Design for a Dual-Frequency Antenna-in-Package

Li Li, Liping Han, Guorui Han, Xinwei Chen, Yanfeng Geng, and Wenmei Zhang

For an antenna-in-package (AiP), via holes are used to connect the antenna ground and system ground. In this letter, a dual-frequency AiP with a U-slot embedded in the patch is proposed. By properly arranging three via holes under the non-radiating edge, an AiP with two resonant frequencies is realized. Then a U-slot is embedded in the patch to further improve the bandwidth of the AiP. To validate the proposed design, an AiP with the bandwidth of 4.49% at 2.45 GHz and 6.02% at 5.32 GHz is achieved and fabricated. The measured results agree with the simulated results.

Keywords: Dual-frequency antenna, antenna-in-package, via holes, wireless communication.

I. Introduction

In wireless communication systems, the compact multifunctional package is driven by the advances in technologies and the great demand from users. An antenna-in-package (AiP) design offers an elegant antenna solution to modern single-chip radio frequency (RF) transceivers.

Zhang proposed the first AiP [1]. Numerous single frequency AiPs operating at 5.2 GHz or 5.8 GHz have been reported [2]-[5]. In [4], Wi proposed an AiP with a 140 MHz bandwidth which has two neighboring resonant frequencies (both excited by two stacked patches) at 5.264 GHz and 5.355 GHz. In addition, a novel microstrip line AiP with a double-resonance technique and meshed ground plane to enhance its impedance bandwidth has been presented [5].

In AiPs, the antenna ground is connected with the system ground by multiple via holes. The number and locations of the ground vias have an influence on the performance of the AiP. In this letter, a dual-frequency AiP operating at 2.45 GHz and 5.32 GHz is achieved by properly arranging three ground vias. Also, by embedding a U-slot in the patch, the bandwidth of the AiP is improved. In order to validate the proposed design, an AiP is fabricated, and the measured and simulated results have been found to be in agreement. Compared with the conventional dual-frequency antenna controlling two resonant frequencies by adjusting the dimensions of the stacked patches, the proposed antenna can operate at two frequencies by properly arranging the number and locations of the vias connecting the antenna and system ground planes. The co-design of the antenna and package can implement the higher level of integration and miniaturization.

II. Antenna Design

The proposed AiP is shown in Fig. 1. The rectangular patch is situated on the top layer. Under the antenna ground plane, the middle substrates are removed from the center portion and form a cavity. The cavity is used to host chip-scale components, which will be packaged together with antenna. At the bottom of the AiP, the metal layer of PCB is the system ground. Multiple via holes are used to connect the antenna and system ground planes. Figure 1(b) shows the locations of these via holes. A dual-frequency AiP, operating at 2.4 GHz and 5.34 GHz, has been designed and realized on an FR4 with a dielectric constant of 4.4 and a loss tangent of 0.02. Each layer substrate has the thickness of 0.8 mm.

For the proposed dual-frequency AiP, the higher resonant frequency is controlled by the patch on the top layer as a normal antenna. The lower one can be determined by the number and locations of via holes. The number and locations of via holes can affect the current distributions of two ground planes. When they are appropriately arranged, the antenna

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Li Li (phone: +86 351 7011433, email: lilizlllz@yahoo.cn), Liping Han (email: ping_sx@yahoo.com.cn), Guorui Han (email: han_gr@sxu.edu.cn), Xinwei Chen (email: chenxw@sxu.edu.cn), Yanfeng Geng (email: yfgeng@sxu.edu.cn), and Wenmei Zhang (corresponding author, email: zhangwm@sxu.edu.cn) are with the College of Physics and Electronics Engineering, Shanxi University, Taiyuan, China.

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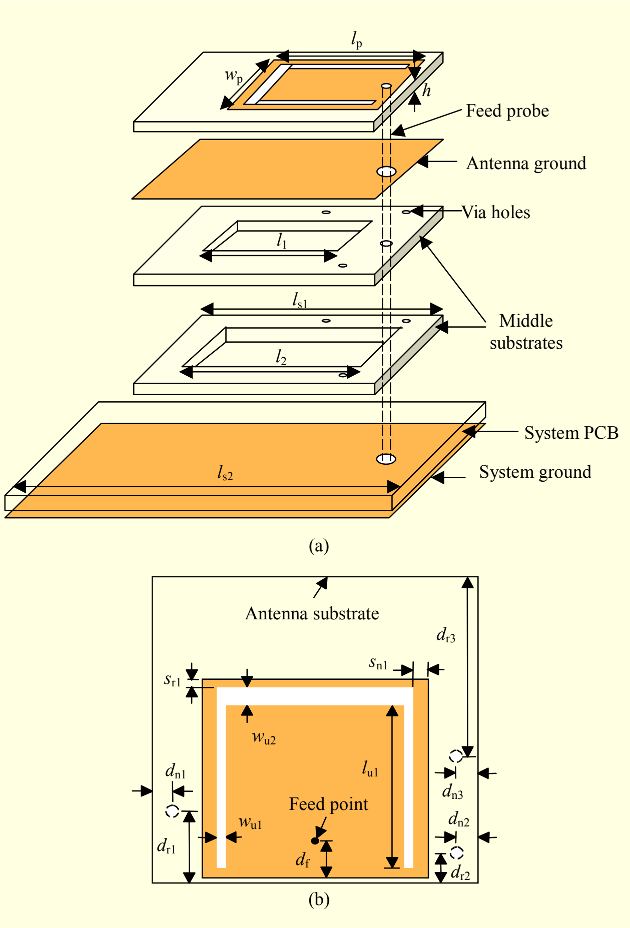

Fig. 1. Architecture of investigated AiP: (a) expanded view and (b) top view. l_p=13.2 mm, w_p=14 mm, h=0.8 mm, l_1=12 mm, l_2=14 mm, l_{s1}=20 mm, l_{s2}=40 mm, d_{n1}=d_{n2}=d_{n3}=2 mm, d_{r1}=5 mm, d_{r2}=2 mm, d_f=2.4 mm, l_{u1}=11.4 mm, w_{u1}=0.5 mm, s_{r1}=0.48 mm, s_{n1}=1 mm, w_{u2}=1 mm.

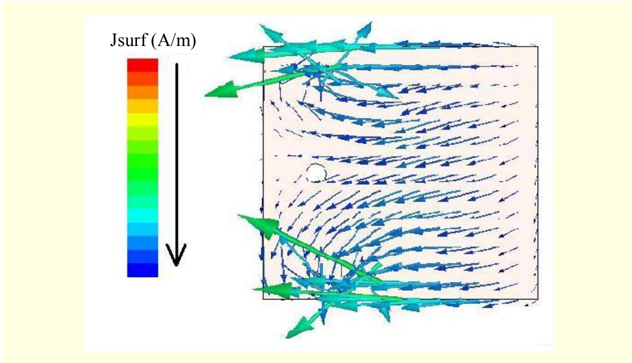

Fig. 2. Surface current distribution on antenna ground.

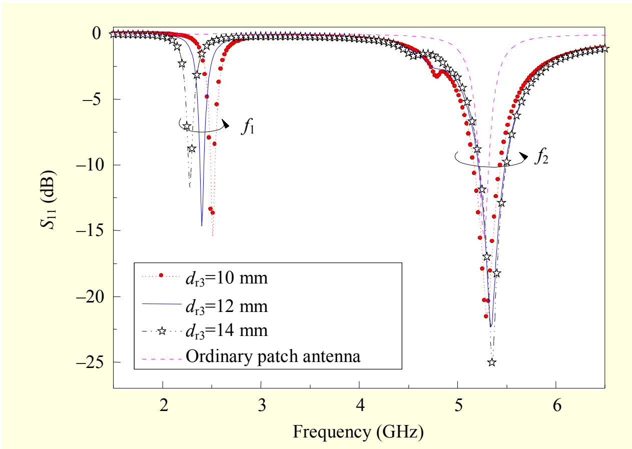

Fig. 3. Simulated S_{11} of ordinary antenna and AiP with three via holes.

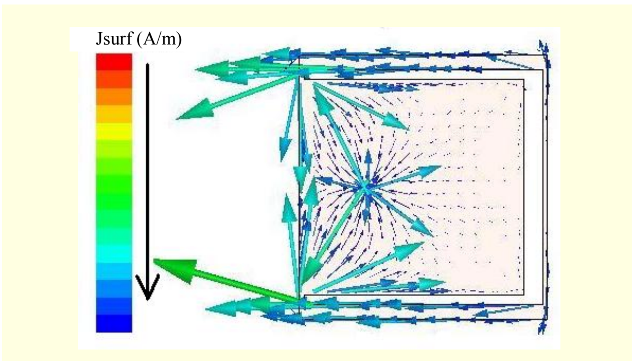

Fig. 4. Surface current distribution on patch with U-slot.

ground plane can become a parasitic patch, and a new resonant frequency (f_1) of TM_{10} mode can be excited. f_1 is mainly decided by the shortest distance (d_r) of vias away from the radiating edge opposite to the probe, and d_r is close to 0.25λ_1 (λ_1 is the guided wavelength at f_1). Figure 2 shows the surface current distribution on the antenna ground plane, and Fig. 3 shows the simulated S parameters when three via holes are placed. In Fig. 2, it can be seen that the current returns to the system ground, and the antenna ground becomes a radiation patch at f_1. In Fig. 3, as the package vias are arranged, f_1 appears and changes with d_{r3}. For the dual-frequency AiP operating at 2.4 GHz and 5.34 GHz, d_{r3} is 12 mm and the simulated bandwidths are 40 MHz and 280 MHz in two bands, respectively.

In order to further improve the performance at the low frequency of the AiP, a U-slot is embedded in the patch. Figure 4 shows the current distribution on the patch with a U-slot at 2.4 GHz. It can be seen that with the presence of the slots, a new patch surface current encircling around the slots is excited. As a result, another new resonant frequency occurs, and it is mainly decided by s_{n1}, s_{r1}, and l_{u1}×w_{u1}. In the case of l_{u1}×w_{u1}= 11.4 mm×0.5 mm, s_{n1}=1 mm, and s_{r1}=0.48 mm, the resonant frequency at 2.45 GHz is excited. Figure 5 shows the simulated S parameters of the AiPs with and without a U-slot. It indicates that the bandwidth of AiP is widened to 110 MHz at the low

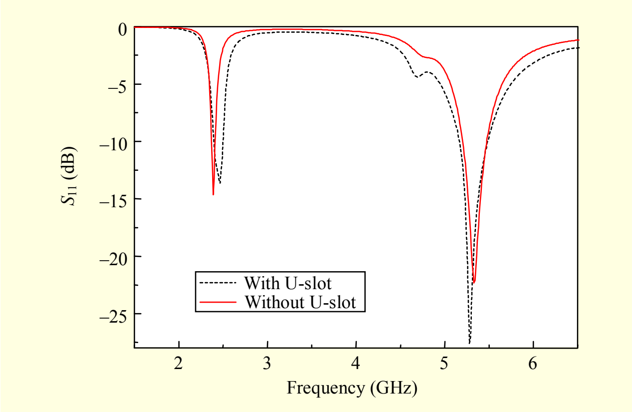

Fig. 5. Simulated S_{11} of AiP with and without U-slot.

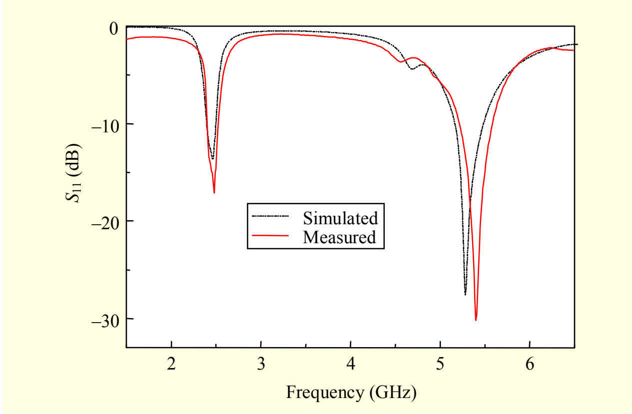

Fig. 7. Measured and simulated S_{11} of AiP.

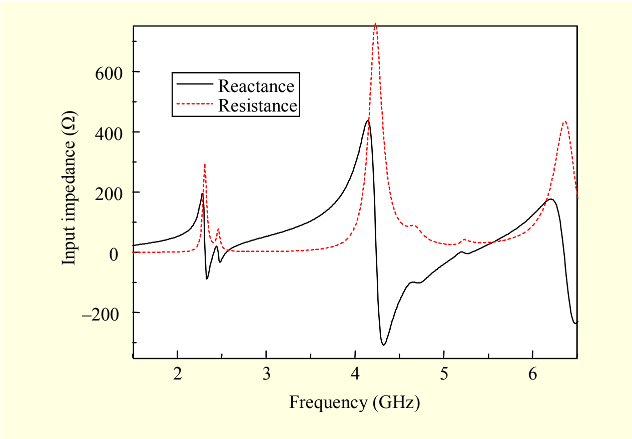

Fig. 6. Input impedance of AiP with U-slot-embedded patch.

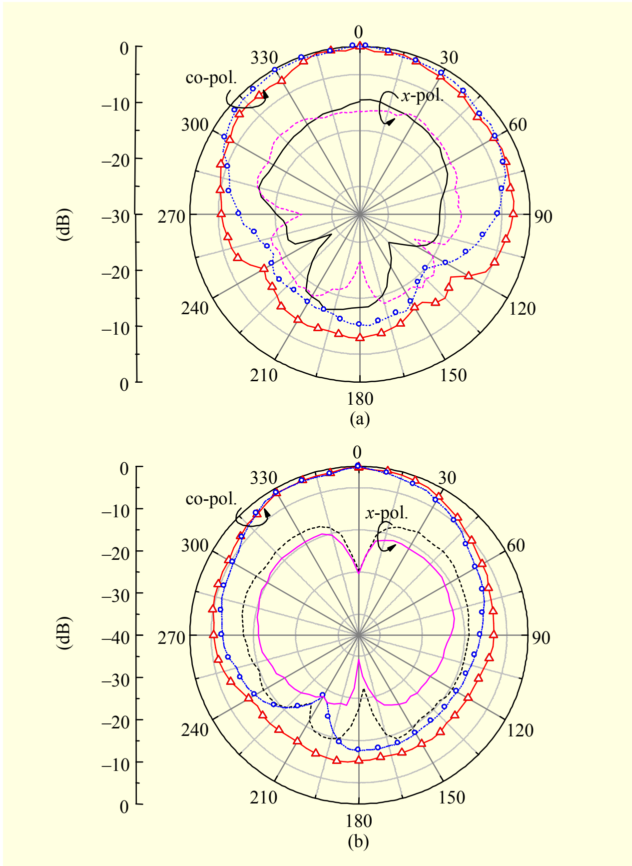

Fig. 8. Measured radiation patterns at two operating frequencies: (a) 2.48 GHz and (b) 5.4 GHz.

frequency due to the cooperation of two resonant frequencies. The input impedance of AiP with a U-slot is shown in Fig. 6. It is obvious that there are two resonant frequencies close to 2.4 GHz.

III. Experimental Results

To verify this design, an AiP without an internal RF chip was fabricated and measured. The antenna is fed with the coaxial probe, and the SMA connector with flexible wire is used for convenient measurement. Figure 7 presents the measured and simulated S_{11}. As can be seen, as compared with the simulated result, the measured center frequencies are 2.48 GHz and 5.4 GHz, which shift 30 MHz and 80 MHz upwards, respectively. Also, the bandwidths at two frequencies are 120 MHz and 370 MHz. The errors between the simulated and measured results are caused by the material and fabricated tolerance.

The measured radiation patterns at two operating frequencies are also plotted in Fig. 8. It is noted that the same polarization planes and similar radiation characteristics are obtained at the two frequencies. The cross-polarization is about 10 dB lower than the co-polarization in the broadside direction at the low resonant frequency. Moreover, the measured gains are 0.5 dBi and 5.46 dBi at the low and high resonant frequencies, respectively. Because the parasitic patch is involved in the dielectric and the energy cannot effectively radiate, the gain at the low frequency is lower. In addition, the antenna efficiencies are 76% and 88% at low and high frequencies, respectively.

IV. Conclusion

In this letter, a dual-frequency AiP with a U-slot is proposed. The proposed antenna can operate at two frequencies by properly arranging the number and locations of the vias connecting the antenna and system ground planes. The co-design of the antenna and package can implement a higher level of integration and miniaturization. A U-slot is embedded in the patch to improve the performance of the low frequency. The measured results agree with the simulated results.

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