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Design of Compact Dual-Band Planar Antenna for WLAN Systems

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Abstract**—**A compact planar monopole antenna with dual-band operation suitable for wireless local area network (WLAN) application is presented in this paper. The antenna occupies an overall area of 18 ×12 mm^2. The antenna is fed by a coplanar waveguide (CPW) transmission line and it combines two folded strips, which radiates at 2.4 and 5.2 GHz. In the proposed antenna, by optimally selecting the antenna dimensions, dual-band resonant modes with a much wider impedance matching at the higher band can be produced. Prototypes of the obtained optimized design have been simulated using EM solver. The simulated results explore good dual-band operation with -10 dB impedance bandwidths of 50 MHz and 2400 MHz at bands of 2.4 and 5.2 GHz, respectively, which cover the 2.4/5.2/5.8 GHz WLAN operating bands. Good antenna performances such as radiation patterns and antenna gains over the operating bands have also been observed. The antenna with a compact size of 18×12×1.6 mm^3 is designed on an FR4 substrate with a dielectric constant of 4.4.

Keywords**—**CPW fed antenna, dual-band, electromagnetic simulation, wireless local area network, WLAN.

I. Introduction

WITH the fast development of wireless communication systems, there is high demand to increase the data rate of wireless communication systems [1]. WLAN systems like Bluetooth, WiFi, ZigBee always operate in 2.4 GHz ISM band. The growing demand for WLAN technology has led to an interest in integrating the 2.4 GHz (IEEE802.11b/g) and 5.2 GHz (IEEE 802.11a) frequency bands into a single device that requires a dual-band antenna. WLAN system of WiFi has a broad band at the operating frequency of 2.4 GHz and 5.2 GHz. WLAN antenna not only has a wider frequency band but also has a high radiation efficiency [2]. Due to space limitation, WLAN system should have multi-band and compact antennas [3]. At present, extensive studies of dual-band microstrip antennas applied in WLAN have been carried out, and various promising antennas which work in a dual-band have been put forward, such as Planar Inverted-F antennas [4]-[6], Planar Monopole antennas [7], Dipole antennas [8], dual-monopole antenna with different lengths [9] or sleeves [10], a bent folded monopole [11], slot antenna [12], [13]. These antennas are simple in structure and low in production cost, which is suitable for the use of WLAN devices. However, the designs of the antenna may increase cost or are complicated to be fabricated or the overall dimensions of the antenna are large. In the design of multi-band antenna, one critical technique is to reduce the radiation caused by the currents distributed on the ground plane to improve the radiation patterns, impedance bandwidth [14]. Multi-band antennas are also researched a lot. CPW fed antennas show better behavior for the wireless applications.

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To cover all the three bands of WLAN, i.e. lower band of 2.4 GHz (802.11b/g standard) and upper bands of 5.15-5.35 GHz and 5.725-5.825 GHz (802.11a standard), two monopoles are used; one working for the lower band and other working for the higher band [15]-[17]. However, there is a limit in most of these antennas to obtain the wideband characteristic especially at 5 GHz band for WLAN applications operating simultaneously at 5.2 and 5.8 GHz. Similarly, several dual-band slot antennas were proposed for 2.4/5.2 GHz WLAN bands [18]-[26]. Though the reported antennas cover all 2.4/5 GHz WLAN bands, they are not very compact in size. Therefore, there is a demand for designing compact multi-band antennas. Table I shows the comparison of antenna size and operating bands of the proposed antenna with antennas reported in [14]-[27]. This paper presents the design of a dual-band planar antennas using EM solver, which works on the concept of Finite Element Method (FEM). The EM simulation results show that the antenna has a satisfactory performance.

The rest of the paper is organized as follows. In Section II, the paper presents antenna design. Mathematical modeling of the antenna is presented in Section III. In Section IV, a parametric study of dual band monopole antenna is carried out. Section V shows all simulated results of the antenna and finally proposed work is summarized in Section VI.

II. Antenna Design

The geometry of the proposed antenna is shown in Fig. 1. The radiator and ground plane of the antenna are etched on a piece of printed circuit board with an overall size of 18 x 12 x 1.6 mm^3. The antenna has two monopole arms resonating at 2.4 GHz and 5.2 GHz. The antenna model consists of a coplanar ground plan, a radiation structure, and a feed line. A CPW transmission line of 50 Ω, which consists of a signal strip width of 2 mm and a gap distance of 0.3 mm between the single strip and the coplanar ground plane, is used for feeding the antenna. In addition, a parametric study of the antenna might be referential for antenna engineers.

The antenna is designed by EM simulation software, EM solver. The dimensions of the proposed antenna are shown in Table II. The antenna is printed on the FR4 antenna substrate with a relative dielectric constant of 4.4. The size of the substrate is W and L; the thickness is 1.6 mm. The ground plane of the antenna is printed on the same side of radiating element, whose length and width are represented by L1, W1, and W2, respectively. The antenna is fed by a CPW line with a characteristic impedance of 50 W, and the size of the microstrip line is Wf x Lf. The radiating element of the antenna is composed of two rectangular strips. The detailed dimensions of the printed monopole antenna elements and design parameter of radiating arm-1 and radiating arm-2 are given in Table I.

TABLE I
COMPARISON OF PROPOSED ANTENNA PERFORMANCE WITH OTHER COMPACT ANTENNAS

S. No	Source	Antenna Size (mm^2)	Total area occupied by the antenna (mm^2)	Frequency bands covered
1	[14]	25 x 25	625	2.4/5.2/5.8 GHz
2	[15]	40 x 20	800	2.45/5.2/5.8 GHz
3	[16]	33 x 28	924	2.4/5.2/5.8 GHz
4	[17]	22 x20	440	2.4/5.2 GHz
5	[18]	75 x 75	5625	2.4/5.2/5.8 GHz
6	[19]	50 x 75	3750	2.4/5.2 GHz
7	[20]	60 x 45	2700	2.4/5.2/5.8 GHz
8	[21]	43 x 41	1763	2.4/5.2/5.8 GHz
9	[22]	50 x 35	1750	2.4/5.8 GHz
10	[23]	40 x 40	1600	2.4/5.2/5.8 GHz
11	[24]	35 x 24	840	2.4/3.4/5.2/5.8 GHz
12	[25]	26 x 25	650	2.4/5.2/5.8 GHz
13	[26]	32 x 16	512	2.4/5.2/5.8 GHz
14	**Proposed Work**	**18 x 12**	**216**	**2.4/5.2/5.8 GHz**

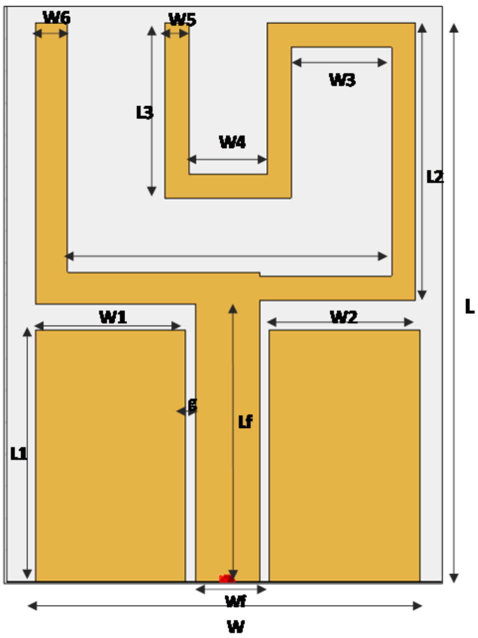


Fig. 1 Geometry of the proposed antenna

Each radiating element is folded and is fed with a CPW located at a distance offset from the middle of the loop. The lengths of the strips should be integer multiples of half the effective wavelength λ_{eff} at the desired frequencies to form resonant antennas. The electrical length of the whole monopole strip is equivalent to the quarter wavelength of the lower frequency band of 2.4 GHz (from point A to the open end at point G). The L-shape branch (from point E to point G), which is a part of the folded loop, is mainly to generate the higher frequency band of 5.2 GHz. The resonant quarter wavelength is obtained by adjusting the feeding network location. Further, the antenna element has been purposely folded not only to reduce the antenna physical dimension but also to reduce the coupling effect between antenna elements. At lower frequency, the quality factor Q for such a resonator is high due to the limited size of the radiation apertures at two open ends and the high Q leads to limited operation bandwidth.

The size of the antenna is mainly determined by the size of the monopole governing the lower band of WLAN application. The impedance bandwidth and resonant frequencies obtained can be varied by variation in the dimensions of folded strips. The width of feed line has been fixed at 2 mm to provide 50-ohm impedance matching. The antenna has a bandwidth of 40 MHz at 2.4 GHz and 2700 MHz at 5.2 GHz, the maximum gain for a signal operating an element of the proposed antenna is -0.16 dBi at 2.4 GHz and 2.1 DBi at 5.2 GHz.

TABLE II
OPTIMIZED PROPOSED ANTENNA PARAMETERS

Sr. No	Parameters	Value(mm)
1	L	12
2	W	17.5
3	Wf	2
4	Lf	8.7
5	g	0.3
6	L1	7.9
7	L2	8.67
8	L3	5.49
9	W1	4.7
10	W2	4.7
11	W3	3.13
12	W4	2.45
13	W5	0.75
14	W6	1

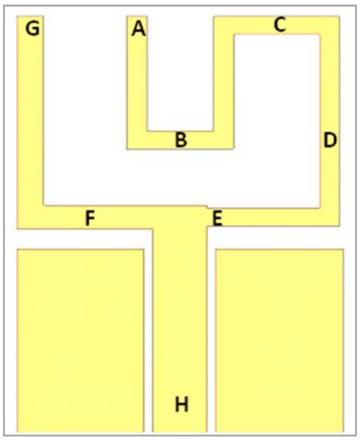


Fig. 2 Workflow of PI analysis

III. Mathematical Modelling

The antenna can be represented by an equivalent circuit of several lumped elements. This approach is based on foster canonical forms that describe the antenna frequency characteristics. Foster canonical forms as shown in Fig. 2, which assumes that no omics loss can be used to represent antenna's input impedance because antennas are linear, passive elements. Dipole and monopole antennas are electric antennas, for modeling electric antennas which behave as an open circuit at DC input signal, Foster canonical form is suitable [29]. The antenna input impedance Zin(ω) is modeled by means of the equivalent network depicted in Fig. 2

$$Z_{in}(\omega) \cong j\omega L_0 + \frac{1}{j\omega C_0} + \sum_{n=1}^{N_{max}} \frac{R_n}{1+jQ_n(\frac{\omega}{\omega_n} - \frac{\omega_n}{\omega})}$$

where $Q_n = \omega_n R_n C_n$ and $\omega_n = (L_n C_n)^{-0.5}$. N_{max} is the number of modes needed to properly describe the frequency behavior of the antenna input impedance. ω is the operating radian frequency, and ω_n is the radian frequency of the nth resonant mode. C_0 is the quasi-static input capacitance, and L_0 is an inductance that considers the higher order modes as well as for feeding effects, while C_n, L_n, R_n and Q_n are the capacitance, inductance, resistance, and quality factor, respectively, describing the lumped resonance processes that take place in the antenna structure [28].

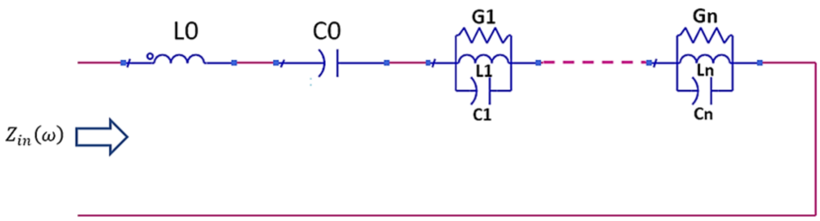


Fig. 3 Foster canonical forms of the equivalent circuit for antenna

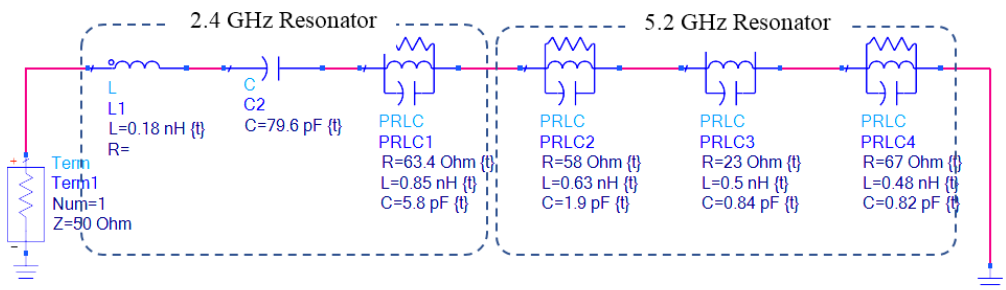


Fig. 3 Equivalent lumped-elements circuit model for antenna in ADS

The antenna equivalent circuit model with actual components is shown in Fig. 3. The values of resistors, capacitors, and inductors are extracted from the ADS simulation results, where these values are adjusted manually to obtain the proper response. C0 and L0 represent the capacitance and inductance of the monopole antenna when the antenna operates at a lower frequency and are properly chosen to resonate at the first resonance frequency of the antenna. Fig. 4 shows the reflection coefficient curves of the considered antenna as obtained from equivalent lumped element circuit model in ADS.

IV. Antenna Design Parametric Study

A series of parametric studies were conducted to achieve the desired antenna performance, particularly tuning the resonant frequencies and impedance levels. In this process, the optimized critical antenna parameters were the resonating length of strips and width of the strip. A complete parametric analysis is performed for different parameter values by varying one parameter and keeping all the other parameters as constant.

A. Influence of Variation of Straight Strip Length 'L2'

The effect of 'L2' was investigated keeping other parameters constant. The study was carried out for 'L2' values of 12 mm, 15 mm, 19 mm and 22 mm. Fig. 5 shows that 5.2 GHz resonant frequency depends on the parameter L2 and the second resonance frequency 2.4 GHz is almost independent of the variation in L3. Variation in the value of L2 from 12 mm to 22 mm leads to shifting in first resonant frequency from 6.5 GHz to 4.5 GHz. The longer the L2 shifted resonating frequency below 5.2 GHz while shorter L2 shift frequency above 5.2 GHz.

B. Influence of Variation of Straight Strip Length 'L3+L4'

Fig. 6 shows the antenna return loss (S11) with a different value of length L3+W4. As it is shown in Fig. 6, the performance and antenna resonance frequency of low band will be in changed if the length (L3+W4) is increased or decreased. However, the high band is not much changing around 5.2 GHz. The 2.4 GHz frequency is mainly determined by L3+W4 length of the strip. The frequency shifts lower obviously as the length of this strip increases. Variation in the value of L3 from 22 mm to 32 mm in step size of 3 mm leads to shifting in first resonant frequency from 3.2 GHz to 2.2 GHz.

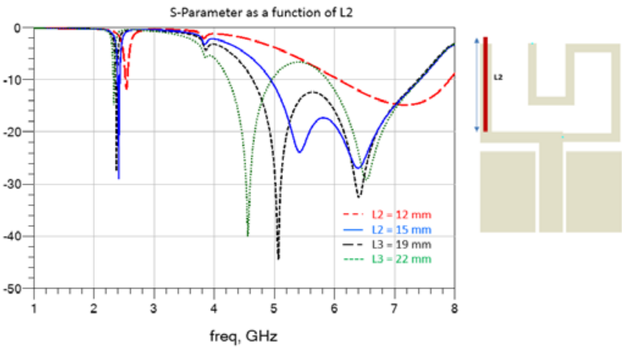


Fig. 5 S-parameter result as a function on length L2 (12 mm, 15 mm, 19 mm and 22 mm)

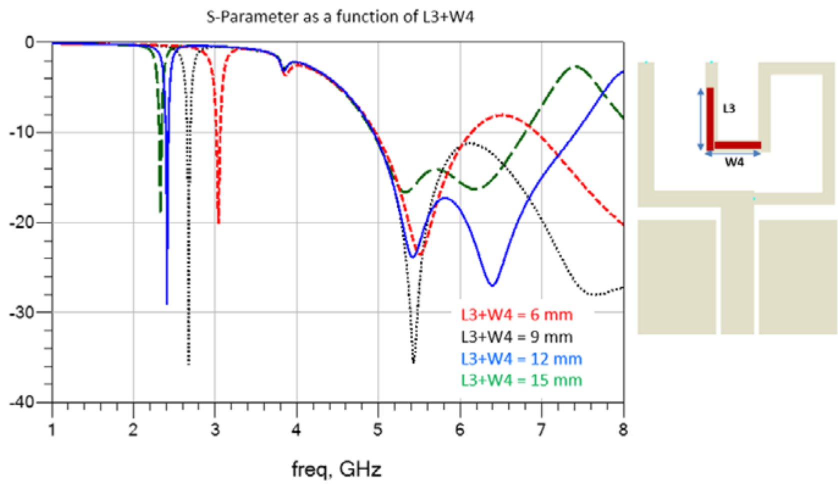


Fig. 6 S-parameter result as a function on length L3+W4 (6 mm, 9 mm, 12 mm and 15 mm)

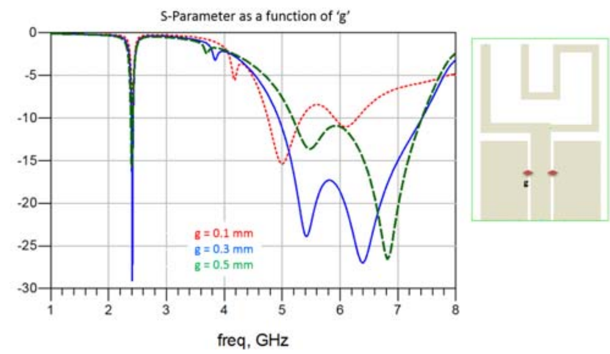


Fig. 7 S-parameter result as a function on length g (0.1 mm, 0.3 mm and 0.5 mm)

C. Influence of Variation of CPW Feed Line Gap with Coplanar Ground 'G'

Fig. 7 shows the antenna return loss (S11) with different value of the gap between CPW feed line and coplanar grounds. Variation of 'g' is not shifting resonance frequency significantly but the performance and antenna resonance frequency of high band is changing if the g is increased or decreased. Optimum antenna performance is achieved with g = 0.3 mm.

V. Simulated Result

This section provides simulation results of dual-band CPW-fed monopole antenna.

A. S-Parameter Result of Optimized Design

The simulated return loss of optimized antenna is shown in Fig. 8; it shows clearly that two operating bands are generated in 2.4 GHz and 5.2 GHz. The antenna elements resonated between 2.37 – 2.42 GHz and 4.9 –7 GHz with a minimum |S11| < -10 dB. The optimized antenna gives a bandwidth of about 40 MHz over a lower band of 2.4 GHz and about 2.7 GHz over an upper band of 5.2/5.8 GHz which is well compatible with the 802.11n WLAN standard.

Simulated input impedance curve as the function of frequency is shown in Fig. 9. It is observed that at resonant frequency 2.4 GHz, antenna provides an input impedance of value 53.45 + j 22.12 ohm which is close to impedance provide by feed line, similarly at 5.2 GHz this value is 52.16 + j 30. The simulated VSWR and input impedance variations indicate good impedance matching between the feed line and antenna structure.

B. Electrical Field Plot

The electric filed distributions with respect to the two frequencies of 2.4 GHz and 5.2 GHz are shown in Figs. 10 (a) and (b), respectively. At the red region, the current has increasingly larger value. Conversely, moving toward the blue region, the current has increasingly smaller value.

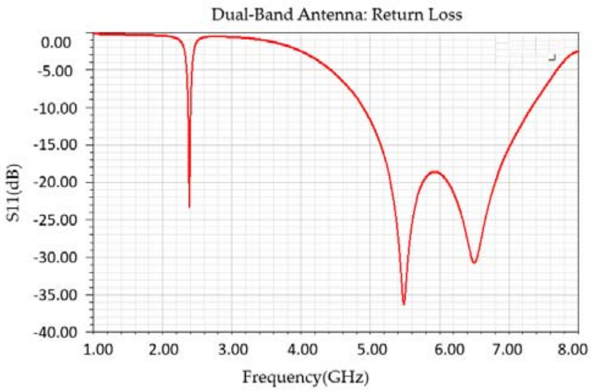


Fig. 8 The simulated antenna return loss (S11) plot with optimized antenna dimension values in EM solver

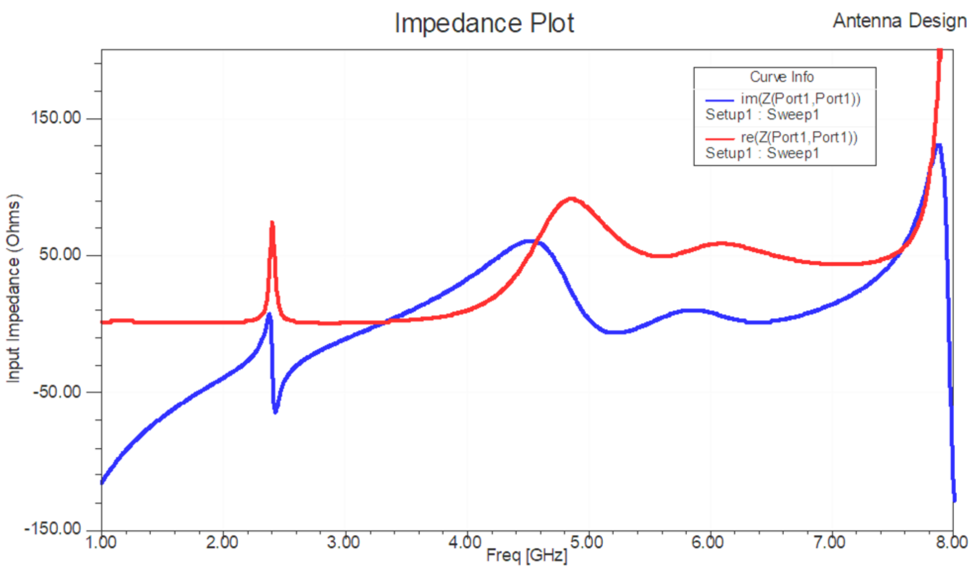
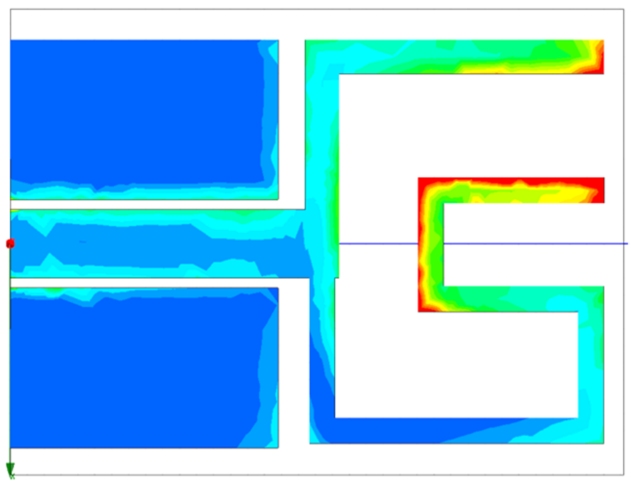
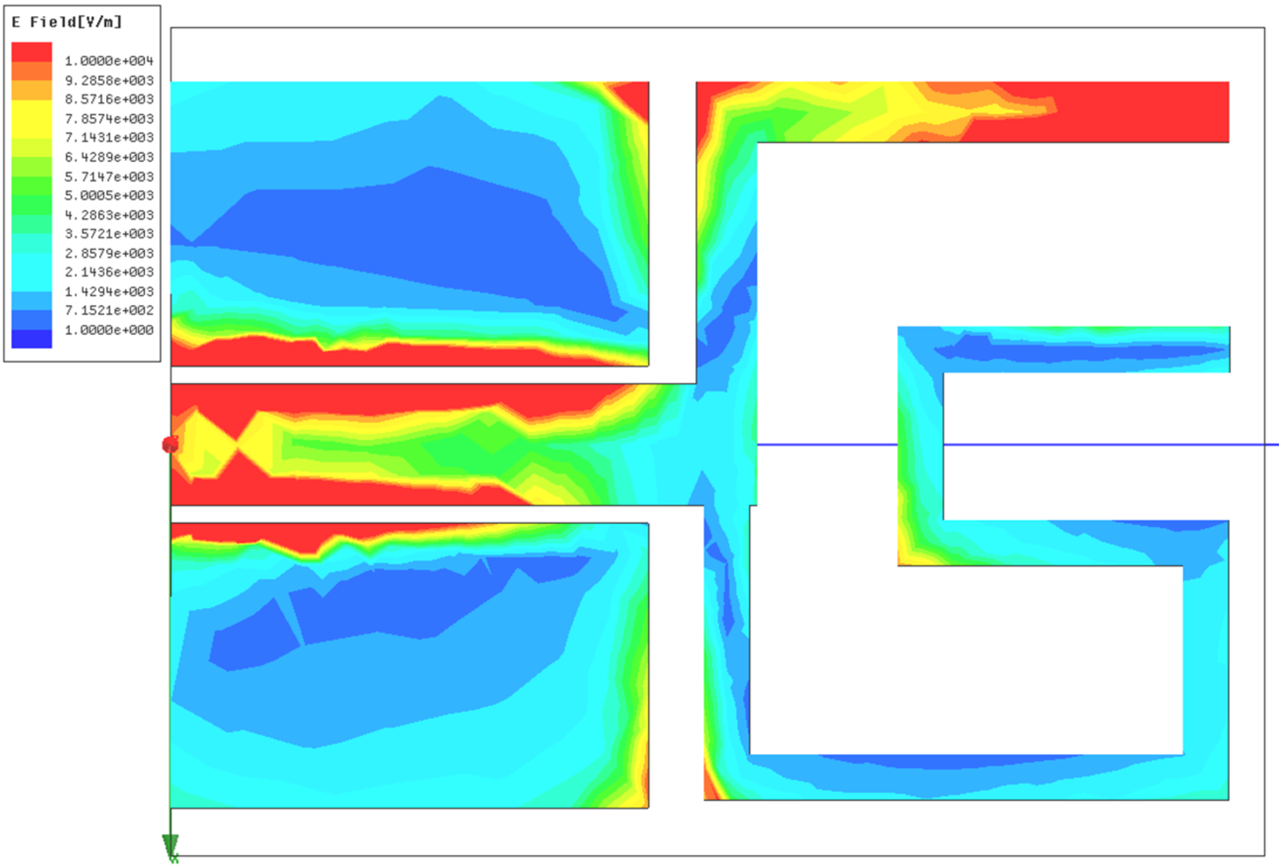


Fig. 9 Simulated input impedance plot for CPW-fed parasitically loaded circular monopole antenna



(a)



(b)

Fig. 10 Simulated E-Field distribution for CPW-fed monopole antenna (a) E-filed plot at 2.4 GHz (b) E-filed plot at 5.2 GHz

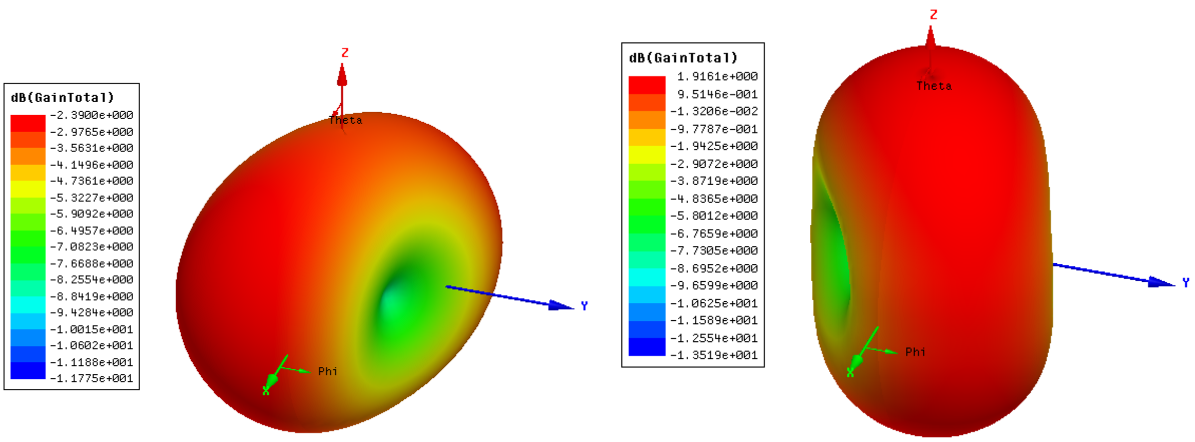


Fig. 11 Simulated 3D Antenna Radiation patter at resonant frequency 2.4 and 5.2 GHz

It is observed that at the resonance frequency, the monopole works as an antenna generating strong surface current mainly on the edge of the strip. In addition, a significant current distribution is also observed along the two straight strips edges. In this antenna design, the ground plane and CPW-fed line affect antenna input impedance. Surface currents appeared on the inner side of CPW-feed line and the ground plane outer side edges. The currents on the two side edges of the ground plane have the same phase with those along the CPW-fed line thus enhancing the co-polarization radiation in the far-field zone.

C. Antenna Radiation Pattern

Simulation result of antenna radiation pattern is shown in Fig. 11. In addition, simulated radiation patterns in two principal planes (xz – plane and yz – plane) at resonant frequency 2.4 and 5.2 GHz are presented in Fig. 11. The radiation pattern is nearly omnidirectional for both bands that is shown in Fig. 12 2D cut of radiation pattern.

The antenna radiation pattern shows a broadside pattern over entire bandwidth with a maximum gain of about 2.1 dBi. The gain of antenna is from -2.1 to 2.1 dBi. Peak antenna gain of 2.21 dBi is experienced at resonant frequency 5.2 GHz and 5.8 GHz, three working frequencies of WLAN.

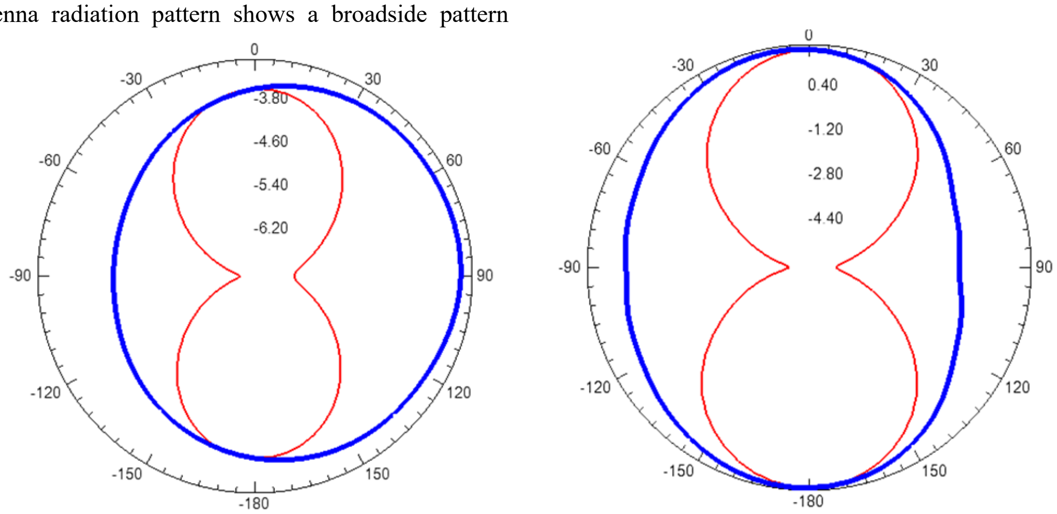


Fig. 12 Simulated 2D radiation patterns of monopole antenna at resonant frequency 2.4GHz and 5.2 GHz

VI. Conclusion

A dual band compact planar monopole antenna for WLAN application has been presented. Antenna overall size is 216 mm^3. Antenna is fed with CPW transmission line. The simulated results show that reflection coefficient, bandwidth and antenna gain are meeting desired antenna specifications. In the proposed design, all the bands are covered with −10 dB reflection coefficient or less than that. The simulated results explore good dual-band operation with -10 dB impedance bandwidths of 40 MHz and 2700 MHz at bands of 2.4 and 5.2 GHz, respectively, which cover the 2.4/5.2/5.8 GHz WLAN operating bands.

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