Analysis of a Miniaturized Modified Multifrequency Printed Antenna with Broadband Characteristics for WLAN Application

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1 Introduction

As the generation of wireless communication systems is escalating to a compact world, the components incorporated into these systems must be reduced in size. Hence, as the microstrip patch antenna is a component of the wireless communication system, its size reduction becomes the foremost apprehension in this field. Several authors have achieved compactness by several design methods [1–14]. The design proposed by Bhunia et al. at [1] reported miniaturization of about 41%. The work presents a very poor frequency shifting. An equilateral triangular patch has been introduced that achieved a size reduction of about 43.47% [2]. It was reported by Chatterjee et al. [3] that dual frequency operation can be achieved with a patch area reduction of 41.8%. A slotted edge-fed patch antenna with a reduction in size by less than 40% was reported by Park and Cho [4]. In ref. [5], the maximum size reduction of about 46.2% was gained by implementing a triangular slot at the upper face of the patch. It was demonstrated in ref. [6] that by adding a cross-shaped slot on the rectangular and trapezoidal patches, the size reduction can be reached to 34%

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and 41%, respectively. Embedding three meandering narrow slots on the antenna surface and a pair of parallel slots near to the radiating edge of the patch leads to the highest miniaturization of about 45% [7]. Gautam et al. [8] proposed a design that achieved 39% compactness by inserting four slits on the square-shaped patch. Maximum compactness of 56% can be achieved by introducing meandered slots on the ground plane [9] of the radiating patch. Elsdon et al. [10] reported a 40% compact planar-fed patch antenna by inserting slots parallel to the non-radiating edge of the patch. In ref. [11], a window-shaped microstrip patch antenna offered 50% size reduction. Miniaturization of about 43.9% was achieved by Song et al. [12] using perturbation of radiating slot. Gosalia and Lazzi reported 51% size reduction by etching out symmetrical crossed slots from the radiating patch [13].

The work proposed in this paper is related to the design of a multifrequency compact (60.55%) microstrip patch antenna with 10% fractional bandwidth at a center frequency 5.58 GHz to cover the bandwidth requirements of WLAN (5.725–5.825 GHz) and HiperLAN (5.47–5.725 GHz) wireless applications. The main objectives of this work are focused on achieving the antenna's size reduction by lowering the resonant frequency, multifrequency operation, and bandwidth improvement without defecting its ground plane. The various geometrical dimensions of the proposed antenna were optimized and configured by using the method of moment or MOM-based simulator IE3D [14].

2 Antenna Configuration

The dimensions of the slots on the radiating patch have been analyzed and manually optimized by using MOM-based IE3D simulator. Both the configurations of the antenna 1 (conventional antenna) and antenna 2 (proposed antenna) are shown in Figs. 1 and 2, respectively. The antennas have the same dimension of 16 mm × 12 mm, where length is 12 mm and the width is 16 mm. It is constructed on an FR4 substrate with a thickness of 1.6 mm and the dielectric constant $(\varepsilon_r) = 4.4$. The conventional patch antenna with an unmodified ground plane can resonate only at 5.5 GHz where a coaxial probe feeding of radius 0.5 mm has been provided at the location of W/2 (8 mm) and L/3 (4 mm) from the right side edge of the patch.

Two slots complementary to each other having equal length and width have been placed at the upper left side and the bottom right side of the patch as portrayed in Fig. 2. The length and the width of these two slots are L1 = L3 = 6 mm and W1 = W3 = 0.5 mm, respectively. An additional slot positioned at the center of the patch plays a very important role to achieve the first frequency. This slot has a length and width of 9 mm (L2) and 0.5 (W2) mm, respectively. The coaxial probe feed location has been changed to $(-3, -1)$ from the center location (0,0) where L4 = 3 mm and W4 = 7 mm.

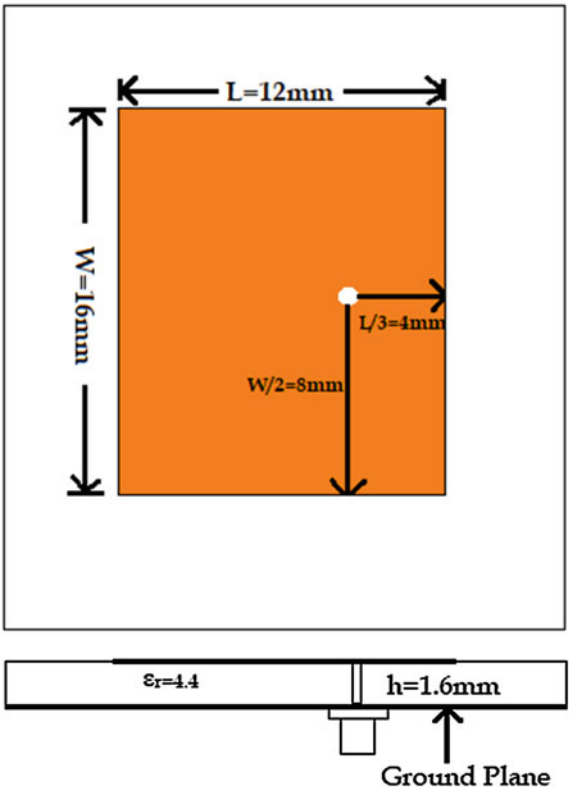


Fig. 1 Antenna 1 (conventional patch)

3 Analysis and Working of the Proposed Antenna

As we know, the conventional antenna only resonates at 5.5 GHz, hence there is a requirement of modifications on the patch to make it resonate at different frequencies. Thus, by introducing new slots and modifying them, make the antenna resonate at three different frequencies which are 3.62 GHz, 5.79 GHz, and 6.36 GHz with a significant bandwidth of 10% in between 5.30–5.86 GHz, which supports WLAN (5.725–5.825 GHz) and HiperLAN (5.47–5.725 GHz). The final structure of the proposed patch has been constructed through three different design steps shown in Fig. 3. Amid three different cases, the first one discusses only having the upper right slot placed horizontally that results in a resonating frequency of 4.20 GHz but the reflection coefficient is −3.38 dB which cannot be taken as the minimum requirement for a microstrip patch antenna to radiate at its far region, and the reflection coefficient must be below −10 dB level. But there are two more frequencies generated at this stage, one is at 5.43 GHz with 15.59 dB and the other is at 6.18 GHz with −22.20 dB of the reflection coefficient. After introducing the complementary slot to the first one, the antenna at the second stage resonates at 4.077 GHz with S_{11} of about −6.44–5.79 GHz with −24.57 dB. As we can see that the former frequency cannot be accepted as per the

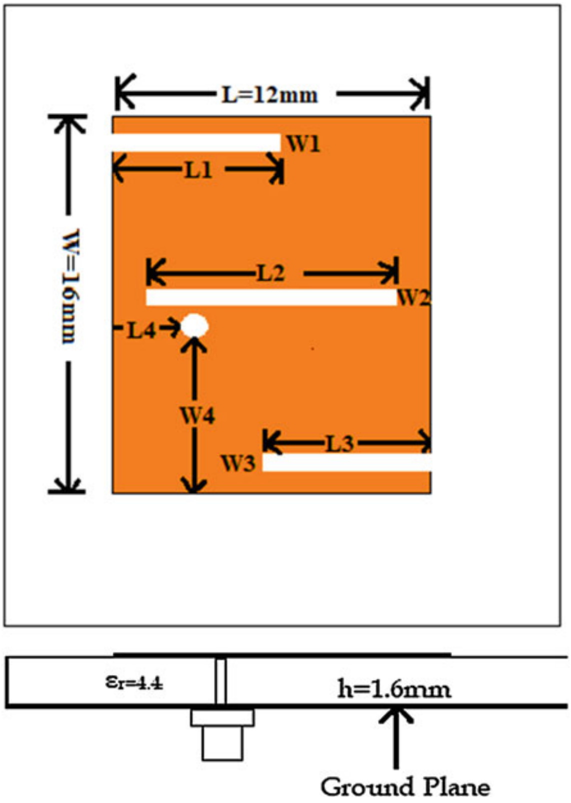


Fig. 2 Antenna 2 (proposed patch)

requirement of the S_{11} parameter, the second frequency is provided with a bandwidth of 560 MHz [5.30–5.86 GHz]. Finally, by introducing the final slot to the patch as shown in case 3, the antenna resonates at three different frequencies 3.624, 5.795, and 6.360 GHz with the reflection coefficients of −13.78 dB, −20.038 dB, and −14.342 dB, respectively. The results of the different design steps are represented in Table 1.

The advantages provided by this proposed antenna are:

I. It provides a calculated size reduction of about 60.55% by lowering the first resonant frequency. So better compactness as compared to the references [1–14].
II. It offers a broad bandwidth of 10% and the achieved bandwidth of about 540 MHz (5.3–5.86 GHz) is sufficient to wireless applications such as WLAN (5.725–5.825 GHz) and HiperLAN (5.47–5.725 GHz).
III. Proper impedance matching with the perfection of the S_{11} parameter, and VSWR makes the antenna resonate at the concerned frequencies.

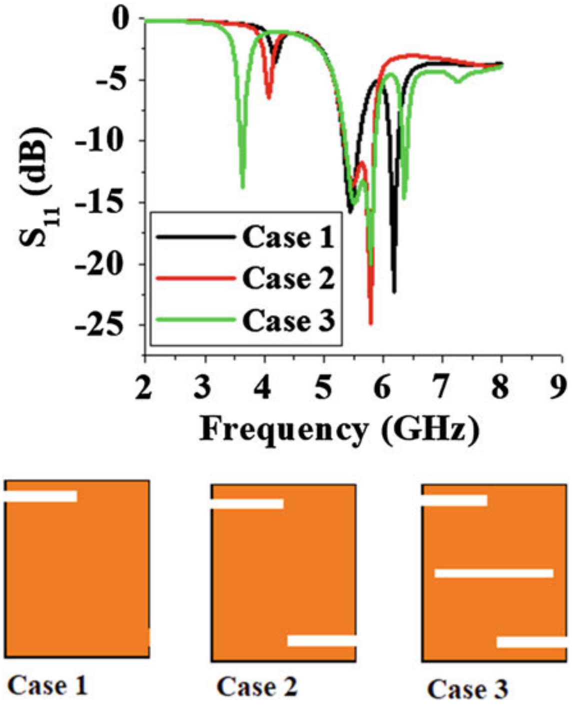


Fig. 3 Case study of S_{11} parameter of the suggested patch for different design steps

Table 1 Simulated results in different cases of the progress of the proposed antenna

Different cases	Resonant frequency (GHz)	S_{11} (dB)	Gain (dBi)	VSWR	Size reduction (%)
Case 1	f1 = 4.20 f2 = 5.43 f3 = 6.18	−3.38 −15.59 −22.20	−2.34 3.12 0.49	1.8403 1.1370 1.0943	46.57
Case 2	f1 = 4.07 f2 = 5.79	−6.44 −24.57	0.78 3.35	1.3676 1.0848	49.90
Case 3 (proposed)	f1 = 3.62 f2 = 5.79 f3 = 6.36	−13.78 −20.03 −14.34	1.32 2.91 0.13	1.1564 1.1050 1.1499	60.55

4 Parametric Study of the Proposed Antenna

The achievement of the desired frequencies is prepared by investigating various dimensions of the proposed antenna in this work through a parametric study. The variations of the slot lengths have a major influence on the resonance characteristics of the designed antenna. The governing parameters of the proposed patch have been

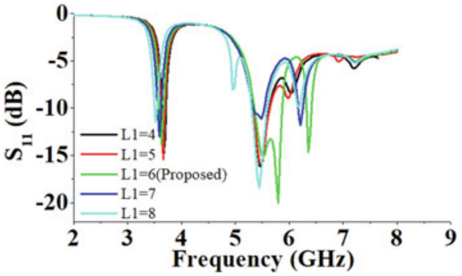


Fig. 4 Variations of S_{11} parameters for different values of L1

optimized by changing any one structural parameter of one slot at a time while other parameters are fixed as its proposed value.

4.1 Effect of Antenna Parameter L1

The parametric study of the design parameter L1 has been shown in Fig. 4. It is observed that when L1 = 4 mm, the antenna resonates at only two different frequencies which are 3.73 GHz with −14.73 dB and 5.43 GHz with −15.23 dB. As this length further increases, the frequencies shift to a lesser value. For L1 = 5 mm and 7 mm, the first resonant frequencies are noted as 3.70 GHz and 3.67 GHz, respectively. But, the S_{11} parameter for the second resonant frequency hardly reaches −10 dB level for L1 = 7 mm without offering any impedance bandwidth, whereas when L1 is set to 5 mm, the second frequency provides a good impedance matching. The first resonant frequency shifts toward the 3.59 GHz, and the second resonant frequency becomes 5.32 GHz for L1 = 8 mm. The impedance matching is very poor at third resonance except for the proposed dimension. So, it is concluded that the designed antenna resonates triple frequencies with the best impedance matching only for the proposed value of L1.

4.2 Effect of Antenna Parameter L2

A profound elaboration of varying the dimension of the design parameter L2 has been shown in Fig. 5. It can be observed that for L2 = 7 mm and 8 mm, the first two resonant frequencies are achieved but the third resonant frequency suffers from a very poor impedance matching. As the value increases to 9 mm which is the proposed value of L2, it provides triple resonant frequencies comparatively with a very good impedance matching. Throughout the parametric study of this design parameter, it was found quite the same bandwidth for the second resonant frequency. When designed with L2 = 10 mm, three different resonating frequencies have been achieved but poor matching at 3.5 GHz. The other frequencies remain almost the same as the proposed

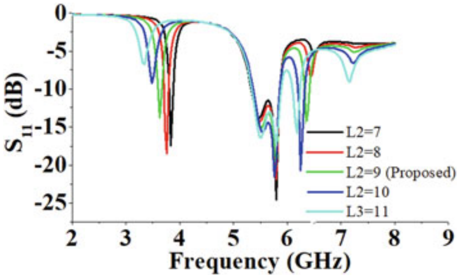


Fig. 5 Variations of S_{11} parameters for different value of L2

one. As the value of L2 increases to 11 mm, the first resonant frequency further shifts to 3.25 GHz but the reflection coefficient is only −7.125 dB, which is not acceptable for any antenna to radiate at the far region. So, increasing the dimension of L2 leads to the shifting of the first resonant frequency but the impedance matching conditions are becoming very poor. It is concluded that the best resonance response is observed for the proposed dimension of L2 = 9 mm.

4.3 *Effect of Antenna Parameter L3*

A clear demonstration of the parametric study of the antenna parameter L3 concerning the S_{11} parameter has been illustrated in Fig. 6. As can be observed, the first resonant frequency remains quite unchanged throughout the entire investigation for different structural dimensions. But the remaining frequencies vary accordingly. As in the case of L3 = 4 mm, the second resonant frequency resonates at 5.45 GHz with S_{11} = −13.56 dB and the third resonance at 7.25 GHz with a reflection coefficient of −7.35 dB which is not acceptable. Then, the length increases to 5 mm, and with this increment, no change is noticed in the second resonant frequency but the impedance matching has improved for the third resonance. With the further increment of L3 to the proposed value, the second resonant frequency is attained at 5.79 GHz with a bandwidth of 560 MHz (5.30–5.86 GHz) and the third resonance is achieved at 6.36 GHz with the best matching. When the value of L3 has increased to 7 mm, there is only the excitation of the first resonant frequency. Now with further increase

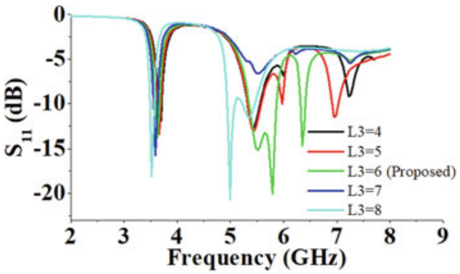


Fig. 6 Variations of S_{11} parameters for different values of L3

in L3–8 mm, the first frequency is slightly shifted toward the lower value and the second resonance is observed around 5 GHz which does not fulfill the bandwidth requirements of the intended applications. Again third resonance is not generated for this value. So, L3 = 6 mm is considered for design.

5 Surface Current Distribution of the Conventional and the Proposed Antenna

A detailed demonstration of the surface current distributions of the conventional and the proposed patch antennas are demonstrated in Figs. 7a–d. The conventional antenna resonates at 5.5 GHz, which indicates very limited current density at the radiating edges of the patch as shown in Fig. 7a. As it can be clearly observed from Fig. 7b, the main reason behind the generation of the first frequency is the slot positioned at the center of the patch. As from [7], introducing new complementary slots to the patch, the density of the surface current can be further improved. Figure 7c shows the surface current distribution at 5.79 GHz. The antenna surface current

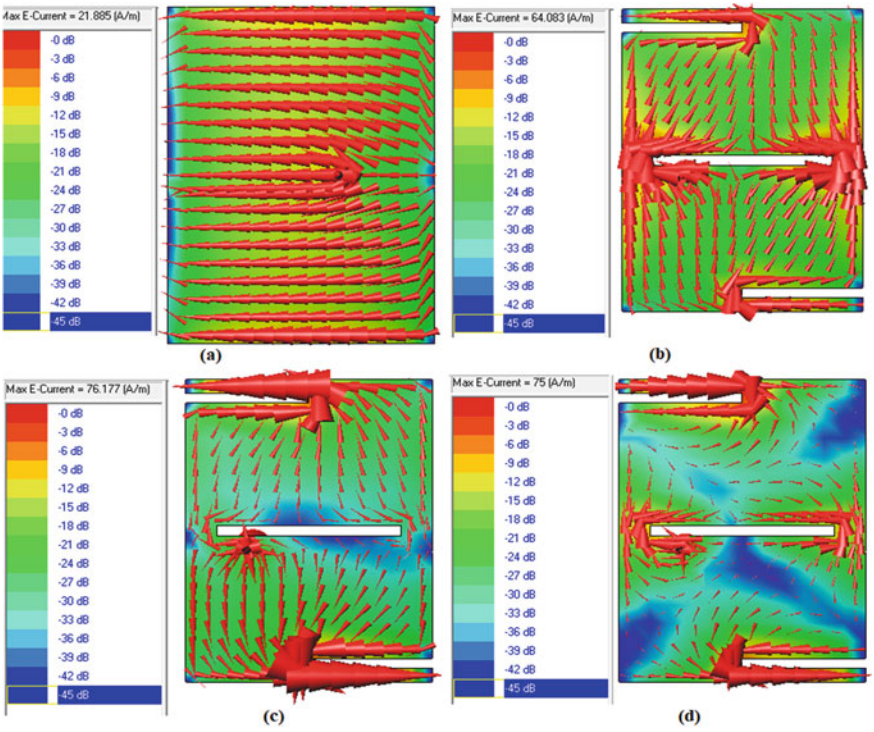


Fig. 7 Surface current distribution for the conventional antenna at **a** 5.5 GHz and for the proposed antenna at **b** 3.62 GHz, **c** 5.79 GHz, and **d** 6.36 GHz

distribution for the frequency 6.36 GHz is illustrated in Fig. 7d. It can be comprehend that the insertion of every slot plays a vital role in achieving the desired resonant frequencies. Both the complementary slots as well as the center positioned slot are important. So from overall study of the proposed structure, it can be stated that the proposed geometrical mechanism is very important to make the antenna resonate at the respective frequencies. The current distribution gets its density around the edges of the slots and in that way the path of the current gets lengthened which increases the electrical length and hence resonant frequency shifts to a lower value. Hence, it can be concluded that the compactness depends upon the proposed geometry.

6 Results and Discussion

The simulated S_{11} parameters for both the conventional and the proposed antennas are shown in Figs. 8 and 9, respectively. From the figures, it can be stated that in the case of the conventional antenna, there is only a single resonance whereas the

Fig. 8 S_{11} parameter of the conventional antenna

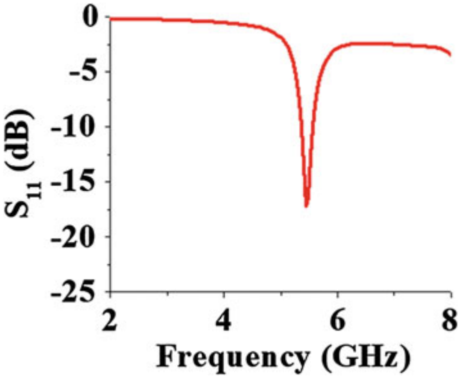
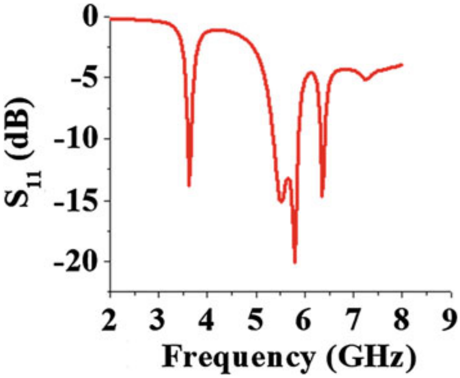


Fig. 9 S_{11} parameter of the proposed antenna



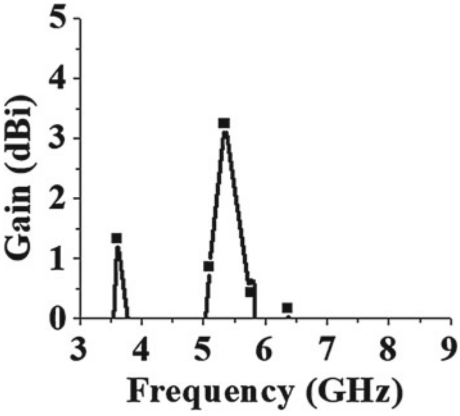


Fig. 10 Gain of the proposed antenna

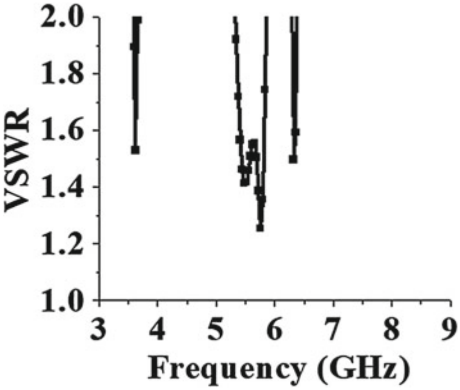


Fig. 11 VSWR of the proposed antenna

proposed structure provides triple frequencies with a very good impedance matching. The peak gain of about 2.96 dBi is quite acceptable [see Fig. 10]. The voltage standing wave ratio has been plotted in Fig. 11. As revealed in Fig. 12, the normalized E-plane radiation characteristics offer an almost indistinguishable broadside pattern for all the resonant frequencies. It is observed that almost indistinguishable steady radiation responses are found at all the working resonant frequencies.

7 Conclusion

A coaxially fed microstrip patch antenna has been proposed which resonates with three distinguished resonant frequencies at 3.62 GHz, 5.79 GHz, and 6.36 GHz with a considerable bandwidth of 560 MHz (5.30 GHz to 5.86 GHz). The designed antenna offers compactness of 60.55% which makes it attractive for miniaturized wireless

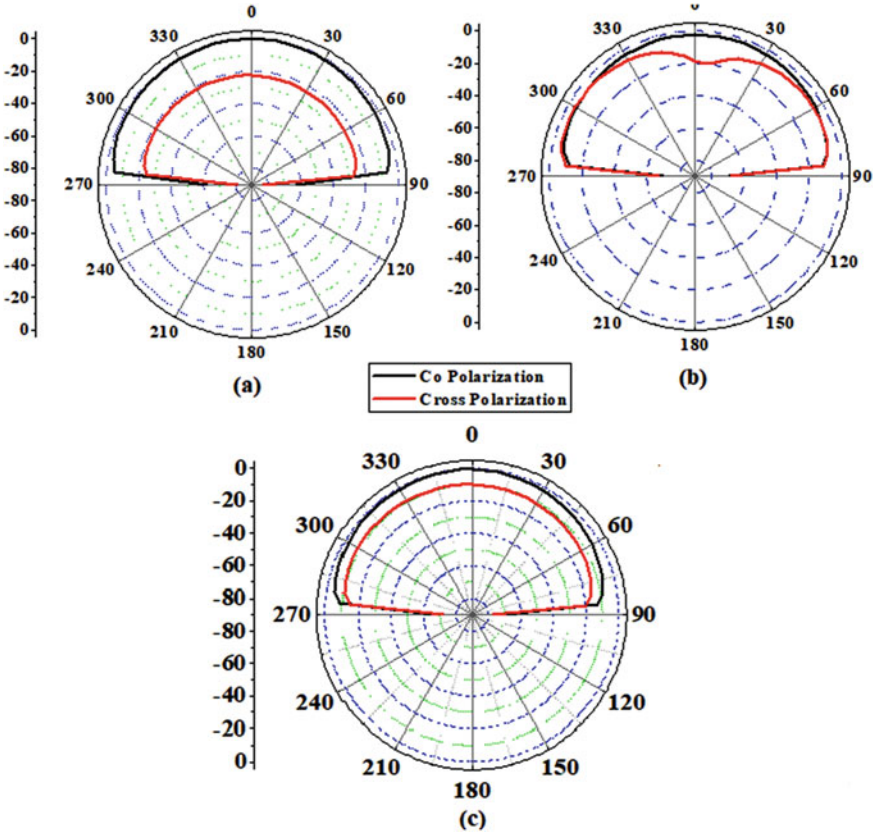


Fig. 12 Normalized E-plane radiation pattern of the proposed antenna at **a** 3.62 GHz, **b** 5.79 GHz and **c** 6.36 GHz

systems. Furthermore, low VSWR, good impedance matching, and stable radiation patterns are also for the proposed antenna. The suggested antenna is suitable for WLAN (5.725–5.825 GHz) and HiperLAN (5.47–5.725 GHz) wireless applications.

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