TABLE II Summary of the Measured Characteristic Parameters of the Fabricated Organic SIP Based FEM

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Type A</th>
<th>Type B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output power level</td>
<td>25 dBm</td>
<td>25 dBm</td>
</tr>
<tr>
<td>Gain @ 25 dBm</td>
<td>25.9 dB</td>
<td>26.6 dB</td>
</tr>
<tr>
<td>Quiescent current</td>
<td>90 mA</td>
<td>108 mA</td>
</tr>
<tr>
<td>Icc @ 25 dBm</td>
<td>387 mA</td>
<td>515 mA</td>
</tr>
<tr>
<td>ACPR 1 @ 885 kHz</td>
<td>50.84 dB</td>
<td>48.25 dB</td>
</tr>
<tr>
<td>PAE</td>
<td>24%</td>
<td>18%</td>
</tr>
<tr>
<td>Insertion loss @ 869–894 MHz</td>
<td>&lt;3.5 dB</td>
<td>&lt;3.5 dB</td>
</tr>
<tr>
<td>Ripple @ 869–894 MHz</td>
<td>&lt;1.3 dB</td>
<td>&lt;1.3 dB</td>
</tr>
</tbody>
</table>

the organic SIP packaging substrate. The organic SIP based FEMs with LC resonant tank circuits are promising for advanced handset applications with various functionalities.

ACKNOWLEDGMENT

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WIDEBAND ANTENNA INTEGRATED IN A SYSTEM IN PACKAGE FOR WLAN/ WiMAX OPERATION IN A MOBILE DEVICE

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ABSTRACT: The integration of a wideband antenna in a system in package (AiSiP) for WLAN/WiMAX dual-network operation in the 2.4/2.5 GHz bands is presented. The AiSiP mainly comprises a wideband printed monopole antenna and a RF shielding/heat sink metal case accommodating the associated RF modules and circuitry. The antenna is printed on both sides of the printed circuit board (PCB) of the AiSiP and integrated to the shielding/heat sink metal case through short-circuiting. When the AiSiP is mounted at the corner of the system ground plane or PCB of a mobile device, the metal case can act as a shielding metal block to reduce possible coupling between the integrated antenna and other RF components in the mobile device. In addition, it is found that the antenna impedance bandwidth is almost not affected by the use of various system ground-plane dimensions. This characteristic makes the proposed AiSiP advantageous for mobile device applications with various possible system ground-plane sizes. © 2006 Wiley Periodicals, Inc. Microwave Opt Technol Lett 48: 2048–2053, 2006; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.21841

Key words: antennas; internal antennas; antenna in a system in package (AiSiP); wideband antennas; WLAN antennas; WiMAX antennas

1. INTRODUCTION

System-in-package (SiP) technologies have been developed to meet the demands of semiconductor industry for low cost, small size, and high performance of an integrated system [1]. The SiP usually incorporates a variety of circuitry, chips, modules, and electronic components, such as filters, switches, and power amplifiers for high system functionality. However, to provide a complete radio function, the antenna also needs to be integrated into the radio-frequency SiP. For this kind of internal antenna design, a compact radiating patch is usually employed and stacked on the top above a small conducting plate as the antenna’s ground plane and the shield for the underlying RF circuitry and modules [2–4]. This configuration in general leads to an increase in the overall height of the package and also results in narrow band operation.

To overcome the problem, a wideband antenna integrated within the front-end module package for application in mobile devices has been proposed [5], in which the antenna is a metal-plate strip monopole integrated at the side edges in the package without increasing the overall height. In this study, we present another promising wideband antenna integrated in a SiP for mobile device applications. The proposed antenna in a system in package (AiSiP) mainly consists of an internal antenna and a RF shielding/heat sink metal case for accommodating the associated circuitry, chips, and modules. The antenna is a low-profile printed monopole, which is printed on both sides of the printed circuit board (PCB) of the AiSiP and arranged parallel to the two adjacent side walls of the metal case to achieve a compact structure (see Fig. 1). In this case, not only the antenna for wideband operation is easy to obtain, but also the height of the AiSiP is not increased. In addition, the metal case in the AiSiP can perform as a shielding metal block to shield undesired coupling between the integrated antenna and nearby electronic components or conducting elements in the mobile device, and, at the same time, can be used as a good thermal conductor to help absorb heat arising from modules or chips in operation [6].

A design example capable of providing a wide bandwidth covering the 2.4 GHz WLAN band (2400–2484 MHz, wireless local area network band) [7] and the 2.5 GHz licensed WiMAX band (2495–2690 MHz, worldwide interoperability for microwave access band) [8] is demonstrated. Results of a constructed prototype are presented and discussed. In addition, a simulation study for analyzing various possible dimensions of the system ground plane of the mobile device on the achievable impedance bandwidth of the antenna is conducted.
2. DESIGN CONSIDERATIONS OF THE PROPOSED AiSiP

Figure 1(a) shows the configuration of the proposed AiSiP applied to a personal mobile communication device such as a personal digital assistant (PDA) phone. The AiSiP has a volume of about $2.8 \times 15 \times 15 \text{ mm}^3$, and can easily be mounted at one corner of the system PCB of the mobile device. Note that the AiSiP is protruded from the two adjacent edges around the corner with a length of 2 mm only. In this small portion, a monopole antenna is printed on both sides of the PCB (0.8 mm thick FR4 substrate of size $15 \times 15 \text{ mm}^2$) of the AiSiP, and has a low profile of 2 mm to the RF shielding/heat sink metal case (size $2 \times 13 \times 13 \text{ mm}^3$) [see Fig. 1(b)]. The metal case provides a coupling-free space for accommodating the associated RF modules, circuitry, and chips. The metal case is further grounded to the system ground plane by using several shorting pins. When the AiSiP is mounted onto the system PCB, the RF shielding/heat sink metal case and the system ground plane together form as the antenna ground plane. For practical applications, the antenna and the metal case are partly encapsulated with a mold compound inside an outer casing (not shown here) to achieve a single RF component.

The antenna consists of a long radiating strip of mean length 53.5 mm and width 1 mm, a feeding stub of length 1 mm, and a
shorting stub of length 0.5 mm. The width of both feeding and shorting stubs is set to 0.8 mm. The radiating strip is folded in half and printed on both sides of the PCB of the AiSiP. Note that the two connecting pins are employed to electrically link the radiating strip on both sides of the PCB of the AiSiP. With the arrangement of the antenna and shielding/heat sink metal case at the corner, the metal case is expected to function as an effective shielding metal block to shield the fringing electromagnetic (EM) fields from entering the interior of the mobile device [9–12]. This characteristic leads to much reduced coupling between the antenna and

**Figure 2** Measured and simulated return loss for the constructed prototype. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

**Figure 3** Measured radiation patterns at 2545 MHz for the constructed prototype studied in Figure 2. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]
nearby conducting elements. The related results of the effects on the antenna performance due to the presence of the nearby conducting element are in general very similar to those reported [9–12], and thus are not presented in this study.

The folded strip monopole can be considered as a modified π-shaped monopole antenna of two different radiating arms [13]. The strip monopole can provide two resonant paths for generating two close resonant modes to be formed into a wide bandwidth for covering the 2.4/2.5 GHz bands for WLAN/WiMAX operation. The longer radiating arm (from points A to D) has a mean resonant path of about 31 mm, while the shorter one (from points A to C) has a mean resonant path of about 26 mm. By short-circuiting the longer radiating arm, which introduces additional inductance to compensate for the capacitive coupling arising between the antenna and the metal case, improved impedance matching can be obtained. For feeding the antenna, a 50 Ω mini coaxial line is used. The central conductor of the coaxial line is connected to the feeding point A, and the outer grounding sheath is connected to the shorting point B through a small via-hole in the RF shielding/heat sink metal case.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Figure 2 shows the measured and simulated return loss for a constructed prototype. The system ground plane is chosen to be of size 100 × 70 mm² (L × W). Fair agreement between the measurement and simulation obtained from Ansoft HFSS (high frequency structure simulator) [14] is seen. The results indicate that two close resonant modes are excited and formed into a wide bandwidth, which covers the 2.4 GHz WLAN band and the 2.5

![Figure 4](https://www.interscience.wiley.com)

**Figure 4** Measured peak antenna gain and simulated radiation efficiency for the constructed prototype studied in Figure 2. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

![Figure 5](https://www.interscience.wiley.com)

**Figure 5** Simulated return loss as a function of the system ground-plane length L; W = 70 mm. Other parameters are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]
GHz licensed WiMAX band. Across the bandwidth, the measured impedance matching is all better than about 7.3 dB (2.5:1 VSWR), which is acceptable for practical mobile phone or PDA phone applications.

Figure 3 plots the measured radiation patterns at 2545 MHz. From the results, comparable $E_x$ and $E_y$ components are seen, especially in the $x$–$z$ plane (the elevation plane) and $x$–$y$ plane (the azimuthal plane). This characteristic is a merit for practical appli-

Figure 6  Simulated return loss as a function of the system ground-plane width $W$; $L = 100$ mm. Other parameters are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

Figure 7  Simulated surface current distributions at 2545 MHz in the integrated antenna, RF shielding/heat sink metal case, and the system ground plane. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]
cations in the complex wave propagation environment. Similar radiation patterns for other frequencies over the operating band were also seen, and the results are not shown for brevity. Measured peak antenna gain and simulated (Ansoft HFSS) radiation efficiency versus frequency is shown in Figure 4. The measured antenna gain varies in a small range of about 1.4–2.2 dBi for frequencies across the bandwidth. The radiation efficiency for frequencies in the 2.4/2.5 GHz bands varies from about 57 to 67% from the simulated results.

Effects of the system ground size \((L \text{ and } W)\) on the impedance matching were studied with the aid of Ansoft HFSS. Figure 5 shows the simulated return loss of the system ground-plane length \(L\) varied from 70 to 100 mm. Small variations in the achievable impedance bandwidth are seen. For the cases of the system ground-plane width \(W\) varied from 40 to 70 mm, the results are shown in Figure 6. Again, small variations in the simulated return loss are obtained. These results indicate that the proposed AiSiP can be applied in mobile communication devices with various possible system ground-plane or PCB dimensions.

The simulated surface current distributions in the proposed design obtained from SEMCAD (simulation platform for electromagnetic compatibility, antenna design and dosimetry) [15] are shown in Figure 7. The major excited surface current distributions at 2545 MHz are found to be in the integrated antenna and two adjacent side surfaces of the metal case next to the antenna. Relatively small surface current distributions are seen to be in the system ground plane. This phenomenon suggests that the proposed AiSiP will be less prone to the effects of the system ground-plane size on the antenna impedance bandwidth. That is, the results confirm that the achievable impedance bandwidth is almost not affected by the use of various system ground-plane dimensions as studied in Figures 5 and 6.

4. CONCLUSION

A novel system in package with an integrated wideband monopole antenna (AiSiP) suitable to be mounted on the system PCB of a mobile device has been proposed, fabricated, and tested. A design example with a low-profile strip monopole for 2.4 GHz WLAN and 2.5 GHz WiMAX operation has been successfully implemented. Experimental and simulated results have also been presented. With the proposed configuration, the antenna is expected to have the EM compatible property with the nearby conducting elements. In addition, the variations in the size of the system ground plane of the mobile device have been found to have small effects on the antenna impedance bandwidth. The results indicate that the proposed AiSiP is very suitable for application in mobile devices with various possible system ground-plane or PCB dimensions.

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FULLY INTEGRATED 1.9-GHz CMOS POWER AMPLIFIER FOR POLAR TRANSMITTER APPLICATIONS

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ABSTRACT: A 1.9-GHz CMOS differential power amplifier for polar transmitter applications was implemented with a 0.25 μm RF CMOS process. All of the matching components, input transformer, and output transformer are fully integrated with 50 Ω input and output matching. Each power transistor in each differential branch is split again and controlled separately to obtain a high power mode and a low power mode. The amplifier achieved a drain efficiency of 32% at the maximum output power of 29.5 dBm. The dynamic range is measured at approximately 27.5 dB with a supply voltage range of 0.7 ~ 3.3 V. © 2006 Wiley Periodicals, Inc. Microwave Opt Technol Lett 48: 2053–2056, 2006; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.21854

Key words: Class-D; Class-E; dynamic range; GSM; polar transmitter; power amplifier; half turn transformer

1. INTRODUCTION

Recently, polar transmitter is still one of the major challenges in today’s pursuit of an RF system. The RF input of the power amplifier for a polar transmitter is decomposed into its low fre-