A PIFA-Type Varactor-Tunable Slim Antenna With a PIL Patch Feed for Multiband Applications

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Abstract—A novel varactor-tuned compact multiband slim antenna for covering the digital cellular system (DCS; 1710–1880 MHz), personal communication service (PCS; 1850–1990 MHz), universal mobile telecommunications system (UMTS; 1900–2200 MHz), WiBro (2300–2390 MHz), and wireless LAN (WLAN; 5150–5350 and 5725–5850 MHz) bands is presented. The proposed antenna consists of a main patch and a planar inverted-L (PIL) patch with a feed line for the broadband characteristic. A varactor diode is attached to the radiating element for frequency shift. This antenna occupies a total volume of 27 mm × 11 mm × 5 mm, which is the typical size of a antenna manufacturing. This fact results in easy fabrication of an-

I. INTRODUCTION

The rapid growth of the mobile handset market has increased the need for small and slim internal antennas with multiple functions applicable in modern communication terminals. Planar inverted-F-type antennas (PIFAs) have been used widely for mobile handsets due to their compactness, low profile, ease of manufacture, reduction of special absorption rate (SAR), and good electrical performance [1]–[3]. On the other hand, PIFA has relatively narrow operation bandwidth, so many techniques have been proposed to achieve wideband or multiband operations such as the use of slot, parasitic patch, and capacitive loads [4]–[6]. Furthermore, the varactor-tunable antenna technique is one of the better solutions to extend the operation frequency range [7]. PIFA is a very suitable antenna for the varactor-tuning technique. Because the varactor diode technique needs a dc (direct current) biasing circuit, two dc block capacitors, and radio-frequency chokes (RFCs) are needed. In the PIFA structure, the antenna element is already connected to the ground plane, so one of the dc block capacitor and RFC can be reduced. Since the varactor diode works as a capacitor, only one RFC is needed. This fact results in easy fabrication of antenna manufacturing.

Index Terms—Broadband antenna, planar inverted-F-type antenna (PIFA), planar inverted-L (PIL), slim antenna, varactor diode, tunable antennas.

II. ANTENNA DESIGN

Fig. 1 shows the proposed antenna mounted on a FR4 (εr = 4.6) substrate with thickness of 1 mm and a dimension of 80 × 45 mm2, which is the typical size of a handset printed circuit board (PCB). The antenna elements are made by copper plate with thickness of 0.2 mm. The proposed antenna is attached at the top of the PCB which includes a dc biasing circuit and 12-V dc battery. A fabricated circuit can supply dc voltage of up to 20 V. Because of this integrated dc circuit, the accuracy of the antenna radiation pattern measurement can be improved. The antenna consists of a main patch with an L-shaped slit in the left part, PIL patch with feed stripline with a width of 1 mm, a varactor diode package (MA46H201) and RFC of 82 nH inductor. The main plate has around 2.2-GHz resonance frequencies. By adding the PIL patch to the operation, the bandwidth can be extended to include four bands [8]. The L-shaped slit in the left part of the main patch generates upper band. The shorting strip line and feed line are located in the same position of the PCB in x-y-plane. By doing so, the matching characteristic of the lower band is improved. The antenna has dimensions of 27 mm in length, 11 mm in width, and 5 mm in height. The total volume of the antenna is small enough to be applied even in slim terminals.

III. EXPERIMENTAL RESULTS

The measured return losses for the newly proposed antenna are shown in Fig. 2 and performed with an Anritsu 37377C network analyzer. The simulation results of the antenna were carried from computer simulation technology (CST) microwave studio. There are two resonance frequency bands around 2 and 5 GHz. The return loss of the antenna is greater than −7 dB over the whole band of interest corresponding to the dc bias voltage. At the 0-V dc bias condition, the proposed antenna can cover DCS, PCS, UMTS, and upper band of 5-GHz WLAN, but if the dc voltage is applied, the lower frequency band extends its bandwidth to include WiBro and the 5-GHz WLAN band change its frequency range from upper band to lower band. The total frequency ranges are 1.61–2.4, 5.1–5.46, and 5.52–5.85 GHz. The lower band does not change a lot corresponding to the dc
bias voltage because there is little current flow through the varactor diode. However, the upper band is shifted significantly and rather the covering band than the lower band is changed due to the larger current flow in the diode. In order to check the radiation mechanism, Fig. 3 shows the surface current distributions. As shown in Fig. 3, the current distributions are dominant around the PIL patch at lower band and L-shaped slit to varactor diode at upper band. Because little current flows through the diode at lower frequency, the return loss characteristic of the proposed antenna does not change a lot. The electrical length of each associated radiating element corresponds to about a quarter-wave-length ($\lambda/4$) from the feed point, to the open end point or shorting pin. As shown in Fig. 3(a) and (c), the length is about 42 mm from the feed point to the shorting pin through the main patch at 1.71 GHz, and 16 mm from the end of the stripline of the diode to the L-shape slit at 5.15 GHz.

Fig. 4 shows the E-H-plane radiation patterns at the frequencies of 1.85, 2.1, and 5.7 GHz at 0 V and 5.15 GHz at 16 V dc bias condition. Good omnidirectional radiation patterns were
obtained in the $x$-$y$-plane for all the measured resonant frequencies. There is good agreement between both simulated and measured radiation patterns. The small discrepancies between these values are mainly attributed to the dc biasing circuit and battery. The measured gains are listed in Table I. Referring to Fig. 4 and Table I, the overall shape of the radiation patterns can be suitable for modern slim mobile communications terminals.

**TABLE I**

<table>
<thead>
<tr>
<th>Frequency</th>
<th>1.71GHz</th>
<th>2.2GHz</th>
<th>5.2GHz</th>
<th>5.7GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(at 0V)</td>
<td>(at 13V)</td>
<td>(at 13V)</td>
<td>(at 0V)</td>
</tr>
<tr>
<td>Gain[dBi]</td>
<td>2.15</td>
<td>3.5</td>
<td>2.9</td>
<td>3.75</td>
</tr>
</tbody>
</table>

**IV. CONCLUSION**

A novel slim PIFA-type varactor-tunable multiband antenna is proposed. Basically, this antenna has wide operation frequency range and multiband operation. By attaching a varactor diode, the proposed antenna achieves more wideband frequency coverage. Moreover, this antenna is very small and slim in size, with a volume of 27 mm $\times$ 11 mm $\times$ 5 mm and is suitable to be placed in the internal area of actual mobile slim handsets for multiband operations. These features make the proposed antenna very attractive for new generation mobile handsets.

**REFERENCES**


