High-Permittivity Substrate Multiresonant Antenna Inside Metallic Cover of Laptop Computer

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***Abstract*—This letter aims to describe a possible method of integrating an antenna inside the metallic cover of laptop computers. The proposed antenna consists of a patch and two parasitic monopoles on the high-permittivity substrate inside a $40 \times 6 \times 4$ mm^3 $(0.36\lambda_0 \times 0.054\lambda_0 \times 0.036\lambda_0)$ cavity of the metallic cover. The -6-dB bandwidth of 2.62–2.81 GHz (7%) is achieved by combining multiple narrow bands from different resonant elements. A prototype of the proposed antenna is designed and measured to validate the design method. The obtained results including reflection coefficient, radiation pattern, and gain are presented and agree well with the simulation results.**

***Index Terms*—Mobile antennas, multiple-band antennas.**

I. Introduction

For modern laptop design, cosmetic and solid industrial design (ID) requirements have been taken into account due to the consumer-oriented consideration. In order to meet the marketing requirement, metallic covers have become more and more popular in laptop designs by major laptop manufacturers. The metallic cover also has advantageous features, such as excellent heat dissipation and working durability, and it is much stronger than a plastic cover. For the system liability, the metallic cover must be well grounded to avoid electronic static discharge (ESD) [1]. However, it would have a great impact on the antenna's bandwidth and efficiency.

For laptop applications, different types of antennas are presented in the recent publications [2]–[5], such as the slot antenna [2], inverted-F antenna [3], monopole antenna [4], [5], and so on. All these designs performed well with compact dimensions, but had to be mounted in the no-ground area extended from the ground. However, for the consideration of simple fabrication and cost competition, a fully metallic cover has become more and more important. In order to maintain the integrity of the metallic cover, the antennas can be arranged in the plastic hinges, which connects the front and rear metal covers—for example, the Macbook Pro series by Apple Corporation. There is still a pressing need for the embedded antenna design in the above-mentioned situation.

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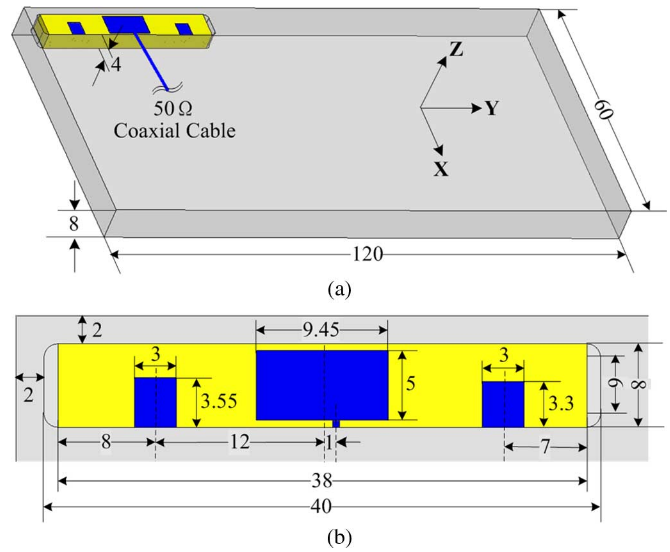

Fig. 1. Geometry and dimensions of the proposed antenna. (a) 3-D view. (b) Detailed dimensions in the planar view (dimensions are in millimeters).

In this letter, another solution is proposed by arranging the antenna inside a cavity at the corner of the metallic cover, maintaining the integrity of the metal covers. In order to overcome the antenna bandwidth limitation in small-volume metal cavity, the antenna is composed of three resonant elements, a main patch and two parasitic monopoles, arranged on a high-permittivity substrate. By combining the three operation bands, the proposed antenna is able to cover a band of 2.62–2.81 GHz inside a cavity of $40 \times 6 \times 4$ mm^3. The proposed antenna has been manufactured and tested. The measured results agree well with simulated ones and validate the design method inside small-volume metal cavity.

II. Antenna Design Approach

As shown in Fig. 1, the proposed antenna is positioned inside a cavity at the corner of the fully metallic cover. The cover is made of copper ($\sigma = 5.8 \times 10^7$ S) for the sake of easy soldering, with the dimension of $120 \times 60 \times 8$ mm^3. The cavity is milled from the metallic cover, with a typical dimension of $40 \times 6 \times 4$ mm^3 for laptop antenna design, required by the project specifications. The 4-mm thickness of the cavity is dictated by total thickness of the laptop, and the 6-mm width is limited by the LCD panel. A $38 \times 6 \times 4$ mm^3-sized ceramic substrate

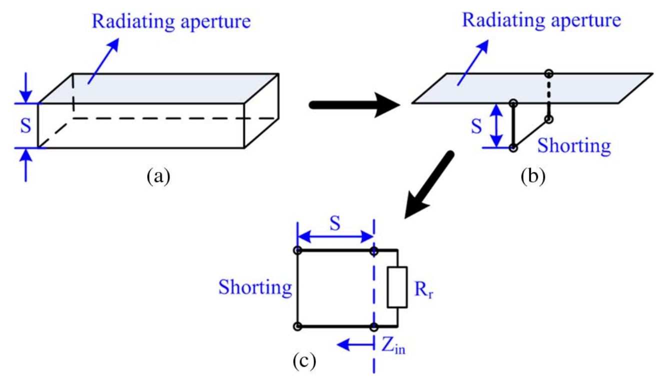

Fig. 2. Equivalent transmission line model of metal cavity.

$(\varepsilon_r = 40, \tan\delta = 0.015)$ is arranged inside the cavity. The air gaps between the cavity and the substrate are introduced due to the chamfer curves (radius $= 1$ mm) at the corner and can be eliminated by using high-precision fabrication. A patch and two parasitic monopoles are on the substrate and fed by a 50-Ω coaxial cable. The two monopoles are connected to the ground. The detailed values of the proposed antenna are shown in Fig. 1. The antenna is radiating from the screen to the users.

Here, we will talk about the effect of cavity with metallic enclosure. As shown in Fig. 2, five faces of the cavity are metallic, leaving one face as the radiating aperture. Seeing from the radiating aperture, the cavity is a short-ended waveguide with large width in the transverse plane and can be treated as a shorted-ended transmission line, shown in Fig. 2(b). The electrical length is determined by the thickness of cavity, marked as S. According to the transmission line theory [6], if there is no high-permittivity substrate filled in the cavity $(\varepsilon_r = 1)$, the input impedance looking toward the load (Z_{in}) is a pure image with small value. It can be treated as a shunt inductor with small values to the radiation impedance (R_r). Therefore, the radiation impedance is difficult to be matched. If a high-permittivity substrate is used in the cavity $(\varepsilon_r = 40)$, the equivalent electrical length (S) is approximately equal to $\lambda_g/4$ (λ_g is the wavelength in the substrate). The cavity can be treated as a shunt inductor with large values, even as an open circuit. As a result, the radiation impedance can be well matched, ignoring the short end. In other words, the high-permittivity substrate is used to lengthen the distance between radiating aperture to the surrounded ground [7].

Based on the above discussion, a patch with two parasitic monopoles is designed on the ceramic substrate, as shown in Fig. 1. Due to the high permittivity, the bandwidth of the patch is narrow. In order to widen the bandwidth, two parasitic monopoles are arranged on each end of the patch with optimized distance. The electric field distributions for each resonant are shown in Fig. 3. As discussed above, the distance between the patch and the cavity bottom is approximately equal to $\lambda_g/4$, much larger than the traditional cavity-backed patch. From the current distribution of Fig. 4, the mode on the patch is quite similar to the normal TM_{01} mode, and we named it a "quasi-patch" mode. As shown in Fig. 3(d), the strength of the electric field decreases from the patch edge to the bottom of the ground. This field distribution is different from the normal

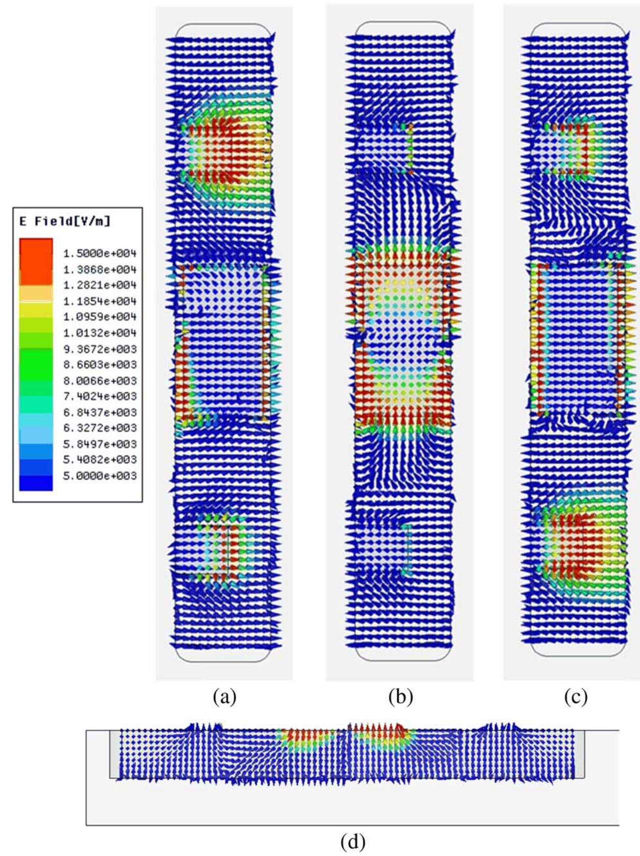

Fig. 3. Top view of electric field distributions at (a) 2.637, (b) 2.701, and (c) 2.781 GHz. (d) Side view of electric field distributions at 2.701 GHz.

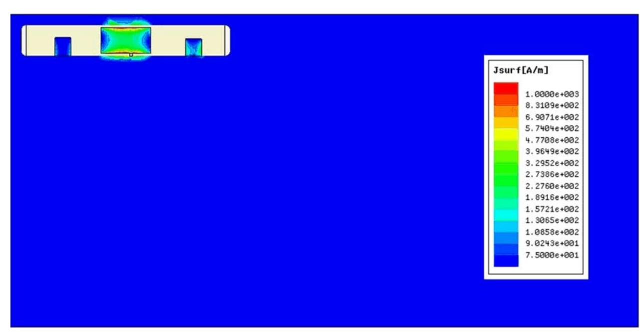

Fig. 4. Top view of current field distributions at 2.701 GHz.

TM_{01} mode, whose electric field is constant between the radiating edges and the ground. The TM_{01} mode cannot exist due to the narrow space along the x-axis and large distance between the patch edge and the ground bottom. In this mode, the patch is the main radiator with the length of half of the wavelength.

The dimensions of the monopoles are selected due to the operating frequency. The value of the length plus half of the width is approximately a quarter of a wavelength. Its width and the position affect the impedance matching. The positions of the monopoles also affect the boundary condition of the patch. The values of each parameter are optimized by using the full-wave simulation software Ansoft High Frequency Structure Simulator (HFSS). From the simulation, the three operating frequencies can be tuned together. By combining the multiple resonant bands, the bandwidth has been widened. The patch and

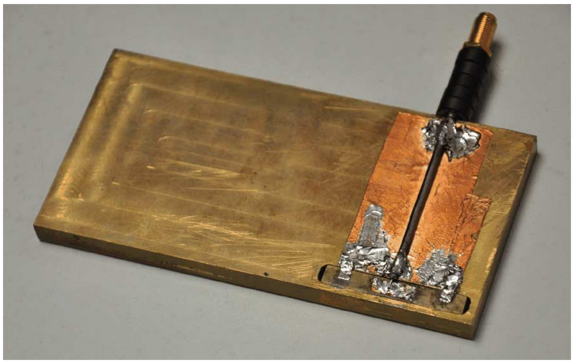

Fig. 5. Photograph of the proposed antenna.

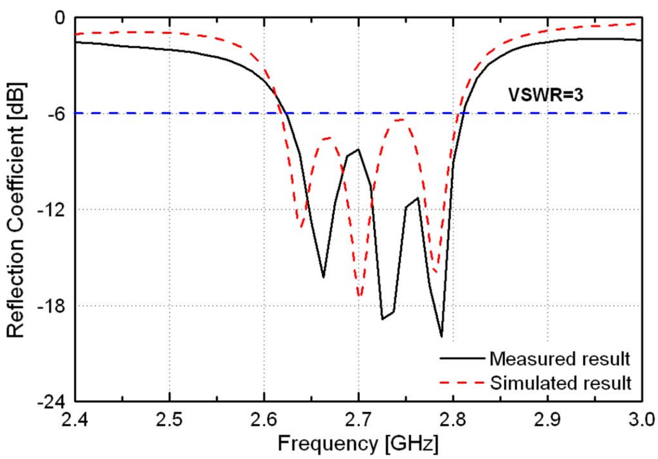

Fig. 6. Simulated and measured results of the reflection coefficient.

two monopoles resonate at the frequencies of 2.701, 2.637, and 2.781 GHz.

III. Experiment Results

To demonstrate the validity of the design method, a prototype of the proposed antenna is fabricated and shown in Fig. 5. The outer conductor of the feeding cable is connected to the metal cover. The measured reflection coefficient is shown in Fig. 6, and compared to the simulated one. Clearly, a bandwidth of 2.62–2.81 GHz (7%) is achieved by combining three operating bands with the reflection coefficient lower than -6 dB. Due to the fabrication error, the three resonant frequencies shift to 2.66, 2.72, and 2.78 GHz.

The measured radiation patterns are illustrated in Fig. 7 and match the simulation results. As shown in Fig. 7(c) and (d), the radiation pattern of "quasi-patch" mode is also different from the traditional TM_{01} mode. For the traditional TM_{01} mode, the beamwidth in E-plane (xz-plane) is wider than that in H-plane (yz-plane). However, for the proposed antenna, the radiation pattern is affected by the boundary condition of metallic cavity. The metallic boundary of cavity can be treated as a reflector, where the horizontal wave is unable to propagate forward. The metallic boundary along the x-axis is much narrower than that along the y-axis. As a result, the beamwidth in E-plane (xz-plane) is narrower than that in H-plane (yz-plane).

The measured gains are compared to simulation in Fig. 8. In the desired band of 2.62–2.81 GHz, the measured gain fluctuates between -3 and -6 dBi, which is acceptable for the industrial

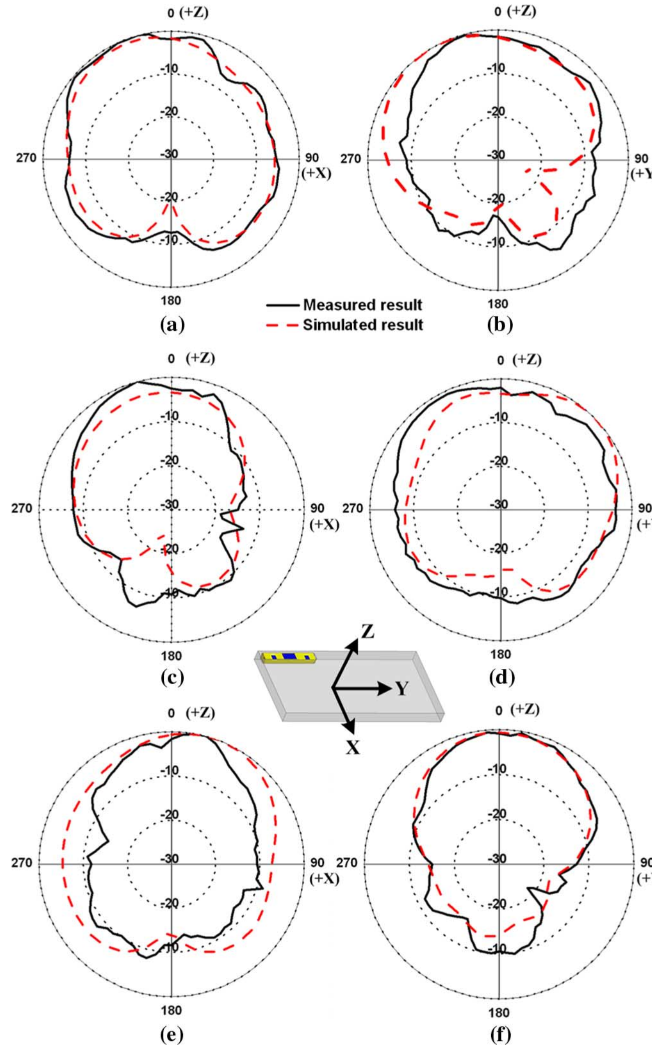

Fig. 7. Simulated and measured radiation patterns of (a) E-plane at 2.66 GHz, (b) H-plane at 2.66 GHz, (c) E-plane at 2.72 GHz, (d) H-plane at 2.72 GHz, (e) E-plane at 2.78 GHz, and (f) H-plane at 2.78 GHz.

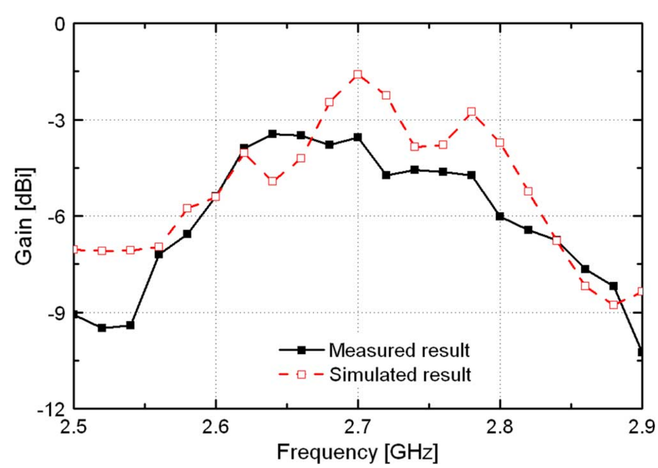

Fig. 8. Measured gain of the proposed antenna.

requirement. The difference between measurement and simulation mainly contributes to the metal loss. From the simulation, the radiation efficiency in this band is 10%–20%. The antenna shows acceptable performance inside the metallic cavity. However, in the practical applications, the environment around the antenna includes metal boundary, LCD, lights, camera, and other items. In this letter, we gave the worst case (all metal boundaries) to show the feasibility of the proposed antenna. Better performance can be achieved in the practical antenna design.

IV. Conclusion

The fully metallic cover is widely adopted in the modern laptop design for the new-coming market requirements. Traditional types of antennas are not suitable to install inside the metallic cavity. This letter proposed an acceptable solution to overcome the antenna design problem. The antenna is supported by high-permittivity ceramic material to lengthen the equivalent distance between the radiating aperture and the bottom of the cavity. Simple antenna structure including a patch and two parasitic monopoles is flexible for the frequency tuning and impedance matching. By combining multiple resonant bands in a cavity with the dimensions of $40 \times 6 \times 4$ mm^3, 7% bandwidth is achieved . The measured gain is better than -6 dBi in the desired band and acceptable for practical use. By varying the size of the antenna and cavity, the design method can be adopted for wireless local area network (WLAN) applications.

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