Dual-resonance-based wideband antenna for integrated module applications

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A wideband module antenna comprised of a small ground radiation antenna in the module and a parasitic radiation loop in the evaluation board is proposed. Unlike conventional ground radiation antennas, the ground radiation antenna in the module works as an exciter to the parasitic radiation loop, which further couples with the evaluation board as a radiator. Thus, a space-saving antenna is obtained with wide bandwidth and easy tuning. Accordingly, dual resonance can be generated by tuning the resonant frequencies of the ground radiation antenna and the parasitic radiation loop equally. When measured, the antennas have wide bandwidths (2:1 voltage standing wave ratio bandwidth of 270 MHz) and high efficiency (ranging from 44 to 74%).

Introduction: With the popularity of wireless communication, WLANs have been widely adopted in handheld devices. Accordingly, antenna modules with passive and active devices as well as various components integrated into a small-sized package have drawn attention, leaving little space for embedded antennas [1]. Thereby, antenna miniaturisation has become an important issue for commercial applications. Although previous antenna designs have been studied for module applications [2–4], some of them occupy large areas/require significant clearance both in the module and on the evaluation board [2, 3]. Some operate at high-frequency bands [3, 4]. At the 2.4 GHz frequency band, the antenna needs more area due to its longer wavelength. Designing small, high-performance antennas is a difficult task.

In this Letter, we present a small wideband antenna operating at 2.4 GHz WLAN band for integrated module applications. The antenna is comprised of a 1.5 mm × 4 mm loop-type ground radiation antenna [5–9] in a 10 mm × 10 mm module, with 4 mm × 7 mm clearance in the evaluation board with a loaded capacitor forming a parasitic radiation loop. Dual resonance and wideband are generated while occupying an ultra-small area in the module with small clearance in the evaluation board. The primary idea of the proposed technique is to excite the evaluation board for radiation. Both simulation and measurement verify that high radiation performance has been achieved.

Antenna configuration: Fig. 1 shows the geometry of the proposed module antenna design. A 10 mm × 10 mm module is integrated above a 60 mm × 60 mm evaluation board with a height of 4 mm, and both are etched on a 1-mm-thick FR-4 substrate ($\varepsilon_r = 4.4$ and $\tan\delta = 0.02$). A conventional ground radiation antenna within an ultra-small area of 1.5 mm × 4 mm clearance is designed in the module, which is comprised of a feeding loop with C_F (0.63 pF) and a radiation loop C_R (0.85 pF) for controlling impedance matching and resonant frequency, respectively. A shorting line is adopted at the bottom centre of the module to model the connection pin between the module and the evaluation board for simplicity. Since the module size is very small compared with its wavelength, the module is difficult to excite as a good radiator by the antenna. Instead, to excite the large-sized evaluation board, a 4 mm × 7 mm clearance in the evaluation board with a loaded capacitor C (0.32 pF) is designed as a parasitic radiation loop. Therefore, the far-field radiation is determined by coupling between the parasitic radiation loop and the evaluation board, and the dual resonance [9] is determined by the coupling between the radiation loop and the parasitic radiation loop, which is further excited by the feeding loop. Accordingly, both high radiation performance and wideband are achieved. It is noted that the proposed technique can be applicable to different cases with varied parameters including the integration location of the module, the size of the evaluation board, and the height between the module and the evaluation board. The antenna operation mechanism is introduced below.

Simulated results and operation mechanism: The simulated reflection coefficients of the proposed antennas with and without the parasitic radiation loop are shown in Fig. 2. It can be observed that the proposed antenna can achieve a 2:1 voltage standing wave ratio (VSWR) bandwidth of 250 MHz (from 2.32 to 2.57 GHz). The antenna without the parasitic radiation loop can only provide a bandwidth of 10 MHz (from 2.445 to 2.455 GHz), confirming that the evaluation board instead of the module itself should be excited as a radiator.

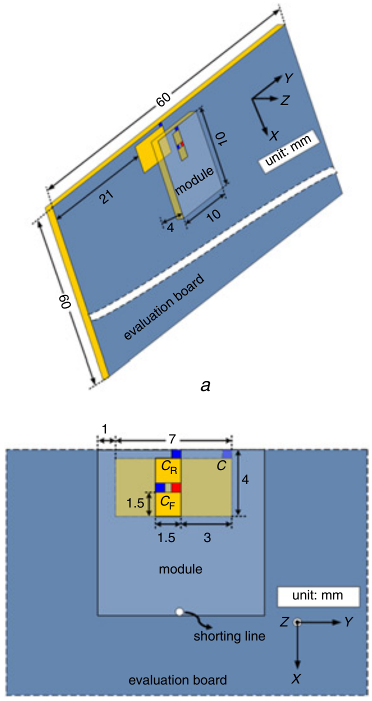

Fig. 1 *Configuration of proposed module antenna*
a 3D view
b Top view

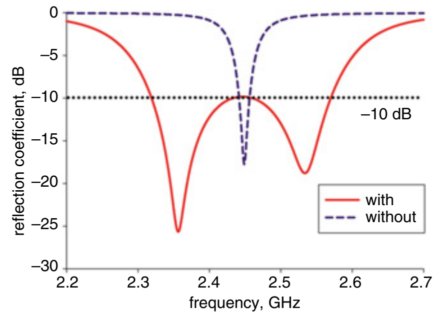

Fig. 2 *Simulated reflection coefficients of proposed antenna with and without parasitic radiation loop*

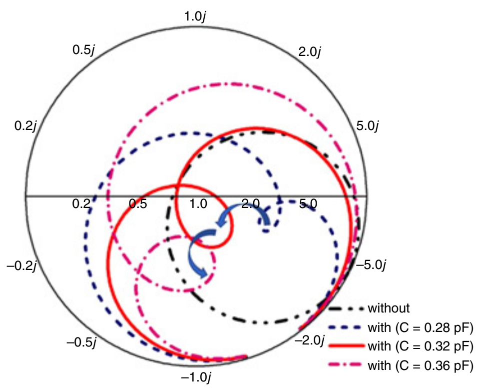

Fig. 3 *Simulated input impedances with and without parasitic radiation loop in Smith chart*

Fig. 3 presents the input impedances of the proposed antenna in a Smith chart. It can be clearly observed that dual resonance (two impedance loci in the Smith chart) is generated when the parasitic radiation loop is adopted. The small locus is generated by coupling between the parasitic radiation loop and the evaluation board, and the locus size is determined by the coupling between the radiation loop and the parasitic radiation loop, which is related to the height between the module and the evaluation board and can be adjusted by their overlapped area. Moreover, the large locus is generated by the radiation loop, and its locus size is determined by coupling between the radiation loop and the feeding loop. Counter-clockwise rotation of the small locus can be observed in Fig. 3 when the capacitor value is increased from 0.28 to 0.36 pF. When the resonant frequency of the parasitic radiation loop is tuned equal to that of the radiation loop, wideband is obtained. It is important to note that the proposed technique does not confine to a particular antenna design, *e.g.* the ground radiation antenna could be a printed inverted-F antenna, while the parasitic radiation loop could be a monopole type.

To verify the proposed technique, the simulated current distributions are plotted at 2.45 GHz in Fig. 4. In the proposed design, a loop-type current mode is generated in the module by the ground radiation antenna, and another loop-type current mode is coupled around the parasitic radiation loop, further coupling with the magnetic fields of the ground mode along the *y*-axis to produce radiation.

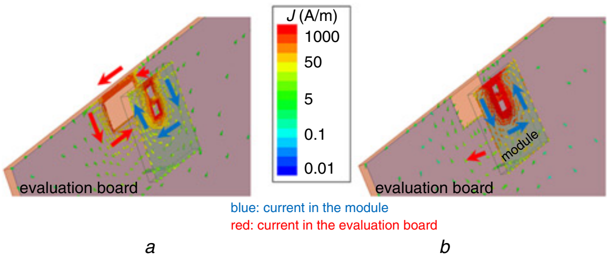

Fig. 4 *Simulated surface current distributions at 2.45 GHz with and without parasitic radiation loop*
a With
b Without (clearance only)

Measurement results: Fabrication and measurement are conducted to verify the radiation performance of the proposed antenna. Fig. 5 presents the measured reflection coefficients, and the 2:1 VSWR bandwidths of 270 MHz (from 2.33 to 2.60 GHz) and 35 MHz (from 2.425 to 2.46 GHz) are achieved with and without the parasitic radiation loop, respectively. Measured total efficiencies of the proposed antenna range from 44 to 74% over the frequency band of 2.3–2.6 GHz, while those without the parasitic radiation loop are below 10%. Both simulation and measurement indicate that greatly improved radiation performance was achieved by utilising the parasitic radiation loop.

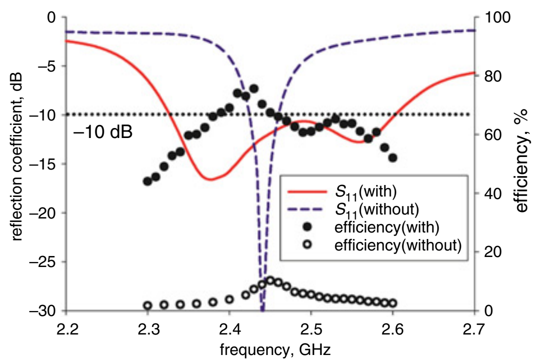

Fig. 5 *Measured reflection coefficients and total efficiencies with and without parasitic radiation loop*

Moreover, their corresponding radiation patterns are also shown in Fig. 6. In the *xz*-plane, it can be observed that the E_φ component is dominant, and an omni-directional radiation pattern is generated, indicating that the proposed antenna works as a dipole-type radiator along the *y*-axis. In both *xz* and *yz* planes, the radiation fields have been greatly improved compared with those without the parasitic radiation loop (above 4 dB).

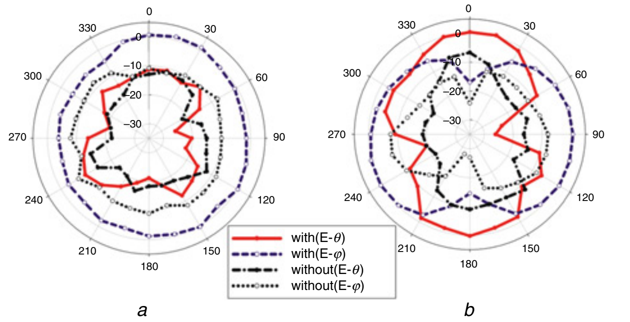

Fig. 6 *Measured radiation patterns with and without parasitic radiation loop*
a xz-plane
b yz-plane

Conclusion: In this Letter, a space-saving ground radiation antenna with dual-resonance performance is designed in an antenna module, which is further integrated over an evaluation board. The most important contribution of the proposed technique is excitation of the evaluation board as a radiator by placing a parasitic radiation loop on the evaluation board below the module. This results in greatly improved radiation performance compared with the antenna without the parasitic radiation loop in terms of bandwidth, total efficiency, and radiation patterns, as verified by both simulations and measurements. The proposed technique is versatile in various evaluation boards at different locations with different heights.

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

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