azimuth and elevation are $55.35^\circ$ and $62.27^\circ$ at $7.0$ GHz, respectively. Thus, excellent broadband radiation patterns are obtained under UWB bandwidth. Figure 5 illustrates the measured gain for the operating frequencies across the UWB band. A flat gain of $3.20–4.00$ dBi is obtained.

3. CONCLUSION
In this paper, a clover-shaped antenna with a partial ground plane is proposed for UWB applications in the $3.1–10.6$ GHz band, then designed, fabricated, and tested. The impedance bandwidth was $8.25$ GHz and the VSWR is less than $2$, covering the required UWB bandwidth. The gain is obtained from $3.20–4.00$ dBi and is matched by UWB specifications. The proposed antenna is designed to be smaller than the antenna proposed in an earlier published paper. The results demonstrate that the proposed Clover-shaped antenna with a partial ground plane can be applied under an UWB system.

ACKNOWLEDGMENT
This research is supported by the University IT Research Center Project of Inha UWB-RC, Korea.

REFERENCES

© 2006 Wiley Periodicals, Inc.

WIDEBAND PRINTED MONOPOLE ANTENNA INTEGRATED IN A SYSTEM IN PACKAGE

Kin-Lu Wong,1 Cheng-Tse Lee,1 Brain Chen,2 Kuo-Tsong Huang,2 and Sam Yang2
1 Department of Electrical Engineering, National Sun Yat-Sen University, Kaohsiung 804, Taiwan, Republic of China
2 Research & Development, Division V, Compal Communications, Inc., Taipei 105, Taiwan, Republic of China

Received 24 March 2006

ABSTRACT: A promising design of integrating a wideband printed monopole antenna in a system in package (AiSiP) for wireless local area network (WLAN) operation in the $2.4$ GHz band is presented. The antenna is an inverted-F monopole antenna printed on the no-ground portion (60 mm2) of the module substrate of the AiSiP (total size $24 \times 18$ mm2). A parasitic shorted strip can also be added in the no-ground portion to double the operating bandwidth of the AiSiP. When mounted on the system ground plane of a wireless device, the AiSiP can provide a complete communication function, without the need of employing additional antennas in the wireless device. The proposed AiSiP is studied in the paper, and obtained results of the constructed prototype are presented. Effects of the system ground plane on the antenna performance of the AiSiP are also analyzed. © 2006 Wiley Periodicals, Inc. Microwave Opt Technol Lett 48: 2113–2117, 2006; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.21868

Key words: printed antennas; mobile antennas; WLAN (wireless local area network) antennas; SiP (system in package); AiSiP (antenna in system in package)

1. INTRODUCTION

The conventional system in package (SiP) for application in a wireless device requires an external antenna for providing a complete function for wireless communications. To enhance the function of the SiP for wireless communications, it has become very attractive to develop the SiP with embedded antennas. To achieve this goal, several design techniques of integrating antennas in the integrated-circuit package or front-end module package [1–4] can be applied. These design techniques include mounting the patch antenna on the top above the circuitry or module in the package [1–3] or integrating the metal-plate monopole antenna to the shielding metal case in the package [4]. The former technique in
general leads to an increase in the overall height of the package, and in addition, it is usually difficult to achieve a wide operating bandwidth for the antenna. For the latter technique, the proposed metal-plate monopole antenna integrated in the package is suitable for the 5 GHz band operation [4]. For lower frequency operation such as the WLAN (wireless local area network) operation in the 2.4 GHz band (2400–2484 MHz) [5], the required dimensions of the proposed metal-plate monopole antenna will become too large to be embedded within the package.

In this study, we demonstrate a promising design of integrating a printed monopole antenna in the SiP (AiSiP) to perform a wideband operation for application in the 2.4 GHz WLAN band. The first example of the antenna integrated in the SiP is an inverted-F monopole antenna printed on the no-ground portion of the module substrate of the SiP. With the integrated antenna, the proposed AiSiP can perform a complete communication function for application in the wireless device. Antenna performances of the proposed AiSiP mounted at various possible positions on the system ground plane of the wireless device are studied. It is expected that, with the variations in the relative position of the integrated monopole antenna in the AiSiP to the system ground plane of the wireless device, some frequency shifting and bandwidth variations will occur. Obtained results for two different sizes of the system ground plane of the wireless device are analyzed in this study.

Further, to achieve an enhanced operating bandwidth for the proposed AiSiP, a second example of the integrated antenna in the AiSiP is studied. In the second example, a parasitic shorted strip is added in close proximity to the inverted-F monopole antenna, without increasing the total occupied area of the antenna. With the added parasitic shorted strip, the operating bandwidth is expected to be doubled. In this case, the proposed AiSiP can provide a wide bandwidth to cover the possible frequency shifting and bandwidth variations due to the relative position change of the AiSiP to the system ground plane of the wireless device. The obtained results of the constructed prototype are presented and studied.

2. PROPOSED AISIP WITH AN INTEGRATED INVERTED-F MONOPOLE ANTENNA

Figure 1 shows the configuration of the proposed AiSiP with an integrated monopole antenna mounted on a 1.6-mm-thick FR4 substrate. Note that the plastic packaging of the AiSiP is not shown in the figure. The possible RF modules (modules C–F in the figure) are located on the module ground plane of size 18 × 18 mm², which is a reasonable size of the practical SiP. The antenna is a printed inverted-F monopole antenna printed on the no-ground portion (6 × 18 mm²) of the module substrate of the AiSiP (total size 24 × 18 mm²). Note that for practical applications, the printed monopole antenna or the no-ground portion of the AiSiP should be protruded from the ground plane of the wireless device (see the configuration shown in Figure 2). In this case, since the protruded no-ground portion is with a small length of 6 mm only, the proposed AiSiP is promising to be concealed within the housing of the wireless device as an internal element, by slightly modifying the housing to accommodate the protruded portion of the AiSiP.

The printed inverted-F monopole antenna is operated as a quarter-wavelength structure, and its operating principle is similar to that discussed in earlier studies [6, 7]. The monopole antenna is shorted to the module ground plane at point B (the shorting point), and the antenna has a uniform strip width of 1 mm. The mean length of the antenna’s radiating strip, starting from point A (the feeding point) to the open end of the radiating strip, is about 22 mm, which is about 0.18 wavelength of the desired center operating frequency at 2442 MHz (center frequency of the 2.4 GHz band for WLAN operation). Note that the antenna’s radiating strip is less than a quarter-wavelength at 2442 MHz; this is mainly due to the substrate effect, which leads to a decreased resonant length for quarter-wavelength operation. In addition, the open end of the antenna’s radiating strip is bent into an inverted-L shape to achieve a compact structure for the antenna.

Figure 2 shows the configuration of the proposed AiSiP mounted on the system ground plane of a wireless device of size $L \times L$, which is printed on a 0.8-mm-thick FR4 substrate in this study. In the figure, the AiSiP is flushed to the left edge of the system ground plane of the wireless device, and the distance of the AiSiP to the right edge of the system ground plane is denoted as $t$ in this study. Notice that there are four via-holes in the substrates of the AiSiP and the wireless device to connect the module ground plane to the wireless device ground plane. To test the AiSiP in this study, a 50 Ω mini coaxial line is used across the 0.5-mm-wide feed gap between the feeding point and the module ground plane of the AiSiP.

The wireless device ground plane with a side length of 30 mm (that is, $L = 30$ mm) was first studied. Figure 3 shows the measured and simulated return loss of the proposed AiSiP in Figure 2. In this case, $t$ is selected to be 12 mm, that is, the AiSiP...
is flushed to the left edge of the wireless device ground plane. Good agreement between the measured data and the simulated results obtained from Ansoft simulation software HFSS (High Frequency Structure Simulator; Ansoft Corporation, http://www.ansoft.com/products/hf/hfss/) is observed. From the measured data, a wide impedance bandwidth, defined by 2:1 VSWR, of 188 MHz (2302–2490 MHz) or about 7.7% with respect to 2442 MHz is obtained, which easily covers the 2.4 GHz band for WLAN operation.

Figure 4 shows the measured return loss of the proposed AiSiP as a function of \( t \). In the figure, the results for five different values of \( t \) are shown. Each value of \( t \) indicates different distances of the AiSiP to the right edge of the wireless device ground plane. When \( t = 0 \), the AiSiP is flushed to the right edge of the wireless device ground plane. From the results, it is seen that large frequency shifting due to the variation in \( t \) is observed. This indicates that the antenna performance of the proposed AiSiP is strongly affected by the relative position of the AiSiP to the wireless device ground plane. However, in the case of \( L = 30 \) mm studied in Figure 4, the maximum frequency shifting of the AiSiP observed for \( t \) varied from 0 to 12 mm is about 100 MHz only, which makes the obtained impedance bandwidth of the AiSiP for all values of \( t \) still cover the 2.4 GHz band for WLAN operation.

A larger wireless device ground plane was also studied. The measured results for the case of \( L = 60 \) mm are shown in Figure 5. In this case, with \( t \) varied from 0 to 12 mm, an even larger frequency shifting (about 200 MHz) is observed; the center frequency for \( t = 0 \) is at about 2525 MHz, while that for \( t = 12 \) mm is at about 2325 MHz. In addition, large bandwidth variations are also seen. For the case of \( t = 12 \) mm, the obtained impedance bandwidth falls outside of the 2.4 GHz band. As for \( t = 3 \) and 6 mm, the obtained impedance bandwidths cannot cover the whole 2.4 GHz band for WLAN operation. These obtained results suggest that, to overcome the effect of various relative positions of the AiSiP to the wireless device ground plane, the proposed AiSiP should have a much larger impedance bandwidth, especially for application in the wireless device with a larger system ground plane size.

3. PROPOSED AISIP WITH AN INTEGRATED INVERTED-F MONOPOLE ANTENNA AND A PARASITIC SHORTED STRIP

To achieve a widened operating bandwidth for the proposed AiSiP, a parasitic shorted strip is added in close proximity to the printed inverted-F monopole antenna (see the configuration shown in Fig. 6). Notice that the parasitic shorted strip has a uniform width of 0.5 mm, and is of a folded structure to achieve a compact size. In this case, the added parasitic shorted strip can be fit into the no-ground portion (6 × 18 mm²) of the AiSiP, without increasing the occupied area of the embedded antenna. Also note that the mean length of the parasitic shorted strip is about 19 mm, slightly less than that of the radiating strip of the inverted-F monopole antenna. Hence, it is expected that the parasitic shorted strip can contribute an additional resonant mode close to the original resonant mode of the inverted-F monopole antenna to form into a much widened operating bandwidth for the AiSiP. The operating principle of the parasitic shorted strip is similar to that discussed in an earlier study [6].

The proposed AiSiP in Figure 6 mounted on the wireless device with a ground plane size of 60 × 60 mm² (\( L = 60 \) mm) was constructed and tested. Figure 7 shows the measured return loss for \( t = 42 \) mm. The definition of \( t \) is the same as given in Figure 2, and for \( t = 42 \) mm, the AiSiP is flushed to the left edge of the wireless device ground plane. The measured data are generally in agreement with the simulated results, and two resonant modes are excited with good impedance matching. Note that the resonant

![Figure 3](http://www.interscience.wiley.com)

**Figure 3** Measured and simulated return loss of the AiSiP in Figure 2; \( t = 12 \) mm, \( L = 30 \) mm. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

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

**Figure 4** Measured return loss as a function of \( t \) for the AiSiP in Figure 2 with \( L = 30 \) mm. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

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

**Figure 5** Measured return loss as a function of \( t \) for the AiSiP in Figure 2 with \( L = 60 \) mm. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]
mode with higher frequencies is contributed by the parasitic shorted strip, while that with lower frequencies is generated by the inverted-F monopole antenna. The two resonant modes are formed into a wide bandwidth of 470 MHz (2230–2700 MHz), about 2.5 times that (188 MHz) of the AiSiP with the inverted-F monopole antenna studied in Figure 3.

The dependence of the obtained bandwidth on the relative position $t$ is also studied. Figure 8 shows the measured return loss as a function of $t$ for the AiSiP studied in Figure 7. In the figure, five curves of $t$ varied from 0 to 42 mm are presented. Note that, for $t = 0$ and 42 mm, the AiSiP is flushed to the right edge and left edge of the wireless device ground plane, respectively. It is interesting to see that the lower or the original resonant mode of the AiSiP is greatly affected by the variation in the relative position $t$. On the other hand, the effects on the higher or the additional resonant mode contributed by the parasitic shorted strip is smaller. This behavior is probably because that the parasitic shorted strip is encircled by the inverted-F monopole antenna and is thus less sensitive to the relative position variation of the AiSiP to the wireless device ground plane. However, from the results, the obtained impedance bandwidth formed by the two resonant modes for $t$ varied from 0 to 42 mm easily covers the 2.4 GHz band for WLAN operation.

The radiation characteristics of the AiSiP studied in Figure 7 were also investigated. Figures 9–11 plot the measured radiation patterns at 2300, 2442, and 2600 MHz, respectively. Similar radiation patterns for the three frequencies are seen. It also indicates that the two excited resonant modes of the AiSiP have similar radiation characteristics. The measured antenna gain and simulated radiation efficiency are shown in Figure 12. Over the operating band of the AiSiP (2230–2700 MHz, see Fig. 7), the measured antenna gain is varied from about 1.0 to 3.2 dBi. Good radiation efficiency obtained from Ansoft simulation software HFSS is also obtained. The radiation efficiency is larger than 50% over the operating band. Over the 2.4 GHz WLAN band, the radiation efficiency is even larger than 85%.

1. CONCLUSION

A novel design of the AiSiP with an integrated wideband printed monopole antenna has been proposed, fabricated, and tested. With the
The use of the printed inverted-F monopole antenna with a parasitic shorted strip, the proposed AiSiP can provide a wide operating bandwidth of 470 MHz centered at about 2450 MHz, allowing it to easily cover the 2.4 GHz band for WLAN operation. Results also indicate that, when the proposed AiSiP is employed in the wireless device for practical applications, the relative position of the AiSiP to the system ground plane of the wireless device has strong effects on the antenna performances of the AiSiP. There are large frequency shifting and bandwidth variations observed for the integrated antenna of the AiSiP. The related effects become more significant when the AiSiP is employed in the wireless device with a larger system ground plane size. However, with the proposed AiSiP having a wide operating bandwidth, the possible frequency shifting and bandwidth variations owing to the relative position variations of the AiSiP to the wireless device ground plane are easily covered. In addition, good radiation characteristics over the operating bandwidth of the AiSiP have been observed. With these attractive antenna performances obtained, the proposed AiSiP is very promising for application in the wireless device to provide a complete communication function, without the external antennas required.

REFERENCES

© 2006 Wiley Periodicals, Inc.

RESEARCH ON ULTRA-WIDE BAND PLANAR VIVALDI ANTENNA ARRAY

Feng T. Wu, Guang F. Zhang, Xue L. Yuang, and Nai C. Yuang
Institute of Electronic Science and Engineering
National University of Defense Technology
Changsha Hunan Province 410073
People’s Republic of China

Received 15 March 2006

ABSTRACT: Planar Vivaldi antenna, with attractive performance compared with conventional TEM horn antennas, was introduced and used to form array. Normalized radiation energy pattern was adopted to characterize the transmit and receive behavior of ultra-wide-band (UWB) antenna array. Finite-difference time-domain (FDTD) was used to analyze the array. Radiation energy pattern in H plane was measured in outdoor region, for the difficulty of installing, E plane pattern was not measured. Measured and simulated results indicate that the planar