Compact triple-band ground radiation antenna using two inner rectangular loops enclosed by two outer loops

L. Qu, R. Zhang, H. Lee and H. Kim✉

A triple-band ground radiation antenna is proposed that can cover the 1575 MHz global positioning system (GPS) band and the 2.45 and 5.5 GHz WLAN bands, within a 6 × 9 mm ground clearance. The proposed triple-band antenna is comprised of two inner rectangular loops, each enclosed by a larger outer loop. Each band can be adjusted for impedance matching by means of respective matching circuits. The −10 dB return loss bandwidths were simulated to be 17, 130 and 1000 MHz. Measurements indicated that sufficient bandwidth and good radiation performance were also achieved.

Introduction: With the rapid development of mobile communication, there has been increasing demand for compact multiband antennas with multiband operation. The WLAN 2.4 GHz (IEEE 802.11b) and 5 GHz bands (IEEE 802.11a) have been widely studied to meet the rapid expansion of user demands for fast data rates. Also, the GPS antenna is an essential part of mobile devices for its navigation function. Most multiband antenna designs for these and similar applications have adopted several radiators to achieve multiple resonances [1, 2], and most of them have large space requirements. In recent years, there have been some studies on the use of the ground radiation antenna to achieve the dual-band operation [3, 4]. The ground radiation antenna is a small loop antenna in which a loop current mode is generated so that the antenna can excite and employ the ground plane as a radiator [5, 6]. However, no multiband techniques have been reported yet for the ground radiation antenna.

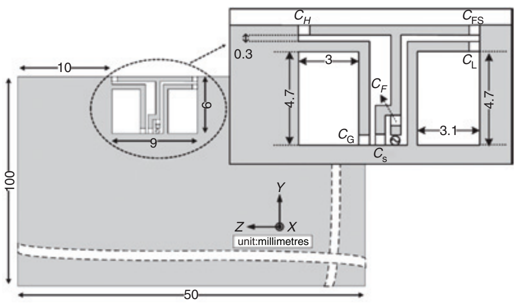

Fig. 1 *Configuration of proposed triple-band antenna*

In this Letter, we demonstrate a new multiband technique in a ground radiation antenna; the design is suitable for GPS and dual-band WLAN applications and has a small size clearance. Multiple-band operation can be achieved by creating separate and distinct loop current modes, and lumped capacitors are used to achieve a compact ground clearance. The proposed triple-band antenna structure is composed of two inner rectangular loops enclosed by two outer large loops on both sides of the feed. The loops on the left side generate 1.575 and 5.5 GHz loop-type current modes, and the loops on the right side form the 2.4 GHz current mode and its matching circuit. By inserting a series capacitor and a shunt capacitor, simultaneous impedance matching can be achieved for the triple bands. This proposed antenna structure was analysed in simulation and then validated by measurements.

Antenna configuration: The proposed configuration of the triple-band ground radiation antenna is shown in Fig. 1. The antenna structure is located on the short side of a 100 × 50 mm ground plane which is printed on a 1-mm-thick Flame Retardant 4 substrate ($\varepsilon_r = 4.4$). The entire structure occupies the compact ground clearance of 6 × 9 mm (~$0.03\lambda \times 0.05\lambda$, $0.05\lambda \times 0.07\lambda$, and $0.11\lambda \times 0.16\lambda$ at 1.575, 2.4 and 5.5 GHz, respectively) and is 10 mm from the left edge of the ground plane. On each side of the feed, there is one inner rectangular loop enclosed by a larger outer loop. On the left side, the inner rectangular loop is composed of inner conductor lines with a series capacitor C_G for the GPS band; an inverted-L loop, which is composed of the feed and the outer conductor line as well as the inner conductor lines and C_H, works in the 5.5 GHz WLAN band. On the right side, the inner rectangular loop including series capacitor C_L resonates at 2.4 GHz and the outer loop including loaded capacitor C_{FS} is used only for impedance matching of the inner loop resonance. By inserting a series capacitor C_F and a 2 mm shunt conductor line with capacitor C_S, each band can be adjusted simultaneously for impedance matching. The gap between the inner and outer loops is 0.3 mm and all conductor lines are 0.5 mm wide. In simulation, the values of C_F, C_S, C_{FS}, C_G, C_L and C_H were set as 4, 0.45, 0.3, 1.07, 0.24 and 0.02 pF, respectively.

Controlling mechanisms and simulation results: Simulated surface current distributions at 1.575, 2.45 and 5.5 GHz are presented in Fig. 2. At 1.575 GHz, a loop-type current mode is generated in the inner rectangular loop of the left side, for which C_G can be used for frequency adjustment. In the inner rectangular loop of the right side, a loop-type current mode is generated at 2.45 GHz, for which the frequency is mainly controlled by C_L. An inverted-L loop-type current mode is observed in the inverted-L loop for the 5.5 GHz WLAN band, where C_H is dominant for frequency adjustment. Since the capacitance of C_G is very large, its impedance is quite small at high frequencies, having little effect on the resonant frequency of the 5.5 GHz WLAN band. In summary, three separate and distinct loop-type current modes are observed for different bands and multiband operations are achieved.

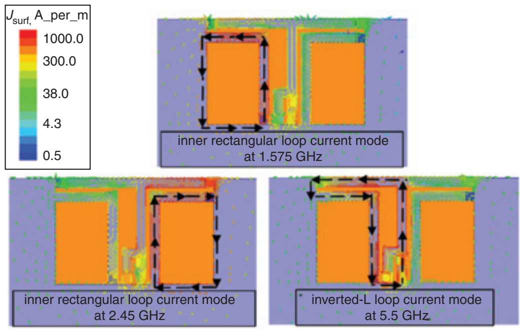

Fig. 2 *Simulated surface current distributions at 1.575, 2.45 and 5.5 GHz*

The simulated reflection coefficients of the proposed triple-band antenna structure over the three operation bands are shown in Fig. 3. The −10 dB impedance bandwidth in the 1.575 GHz GPS band is 17 MHz (from 1569 to 1586 MHz), sufficient for mobile applications. In the 2.4 GHz WLAN band, the −10 dB return loss bandwidth is 130 MHz (from 2385 to 2515 MHz) covering the entire low band. In the 5.5 GHz WLAN band, the −10 dB impedance bandwidth is 1 GHz (from 4.960 to 5.960 GHz). The simulation results indicate that the proposed antenna structure achieves multiband resonance and has good bandwidth performance.

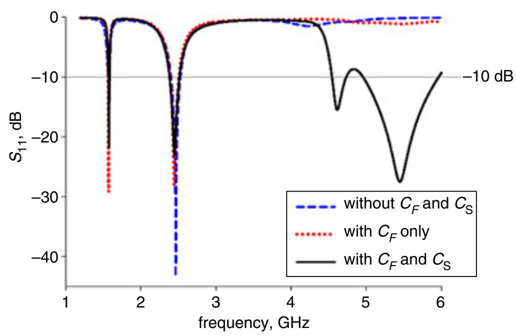

Fig. 3 *Simulated reflection coefficients of proposed antenna*

Furthermore, the proposed antenna can achieve simultaneous impedance matching for each band. The series capacitor C_F is responsible for the impedance matching of both the GPS and 2.4 GHz WLAN bands; the input impedance of 5.5 GHz WLAN band is almost unchanged by changes to C_F. The shunt capacitor C_S can be adjusted to change the impedance of 5.5 GHz WLAN band and has little effect on the lower bands. The capacitor C_{FS} in the outer loop of the right side is used for impedance matching of the 2.4 GHz WLAN band.

To fine-tune the antenna's performance, we first built a simple structure of two inner rectangular loops enclosed by two outer loops without the inserted C_F or shunt C_S, and the 2.4 GHz band was well matched by tuning C_{FS}. Secondly, by inserting C_F, the GPS and 2.4 GHz bands were both well matched together with C_{FS}. Then, the 5.5 GHz band was adjusted with the inserted shunt C_S for impedance matching. Finally, we tuned all the values together to optimise each band, yielding the simulation results as shown in Fig. 3.

Experimental results: The proposed triple-band antenna was fabricated and its reflection coefficients were measured over the three operation bands (Fig. 4). The measurement and simulation results agreed well, and the impedance bandwidth was also sufficient to cover all the operation bands. Table 1 lists measurements of radiation efficiency; the average efficiencies in the proposed three operation bands were 50, 76 and 69%. The proposed antenna structure generated omnidirectional radiation patterns on the *xy*-plane at 1.575, 2.4 and 5.5 GHz, indicating good radiation performance (Fig. 5).

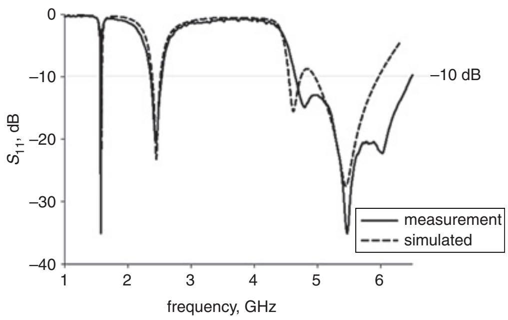

Fig. 4 *Measured and simulated reflection coefficients of proposed antenna*

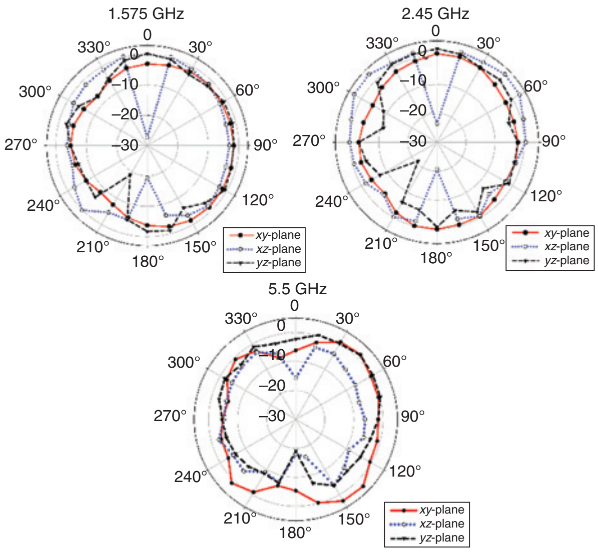

Fig. 5 *Measured radiation patterns at 1.575, 2.45 and 5.5 GHz*

Table 1: Measured radiation efficiencies

Frequency (GHz)	1.575	2.4	2.45	2.5	5.2	5.5	5.8
Efficiency (%)	50.8	76.1	77.7	75.5	68.5	70.5	69.1

Conclusion: In this Letter, a new multiband technique using a small ground radiation antenna has been proposed for GPS and dual-band WLAN operation. The controlling mechanisms of frequency adjustment and impedance matching were analysed in simulation. Measurements showed that sufficient impedance bandwidth was achieved, as well as good performance in radiation efficiency and radiation patterns. Therefore, the proposed antenna structure can be effectively used for multiband operations in mobile applications.

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One or more of the Figures in this Letter are available in colour online.

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