Hybrid Planar Inverted-F Antenna with a T-Shaped Slot on the Ground Plane

Sinhyung Jeon, Hyengcheul Choi, and Hyeongdong Kim

ABSTRACT—In this letter, a novel hybrid planar inverted-F antenna (PIFA) with a T-shaped slot on the ground plane is proposed. The loop structure formed by the feed line and shorting pin can be operated as a series and shunt inductance for the PIFA and the T-shaped slot antenna, respectively. The PIFA operates at a frequency of 1.75 GHz, while the T-shaped slot on the ground plane operates at 2.4 GHz by the same voltage feeding source. The height of the PIFA is 6.5 mm, and the size of an upper patch is designed to be 30 mm×16 mm. The measured relative impedance bandwidth of the PIFA and the T-shaped slot are about 12% and 21%, respectively. In addition, good antenna performance was achieved.

Keywords—Hybrid antenna, planar inverted-F antenna, PIFA, slot antenna, modified ground plane.

I. Introduction

Recently, wireless communication systems have been increasingly required to provide a variety of services, and antennas for mobile handsets covering multiple bands are being developed. In modern mobile handsets, planar inverted-F antennas (PIFAs) are generally used as built-in antennas; however, conventional PIFAs have a narrow and single band impedance bandwidth. To overcome this shortcoming, various methods related to PIFAs for multiple bands operation have been devised, such as designing shapes for an upper patch [1], [2] and adjusting the location of the feed line and shorting pin [3]. Research on the modified ground plane of the PIFA for multiple bands or wide bandwidths has been carried out [4], [5]. In [4] and [5], the operational bandwidth is increased because the electrical length of the ground plane increases when meandering or open-end slots are used on the ground plane, although its physical size is fixed. In this letter, we propose a hybrid antenna which simultaneously resonates in different bands when excited by the same voltage feeding source. The PIFA operates at the lower frequency (1.75 GHz), while the T-shaped slot on the ground plane operates at the higher frequency (2.4 GHz). The proposed antenna is designed to operate at Digital Communication System (DCS1800, 1710 MHz to 1880 MHz), Wireless Broadband (Wibro, 2300 MHz to 2390 MHz), Bluetooth (2400 MHz to 2480 MHz), and Satellite Digital Multimedia Broadcasting (S-DMB, 2630 MHz to 2655 MHz) frequency bands. Simulations were carried out using Ansoft HFSS commercial software.

II. Theory and Proposed Antenna Design

The geometry of the proposed antenna is shown in Fig. 1. The antenna is printed on an FR4 PCB with $\varepsilon_r = 4.9$ and $\tan \delta = 0.025$. Figure 2 shows the schematic geometry of the proposed antenna, including a side-view, upper patch, and the T-shaped slot on the ground plane in detail. Figure 2(c) shows the T-shaped slot, which is composed of two symmetrical L-shaped slots with parameters S_{L1}, S_F, and S_W. Although the feeding voltage source simultaneously excites both the upper patch and the ground slot, the proposed antenna can be treated as two independent antennas. One antenna is the general PIFA, and the other is the slot antenna on the ground plane.

To understand the operation mechanism of the proposed hybrid antenna, consider the two equivalent circuits based on

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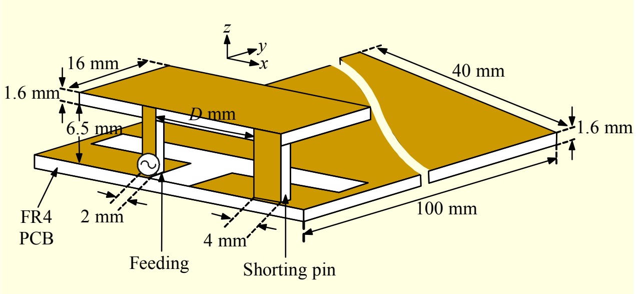

Fig. 1. Three-dimensional view of the proposed antenna.

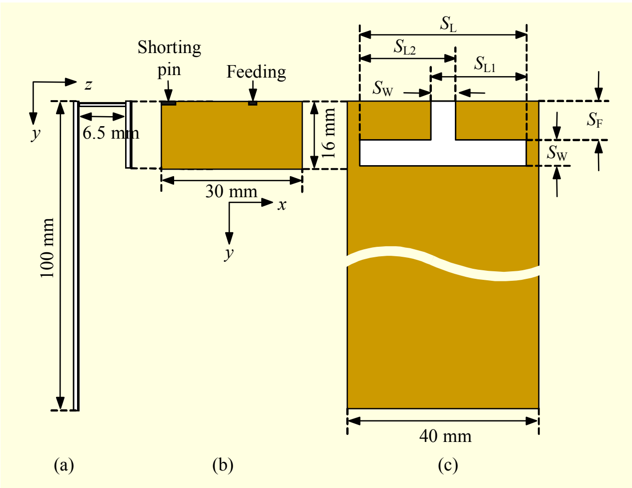

Fig. 2. Detailed geometry of the proposed antenna: (a) side-view, (b) upper patch, and (c) the T-shaped slot antenna on the ground plane.

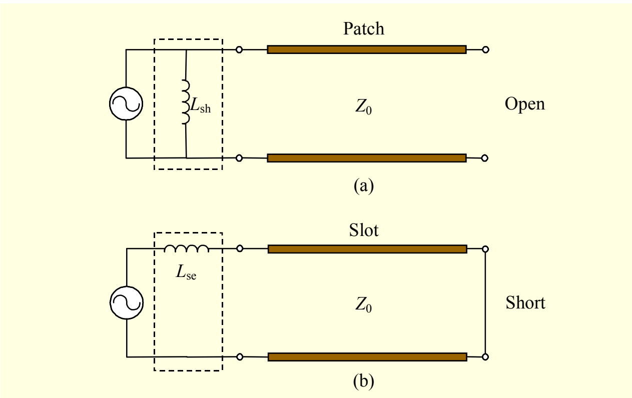

Fig. 3. Equivalent circuit models of (a) the PIFA and (b) the T-shaped slot on the ground plane.

transmission line shown in Fig. 3. Typically, a PIFA consists of an upper patch, a ground plane, a feeding line, and a shorting pin. The upper patch operates at the size of nearly its quarter wavelength. Conventional PIFA operation can be understood by the equivalent circuit of Fig. 3(a) [6]. The loop structure formed by a shorting pin and feeding line is modeled as a shunt inductance L_{sh}. The upper patch and the ground plane is modeled as an open circuit transmission line. Impedance matching of the PIFA can be achieved by adjusting the amount of L_{sh}, which is generated by the loop structure. The slot antenna on the ground plane is modeled as a short circuit transmission line as shown in Fig. 3(b). In the case of the slot antenna on the ground plane, the previously mentioned loop structure can be modeled as a series inductance L_{se} in contrast with the shunt inductance L_{sh} in the PIFA.

The slot antennas of half-wavelength structures are generally used to operate at the fundamental resonant mode [7]. The electrical length of the slot of Fig. 2(c) is between a quarter and half of a guided wavelength. However, its half-wavelength resonance at the desired resonant frequency can be achieved because the impedance of the slot antenna is transformed to the series resonance by L_{se}, which is generated by the loop structure of the feed line. Thus, the amount of L_{sh} and L_{se} is dependent on the loop size formed by the feed line and the shorting pin. Hence, the resonant frequencies of the proposed hybrid antenna can be controlled by adjusting the distance between the feed line and the shorting pin. Distance parameter D for the desired resonant frequency is chosen by parametric studies to be 14.5 mm. To satisfy the desired specification, the parameters S_L and S_W are chosen to be 36 mm and 5 mm, respectively, and the parameter S_F is chosen to be 8.5 mm.

III. Experimental Results and Discussion

To show the influence of the T-shaped slot on the ground plane, simulations of the ordinary PIFA without the T-shaped slot on the ground plane and the hybrid PIFA with the T-shaped slot on the ground plane were conducted. The height of the upper patch was fixed at 6.5 mm from the ground plane, and the other parameters were kept constant except for the slot of the ground plane. Figure 4 shows the simulated voltage

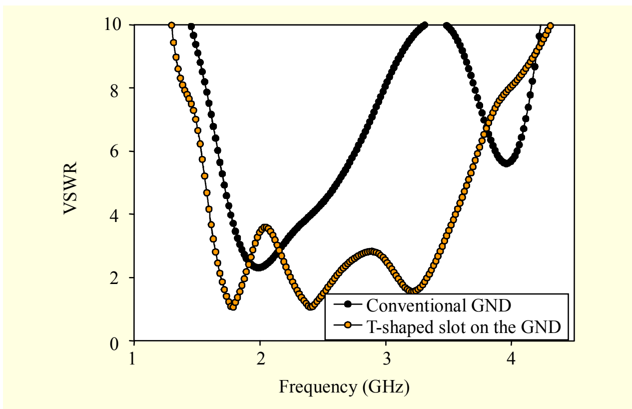

Fig. 4. Comparison of simulated VSWR with the T-shaped slot and without the T-shaped slot.

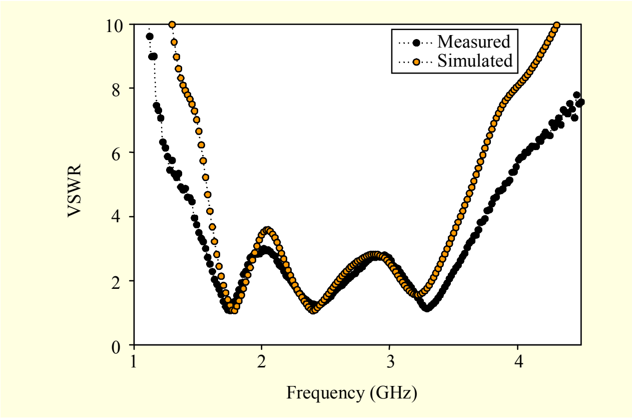

Fig. 5. Simulated and measured VSWR.

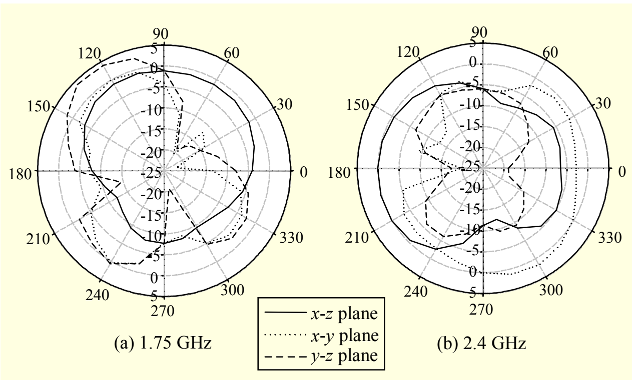

Fig. 6. Measured radiation pattern at (a) 1.75 GHz and (b) 2.4 GHz.

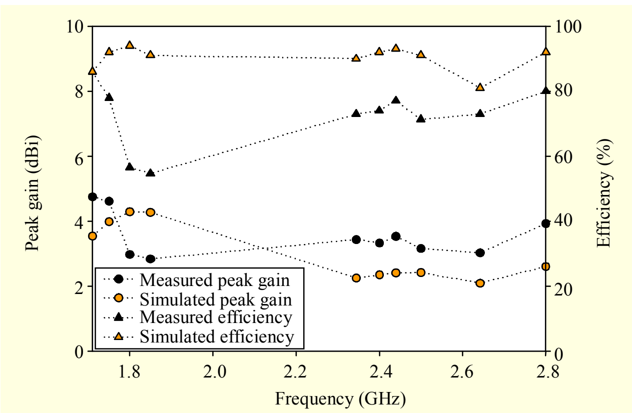

Fig. 7. Simulated/measured peak gain and radiation efficiency of the proposed antenna.

standing wave ratios (VSWR) with the ordinary PIFA and the proposed hybrid PIFA. Resonance is achieved at the lower band (1.75 GHz) by the PIFA and at the higher band (2.4 GHz) by the slot on the ground plane. The third resonance may be due to the high-order mode of the PIFA which is impedance-matched by the extra shunt inductance provided by the slot. The simulated and measured VSWR of the proposed antenna are shown in Fig. 5. The measured and simulated results show good agreement. The measured impedance bandwidths for VSWR=2 are 210 MHz (1.69 GHz to 1.90 GHz) and 520 MHz (2.20 GHz to 2.72 GHz), which can cover DSC, Wibro, Bluetooth, and S-DMB bands. Figure 6 shows radiation patterns measured in the *x-z*, *x-y*, and *y-z* planes at 1.75 GHz and 2.4 GHz. A good omni-directional radiation pattern in the *x-y* plane is shown for mobile handsets. The radiation patterns and efficiency were measured in an anechoic chamber. The measured antenna efficiency includes reflection loss at the input and ohmic/dielectric losses. The measured peak gain and radiation efficiency of the proposed antenna are 4.6 dBi and 78% at 1.75 GHz and 3.3 dBi and 74% at 2.4 GHz, respectively, as shown in Fig. 7.

IV. Conclusion

We proposed a novel hybrid PIFA with a T-shaped slot antenna on the ground plane for DCS, Wibro, Bluetooth, and S-DMB applications. Its resonant frequency can be controlled by adjusting the inductance of the loop structure formed by the feed line and shorting pin. Thus, the PIFA for the lower band (1.75 GHz) and the slot for the higher band (2.4 GHz) operate using the same feeding voltage source. The proposed hybrid antenna was presented using an equivalent circuit model. Reasonable agreement between simulated and measured was achieved in addition to good antenna performance.

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