Progress In Electromagnetics Research Letters, Vol. 51, 73–78, 2015

Very Compact Open-Slot Antenna for Wireless Communication Systems

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Abstract—A new very compact open slot antenna for wireless communication systems application has been designed and fabricated. With antenna overall dimension of $9.2 \times 9.8\,\text{mm}^2$, the proposed design can be used in many modern communication devices with size constraints. Experimental measurements have also been performed to validate the performance of the proposed antenna. The measured results show that the antenna provides a wide bandwidth of 48% (5–8.17 GHz) with an average size reduction of about 88% with respect to a conventional microstrip patch antenna.

1. INTRODUCTION

In recent years, interest in compact, low cost, low profile antennas has increased as the demands for high mobility and higher bandwidths wireless communication devices increased. Currently, several wireless local area network (WLAN) communication systems are used which provide different operating frequencies and data rates for different applications, such as sensor networks and smart buildings. Such wireless systems require antennas that are wideband while also being compact enough to be fabricated in portable devices.

WLAN protocol IEEE 802.11a which is usually found on business networks with frequency ranges of 5.15–5.35 and 5.725–5.825 GHz in the US and 5.15–5.35 and 5.470–5.725 GHz in Europe are used for a wireless local area network that offer data rate up to 54 Mb/s. Different designs of WLAN IEEE 802.11a antenna have been reported. In [1], Anthony et al. proposed a microstrip antenna by using passive parasitically coupled sub patches. A dual band microstrip antenna has been reported in [2] by combining two single slotted patch antennas with rectangular ground slot. Ali et al. in [3] proposed a dual-band/wideband packaged antenna by using the proximity parasitic coupling between a folded radiator and an extended printed circuit board ground plane. A U-slot antenna with wideband performance is used in [4]. In [5], a grid array antenna loaded with two parasitic patches was designed to cover the desirable band. A wide-band asymmetric coplanar strip fed monopole antenna for WLAN applications is presented in [6]. Several dual band antennas for WLAN applications are reported [7–10]. In [11], a desktop shaped and triangular base desktop shaped broadband patch antennas are designed for wireless communication applications. However, the large physical size and the complex geometry are considered the main drawbacks of all these designs. For these reasons, the motivation of this research is to design a simple, very compact, low profile and low cost antenna and extend the impedance bandwidth of it for application in wireless communication systems.

In this letter, the design of a simple, low cost and very compact antenna for wireless communication systems that cover the bandwidth requirement of WLAN IEEE 802.11a band application is realized. The simple structure is achieved by using a cut shape patch and inserting an open slot in the ground plane. The introduced slot in the ground plane creates a slow wave effect which will slow down the propagation phase velocity and shifts down the resonant frequency to a lower value. The antenna configuration

Received 21 December 2014, Accepted 19 January 2015, Scheduled 22 January 2015
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proposed in this paper can increase the equivalent capacitance and inductance on antenna's resonant route. According to Equation (1), the propagation phase velocity can be decreased significantly by increasing the values of the inductance and the capacitance

$$v_p = 1/\sqrt{LC}, \tag{1}$$

where v_p is the phase velocity, L and C are the equivalent inductance and capacitance, respectively.

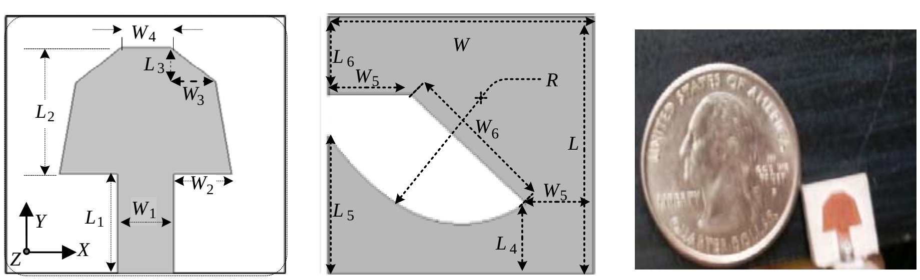
It is clear from Equation (2) that at the same resonant frequency (f), the resonant wavelength (λ) and antenna length can be reduced by decreasing the propagation phase velocity.

$$v_p = f \cdot \lambda \tag{2}$$

The proposed antenna shows a simulated impedance BW of 52.16% (4.79–8.17 GHz), a numerical gain of larger than 2.65 dBi and consistent radiation patterns across the whole band. In addition, the proposed antenna has a size of only 9.2 mm × 9.8 mm × 1.52 mm. The 3D electromagnetic simulation software, Computer Simulation Technology (CST) is used to verify the proposed configuration and it was followed by experimental verifications. The measured and simulated patterns with good agreements are given.

2. ANTENNA CONFIGURATION

The geometry of the proposed antenna is shown in Figure 1. The antenna is printed on a Rogers RT5880LZ substrate with relative permittivity equal to 1.96, thickness 1.52 mm and loss tangent of 0.0019. The overall size of the substrate is 9.2 mm × 9.8 mm. The detailed dimensions of the proposed antenna are listed in Table 1. The structure consists of the patch which is fed by using a transmission line and the ground plane with an open slot.



(a) (b) (c)

Figure 1. Proposed antenna configuration, (a) front view, (b) back view, (c) photograph of the fabricated antenna.

Table 1. Geometry details in millimeters of the proposed design.

L	W	L_1	L_2	L_3	L_4	L_5	L_6
9.2	9.8	3.5	4.5	1.2	2.52	4.93	2.78
W_1	W_2	W_3	W_4	W_5	W_6	W_7	R
1.96	2	1.56	1.75	3	5.77	2.51	5

3. SIMULATIONS AND MEASUREMENTS

As an initial design step, a conventional microstrip antenna with a patch size of 4.55 mm × 6.05 mm is used as a reference antenna (Antenna (1)). In the second design step, an open slot in the ground plane is inserted (Antenna (2)). Finally, the proposed antenna (Antenna (3)) is obtained by cutting the top corners of the patch in Antenna (2) design. The evolution process of the proposed antenna with the simulated negative return loss in dB of each configuration is shown in Figure 2. All the configurations are of the same overall size of 9.2 mm × 9.8 mm × 1.52 mm and are using the same substrate material RT5880LZ for the design process. For the fundamental mode rectangular patch, the resonant frequency is given by [12]

$$f = \frac{c}{2(L+h)\sqrt{\varepsilon_e}} \tag{3}$$

where

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{w}\right)^{-1/2} \tag{4}$$

f is the resonant frequency, c is the speed of light, L is the patch length, W is the patch width, h is the substrate height, and ε_r is the relative dielectric constant of the substrate. According to Equation (3), Antenna (1) design will give a fundamental mode resonant frequency of 18.8 GHz.

Introducing the open slot in Antenna (2) shifts the resonant frequency of the reference antenna to a lower value due to the slow wave effect and also introduces another overlapping resonant mode due to the coupling between the slot and the top layer structure. This gives a fractional bandwidth of 52.16% from 4.79 to 8.17 GHz. A modified cut shape patch is introduced (Antenna (3)) to enhance the impedance matching. The center frequencies of the reference antenna and the proposed antenna are

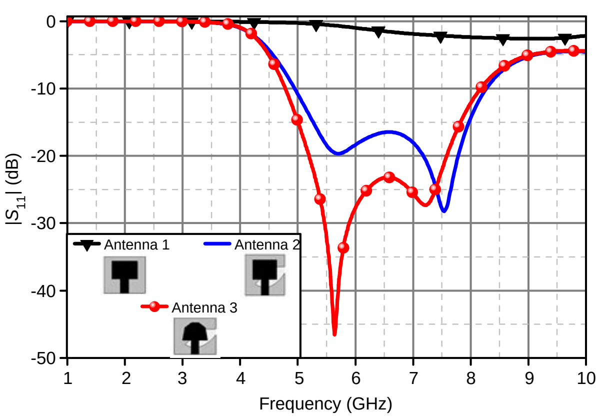


Figure 2. Return loss response of design steps configuration.

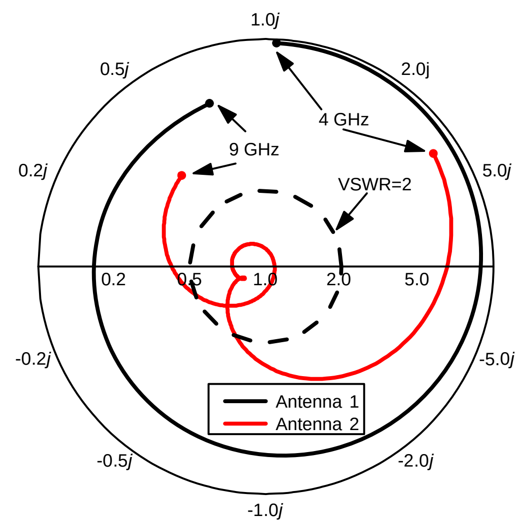


Figure 3. Simulated reflection coefficients for Antenna 1 and Antenna 2.

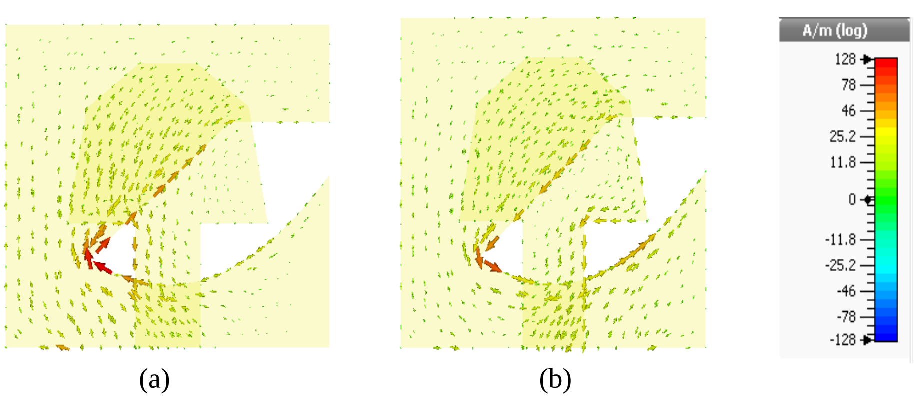


Figure 4. Simulated magnetic field distribution of the antenna at: (a) 5.64 GHz, (b) 7.23 GHz.

18.8 GHz and 6.585 GHz, respectively. According to Equation (5), the size reduction of the proposed antenna is about 88%.

$$\text{size reduction } (\%) = 1 - \left(\frac{f_{c(\text{proposed})}}{f_{c(\text{reference})}}\right)^2 \tag{5}$$

Figure 3 shows the simulated reflection coefficients of Antenna 1 and Antenna 2 plotted in the Smith chart. New two overlapping resonant frequencies are introduced in Antenna 2, which explains the wider impedance bandwidth of the antenna. It can also be observed that inserting the open slot in the ground plane increases the equivalent inductance of the antenna which will slow down the phase velocity and miniaturize the size of the antenna.

Figure 4 depicts the magnetic field distribution of the antenna at the two resonant frequencies. It is clear from the field distribution at the two resonant frequencies and the Smith chart plot in Figure 3 that inserting the slot in the ground plane generates two overlapping resonant modes, which explains

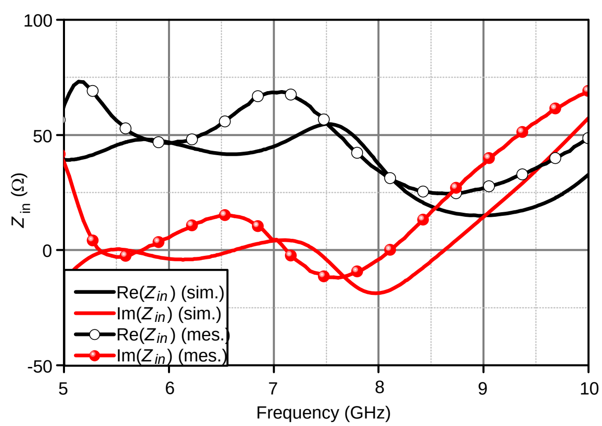


Figure 5. Simulated and measured input impedance of the antenna.

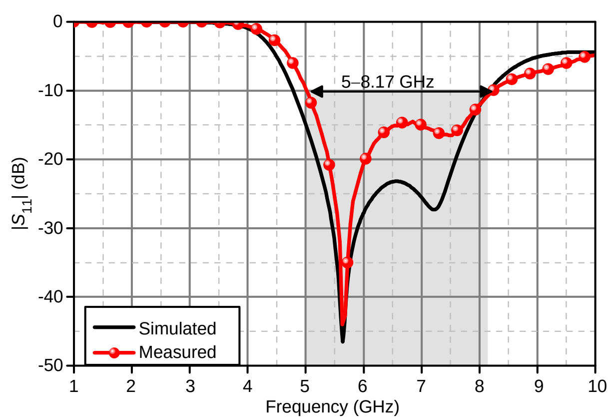


Figure 6. Simulated and measured return loss of proposed antenna.

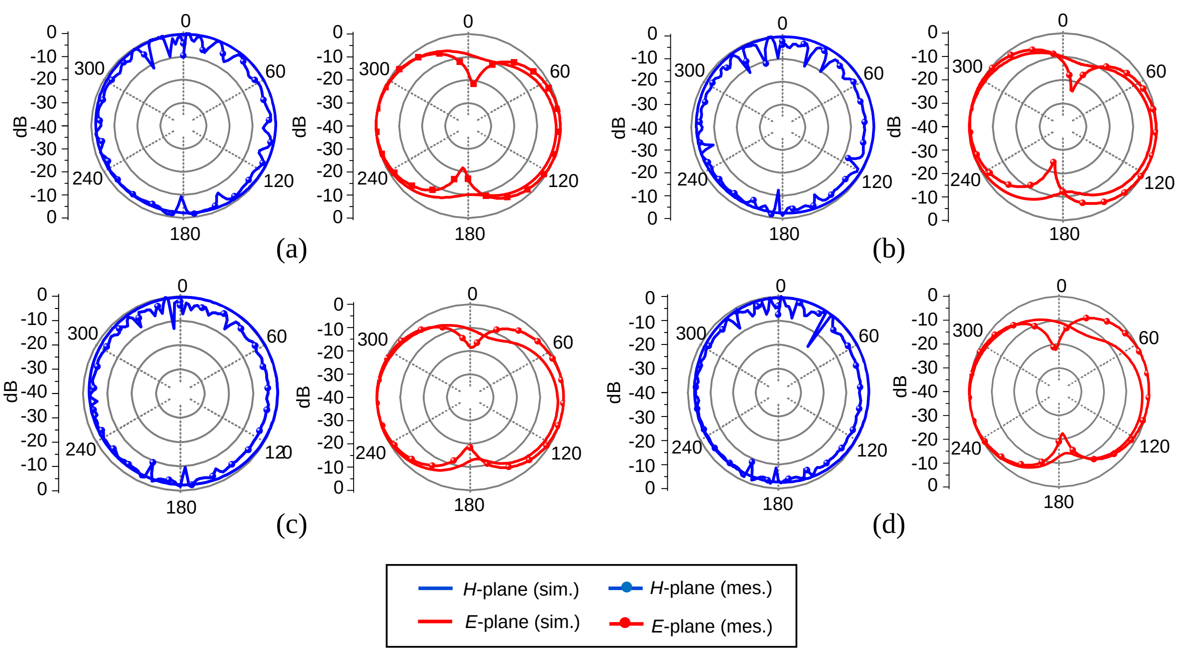


Figure 7. Measured and simulated radiation patterns at: (a) 5 GHz, (b) 5.5 GHz, (c) 6 GHz, (d) 6.5 GHz.

the wide bandwidth performance of the proposed antenna.

The proposed antenna was fabricated using LPKF ProtoMat S62, which is especially designed for RF and microwave circuit boards. The simulated and measured real and reactive part of the input impedance of the antenna are shown in Figure 5. It is evident that, along the bandwidth from 5 GHz to 8.17 GHz, the measured resistive input impedance is varied from 31 to 73 while the reactive impedance is varied from −11.5 to 37.

The return loss of the fabricated antenna was measured using HP 8510C vector network analyzer over the frequency range 1 to 10 GHz. A good agreement between simulated and measured return loss is obtained as can be seen in Figure 6.

The simulated and measured radiation patterns in the E-plane (or x-y plane) and H-plane (or x-z plane) observed at four frequencies points are plotted in Figure 7. Nearly omnidirectional could be observed in H-plane while the E-plane has a dipole like radiation pattern in the whole frequency band points. Some slight discrepancies are observed between simulated and measured patterns especially in H-plane which is due to feeding cable effect in the anechoic chamber.

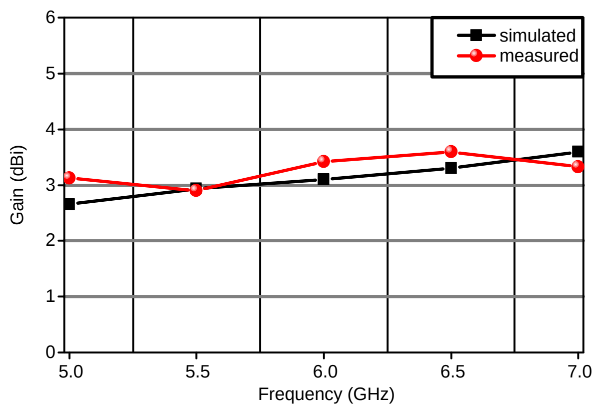


Figure 8. Simulated and measured peak gain of proposed antenna.

Table 2. Dimensions of published antennas.

No.	**Published literature/ proposed**	**Frequency band (GHz)**	**Maximum gain (dBi)**	**Total radiation efficiency (%)**	**Antenna size dimension (mm^3)**	**Total area occupied by the antenna (mm^2)**
1	Ref. [1]	5–6	8.1	97.2	$50 \times 50 \times 3.175$	2500
2	Ref. [2]	5.15–5.35 and 5.725–5.825	2.12	-	$24 \times 16 \times 1.5875$	384
3	Ref. [3]	5–6	1.8	-	$120 \times 80 \times 2$	9600
4	Ref. [4]	5.18–5.8	7.92	95	$67 \times 74 \times 3.175$	4958
5	Ref. [5]	5.6–6.3	11	-	$58.5 \times 111 \times 1.52$	6493
6	Ref. [6]	5.1–6.2	3.3	-	$21 \times 7.35 \times 1.6$	154
7	Ref. [7]	2.4/5.5	3.73	-	$30 \times 40 \times 0.8$	1200
8	Ref. [8]	2.4/5.2/5.8	3.65	75.54	$60 \times 45 \times 1.6$	2700
9	Ref. [9]	2.4/5.8	1.25	-	$17 \times 12 \times 1.6$	204
10	Ref. [10]	2.4/5.2	-	-	$26.5 \times 5.7 \times 1.6$	151
11	Ref. [11]	4.53–7.47	4.1	-	$32 \times 42 \times 1.6$	1344
12	**Proposed antenna**	**5–8.17**	**3.6**	**95**	$\mathbf{9.2 \times 9.8 \times 1.52}$	**90**

Figure 8 shows the gain of the antenna. The maximum measured peak gain is 3.6 dBi with a variation < 0.7 dBi over the operating bandwidth.

By using Rogers RT5880LZ as a substrate material which has low relative permittivity of 1.96 with low tangent loss of 0.0019, the minimum value of total efficiency of the proposed antenna is 95%.

A comparison between the proposed antenna and other published works in terms of parameters such as antenna size, total area occupied by the antenna and its frequency of operation has been given in Table 2.

4. CONCLUSION

A new very compact and low profile open slot wideband antenna has been proposed. The wide impedance bandwidth with a compact size of the antenna is mainly realised by inserting an open slot in the ground plane structure. The proposed antenna has a wide impedance bandwidth of 48% from 5 to 8.17 GHz. With a simple structure, high efficiency and omnidirectional radiation pattern, the proposed antenna can be used in many wireless communication applications.

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