Ground radiation method using slot with coupling capacitors

Y. Liu, J. Lee, H.H. Kim and H. Kim

An innovative antenna radiation method for exciting a dipole-type radiation mode in the ground plane of mobile devices is proposed. This method is based on a capacitively loaded slot placed at the centre of the ground plane. The ground plane is 50 × 15 mm in length and width, respectively, which is the size typically used in USB dongles and headsets. The −10 dB impedance bandwidth is 12.9% at 2.4 GHz, fully covering the WiMax, Wi-Fi and Bluetooth frequency bands.

Introduction: Mobile antennas are required to be small because of the space constraints of modern mobile devices. However, it is difficult to achieve a wide impedance bandwidth and high radiation efficiency using small internal antennas [1, 2]. It was observed in [3, 4] that a wide impedance bandwidth can be achieved by enhancing the coupling between an antenna and the ground plane, even when the antenna is a non-radiating coupling element. Recently, several ground antennas formed by large loop-type current distributions in the ground plane have been studied, demonstrating that the ground plane can act as a major radiator able to produce wide impedance bandwidths [5, 6].

The ground plane of mobile devices is usually rectangular in shape, and therefore the structure can be considered to be a thick-dipole-type antenna. There are several methods for exciting the fundamental mode of this type of antenna. A direct feeding method can be used to apply a voltage source at the centre of the structure, but this requires the ground plane to be divided into two individual parts, and the resonant frequency will fully depend on the length of the ground plane, and is thus difficult to implement in practice. The electric coupled feeding method involves placing a probe-type structure close to the electric field maximum of the ground plane, as in the configurations of conventional monopole or inverted-F antenna (IFA) located at the end of the ground plane. To achieve optimal coupling between the antenna and the ground plane, the antenna size cannot be decreased arbitrarily. In this Letter, we propose a magnetic coupled feeding method for exciting the dipole-type current mode of the ground plane. This method is based on placing a capacitively loaded slot at the centre of the ground plane, which is close to the magnetic field maximum of the ground plane. Thus, a loop-type current distribution can be generated around the slot, which produces magnetic flux to drive the dipole-type current mode of the ground plane. Details of the antenna design and experimental results are discussed.

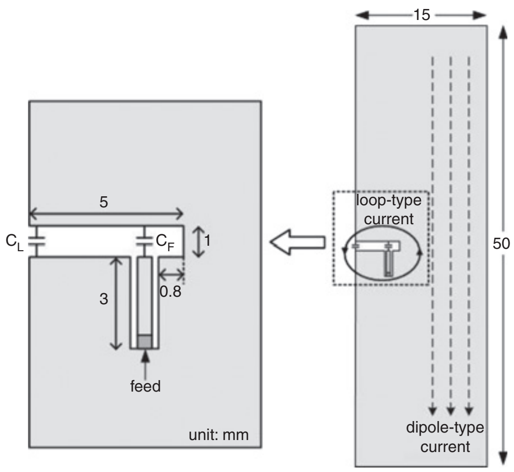

Fig. 1 *Geometry of proposed antenna*

Antenna design and tuning mechanisms: As shown in Fig. 1, the ground plane is 50 × 15 mm and is printed on a 1 mm-thick FR4 substrate, where $\varepsilon_r = 4.4$. The slot is 5 mm (0.04λ) by 1 mm (0.008λ) in length and width, respectively, and is loaded by a capacitor C_L, which is further excited using a resonated loop feed structure [6], including a capacitor C_F. It can be seen that the dipole-type currents flowing on the ground plane are induced through the magnetic flux produced by a loop-type current generated around the slot. The resonant frequency is determined by C_L. Fig. 2 demonstrates that, when C_L is changed from 0.5 to 0.7 pF, the resonant frequency varies from 2.7 to 2.3 GHz. The input impedance can be adjusted by C_F, which changes the mutual impedance between the feed and the radiator. It is clear from Fig. 3 that a well-matched impedance can be achieved by choosing an appropriate capacitance for C_F. Circular markers on each impedance trace denote the resonant frequency of 2.4 GHz, and show that the resonant frequency is almost unchanged when varying C_F. Thus, the frequency and input impedance can be controlled independently, which would allow for antenna tuning [7]. All antenna simulations in this work were performed using Ansoft HFSS.

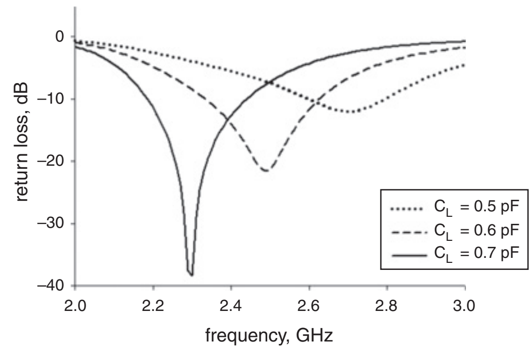

Fig. 2 *Variation in resonant frequency with different C_L*

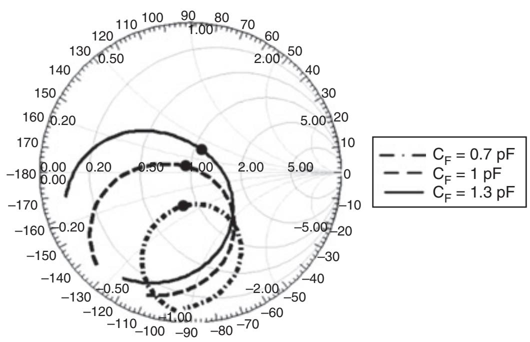

Fig. 3 *Variation in input impedance with different C_F*

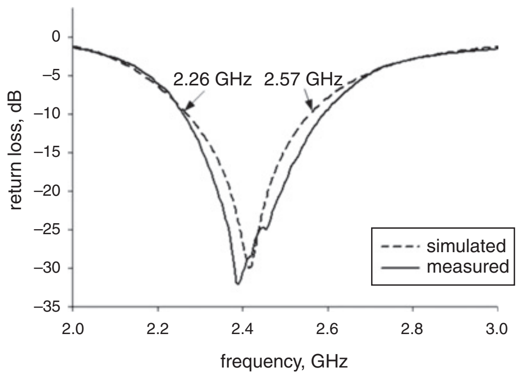

Fig. 4 *Simulated and measured return loss*

Experimental results and discussion: Fig. 4 shows the simulated and measured return loss of the proposed antenna when the values of C_L and C_F are chosen to be 0.65 and 1 pF, respectively. The −10 dB bandwidth is simulated as 310 MHz (12.9%) at 2.4 GHz, from 2.26 to 2.57 GHz. The measured result agrees well with the simulation result. Fig. 5 shows that the measured efficiencies and peak gains are higher than 70% and 2 dBi, respectively, representing sufficient performance for use in practical applications.

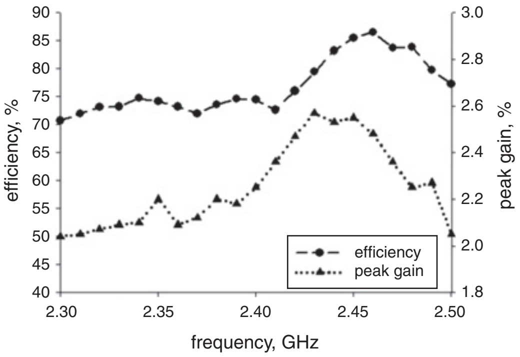

Fig. 5 *Measured efficiencies and peak gains*

As mentioned above, the dipole-type current mode of the ground plane is excited through magnetic coupling from the slot. To achieve a tight coupling, the slot is placed at the centre of the ground plane, where the strength of the magnetic field is at maximum. If the slot is moved to a position that is a quarter of the ground plane, the impedance bandwidth is reduced by approximately half (6.7% at 2.4 GHz). Moreover, the coupling is influenced by the width of the ground plane: the larger the width, the less the coupling. This is because the dipole-type currents flowing at the centre of the ground plane can be dispersed as the width increases, resulting in a weak magnetic coupling. On the other hand, the coupling can be enhanced by reducing the width of the ground plane or by placing an additional slot on the opposite side. Table 1 shows the variation in the relative bandwidth at 2.4 GHz that occurs when the width of the ground plane changes from 20 to 10 mm. The coupling can also be enhanced by increasing the size of the slot. Related research to enhance the coupling without changing the ground structure or the slot size is being carried out.

Table 1: Comparison of relative bandwidth at 2.4 GHz with different ground plane widths

Size of ground plane	20 × 50 mm	15 × 50 mm	10 × 50 mm
Relative bandwidth (%)	7.9	12.9	19.2

Conclusion: By placing a capacitively loaded slot at the centre of the ground plane, the dipole-type ground radiation mode is well-excited, producing good radiation efficiency and wide impedance bandwidth. The resonant frequency can be controlled by the capacitor, and the input impedance can be adjusted by another capacitor included in the loop feed structure. Consequently, antenna tuning can be conveniently implemented without changing the entire structure. Investigation of the variation in the relative bandwidth with different ground plane widths, showing that a wider impedance bandwidth can be achieved by increasing the coupling between the slot and the ground plane, has been reported.

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