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Design and Analysis of Dual Band Crescent Shape Monopole Antenna for WLAN Applications

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Abstract A dual band crescent shape planar monopole antenna for wireless local area network (WLAN) application is proposed. The crescent antenna is evolved from an arc patch antenna. By adjusting the feed line position along the arc, two distinct bandwidths that meet the requirements for the WLAN standards can be obtained. The proposed antenna covers the frequency bands of the IEEE 802.11 a/b/g (2.4-2.48 GHz, 5.15-5.35 GHz, and 5.725-5.825 GHz). The proposed antenna is investigated using CST software package. The reflection coefficient, radiation pattern, gain and efficiency for various design parameters are investigated. Average gains of 2.3dB_i and 3.98dB_i are achieved in the lower and higher frequency band, respectively.

Keywords Crescent Shape Monopole Antenna, Dual Band Antenna, Wireless Local Area Network WLAN

1. Introduction

With a growing interest in the field of wireless communication systems and a competitiveness to design devices that provide multiple services, there is a need for miniaturized multipurpose antennas for the modern communication systems[1]. Multi-band antennas should support multi-frequency operations with suitable radiation characteristics for the desired applications[2]. During recent years, there have been rapid developments in the applications of wireless local area network (WLAN). The 2.45GHz, 5.2and 5.8GHz bands are demanded in practical WLAN applications[3]. The demand of WLAN's are increasing numerously worldwide, because they provide high speed connectivity and easy access to networks without wiring[4]. The printed monopole antenna has become very popular in these applications because of its low cost factor and fabrication simplicity. Printed monopole antenna can easily be integrated in communication systems and fabricated on printed circuit boards e.g. fabricated on laptops for WLAN applications[5].

Many types of antennas have been designed for the WLAN application in the 2.4GHz (2.4-2.484GHz), 5.2GHz(5.15-5.35GHz) and 5.8GHz(5.725-5.825GHz) operating bands. The fractal geometry was used either to miniaturize the antenna, or to produce multiband radiators. Due to the self-similarity property of fractals there are multiple copies of the geometry in the fractal object and hence the fractal geometry has been utilized for multiband antennas[6-9]. Printed monopole antennas with folded structure or meander line shape have received much attention. Since the radiating elements of the antenna can consist of many strips, different modes would be excited and the antenna could be applied for dual band purposes[10-12]. Among the used antenna configurations, the ring geometry has many favorable advantages. It requires smaller size than the corresponding rectangular patch to resonate at the same frequency. It also offers wide bandwidth and high radiation resistance when it is excited to operate at higher order modes[13]. Several antennas having ring shape, and operating at dual resonance frequencies have been reported in literature[14-17]. Other interesting shapes, that were used for the printed monopole antennas, are; F-shaped, L-shaped, Omega-shaped, Fork–like with a rectangular ring,[18-21]. All these shapes have been deployed for WLAN applications, and showed dual band operation.

A crescent-shaped multiband monopole antenna has been presented recently for mobile wireless applications[22]. The antenna uses a patch radiator, microstrip feed line, and defected ground structure. The realized antenna structure showed a relative bandwidth of 51.8% and gain above 1.5dB_i over the frequency interval 1.75 to 3.1GHz. The antenna size was optimized to a volume of 57*37.5*0.8mm^3[22].

In this contribution a dual band planar monopole antenna for WLAN application is proposed. The antenna has the form of sections of two circles, each having a different radius but the same center, thus forming a crescent shape. The resonance frequencies of the two WLAN bands are adjusted by varying the lengths of the two parts of the arc, which are

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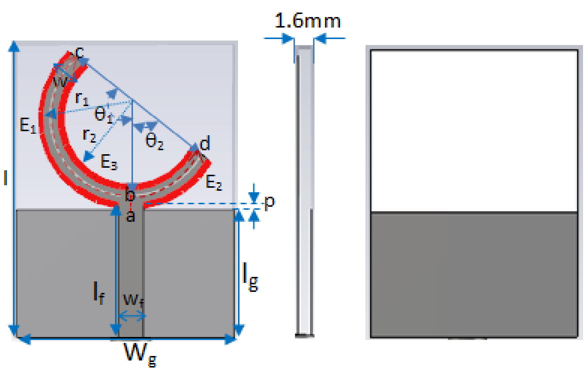
created by the feed line. The results show two distinct operating bands within s_{11}<-10dB limit. These bands are; 342MHz (2.363- 2.705 GHz) and 4.075GHz (4.46-8.5358GHz), which cover all the 2.4/5.2/5.8 GHz WLAN bands. The antenna has a simple planner structure, a volume of 38*28*1.6 mm^3, and acceptable gains are obtained over the two operating bands. This paper is organized as follows. The antenna design is presented in section 2. Detailed discussion of the results and the effect of various antenna parameters are shown in section 3. Performance comparison with other published results are given in section 4, followed by the conclusions.

2. Antenna Design

To satisfy the IEEE802.11 WLAN standards in the 2.4/5.2/5.8GHz operating bands, dual band antennas with simple structure and desirable radiation performance are required. One way to obtain a dual band operation is that, the antenna structure should have two elements with different lengths so that each one of them corresponds to about a quarter of the wavelength at the resonant frequency[10]. For antenna structures like the arc, two distinct bandwidths that meet the requirements for the WLAN standards can be obtained by adjusting the feed line position along the arc. Thus the arc can be considered as divided into two parts, where each part of them corresponds to one of the two bands. The geometry of the proposed antenna is shown in Fig.1. The antenna was simulated assuming a dielectric FR4 substrate of 1.6 mm thickness, ε_r of 4.3, and dielectric loss tangent of 0.025. The design parameters of the antenna are listed in Table 1.



(a) front view, (b) side view, (c) back view

Figure 1. Geometry of the dual band crescent shape monopole antenna

Table 1. Parameters of the designed antenna. All dimensions are in millimeters except theta in degree

parameter	value	parameter	value
r_1	11.5	l	38
r_2	9	E_1	26
w	2.5	E_2	10.67
w_f	3.2	E_3	32
l_f	17.2	θ^o_1	137°
w_g	28	θ^o_2	60°
l_g	16.6		

The length of a monopole is set equal to about a quarter of the wavelength at the resonant frequency. The antenna shown in Fig.1 consists of two elements (short arc and long arc) with lengths that correspond to about a quarter of the wavelength at 2.4GHz and 5.2GHz respectively. The long arc-shaped monopole strip (point a → point b → point c) is used to excite the first resonant frequency (f_{r1}=2.44 GHz) band. The length (L_L) of the long arc-shaped strip is calculated from Eq.1:

$$L_L=0.25\,\lambda_e = 0.25\,c/f_{r1}\,k \quad (1)$$

Where L_L= p + w/2 + average length of long arc, λ_e is the effective wavelength in the substrate, k is a correction factor, taken as $k = \sqrt[2]{\varepsilon_{eff}}$ [13], and the approximated value of ε_{eff} is given by:

$$\varepsilon_{eff}=(\varepsilon_r+1)/2 \quad (2)$$

Equation (2) is mostly used in monopole designs, while the following equation (3) has been used for microstrip antennas and feed lines[13].

$$\epsilon_e = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{W}\right)^{-1/2} \quad (3)$$

Equation (3) was used to calculate the impedance value of the feed line. For FR4 substrate with thickness of h = 1.6 mm then Eq. (2) gives k= $\sqrt{\varepsilon_{eff}}$ =1.627. However, k was empirically taken equal to 1.15 as in[23], while the value of k has been considered as $k = \sqrt[4]{\varepsilon_{eff}} = 1.275$ as a moderate value[24]. In this work the value of k has been considered as k=1.15, as an empirical value. This value (k=1.15) gives better agreement between simulated and reported values as concluded in[23].

According to Eq.1, the long arc-shaped monopole strip (L_L) should have a total length of 26.7mm to excite low band resonance frequency of f_{r1}=2.44GHz. As the long arc-shaped monopole strip (L_L) has a total length given by (p+ w/2+average length of long arc), thus the average length of long arc is found to be equal to 24.8mm.

The short arc-shaped monopole strip (point a → point b → point d) is used to excite the second resonant frequency (f_{r2}=5.25GHz) band. The length (L_s) of the short arc-shaped strip is calculated from Eq. 4 as:

$$L_s=0.25\,c\,/\,f_{r2}\,k \quad (4)$$

Where ; L_s= p + w/2 + average length of short arc

According to Eq.4, the short arc-shaped monopole strip (L_S) must have a total length of 12.4mm in order to excite high band resonance frequency at f_{r2}=5.25GHz. As the short arc-shaped monopole strip (L_S) has an estimated total length of (p + w/2 + average length of short arc), then the average length of short arc is found to equal to 10.6 mm. As the crescent shape consists of adding the two parts (long arc and short arc), so the total length of crescent shape is equal to 35.2mm.

3. Results and Discussion

The proposed antenna was simulated and analyzed using

CST Microwave Studio (CST MWS). Figure 2 shows the obtained reflection coefficient response of the antenna with parameters shown in Table 1. It can be seen that the antenna is matched at two resonating frequencies which indicate that the antenna is suitable for WLAN applications. Two resonating modes at 2.5 and 5.77GHz can be clearly observed in the investigated bands. The first band at 2.5GHz has bandwidth of 342MHz (2.363- 2.705 GHz) with reflection coefficient -16dB, which covers the first band of WLAN applications (2.4-2.48GHz). The second band at 5.77GHz has a bandwidth of 4.075GHz (4.46-8.535GHz), with reflection coefficient -37.2dB, covering the second and third bands of WLAN applications (5.15-5.35), (5.725-5.825).

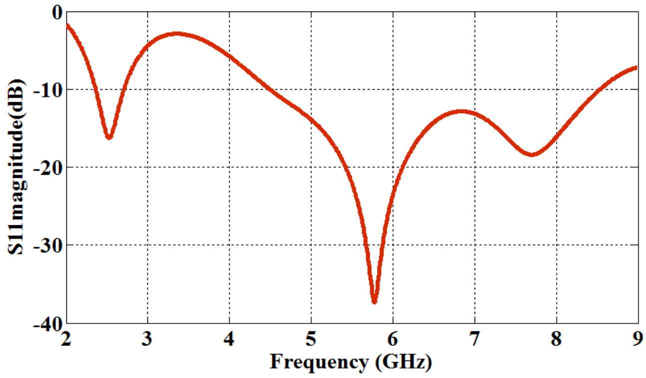


Figure 2. Reflection coefficient response for the antenna whose dimensions are shown in Table1

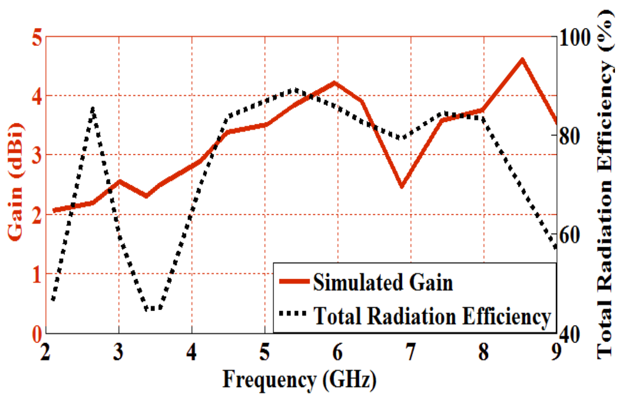


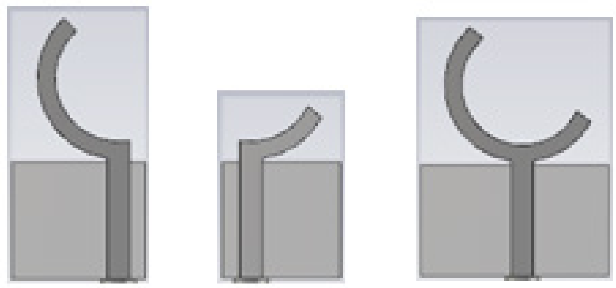
Figure 3. ariation of simulated gain, and total radiation efficiency with frequency for the dual band crescent monopole antenna, of dimensions shown in Table 1

The gain and efficiency of the dual band crescent shape monopole antenna were calculated using the CST package, and the obtained results are shown in Fig. 3. The peak gain varies in the range of 2.123-2.5dB$_i$ for the lower band and 3.35-4.6dB$_i$ for the higher band. Comparing Figs. 2 and 3, it can be seen that in the range (5-6 GHz), the gain of the antenna increases to a maximum value of 4.2 dB$_i$ at the frequency of 5.95GHz. The radiation efficiency was also calculated, and it is plotted on the same Fig.3. The maximum radiation efficiency equals to 89.2% at a frequency equals to 5.388GHz. This is due to the good reduction in the reflection coefficient (down to about -20 dB) at this frequency. The gain and efficiency drop to a minimum at frequency equals to 6.877GHz. This is due to the fact that the reflection coefficient is about -12.97dB.

3.1. Effect of Arc Length

It has been noticed from the simulations, that the resonance frequencies and bandwidths of the proposed antenna depend on the length and width of the arc antenna. Therefore the influences of these parameters are investigated in the following.

The crescent shape antenna can be decomposed into two parts; long arc and short arc as shown in Fig. 4. The following investigations consider the effect of varying the length of each part on the obtained results of the part itself as well as the whole crescent antenna.



(a) long arc (b)short arc (c) crescent antenna

Figure 4. Decomposition of the crescent antenna (c) into; a long arc (a), and a short arc (b)

3.1.1. Effect of the Length of Long Arc

To study the effect of the length of the long arc, some arbitrary values may be considered. However, certain values corresponding to the frequencies, for example, of UMTS (1.920-2.170 GHz) or WIMAX (3.4-3.69 GHz) were considered here to show the design flexibility as well. According to Eq.1, the average length of long arc is equal to 31mm and 16.5mm for these two frequencies respectively. Figure 4.a shows the geometry of the long part of the arc monopole, while Fig. 5 shows the reflection coefficient curve for long arc monopole antenna for three values of its lengths. It can be seen from Fig. 5 that, with increasing the length of long arc from 16.5mm to 31mm, the resonance frequency decreased from 3.4GHz to 2.2GHz. Figure 6 shows the reflection coefficient curves for crescent shape monopole antenna for the above three values of long arc lengths. It can be seen that, with increasing the length of long arc from 16.5mm to 31mm, the reflection coefficient at the first band increases and the bandwidth becomes narrower. This is because the quality factor is inversely proportional to the bandwidth and depends on the reflection coefficient. A lower quality factor means lower reflection back into the "neck" of the monopole antenna towards the source[25]. The resonance frequency decreased as expected. In the higher frequency band, the resonant frequency is decided by the combination of the second resonant frequency due to the short arc and the higher mode of the long arc monopole. Consequently the second frequency band is also slightly affected by varying the length of the longer arc. It can be seen from Fig. 6, that the higher mode of the long arc monopole is shifted up in two cases (long arc=16.5 mm, and 31mm). This leads to increase the bandwidth of the higher frequency band but with less matching.

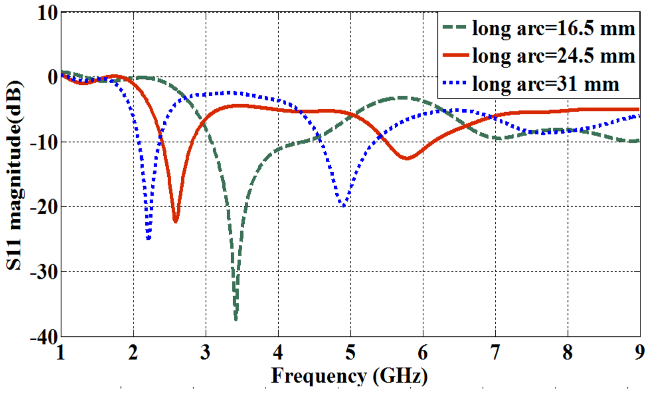


Figure 5. Reflection coefficient curves for long part of the arc monopole antenna for various values of its length

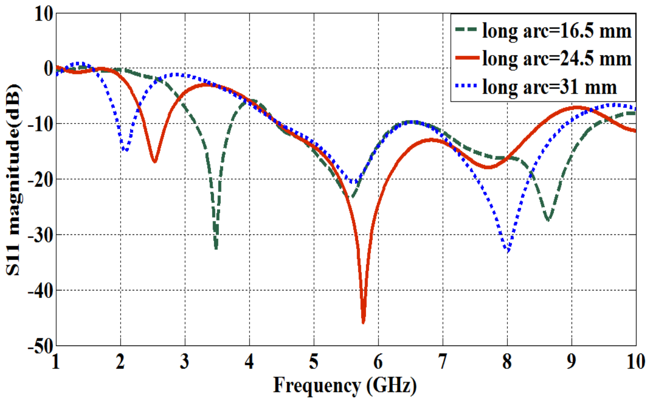


Figure 6. Reflection coefficients versus frequency for crescent shape monopole antenna for various lengths of long part of the arc

3.1.2. Effect of the Length of Short Arc

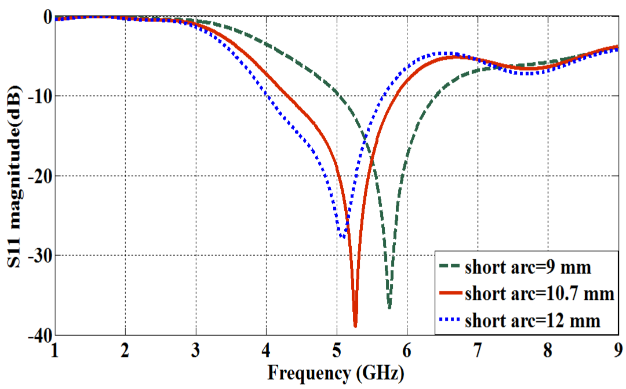


Figure 7. Reflection coefficient curves for short arc monopole antenna for various lengths

Figure 4.b shows the geometry of the short arc monopole, while Fig. 7 shows the obtained reflection coefficient curves for this part of the arc monopole antenna for various lengths of short arc. It can be seen from Fig. 7 that, with increasing the length of short arc from 9mm to 12mm, the resonance frequency decreased from 5.74GHz to 5.1GHz. When the length was set to 9mm, 10.7mm and 12mm, the corresponding frequency bands were found to be 4.99-6.4GHz, 4.3-5.84GHz and 4-5.67GHz respectively. Figure 8 shows the reflection coefficient curves for the crescent shape monopole antenna for various lengths of short arc. It can be seen that, increasing the length of short arc from 9mm to 12mm, the second band is shifted down from 5.22.

GHz at length=9mm to 4GHz at length=12mm. This leads to an increase in bandwidth from 3.392GHz at length=9mm to 4.5GHz at length=12mm. The lower band shows a slight change in bandwidth. It can be concluded that, the resonance frequency of the upper band is specified by the length of short arc monopole antenna, which also controls the start of the second operation band.

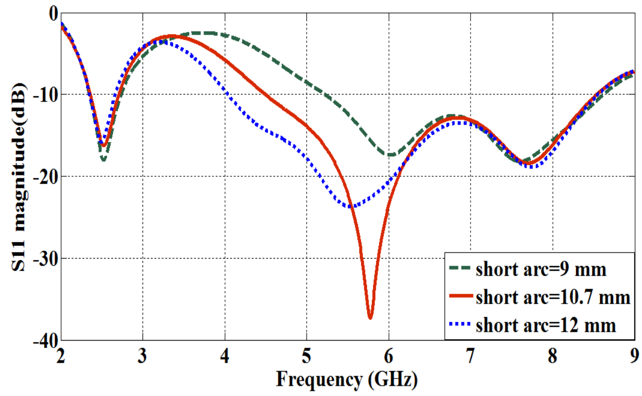


Figure 8. Reflection coefficient versus frequency for crescent shape monopole antenna for various lengths of short arc

3.2. Effect of the Arc Width

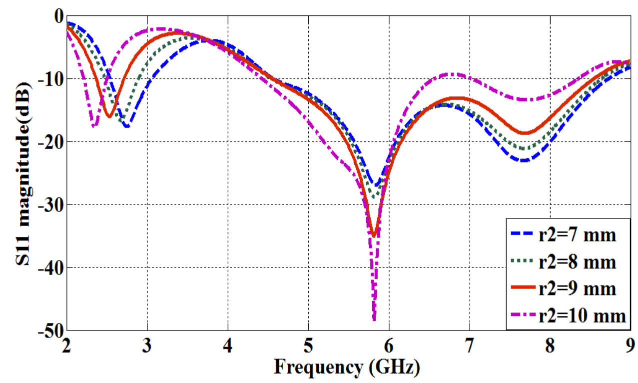


Figure 9. Reflection coefficient versus frequency for various values of arc width (w=4.5mm, 3.5mm, 2.5mm, 1mm)

Referring to Fig. 1, the width of the arc can be varied by changing the value of one or two of the radii r_1, and r_2. The value of the radius r_2 was varied in this study, so that to keep length/height of the monopole constant, and the resulting reflection coefficient is shown in Fig. 9. It can be seen that, when increasing the value of r_2 from 7mm to 10mm, the width of the arc decreased from 4.5mm to 1.5mm. The bandwidth also decreased. The resonance frequency of the first band is shifted down from 2.75GHz at r_2=7mm to 2.35GHz at r_2=10mm. This can be attributed to the fact that, the average lengths of two parts of the arc (long part and short part) are increased slightly as the width of the arc is decreased. The upper band showed little effect on its center frequency, but noticeable change in its bandwidth.

3.3. Effect of the Thickness of Dielectric Substrate

The proposed antenna, whose dimensions are shown in Table 1, was tested for various substrate thicknesses of 0.8mm, 1mm and 1.6mm. From the obtained results that are shown in Fig. 10 and Table 2, it can be seen that, as the substrate thickness increases, the frequencies of both bands decrease. This is due to the fact that as the substrate thickness increases, more portion of the electric field under the conducting structure fringes out leading to increased effective lengths, which result in lower frequencies. An alternative explanation is that the effective dielectric constant of the substrate increases slightly and produces a decrease in resonance frequency. The bandwidths of both bands show little increase, apart from that of the upper band which exhibited large change for the larger substrate thickness (h=1.6mm).

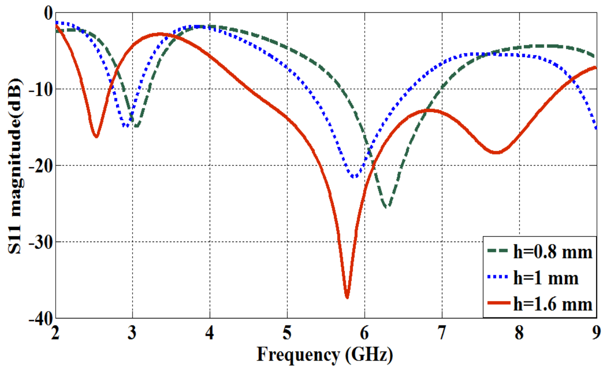
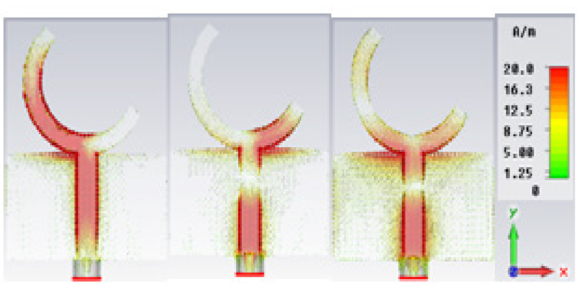


Figure 10. Reflection coefficient versus frequency for various values of the substrate thickness (h)

Table 2. Comparison of the frequency response characteristics of proposed antenna for various values of the substrate thickness

h (mm)	Frequency range (GHz)	Resonance frequency (GHz)	S_{11}(dB) 1st Band 2nd Band	B.W (MHz) 1st Band 2nd Band
0.8	2.87-3.2 5.69-6.99	3.026 6.288	-14.72 -25.52	330 1300
1	2.74-3.08 5.24-6.59	2.88 5.86	-14.78 -21.55	350 1350
1.6	2.35-2.7 4.486-8.5	2.5 5.76	-16.2 -37.2	350 4014

3.4. Current Distributions & Radiation Patterns



(a) 2.44GHz (b) 5.25GHz (c)5.775GHz

Figure 11. Surface current distributions of the proposed dual band crescent monopole antenna, at the indicated frequencies

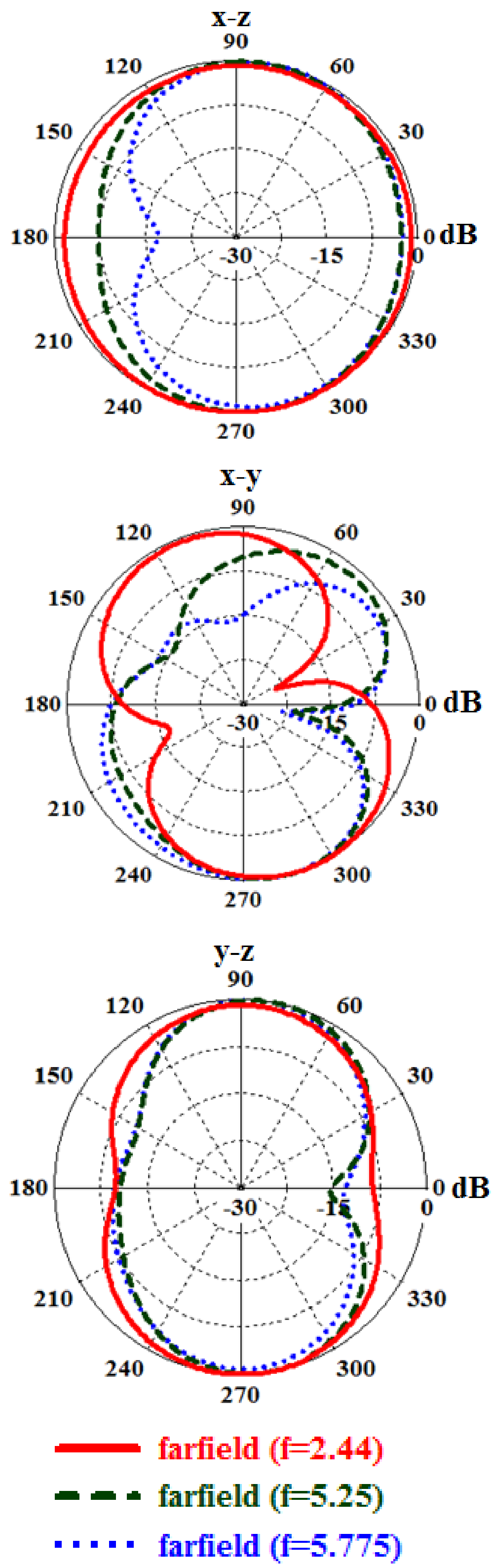


Figure 12. The simulated radiation patterns in the three principal planes for the dual band crescent shape monopole antenna

Figure 11, illustrates the calculated surface current distributions at three operating frequencies of 2.44 GHz, 5.25GHz and 5.775GHz. The surface current at 2.44GHz is mainly distributed along the edges of the long arc as well as the feed line, which means that the longer part is resonating at the lower frequency. The surface current at 5.25 GHz frequency is mainly distributed along the edges of the short arc as well as the feed line, while very little current distribution is observed along the long arc. This proves that the shorter arc resonates at the upper band, while the longer arc resonates at the lower frequency. When the frequency is increased to 5.77GHz, the surface current is still rich on the shorter arc. There is also some current density on part of the longer arc nearest to the feed line. These results also verify that the conclusions of section 3.1 that the long arc influences the lower frequency band, while the short arc controls the upper frequency band.

The obtained polar far-field radiation patterns for the proposed antenna are shown in Fig. 12 at the frequencies.

2.44GHz, 5.25GHz, and 5.775 GHz. The shown shapes correspond to a typical monopole-like omnidirectional radiation pattern especially for the XZ-plane. The pattern in the XY-plane shows some asymmetry since the crescent radiating patch is not symmetrical with respect to the Y-axis.

4. Comparison of Obtained Results with Those of Published Works

The performance of the proposed antenna is compared with those of the recently reported WLAN antennas [10,12,14,15,17,20], with respect to antenna size, gain and bandwidth as shown in Table 3. It can be seen from Table 3 that the area of the proposed antenna is slightly larger than the antennas reported in[12,14,15,20], but smaller than that for the antennas reported in[10,17]. The bandwidth of the first band is less than that of most of the reported antennas. At the higher frequency band the proposed antenna is providing better bandwidth compared to the other indicated ones. At the lower frequency band, the proposed antenna has higher gain than those reported in[12, 14, 20]. At the higher frequency band, the proposed antenna has higher gain than those reported in[10,12,20]. The proposed antenna is shown to provide a moderate gain compared to existing published antenna structures.

5. Conclusions

The design and analysis of a dual band crescent shape planar monopole antenna for wireless local area network (WLAN) application has been demonstrated. The crescent antenna is evolved from an arc patch antenna. The lower and higher resonant frequencies can be tuned, at will, simply by adjusting the lengths of the two parts of the arc, and/or positioning of the feed line. The antenna showed dual band of operation at 2.4 GHz and 5.2 GHz frequencies and thus can be used for WLAN applications. The designed antenna satisfies VSWR requirement that is less than 2.0 in the two frequency bands (from 2.36 to 2.7 GHz for the first band and from 4.46 to 8.535 GHz for the second band).

It has been shown that the antenna operation is influenced by number of parameters; like arc lengths (long arc and short arc), arc width and the thickness of the dielectric substrate. The influence of these parameters on the antenna performance was investigated, and how the change of different antenna parameters impacts the frequency response and bandwidth of the antenna. The antenna has very low return loss and adequate impedance bandwidth at both bands and especially at the upper resonance frequency.

Table 3. Performance comparison of the proposed antenna with other antennas in the literature

Ref.	Dimensions (mm)	Area (mm^2)	Frequency range(GHz)	BW (MHz) 1st Band 2nd Band	Gain (dB_i) 1st Band 2nd Band
10	42.4*48*0.76	2035	2.184-2.587 3.88-7.884	403 4004	2.5 3.4
12	31*21*1.6	651	2.33-2.83 4.3-6.67	500 2370	2.02 2.52
14	24*24*1.6	576	2.29-2.66 4.22-7.1	470 1610	2.2 4.2
15	42*25*1	1050	2.37-2.720 4.920-6	350 1080	2.79 4.36
17	50*50*1.6	2500	2.384-2.991 4.959-6.41	607 1451	2.4 4.8
20	26*37*1.6	962	2.29-2.6 3.9-7.27	410 2690	1.5 3.6
This work	28*38*1.6	1064	2.363-2.705 4.46-8.535	342 4075	2.3 3.98

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