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Miniaturized Shorted-Patch Antenna Designs in Multilayered Structures

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1. Introduction

Microstrip patch antennas have been widely used in many communication systems. The size of a conventional patch antenna, however, is still somewhat large for practical applications. Various techniques have been proposed to reduce the antenna size recently [1]-[5]. On the other hand, as multilayered-circuit technologies (e.g., low-temperature co-fired ceramic, LTCC) have been substantially developed in recent years, many microwave circuits and components can be now implemented in a multilayered structure. In a modern multilayered-circuit design, the number of the substrates can be more than 10 layers. Since circuits can be fabricated in different substrate layers, the multilayered-structure design is a very efficient method for miniaturizing a microwave circuit [6]-[7]. In this work, we present a simple technique to implement a shorted-patch antenna in a multilayered structure. In this design, a conventional single-layered quarter-wavelength shorted-patch antenna is first segmented into several sub-sections. Each sub-section is then fabricated in a substrate layer. By stacking the substrates and connecting the sub-sections by posts, a multilayered shorted-patch antenna can be achieved in a compact module. The proposed antenna can be readily characterized by an equivalent transmission-line model. The design concepts and guidelines for such a multilayered antenna structure can be therefore obtained very easily. Two preliminary examples, that is, the two- and four-layered shorted-patch antennas are presented in the paper. The return loss and the radiation pattern of the multilayered antennas are simulated and compared with the conventional single-layered shorted-patch antenna to reveal the performance and feasibility of the proposed antenna design.

2. Antenna Designs

The design concept of the proposed multilayered shorted-patch antennas can be illustrated by the equivalent transmission-line model. Fig.1 shows a quarter-wavelength ($\lambda/4$, λ is the guide wavelength in the substrate) shorted-patch antenna fabricated in a single substrate, where a set of shorting posts connecting the antenna patch and the ground plane forms the shorting path. Also, a microstrip feeding line is used in the design to facilitate the circuit integration. From the transmission-line model, the $\lambda/4$ antenna can be modeled by a transmission line with the two ends being respectively terminated by a short circuit and a parallel RC network (Fig. 2(a), (b)), where the RC network is used to characterize the power radiation and the fringing field at the radiating slot. When the antenna operates at the fundamental mode, the transmission line has a length L of ~$\lambda/4$. By dividing the transmission line into two sub-sections and collocating the two lines vertically (A-A' and B-B' in Fig. 2(d)), a two-lines circuit with the length being about $\lambda/8$ as shown in Fig. 2(d) can be obtained. The obtained two-lines circuit are then realized in a two-layers structure. As illustrated in Fig. 2(c), the first line A-A' is formed by the lower patch and the lower surface of the ground plane, whereas the second line B-B' is composed of the upper patch and the upper surface of the ground plane. The upper and lower patches are then connected by the connecting posts passing through a slot in the ground plane to construct a two-layered $\lambda/8$ shorted-patch antenna. Similarly, dividing the transmission line into four pieces, A-A', B-B', C-C', and D-D', would further reduce the circuit length to $\lambda/16$ and result in the four-lines circuit shown in Fig. 2(f). A four-layered shorted-

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patch antenna is then designed to correspond to the four-lines equivalent circuit. Fig. 2(e) depicts the four-layered antenna, in which each transmission line is constructed by the metals on the upper and lower interfaces of a dielectric layer. For example, the upper surface of the ground plane 1 and the lower surface of the middle patch form the line B-B', while the lower surface of the ground plane 2 and the upper surface of the middle patch can be regarded as the line C-C'. With the similar procedures, more substrate layers could be used to further reduce the size of a shorted-patch antenna.

3. Results

To demonstrate the antenna performances of the proposed multilayered antenna, a two-layered and a four-layered antennas are designed and compared with the single-layer λ/4 shorted-patch antenna (Fig. 1). Figs. 3 and 4 illustrate the design configurations of the two- and four-layered shorted-patch antennas, respectively. The antennas are designed to resonate at 2.4GHz and the substrates used in these examples are the ROGERS RO4003 laminate of thickness h = 0.813 *mm* and relative permittivity ε_r = 3.38. Also, the diameter of the posts is 0.5 *mm*. Under such parameters, the length L and width W of the designed λ/4 shorted-patch antenna are 15.8 *mm* and 42 *mm*, respectively. By the procedures described in Section 2, the length of each patch in the two- and four-layered antennas can be initially designed based on the data of the λ/4 shorted-patch antenna. A fine adjustment of the patch length is then conducted to compensate the effects of the connecting posts. The final obtained designs for the two- and four-layered antennas are implemented in the length L of 9.8 *mm* and 5.1 *mm*, respectively. Fig. 5 compares the return loss of the designed single-, two-, and four-layered antennas. The results are calculated by the EM simulator IE3D. It can be observed that the responses of the return loss for the multilayered antennas (especially the two-layered antenna) are very close to that of the single-layered shorted-patch antenna. The bandwidth of the four-layered antenna is slightly narrower than that of the single- and two-layered ones, as more fields are confined to the substrates. Also, a puny spurious resonance near 2.7 GHz is observed for the four-layered antenna. This spurious resonance can be mitigated by increasing the number or diameter of the connecting posts. The radiation patterns of the antennas are displayed in Fig. 6. Note that the radiating slots of the three considered antennas are oriented to the same direction (x-direction). It is found that the three antennas have similar patters (especially that at broadside), as the radiation of these antennas is yielded by the same radiating slots.

4. Conclusions

A multilayered shorted-patch antenna design has been presented. The proposed antenna design not only has the merits of miniature antenna size and easy integration with modern multilayered microwave circuits, but also can be readily interpreted by an appropriate equivalent transmission line model. The simulated results show that the presented multilayered antennas have the performance close to that of a conventional single-layered shorted-patch antenna, indicting the feasibility of the proposed antenna design. Further studies such as the experimental measurements, the development of a more accurate transmission-line model including the effects of the posts, and the designs using the multilayered structures composed by different substrate materials are conducting and will be presented in the conference.

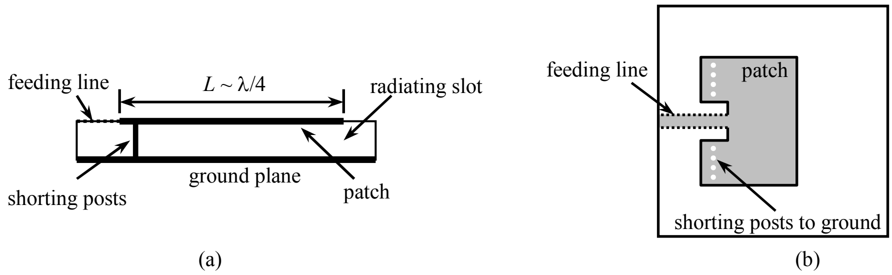

Figure 1: Conventional Single-Layered Shorted-Patch Antenna. (a) Side View, (b) Top View.

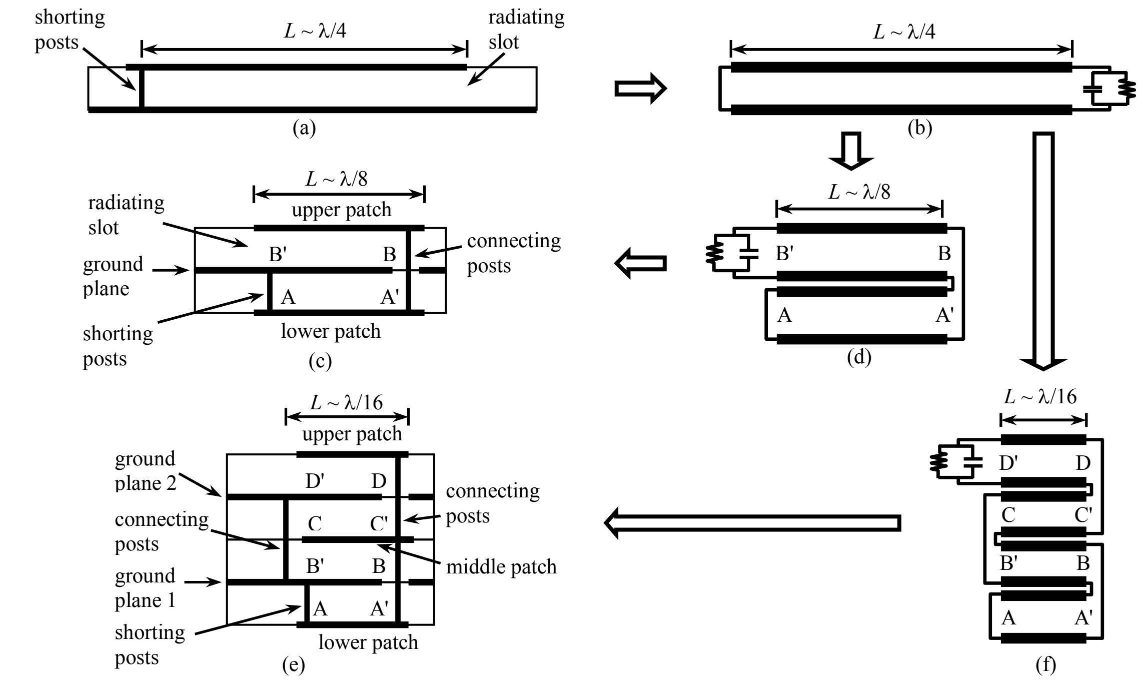

Figure 2: Design Concepts of Multilayered Shorted-Patch Antennas.

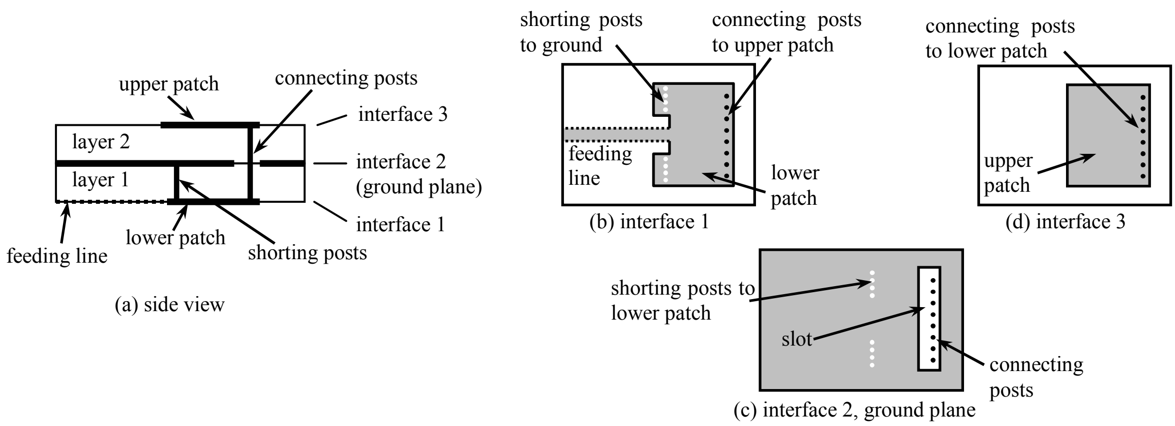

Figure 3: Design Configuration of Two-Layered Shorted-Patch Antenna.

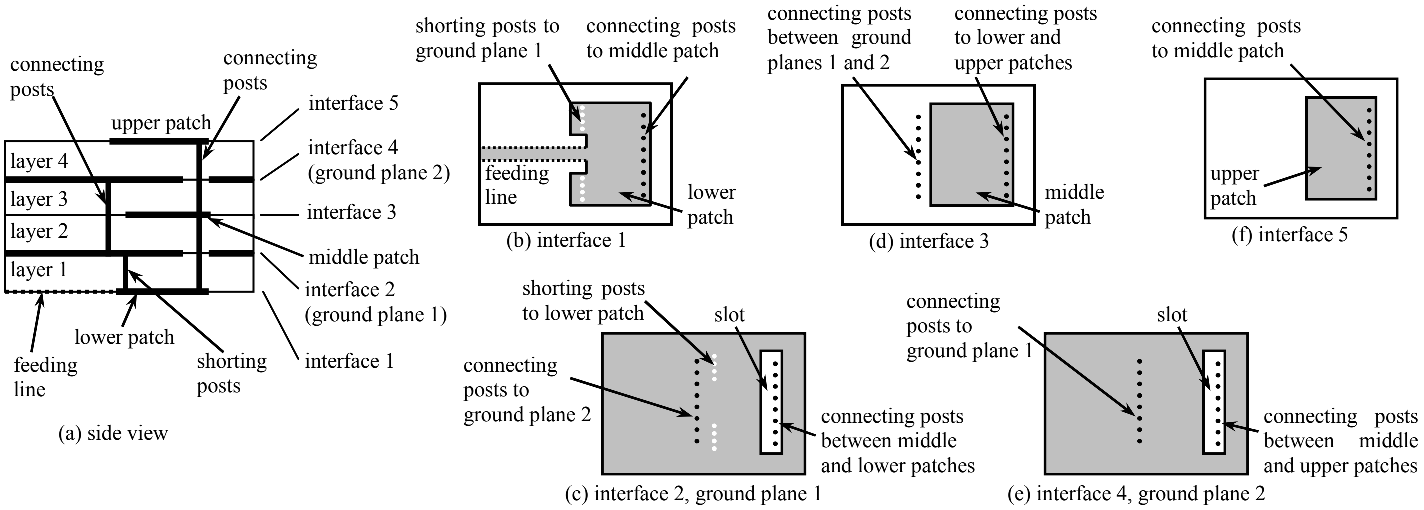

Figure 4: Design Configuration of Four-Layered Shorted-Patch Antenna.

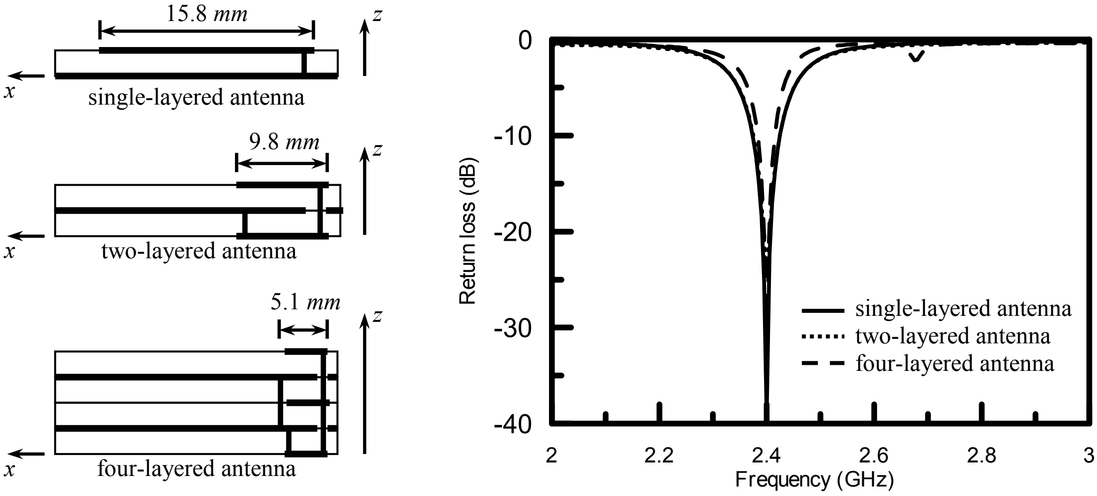

Figure 5: Return Loss of the Single-, Two-, and Four-Layered Shorted-Patch Antennas.

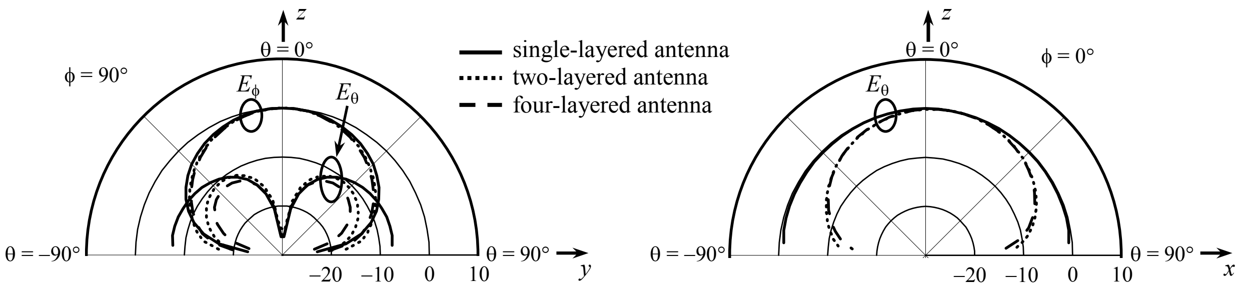

Figure 6: Radiation Pattern of the Single-, Two-, and Four-Layered Shorted-Patch Antennas.

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