JOURNAL OF ELECTROMAGNETIC ENGINEERING AND SCIENCE, VOL. 17, NO. 2, 71~75, APR. 2017

http://dx.doi.org/10.5515/JKIEES.2017.17.2.71
ISSN 2234-8395 (Online) · ISSN 2234-8409 (Print)

Tunable-Slot-Type Ground Radiation Antenna with Dual Band Operation Using LC Resonator

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Abstract

A dual-band tunable-slot-type ground radiation antenna is proposed. The feeding structure consists of a coplanar waveguide and a lumped capacitor to excite currents for first- and second-order resonant modes of the ground. The resonant frequencies of both bands are controlled using a series combination of a capacitor and an inductor. The proposed design may be an attractive choice for mobile devices owing to its compact geometry and tunable operating frequencies. The measurement and simulation results of the proposed antenna show good agreement, indicating good impedance matching and radiation performance.

Key Words: Coupling, Dual Band, Ground Radiation Antenna, Impedance Matching, Tuning.

I. INTRODUCTION

As the design complexity of modern mobile devices is increasing, the room available for antennas is decreasing. Therefore, compact antennas are becoming more desirable. However, the radiation performance of antennas is greatly affected by their miniaturization [1], thereby posing a challenge for antenna designers. Furthermore, antennas in modern mobile devices need to support multiband operation. A ground radiation antenna has a small profile and good performance [2]. Various dual-band antennas have already been proposed [3–6]; for example, a loop-type ground radiation antenna has rectangular clearance in the ground plane.

Slot-type antennas [7] are relatively compact and do not require rectangular ground clearance. One slot-type antenna [8] used meandered slots for achieving dual-band operation; the number of slot turns had to be changed for frequency tuning. Behdad and Sarabandi [9] proposed a tunable dual-band slot-type antenna in which the feeding mechanism was based on an open-circuit microstrip line that was electromagnetically coupled with the slot. Ren [10] used a similar feeding technique to achieve dual-band operation. The proposed antenna is based on a coplanar waveguide (CPW) feeding technique; therefore, the antenna has a compact profile, in turn providing sufficient room to fabricate other electronic components on the same ground plane.

The feeding and slot excite suitable currents on the ground plane to produce radiation in both bands; this is called the ground radiation technique. CPW-fed compact dual-band antennas have also been reported [11–13]. However, with these antennas, the slot geometry uses the whole ground plane, thus limiting the space available for fabricating other electronic components. In our proposed antenna, an LC resonator was used to control the resonant frequency of both bands. This antenna was designed for the 2.4–2.5 and 5.15–5.85 GHz bands, and it satisfies the IEEE 802.11 (a, b, g) standards. The design was simulated using full-wave simulation software, and the measured and simulated results were found to be in good agreement.

Manuscript received October 20, 2016 ; Revised March 16, 2017 ; Accepted March 25, 2017. (ID No. 20161020-038J)

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II. ANTENNA DESIGN OPERATION MECHANISM

The proposed antenna is designed on a ground plane of size 50 mm × 25 mm, as shown in Fig. 1. FR 4 ($\varepsilon_r = 4.4$, $\tan(\delta) = 0.02$, thickness = 1 mm) is used as the substrate. The structure consists of horizontal and vertical slots of lengths 3 and 7.7 mm, respectively; both slots are 0.5-mm wide. The feeding structure consists of a 4-mm-long CPW and a capacitor C_f. The structure is located at 12.5 mm from the left corner of the ground plane. This location was decided based on the optimum coupling of the feed structure with the slot modes of lower- and higher-frequency bands. The optimum location of the feed circuit was evaluated using the reaction theorem of electromagnetic theory [14], as given below:

$$<\mathbf{H}^c, \mathbf{M}^s> = -\iiint \mathbf{H}^c \cdot \mathbf{M}^s dv = -K^s \oint \mathbf{H}^c \cdot \mathbf{dl} \qquad (1)$$

where $\mathbf{H}^c$ denotes the magnetic field due to the characteristic modes of the ground, and $\mathbf{M}^s$ is the impressed magnetic current density produced by the voltage source K^s. According to Eq. (1), magnetic coupling can be enhanced by placing the magnetic coupler into the region of the ground plane where the magnetic field is strong. The feeding mechanism of the loop-type ground radiation antenna is considered a voltage source (K^s). Therefore, the optimum location of the loop-type feeding structure is near the middle of the ground plane. Generally, the ground plane of mobile devices is rectangular. Studies have shown [3] that optimum coupling can be achieved by placing the feeding structure along the longer side of the ground plane. However, for the second-order mode, the magnetic field is the minimum at the center of the ground plane, where the slot-type structure would couple weakly with this mode. Therefore, the proposed location improves coupling with the second-order current mode while maintaining good coupling with the fundamental mode.

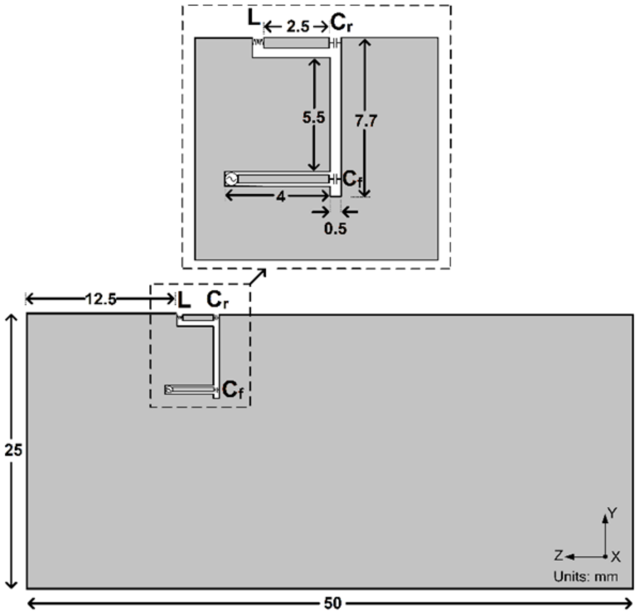
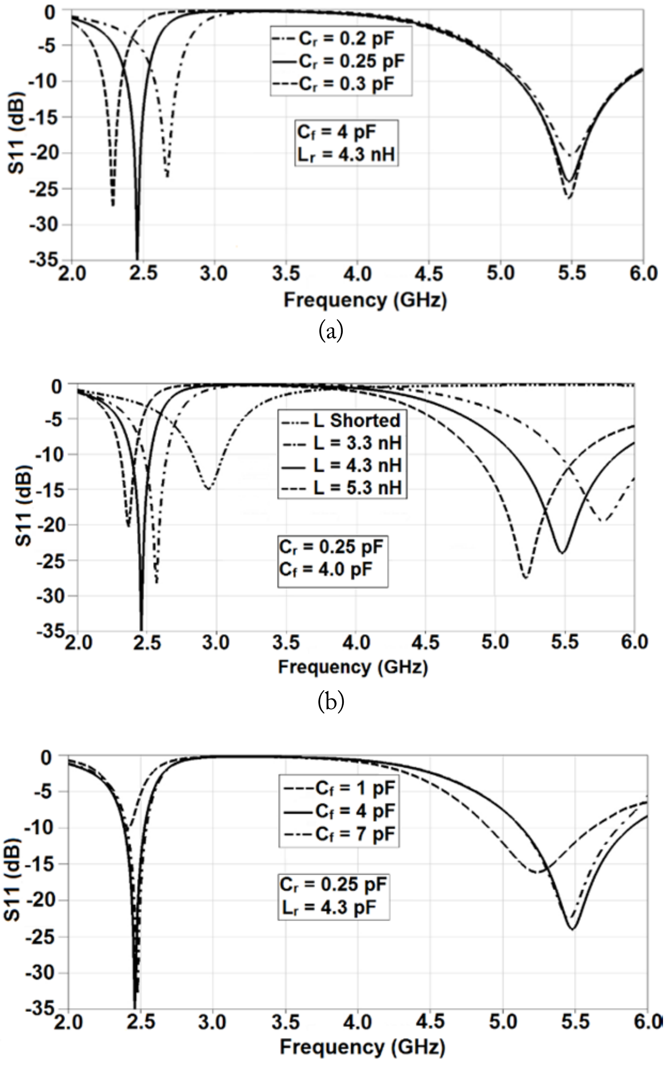


Fig. 1. Geometry of proposed antenna.

III. TUNING MECHANISM OF ANTENNA

The lower and higher resonant frequencies are controlled by the capacitor C_r and inductor L, respectively. At the lower resonant frequency, the inductor approximately acts as a short circuit; therefore, tuning and impedance matching are accomplished by C_r and C_f. The fundamental mode is excited at the lower resonant frequency, and the structure acts as a thick dipole [7]. On the other hand, at the higher resonant frequency, C_r acts as a short circuit, and thus, L controls the tuning mechanism. Loop-type currents are excited in the ground plane at the higher resonant frequency. Simulations were conducted to observe the effects of C_f, C_r, and L on the tuning and matching of the pro-



(a)

(b)

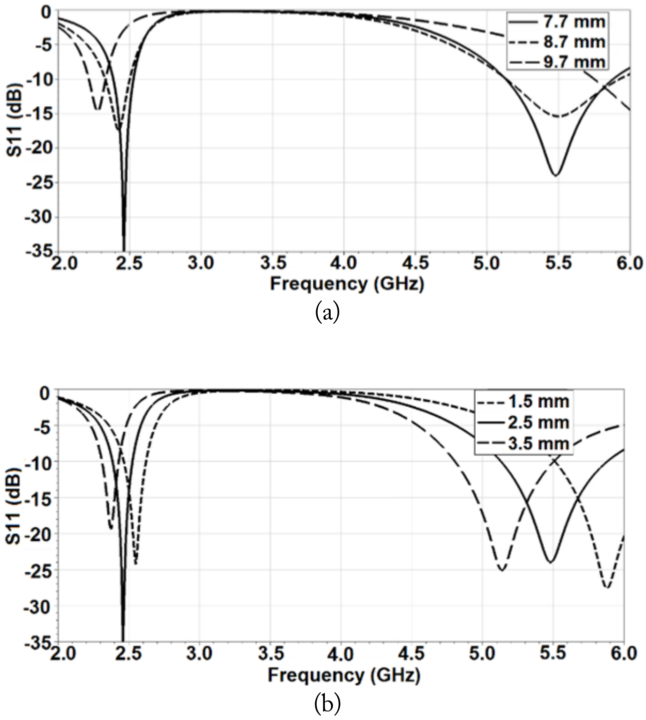
(c)

Fig. 2. Effect on return loss of antenna by (a) varying C_r, (b) varying L, and (c) varying C_f.

posed antenna, as shown in Fig. 2. Fig. 2(a) shows that increasing the value of C_r from 0.2 to 0.3 pF decreases the lower resonant frequency from 2.67 to 2.29 GHz while having little effect on the higher-frequency band. Fig. 2(b) shows that increasing the value of L from 3.3 to 5.3 nH decreases the resonant frequencies of both bands: the higher resonant frequency decreases from 5.78 to 5.22 GHz, whereas the lower one decreases from 2.57 to 2.37 GHz. Furthermore, when L is short-circuited, the second-order resonance of the structure occurs at 8.5 GHz. The inductor L is responsible for tuning the higher-order resonant frequency to the desired 5.5 GHz. Fig. 2(c) shows the effect of three values of C_f: 1, 4, and 7 pF. The matching of both bands is improved when C_f increases from 1 to 4 pF; increasing it further to 7 pF has no significant effect.

The slot has two dimensions: vertical length and horizontal length (between C_r and L_r). Simulations have been conducted to observe the effect of a change in both dimensions of the slot, and the results are shown in Fig. 3. In these simulations, the values of C_r, L_r, and C_f were fixed at 0.25 pF, 4.3 nH, and 4 pF, respectively. Fig. 3(a) shows that as the vertical length of the slot is increased, the difference between the resonant frequencies also increases, that is, the lower resonant frequency decreases and the higher resonant frequency increases. Fig. 3(b) shows that the resonant frequency of both bands is inversely proportional to the horizontal length of the slot. This means that as the horizontal length increases, the resonant frequency of both bands decreases.

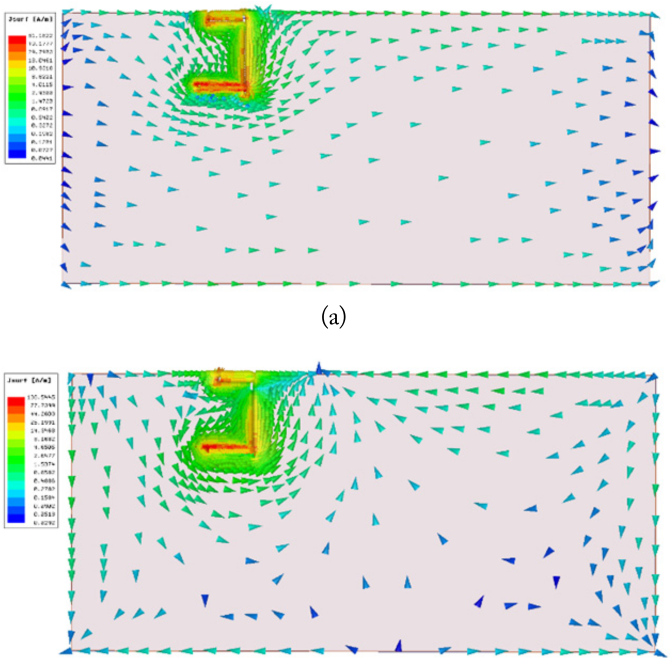
Fig. 4 shows the current distributions on the ground plane at lower and higher operating frequencies. Fig. 4(a) shows the surface current distribution at 2.45 GHz; it can be observed that loop-type currents are excited around the slot. However, a dipole-type current is excited on the ground plane, which is the fundamental current mode. Fig. 4(b) shows the surface current density at 5.5 GHz; it shows a second-order mode on the ground plane. Loop-type currents are again excited around the slot, and the second-order mode is excited on the ground plane. The current null of the second-order mode appears near the middle of the ground plane. Therefore, the proposed location of the slot, namely, away from the middle of the ground plane, is suitable for achieving good coupling with the second-order mode.



(a)

(b)

Fig. 3. Effect of change in slot dimensions: (a) vertical length and (b) horizontal length.



(a)

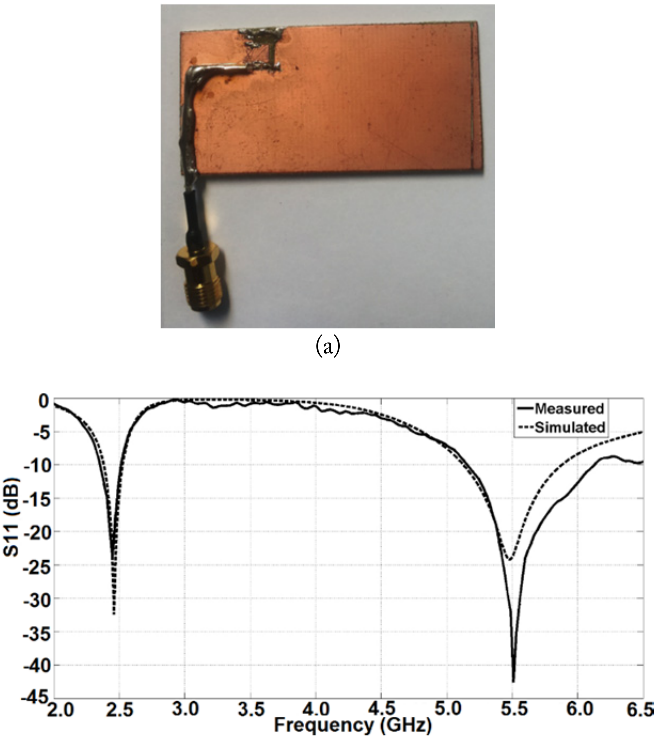
(b)

Fig. 4. Simulated surface current density on the ground plane at (a) 2.45 GHz and (b) 5.5 GHz.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

Fig. 5(a) shows the antenna that was fabricated for the experiment. Fig. 5(b) shows the measured and simulated return loss of the antenna. The experimental values of C_f, C_r, and L are 4 pF, 0.2 pF, and 4.7 nH, respectively.

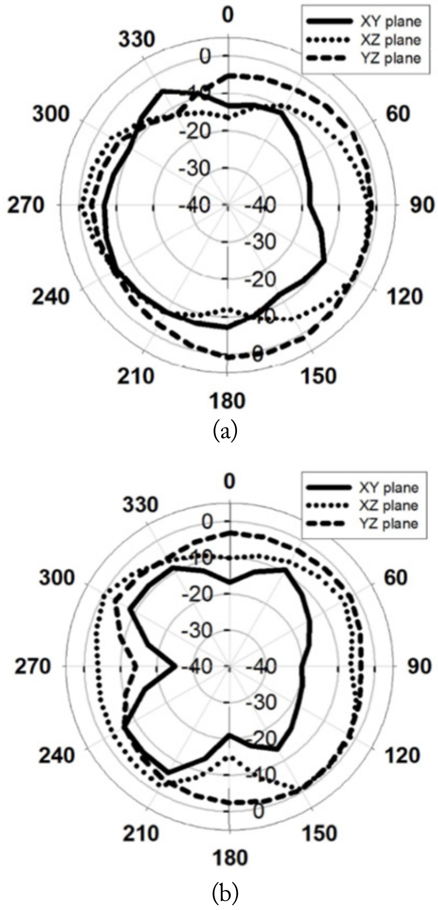
The measurement and simulation results show good agreement. The measured -10 dB bandwidth in the lower band (2.35–2.51 GHz) is 160 MHz, whereas that in the higher band (5.15–6.13 GHz) is 980 MHz. These results indicate that the proposed antenna covers sufficient bandwidths in the 2.45 and 5.5 GHz bands. The radiation patterns of the antenna are measured at the lower and higher resonant frequencies, as shown in Fig. 6(a) and (b), respectively. The radiation patterns



(a)

(b)

Fig. 5. Experimental investigation of (a) fabricated antenna and (b) measured and simulated return loss.



(a)

(b)

Fig. 6. Measured radiation patterns at (a) 2.45 GHz and (b) 5.5 GHz.

Table 1. Measured total efficiency and peak gain

Frequency (GHz)	Efficiency (%)	Gain (dB)
2.4	54.99	0.40
2.45	62.52	1.24
2.5	40.96	0.62
5.15	51.30	1.37
5.5	65.83	3.65
5.85	54.33	2.53

in the XY, XZ, and YZ planes resembles omnidirectional patterns, suggesting that they are suitable for mobile devices. Table 1 lists the measured data for the total efficiency and peak gain.

The peak gain and efficiency obtained at 2.45 GHz are 1.24 dBi and 62.52, respectively, whereas those at 5.5 GHz are 3.65 dBi and 65.83%, respectively. The total radiation efficiency of the antenna is well above 50%, and the gain variation is less than 3 dB. The measured data shows that the proposed antenna shows good radiation performance in both operating bands.

V. CONCLUSION

A dual-band slot-type ground radiation antenna operating in the 2.4–2.485 and 5.15–5.85 GHz bands is proposed. The geometry of the antenna is compact and is suitable for modern mobile devices. The proposed antenna is versatile, as the resonance frequencies of both bands can be controlled by varying the values of the lumped capacitors and an inductor. The measured return loss agrees well with the simulated results. Good radiation performance is observed at the operating frequencies.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. 2015R1A2A1A15055109).

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