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Compact WLAN Monopole Antenna with L-shaped Strip Line and Spiral Line Loaded Ring Resonator

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Abstract **-** In this paper, a compact monopole microstrip antenna is presented for dual-band WLAN mobile modules operating in 2.4GHz and 5.2GHz bands. The proposed antenna design is based on direct connection of two separate microstrip resonators, one of which is in the form of spiral resonator loaded ring resonator while the other resonator is the conventional $\lambda/4$ L-shaped strip resonator. The overall size of the antenna is $0.08\lambda_0$ x $0.16\lambda_0$ at 2.4GHz resonance frequency. The reflection coefficient, S11 of the antenna is smaller than -10dB between 2.37GHz and 2.43GHz with 60MHz bandwidth in the lower frequency band, and between 5.01GHz and 5.41GHz with 400MHz bandwidth in the higher frequency band. The radiation efficiencies are 46%and 95% at 2.4GHz and 5.2GHz, respectively with the omnidirectional radiation pattern. The proposed antenna can be integrated into compact wireless modules operating 2.4GHz and 5.2 GHz WLAN bands.

Keywords**:** WLAN compact antenna, spiral resonator, L-shaped strip resonator, ring resonator

1. Introduction

The current technological trend in wireless communication applications concerning mobile wireless devices imposes the design requirement of compact antennas with planar resonator geometries in low-profile form for low-cost manufacturing and high integrability with printed circuit boards. On the other hand, the dual-band operability of the compact antennas within the allocated bandwidths has become a common sense for high speed data transmission enabling multifunctional services in one electronic device. The customer demands in wireless services for diverse WLAN applications have initiated different antenna structures to be designed with low-profile, light weight, flush mounted to fit into the limited physical space of portable components. Several antenna types with compatible operability to WLAN standard requirements have been developed [1-17]. In the class of well-known microstrip antennas, the planar monopole antennas have especially received much more interest than other antenna types due to their potentials satisfying desired radiation properties of dual band or multiband, wide bandwidth, and low profile for a wireless communication system[1-13]. Artificial material based antenna design is one of emerging compact microstrip antenna design methods for desired antenna radiation performance in a limited volume [14-19].

In this paper, a compact dual-band WLAN antenna composed of two strip line resonators in the form of spiral resonator loaded ring resonator and an L-shaped resonator is proposed for dual band operation. To decrease the antenna physical length, $\lambda/2$ resonance at the lower frequency is excited in a resonator configuration composed of ring and spiral resonators. The higher resonance is excited in an L-shaped resonator in the form of $\lambda/4$ resonance. The higher resonance frequency can be adjusted in an independent manner from the lower resonance frequency, which increases the design flexibility of operating bands. These two resonators are directly connected to an asymmetric feeding line. Due to the application possibility of using the proposed antenna in wireless modules, one side of the substrate is structured while remaining the other side unmetallized.

The paper is organized in the following manner. In Section II, the design principle of the proposed antenna is explained with the geometric parameters. In Section III, the numerical calculations of the reflection parameter is illustrated with the surface current distributions at the resonance frequencies to explain the antenna operation principle. The radiation patterns at the lower and higher frequency bands are also shown at three orthogonal planes.

2. Antenna Design

The proposed compact dual-band WLAN antenna is shown in Figure 1. The geometric parameters of the antenna are tabulated in Table 1.

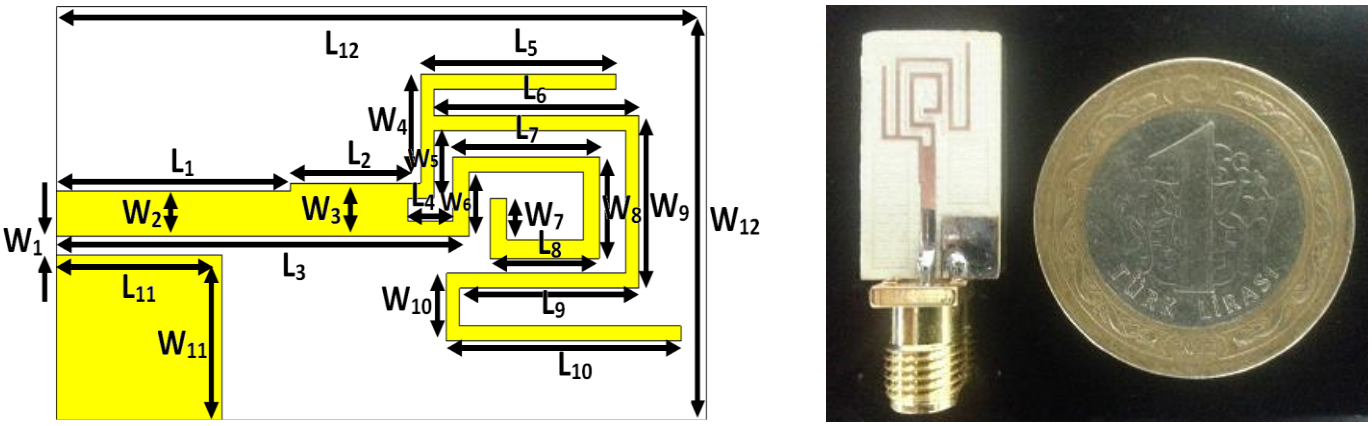


Fig. 1: The proposed compact dual-band WLAN antenna design.

Table 1: Antenna Geometric Parameters.

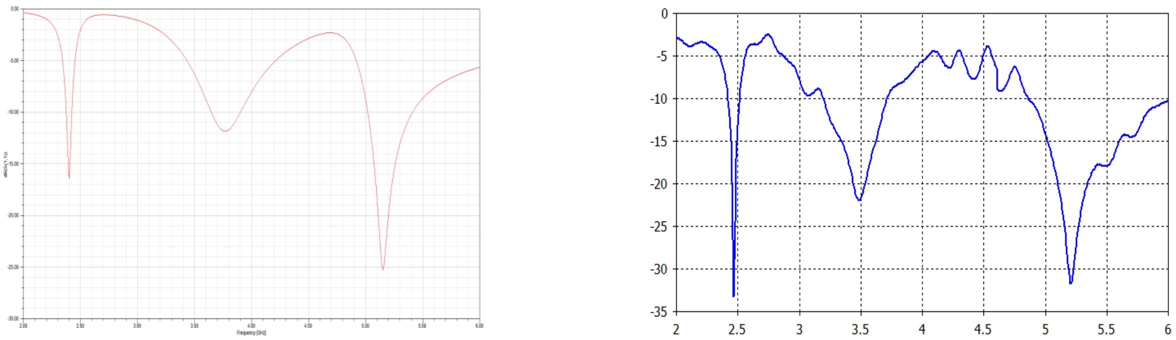
L_1 = 7.20	L_2 = 4.00	L_3 = 12.7	L_4 = 1.40
L_5 = 6.00	L_6 = 6.30	L_7 = 4.50	L_8 = 3.34
L_9 = 5.50	L_{10} = 7.20	L_{11} = 5.10	L_{12} = 20.0
W_1 = 0.50	W_2 = 1.20	W_3 = 1.40	W_4 = 2.90
W_5 = 1.80	W_6 = 1.70	W_7 = 1.10	W_8 = 2.68
W_9 = 4.60	W_{10}= 1.80	W_{11}= 4.40	W_{12} = 11.0

The proposed WLAN monopole antenna is basically composed of two microstrip line resonators on the top of 1.52mm thick FR4 substrate with the material parameters of relative permittivity 4.4 and loss tangent 0.02. These resonators are directly connected to the feeding line in the form of an asymmetric coplanar transmission line to have more efficient field coupling through the galvanic connection. The proposed antenna has the overall size of $0.08\lambda_0$ x $0.16\lambda_0$ at the lower resonance frequency.

The physical parameters of L-shaped resonator are determined to have $\lambda_0/4$ resonance at the higher frequency band. The resonance current distribution at the lower frequency band is due to $\lambda_0/2$ resonance excitation of the combination of ring and spiral resonators. In other words, the electrical length of the ring resonator is increased with the additional spiral resonator. The important point in the design is to determine at which part of the resonator has to be directly connected to the feeding line. The ground plane size and feeding line length are optimized for best return loss in two frequency bands due to the impedance transformation feature of feeding line and ground plane.

3. Numerical Computation Results

The return loss of the compact WLAN antenna is numerically calculated with commercial 3D FEM based electromagnetic field simulator HFSS. The reflection parameter is shown in Figure 2.

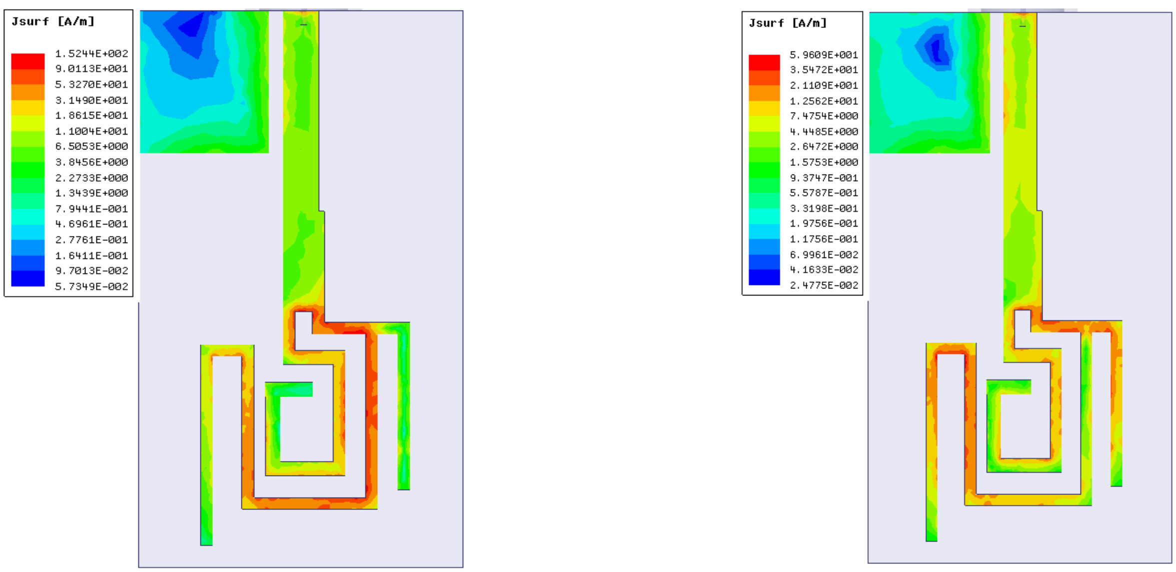


(a) (b)

Fig. 2: (a) Simulated and (b) measured reflection parameter of compact dual-band WLAN antenna.

The antenna return loss is better than 10dB in the lower frequency band between 2.37GHz and 2.43GHz with the maximum value of 16.46dB at 2.4GHz, and in the higher frequency band between 5.01GHz and 5.41GHz with the maximum value of 25dB at 5.15GHz.

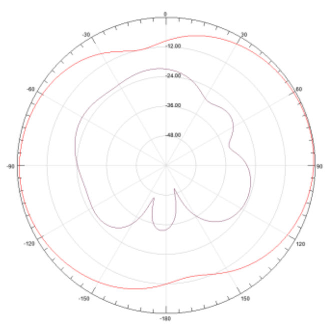
The surface current distributions at two resonant frequencies are shown in Figure 3, which indicates the main operation principle of the antenna.

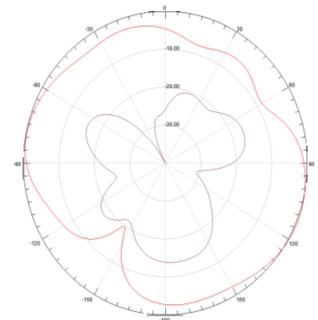


(a) (b)

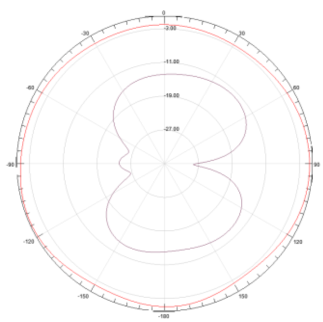
Fig. 3: Surface current distribution at (a) 2.4GHz and (b)5.2GHz.

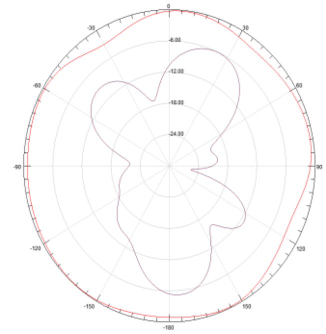
As it can be deduced from Figure 3, the surface current distribution at 2.4GHz is in the form of λ/2 resonance current distribution in the spiral and ring resonator combination. At 5.2GHz, the surface current on L-shaped strip resonator has a similar form of λ/4 resonant current distribution with the excitation of adjacent ring resonator in λ resonance mode. This is an expected consequence of λ/4 impedance transformation of open-circuited line into a short circuited line, which increases the surface current at the short circuited location. The resonant excitation of L-shaped resonator has a quite minor effect on the resonance frequency in the lower band due to the field resemblance of the resonance current distributions of spiral resonator loaded ring resonator at 2.4GHz and 5.2GHz at the antenna foot-point. It can be implied that any type of resonator geometry, designed for the higher frequency operation, which has no effect on the resonant current distribution in the lower frequency band results into the resonator decoupling. This simplifies the resonance frequency tuning of the antenna for the dual-band operation due to the independent geometric modification of decoupled resonator geometries. The normalized radiation patterns for the co- and cross-polarizations are shown in Figure 4 for each of three orthogonal planes.



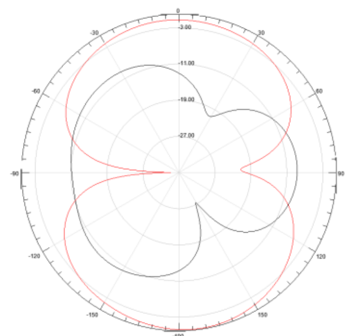


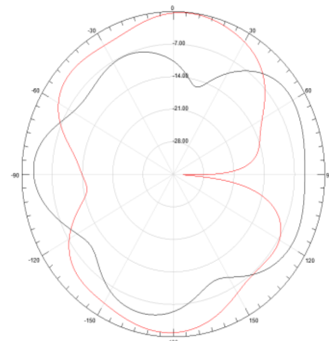
xy-plane at 2.4GHz xy-plane at 5.2GHz





xz-plane at 2.4GHz xz-plane at 5.2GHz





xy-plane at 2.4GHz xz-plane at 5.2GHz

Fig. 4: Normalized co- and cross-polarization radiation patterns on xy, yz and xz planes at 2.4 GHz and 5.2GHz.

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As shown in Figure 4, the radiation patterns are quite similar to the omnidirectional radiation patterns on xy and yz planes at 2.4GHz with maximum -24dB cross polarization level in the main beam direction. The radiation patterns at 5.2GHz have higher cross polarization levels at xy and yz planes in comparison to the radiation patterns on the same planes at 2.4GHz. However, the signal reception in dual frequency bands is accomplished with permissible co-polarization level of better than -13dB in the main beam direction at both planes. The radiation efficiencies are 46% and 95% at 2.4GHz and 5.2GHz, respectively.

4. Antenna Performance Comparison

The proposed WLAN antenna has been compared with three modified versions of a WLAN antenna composed of monopole and loop strips designed to be mounted along the hinge of the ultrabook computer for dual-band operation[12]. The design principle of the reference antenna is based on the use of grounded loop strip for $\lambda/2$ resonance and open-ended monopole strip for the wideband $\lambda/4$ resonance mode to excite for dual-band operation with the effect of electrically large metal ground plane of ultrabook computer. Because the reference antenna has been designed to operate within the top and bottom metal covers of ultrabook computer, the original form of the reference antenna has been modified into three new versions in order for the current design to be used in free space applications. The resulting additional three versions suitable for the operation without metal housing effects of ultrabook computer are shown in Figure 5 with antenna radiation parameters tabulated in Table 2.


WLAN Antenna Version1


WLAN Antenna Version2


WLAN Antenna Version3

Fig. 5: Three versions of reference antenna and proposed compact WLAN antenna.

Table 2: Antenna Geometric Parameters.

	WLAN-1	***WLAN-2***	***WLAN-3***	***Current Antenna Design***
-10 dB bandwidth	110MHz (2.34GHz - 2.45GHz) 600MHz (4.74GHz - 5.34GHz)	130MHz (2.47GHz - 2.60GHz) 570MHz (5.08GHz - 5.65GHz)	S11 (-8.74dB at 2.47GHz -8.58dB at 5.79GHz) unmatched	60MHz (2.37GHz - 2.43GHz) 400 MHz (5.01GHz - 5.41GHz)
Radiation Efficiency	77% at 2.4GHz 93% at 5.3GHz	93% at 2.4GHz 94% at 5.4GHz	81% at 2.4GHz 81% at 5.8GHz	46% at 2.4GHz 95% at 5.2GHz
Directivity	1.85dBi at 2.4GHz 3.88dBi at 5.3GHz	2.08dBi at 2.4GHz 3.75dBi at 5.4GHz	1.66dBi at 2.4GHz 4.69dBi at 5.8GHz	2.43dBi at 2.4GHz 3.76dBi at 5.2GHz
Gain	0.73dBi at 2.4GHz 3.58dBi at 5.3GHz	1.78dBi at 2.4GHz 3.5dBi at 5.4GHz	0.58dBi at 2.4GHz 3.78dBi at 5.8GHz	-0.96dBi at 2.4GHz 3.57dBi at 5.2GHz
Antenna size	$0\lambda 216\ \lambda_0$ x 0.236 . $_0$	$0\lambda 216\ \lambda_0$ x 0.236 . $_0$	$0\lambda 216\ \lambda_0$ x $0\lambda 180\lambda_0$	$0\lambda 16\lambda_0$ x 0.08 λ_0

5. Conclusion

This paper presents the design and operation principles of a compact monopole microstrip antenna for dual-band WLAN operations in 2.4GHz and 5.2GHz bands. The antenna has 60MHz bandwidth between 2.37GHz and 2.43GHz in the lower frequency band, and 400MHz bandwidth between 5.01GHz and 5.41GHz in the higher frequency band. The radiation efficiencies are 46%and 95% at 2.4GHz and 5.2GHz, respectively with an omnidirectional radiation pattern at two orthogonal planes. The proposed monopole WLAN antenna has been compared with three new versions of a reference antenna in terms of antenna parameters in addition to antenna compactness. The antenna is electrically small with the overall size of 0.08. $_0$ x $0\lambda 16\lambda_0$ at 2.4GHz resonance frequency, which is at most 33% of three benchmarking antennas. The proposed antenna has lowest gain and radiation efficiency at the lower frequency with the highest directivity. The low gain at the lower frequency can be enhanced in 3dBi with the result of gain enhancement in the higher frequency band by the use of the proposed radiator geometry in 2x1 antenna array form, which results the proposed antenna even more compact than the other remaining three versions of the reference antenna. Therefore, the proposed antenna has a technical potential to be used in the transceiver modules of compact wireless devices operating in WLAN bands.

Acknowledgements

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