterns are depicted in Fig. 3.

3.3. Vertical Polarization

A fractional bandwidth of 1.68% is obtained for vertical polarization. Input impedance magnitude varies from 89.7 to 27 Ohm, and impedance angle takes values between 14.6° to −14.4°. Antenna efficiency is above 56% and radiation efficiency is almost stable and equal to 67%.

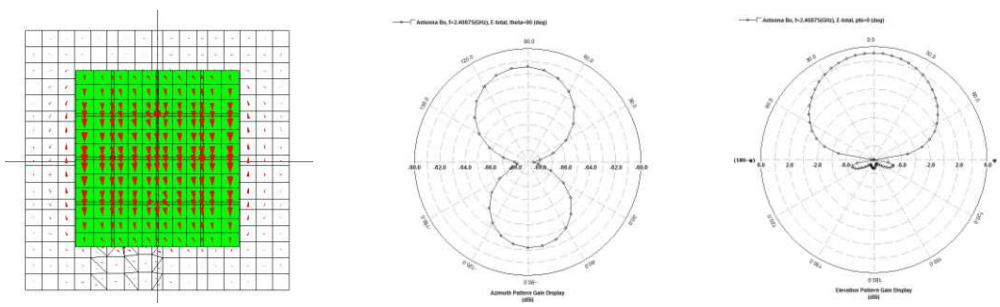
3.4. Diagonal Polarization

The proposed configuration can also offer diagonal polarization, yet throughout a lesser bandwidth (0.41%). For this case, the antenna efficiency reaches a maximum of 61.9%, and radiation efficiency is 60% with small variations. Input impedance takes intermediate values compared to the horizontal and vertical polarization modes. Current distribution as well as power gain patterns are depicted



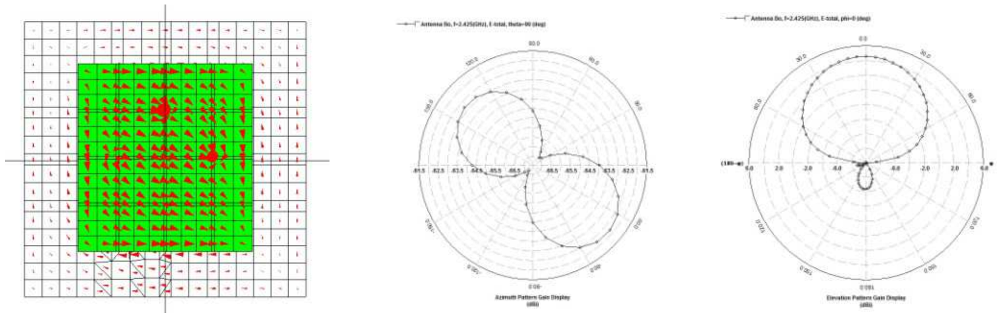
(a) (b) (c)

Figure 3: (a) Current distribution, (b) azimuth power gain pattern and (c) elevation power gain pattern for horizontal polarization.



(a) (b) (c)

Figure 4: (a) Current distribution, (b) azimuth and (c) elevation power gain patterns for vertical polarization.



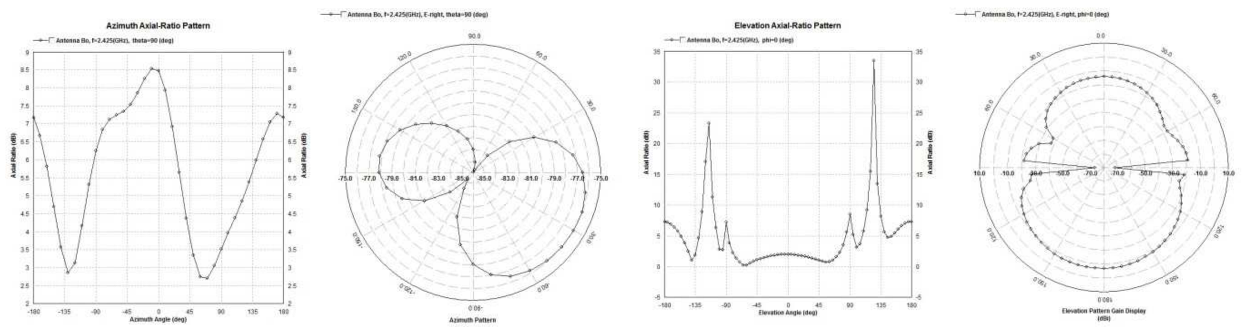
(a) (b) (c)

Figure 5: (a) Current distribution, (b) azimuth and (c) elevation power gain patterns for diagonal polarization.

in Fig. 5.

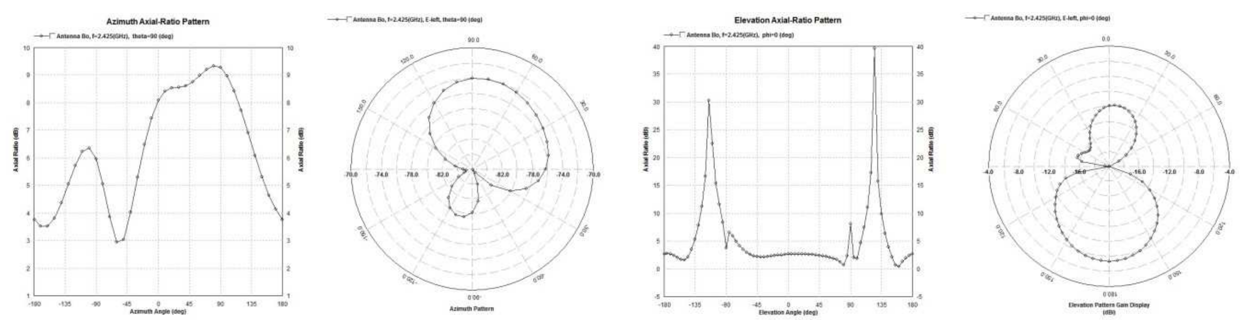
3.5. Right-hand Circular Polarization

RHCP mode (as well as LHCP and diagonal polarization modes) presents a fractional bandwidth of 0.41%, as it can be excited only between the frequency points where both S_{11} and S_{22} are below -10 dB. Antenna efficiency reaches a maximum of 63.2% and radiation efficiency a maximum of 68.5%. In Fig. 6, azimuth and elevation axial ratio graphs and azimuth and elevation power gain patterns are presented.



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

Figure 6: (a) Azimuth axial ratio, (b) azimuth power gain pattern, (c) elevation axial ratio and (d) elevation power gain pattern for RHCP.



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

Figure 7: (a) Azimuth axial ratio, (b) azimuth power gain pattern, (c) elevation axial ratio and (d) elevation power gain pattern for LHCP.

As the azimuth power gain pattern exhibits a maximum of -76 dB, the corresponding axial ratio pattern is of little concern. On the contrary, the elevation pattern is quite uniform and the elevation axial ratio behaves well throughout the 3 dB bandwidth reaching a maximum of 7.5 dB, still remaining below 3 dB for most elevation angles of interest.

3.6. Left-hand Circular Polarization

The antenna efficiency reaches 59.7% for this case, and the radiation efficicy a maximum of 66.4%. Again, azimuth power gain pattern is negligible, and the elevation pattern is not as uniform as in the previous case. Yet still, the elevation axial ratio behaves compensatory for angles of interest, i.e., especially between $-45°$ and $45°$.

4. CONCLUSIONS

A novel patch antenna was designed and simulated. The novelty lies on the capability of polarization diversity over augmented bandwidth, reaching values of 1.82% for horizontal polarization. Bandwidth augmentation (i.e., for horizontal and vertical polarization mode) is achieved, as the pair of points exciting a specific mode are fed through a network which introduces a path inequality of 90° between them. Polarization diversity is achieved by using two voltage sources, each of them feeding a pair of specular points on the patch. Assigning the appropriate values to each source, horizontal, vertical, diagonal, RHC or LHC polarization modes can be generated. Futhermore, all modes are well-matched and efficient throughout their corresponding bandwidth.

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REFERENCES

1. Xiong, J., Z. Ying, and S. He, "A broadband low profile patch antenna of compact size with three resonances," *IEEE Trans. Antennas Propag.*, Vol. 57, No. 6, 1838–1843, Jun. 2009.
2. Kumar, G. and K. C. Gupta, "Directly coupled multiple resonator wideband microstrip antenna," *IEEE Trans. Antennas Propag.*, Vol. 33, 588–593, Jun. 1985.
3. Wong, K. L. and Y. F. Lin, "Small broadband rectangular microstrip antenna with chip-resistor loading," *Electron. Lett.*, Vol. 39, 1593–1594, 1997.
4. Garg, R., P. Bhartia, I. Bahl, and A. Ittipiboon, *Microstrip Antenna Design Handbook*, 534–538, Artech House, Boston, MA, 2001.
5. Koutinos, A. G., G. A. Ioannopoulos, M. T. Chryssomallis, and G. A. Kyriacou, "A dual-feed rectangular patch antenna for bandwidth enhancement," *2014 Loughborough Antennas and Propagation Conference*, Loughborough, UK, Nov. 2014.
6. IEEE Std 802.11™-2012 (Revision of IEEE Std 802.11-2007), 2012.
7. Schaubert, A. D. H., F. G. Farrar, A. Sindoris, and S. T. Hayes, "Microstrip antennas with frequency agility and polarization diversity," *IEEE Transactions on Antennas and Propagation*, Vol. 29, No. 1, Jan. 1981.