Design of A Circularly Polarized E-shaped Patch Antenna with Enhanced Bandwidth for 2.4 GHz WLAN Applications

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Abstract

This paper presents the design of a wideband circularly polarized E-shaped patch antenna for 2.4-GHz wireless local area networks (WLAN) applications. The proposed antenna is a modified form of the conventional circularly polarized E-shaped patch antenna. By incorporating additional slots into the antenna patch, the impedance bandwidth and return loss of the circularly polarized antenna are improved by about 6.5% and 12 dB, respectively. Measurements of the fabricated antennas show good agreement with simulated results.

Manuscript communication: received 30 April 2014, revised 04 May 2015, accepted 25 June 2015
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Keywords: Axial Ratio, Circular Polarization, E-shaped Patch, WLAN.

1. Introduction

Circularly-polarized antennas have been employed in many modern wireless communication systems such as navigation, satellite communication systems, radio frequency identification (RFID), WLAN and WiMAX. One of the attractive advantages of the circularly polarized antennas is that they can reduce transmission loss caused by the misalignment between antennas of transmitter and receiver. In addition, circular polarization provides better ability to combat multi-path fading problem and thus enhances overall system performance.

In [1], the authors have presented a circularly polarized E-shaped patch antenna with unequal slots that offers wideband axial ratio bandwidth compared to the U-slot patch antennas. The design introduced in [1] has provided a simple approach to achieve circularly polarized radiating fields from a single-feed microstrip antenna without the necessity of it being square or comer-trimmed. In [2], the size and position of the slots of the E-shaped patch antenna have been tuned to improve the impedance bandwidth and return loss. The results from [2] have shown that the –10 dB impedance bandwidth of about 21.6% was obtained (2.28-2.81 GHz), with a lowest value of S_{11} of –17.5 dB in the 2.4-2.5 GHz band. The axial-ratio of this antenna was kept below 3 dB in the 2.4 GHz WLAN band.

In this paper, we present the design of a modified E-shaped patch antenna that offers wider impedance bandwidth and better return loss compared to the conventional one. By properly incorporating additional slots to the E-shaped patch, the impedance bandwidth and return loss S_{11} of the proposed antenna are improved by about 6.5% and 12 dB, respectively. The axial ratio remains below 3 dB in the 2.4 GHz WLAN band. Measurements of the fabricated antennas show good agreement with simulated results.

2. Features of the E-shaped Patch Antennas

Fig. 1 presents the geometry of the conventional E-shaped patch antenna [1] and the modified one. As shown in Fig. 1b, compared to the conventional E-shaped patch antenna, the proposed antenna has 3 additional slots incorporated into the patch. Two slots having length of d_1 and width of d_2 are made on the top and bottom arms of the E-shaped patch and another slot having length of d_3 and width of d_4 is added to the center of the patch. The dimension and position of the slots are key parameters in controlling the antenna bandwidth. They should be appropriately chosen to obtain the achievable bandwidth.

The principle of the bandwidth improvement can be explained using equivalent circuits of the patch. Fig. 2 illustrates the fundamental idea of the wideband mechanism of the E-shaped patch antenna. The upper and lower parts of the patch can be modeled as the L_1C_1 and L_2C_2 resonant circuits, respectively [3]. When the additional slots are incorporated into the lower and upper arms of the E-shaped patch, the values of L and C in the resonant circuits are changed. By tuning the length d_1, width d_2 and position P_1 of the slots, the resonant feature of the L_1C_1 and L_2C_2 resonant circuits can be altered to extend the impedance bandwidth of the antenna.

3. E-shaped Patch Antenna Design for 2.4 GHz WLAN Applications

The initial parameters of the rectangular microstrip patch antenna defined in [4] are used in the first step of the design process.

The width W of the rectangular patch is:

$$W = \frac{c}{2f_r\sqrt{\varepsilon_r + 1}} \tag{1}$$

where f_r is the resonant frequency of the antenna.

The actual length L of the patch:

$$L = \frac{c}{f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{2}$$

Extended length of the patch ΔL (according to the Hammerstad formula):

$$\Delta L = 0.412 \times h\,\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{3}$$

Effective permittivity of the patch ε_{reff}:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \tag{4}$$

Coaxial-probe feeding is located at the distance F from the edge of the patch:

$$F = y_0 = \frac{49.5}{\pi}\cos^{-1}\sqrt{\frac{50}{197.1}} = 16.4 \quad (mm) \tag{5}$$

In the second step, we follow the design procedure described in [1] to simulate and optimize the E-shaped patch antenna with two unequal slots for 2.4 GHz frequency band. As the last stage, three parallel slots are incorporated into the E-shaped patch to improve resonant feature of the patch antenna: two identical slots are added to the upper and lower arms of the E-shaped patch; and one small slot is cut at the middle of the patch. The target of this step is (a) to extend the impedance bandwidth of the antenna and simultaneously maintain the axial-ratio level below 3 dB over the desired frequency band, and (b) to align the axial-ratio and impedance bandwidths together. Dimensions and positions of the additional slots are tuned to meet the design goal. It can be seen from Fig. 3 and Fig. 4 that the dimensions of the two slots in the upper and lower arms of the patch keep an important role in widening impedance bandwidth of the antenna. They are symmetrically placed about the *y*-axis to maintain the orthogonality of currents on the patch. Besides, the third slot cut at the center of the patch can be used to control the level of return loss S_{11}, as presented in Fig. 5 and Fig. 6.

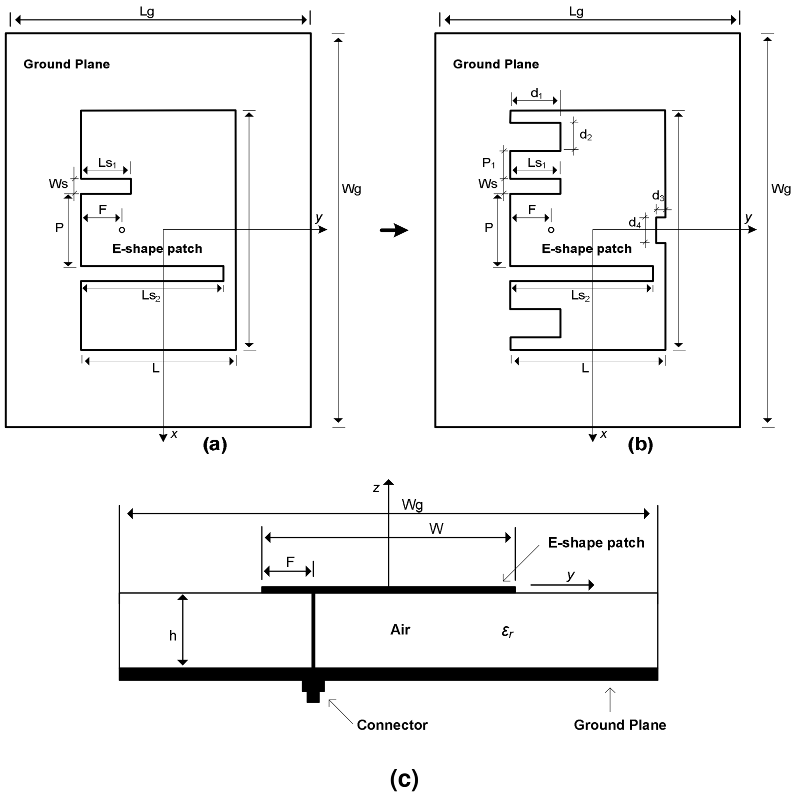


Fig. 1. Geometry and dimensions of the E-shaped patch antenna: (a) the conventional form, (b) the proposed antenna, and (c) side view of the antenna.

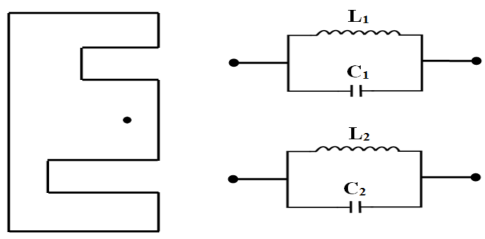


Fig. 2. Resonance mechanism of the E-shaped patch antenna.

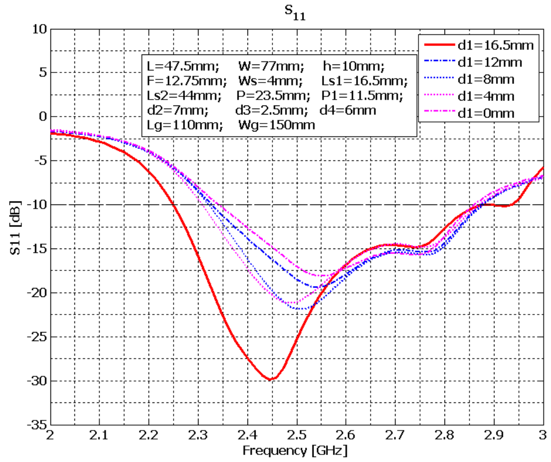


Fig. 3. Simulated results of return loss S_{11} at different values of d_1 while other parameters are fixed.

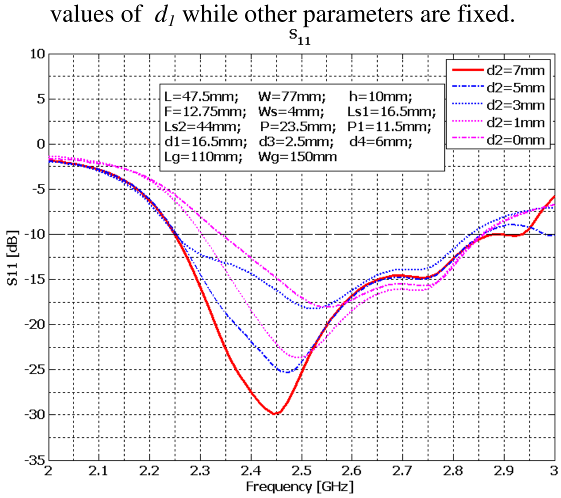


Fig. 4. Simulated results of return loss S_{11} at different values of d_2 while other parameters are fixed.

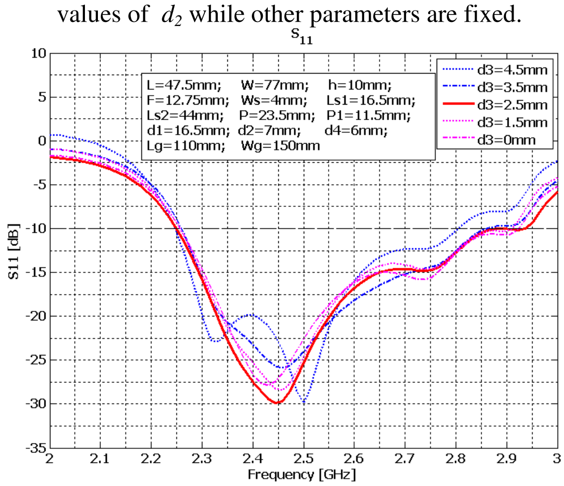


Fig. 5. Simulated return loss S_{11} at different values of d_3 while other parameters are fixed.

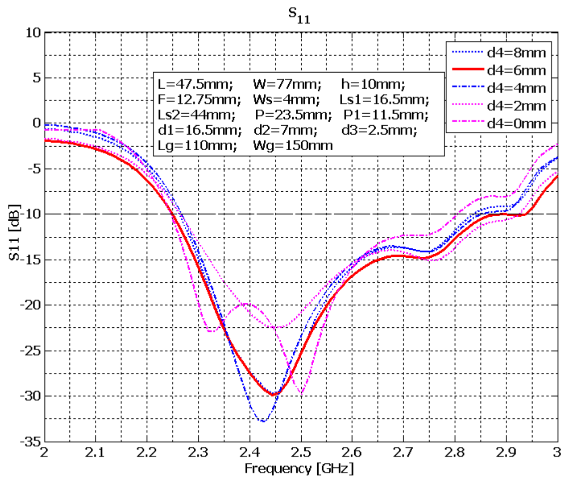


Fig. 6. Simulated return loss S_{11} at different values of d_4 while other parameters are fixed.

The optimized dimensions of the proposed antenna are determined through parametric analysis, and are listed in Table I. Antenna simulations are performed using the ANSYS High Frequency Structure Simulator (HFSS) [5].

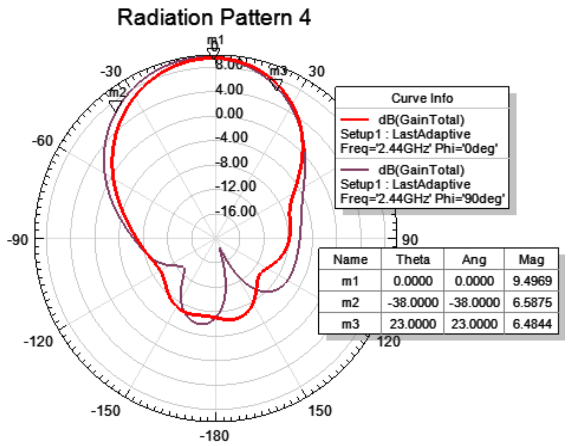
TABLE I
THE DIMENSIONS OF THE PROPOSED CIRCULARLY POLARIZED E-SHAPED PATCH (IN MM).

L	W	h	F	W_s	L_{s1}	L_{s2}
47.5	77	10	12.75	4	16.5	44

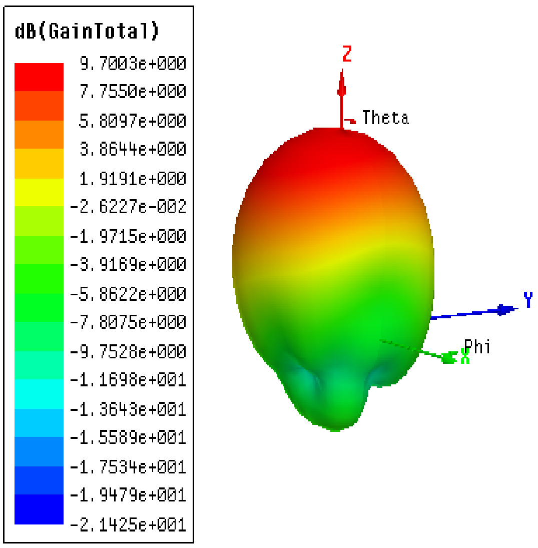
P	P_1	d_1	d_2	d_3	d_4	L_g	W_g
23.5	11.5	16.5	7	2.5	6	110	150

The calculated far-field 2-D and 3-D radiation patterns of the antenna at 2.44 GHz are plotted in Fig. 7. It can be seen that the half-power beam width of the designed antenna is about 60 degrees. The calculated peak gain of the antenna is 9.7 dBi at the center of the 2.4 GHz WLAN band.

The simulated return loss S_{11} results are depicted in Fig. 8, where the return loss of proposed antenna is improved by about 12 dB compared to that of the conventional E-shaped patch antenna in [2]. It can also be seen from Fig. 9 that the calculated axial-ratio of the designed antenna remains below 3 dB in the 2.4 GHz WLAN band. It is worth noting that the return loss of the conventional antenna can be improved further. However, this improvement will lead to the reduction of the 3-dB axial ratio bandwidth of the antenna. Comparisons of the left-hand circular polarization (LHCP) and right-hand circular polarization (RHCP) patterns in the *xz* plane at 2.44 GHz are shown in Fig. 10. The current distribution on the E-shaped patch of the proposed antenna is presented in Fig. 11.



(a)



(b)

Fig. 7. Simulated (a) 2-D and (b) 3-D radiation patterns of the proposed antenna at 2.44 GHz.

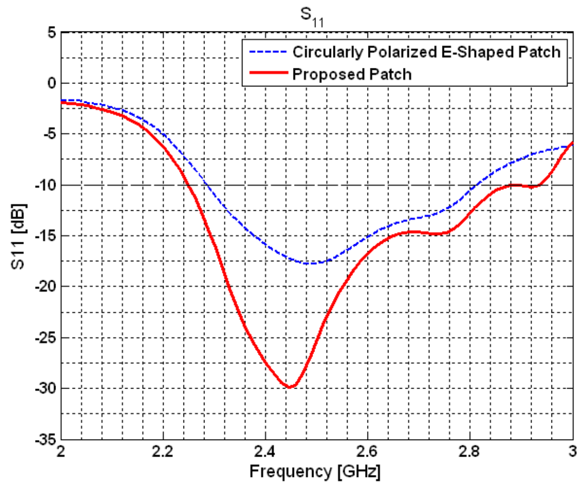


Fig. 8. Comparison of return loss S_{11} between the conventional E-shaped patch antenna (dash line) and the proposed antenna (solid line).

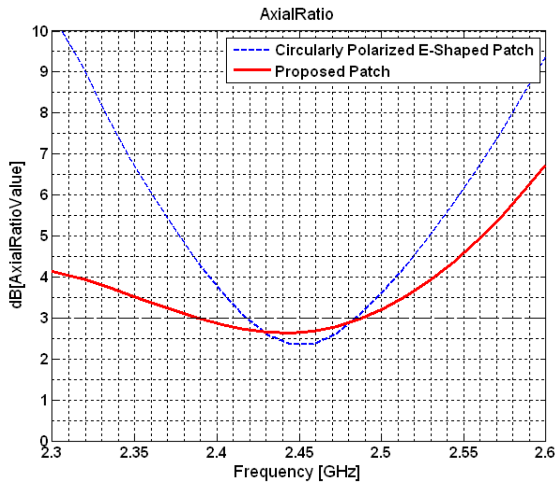


Fig. 9. Comparison of axial ratio between the conventional E-shaped patch antenna (dash line) and the proposed antenna (solid line).

4. Experimental Results

A prototype of the proposed antenna was fabricated and measured. The front view of the antenna prototype is shown in Fig. 12.

Fig. 13 shows the measured return loss S_{11} of the proposed antenna (dash lines) compared to the simulated ones (solid lines). As shown in

Fig. 13, throughout the WLAN frequency band (2.42-2.484 GHz), the values of S_{11} are better than – 22.5 dB. The lowest value of S_{11} of about –31 dB was obtained at 2.42 GHz. The measured results agree well with the simulated ones. Measurements were performed using the Anritsu Antenna Analyzer S331D.

In order to verify the antenna performance in practical applications, the designed antenna was connected to the antenna connector of a commercial 2.4-GHz WLAN access point (D-Link DIR-600) serving as a transmitter, and a laptop computer was employed as a receiver. The NetStumbler software [6] installed on the computer was used to measure the WLAN signal strength transmitted from the access point. The measurements were carried out under non-line-of-sight condition. It can be seen from Fig. 14 that the proposed antenna greatly improves WLAN signal reception compared to that of the 2-dBi omnidirectional one. Performance comparisons between the two E-shaped patch antennas are summarized in Table II.

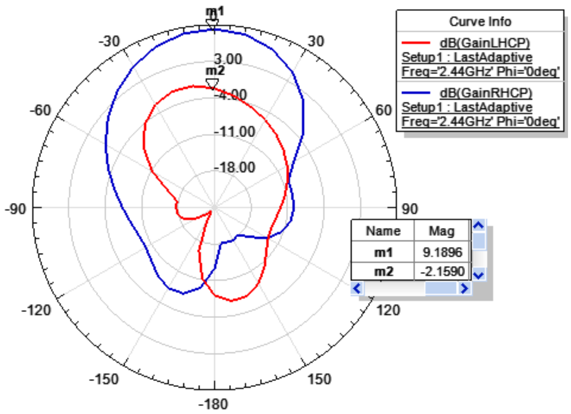


Fig. 10. The radiation patterns of left-hand circular polarization (red) and right-hand circular polarization (blue) in the *xz* plane.

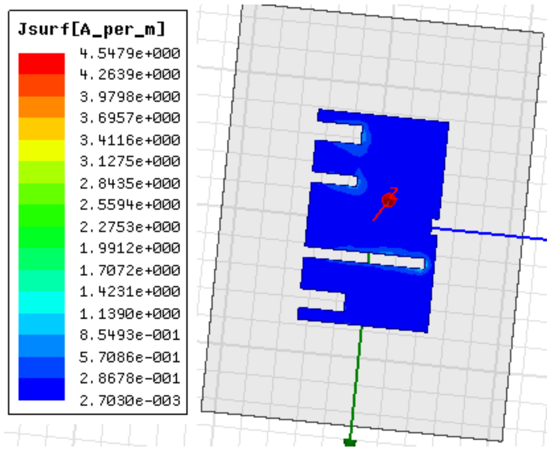


Fig. 11. Current distribution on the patch of the proposed antenna.

Fig. 12. Front view of the prototype of the proposed E-shaped patch antenna.

Table II
Antenna Performance Comparison

Parameters	Conventional E-shaped patch antenna [2]	The proposed antenna
Impedance bandwidth	21.62% (2.28 ÷ 2.81 GHz)	28.15% (2.24 ÷ 2.93 GHz)
Lowest value of S_{11}	–17.5 dB	–30 dB
Axial-ratio bandwidth	2.72% (2.41 ÷ 2.48 GHz)	4.1% (2.38 ÷ 2.48 GHz)
Peak gain	9.7dBi	9.7dBi

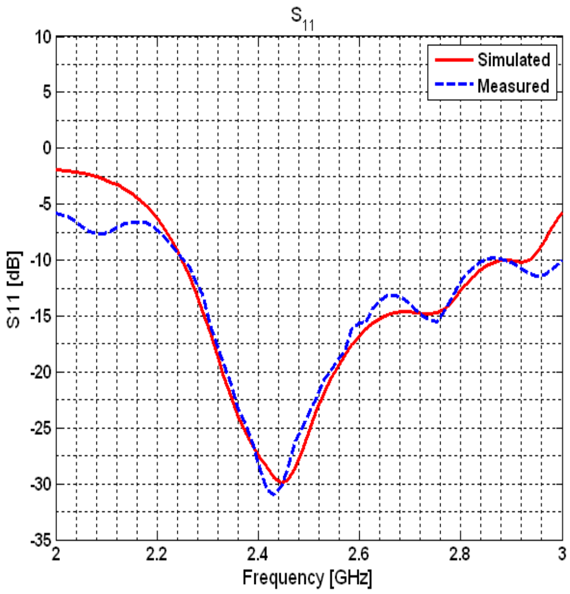


Fig. 13. Measured and simulated return loss S_{11} of the proposed antenna.

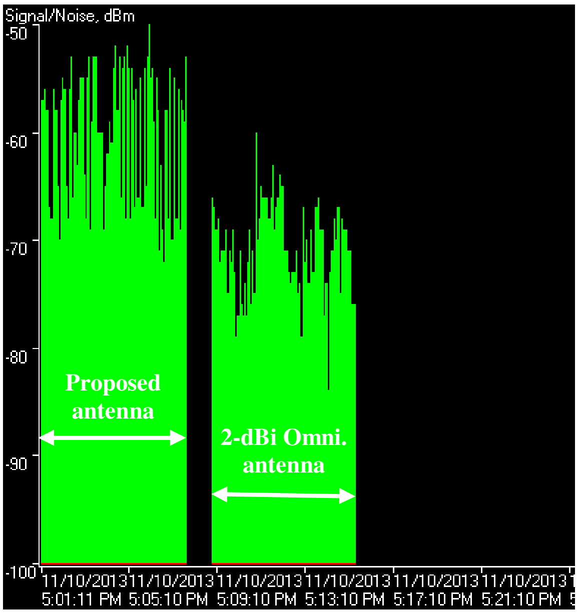


Fig. 14. Compared antenna gains under non-line-of-sight condition.

5. Conclusion

The circularly polarized E-shaped patch antenna with improved bandwidth is presented in this paper. The proposed E-shaped patch has been designed, fabricated, and measured for the 2.4-GHz WLAN band. Compared to the conventional E-shaped patch antenna, the –10 dB impedance bandwidth and return loss of the proposed antenna are improved by about 6.5% and 12 dB, respectively. The axial ratio of the antenna remains below 3 dB in the 2.4 GHz frequency band. The proposed antenna is expected to be suitable for 2.4-GHz WLAN applications and other wireless communication systems operating in the 2.3-2.7 GHz frequency range.

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