A Compact and Low-profile Antenna with Stacked Shorted Patch Based on LTCC Technology

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***Abstract* - In this letter, a compact stacked shorted patch antenna is proposed using low temperature cofired ceramic (LTCC) technology. The height of the antenna is decreased due to the shorted pin, and this greatly improves the polarization performance of the antenna. At the same time, the height (about λ /25) of the antenna and its polarization state are determined by both the feeding and the shorting pin of antenna integrated. The antenna is mounted on a 44×44 mm^2 ground plane to miniaturize the volume of the system. The designed antenna operates at a center frequency of 2.45GHz, and its impedance bandwidth is about 200 MHz, resulting from two neighboring resonant frequencies at 2.41 and 2.51 GHz, respectively. The average gain in the frequency band of interest is about 5.28dBi.**

I. INTRODUCTION

Recent developments in microelectronic technology have created a probability for system-on-package (SoP) antennas [1] in a smaller size. As a result, low temperature cofired ceramic (LTCC) package technology is becoming more and more popular for the production of highly integrated, specifically complicated multilayer modules and antennas. At the same time, this technology is applicable to complex structures and an arbitrary number of layers for its flexibility. However, due to the high dielectric constant of LTCC materials, the size of antenna is decreased. Consequently, it also reduces the impedance bandwidth. The contradiction between the size reduction and bandwidth enhancement of the antenna for a practical wireless communication system is more difficult to be solved, therefore this problem is more challengeable.

In order to reduce the antenna size while maintaining the bandwidth even improving it, some techniques have been proposed and reported by researchers for designing compact broadband antennas over the past several years, e.g., slotting ground plane or embedding narrow slits at the patch's non-radiation edges [2, 3], stacked shorted patches [4-6], and aperture-coupled stacked patch [7]. When slots are embedded in the ground plane or the aperture-coupled feed method is applied for exciting stacked-patch antennas for broadband operation, the backward radiation is increased compared with the traditional patch antenna. This increase in the back-radiation is contributed by the embedded slots in the ground plane and the decreased ground-plane size in wavelength. The backscattered component is detrimental to the chip in the package cavity, that is to say, the back-radiation strengthens electromagnetic coupling between the antenna system and the system on chip. In addition, stacked patch antennas are used for LP or CP, and dual-polarization. However, the total height is still high and not enough compact.

In this letter, a low temperature co-fired ceramic (LTCC) antenna is investigated for a 2.45GHz wireless transceiver module. At first, the size reduction technique using shorting pin is introduced. Note that the position has a significant effect on the polarization state. The bandwidth broadening technology using stacked patches is then described to obtain a broadband microstrip patch antenna. It is noted that the location of the feed point is different from the previous antennas for LP. By placing a shorting pin along the null in the electric field across the patch, the resonant length is reduced and the polarization performance within the frequency band is also greatly improved. Thirdly, the influences of the structure dimensions of the antenna on the performance of the antenna are considered and carefully discussed.

II. ANTENNA STRUCTURE AND OPERATION MECHANISM

The geometry of the proposed LTCC multilayer antenna in this paper is shown in Fig. 1. The shorted stacked-patch antenna is embedded on the top of a RF frond-end module in an LTCC multilayer package. For the sake of simplicity, we consider a probe-fed square patch antenna on a square grounded substrate with thickness h_f=0.79mm. In order to miniaturize the antenna, the shorting technique is applied to the design scheme in this letter. A wide impedance bandwidth is achieved with the stacked patches. Both the upper layer and the lower layer are square patches, but it should be worth noting that the center of the lower patch is offset 2mm from the coordinate center along x and y directions, respectively. The antenna ground plane is under the lower patch. Just for fabrication convenience, all the LTCC substrates use the same material, with the relative dielectric constant $\varepsilon_r = 7.8$ and a dielectric loss tangent $\delta = 0.0015$. In order to reduce patches' size and the height of the antenna, the probe is placed at the corner of the lower patch. The position of the shorting pin depends on the location of the feed, because the antenna polarization state is usually CP due to the phase-angle difference of the two orthogonal components of the electric field when the feed is placed at the corner of the patch without the shorting pin. But the desired polarization in this paper is LP. By adjusting the position of the shorting pin to the

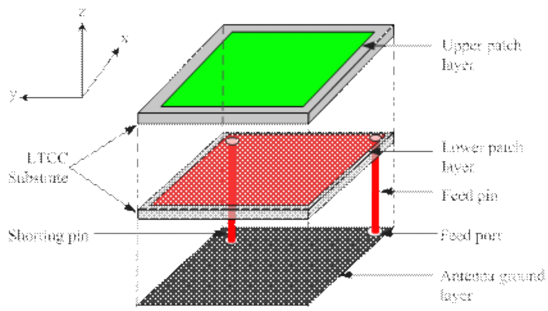


Fig. 1. Expanded view of the proposed antenna integrated in package.

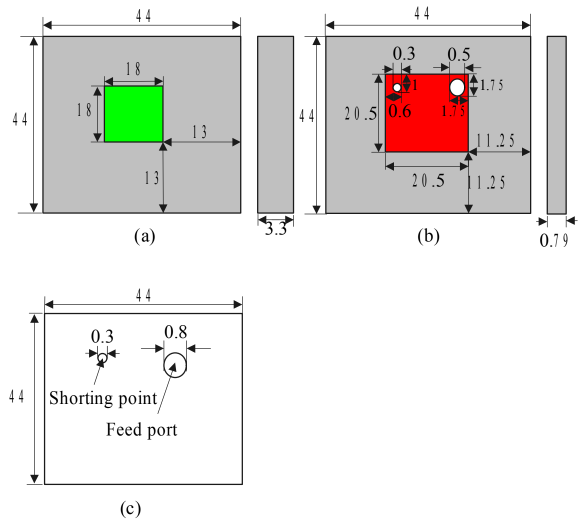
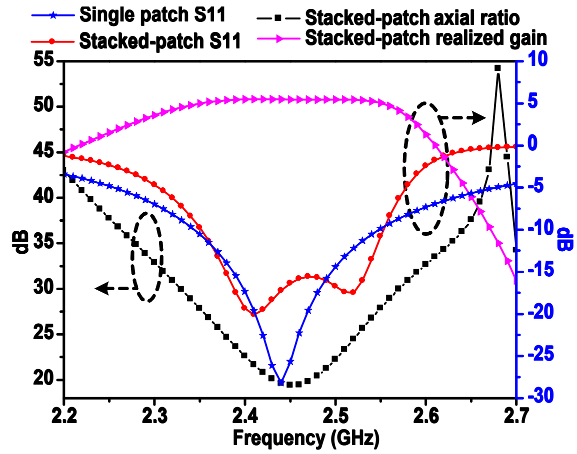


Fig. 2. Design parameters of each layer, (a) Upper patch layer, (b) Lower patch layer, (c) Antenna ground layer. All are in mm.

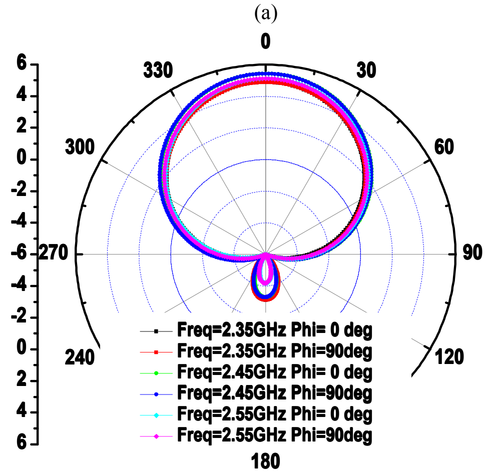
optimum position in *y*-direction and *x*-direction and canceling the phase-shift of the two orthogonal components, good linear polarized radiation over a wide operating bandwidth can be achieved.

The patch sizes were initially estimated by using simple approximations and then patch sizes and positions are optimized by GA algorithm. The upper patch and the lower patch interact with each other, which must be adjusted in length for the proper impedance matching bandwidth. The position of the shorting pin must be also modified appropriately for a wide impedance bandwidth and the desired state of the polarization.

To meet the design requirement of the antenna, the antenna thickness should be less than 5mm without the supersubstrate thickness, while the antenna ground plane's size is assumed to be 44×44mm^2. The sizes of the upper patch and the lower patches are determined to be 18×18mm^2 and 20.5×20.5mm^2, respectively. Due to the different sizes of the two patches and the mutual coupling between each other, these two patches resonate at different modes. At the same time, the patches of variable size have a profound impact on the impedance matching and their influences on the performance of the antenna will be carefully considered and discussed in Section III.



(a)



(b)

Fig. 3. The calculated characteristics of the proposed (a) S11 including single patch and stacked-patch antenna, stacked-patch antenna realized gain and its axial ratio versus frequency, and (b) Radiation pattern at 2.45GHz of stacked-patch antenna.

The detailed configuration of the proposed antenna as well as the design parameters of each layer is shown in Fig. 2. It is shown that the total height of the antenna is 4.09mm illustrated in Fig. 2. Instead of microstrip line feed, the coaxial feed could be used to excite the lower patch and produce two operating modes. The center frequency is at about 2450MHz, and the simulated S11 is shown in Fig. 3 (a). The substrate thickness of the single patch antenna is 12mm, and the size of the patch is 17.1mm. Comparing the stacked-patch antenna and the single patch antenna, from Fig. 3 (a), we can see that the height of the single patch antenna is much larger than that of the stacked-patch antenna with a same impedance bandwidth. The results are shown in Fig. 3, where the two neighboring resonant frequencies of the designed antenna are 2.41GHz and 2.51GHz for the lower and upper patches and the mutual coupling between them, and -10dB absolute impedance bandwidth of S11 is 200MHz from 2.35GHz to 2.55GHz. The impedance matching characteristic at the low resonant frequency is better than the high one because the current distributing in the lower patch is changed due to the shorting pin. For the present proposed structure, the antenna achieves two resonant frequencies, resulting from the mutual coupling between the upper and lower patches. In this case, the impedance bandwidth, defined by the -10-dB S11, is about 8.16% referenced to the center frequency at 2450 MHz. The minimum axial ratio is 19.3 dB. Fig. 3 (a) shows that the gains across the frequency band are nearly unchanged. The maximum gain of the proposed antenna is 5.48 dB and the average gain is 5.28 dB across the operating frequency band. The broadside radiation patterns are observed in Fig. 3 (b). The broadside patterns are symmetrical because of the modeling structure. The beamwidth within the required gain is greater than 100°.

III. Antenna Parameters Analysis

As described above, the proposed antenna structure is determined owing to a relatively small volume. Considering the mutual coupling between the two patches, the proper sizes of the patches have to be selected. The bandwidth and impedance matching of the antenna are influenced by various structure parameters. That is to say, the performance of the stacked shorted patch antenna is mainly determined by the characteristics of the configuration of the patches including dimensions and heights, and the positions of the feeding pin and the shorting pin. In this Section, the effects of these parameters on the antenna performance are studied in detail. To better understand the effects of the parameters on the performance of the proposed antenna, only one parameter will be varied at a time, while the others are kept unchanged unless especially indicated.

Firstly, the effects of the dimensions of the two patches on the antenna performance are discussed. Fig. 4 (a) compares S11 in different dimensions of the lower patches. The fundamental mode disappears and the impedance bandwidth is decreased as the size of the lower patch increases. For increasing the upper patch L_1 shown in Fig. 4 (b), it is seen that the fundamental resonant frequency is quickly lowered, at the same time, the high mode vanishes. Thus, we know from Fig. 4 (a) and (b) that the upper patch should be increased when the lower patch increases for a good impedance matching in the frequency band of interest.

The thickness of the dielectric substrate under the lower patch of the antenna, h_1, is then considered. Generally speaking, the thicker the substrate, the wider the impendence bandwidth. It is well understood that the inductance of the feeding pin becomes larger and the impedance matching becomes better as the height of the feeding pin increases. With such a large length, the effect of the inductive reactance of the probe pin in the air substrate on the impedance matching is large and makes the antenna match well in the operating frequency band of interest. Fig. 4 (c) gives the effect of substrate thickness under the lower patch on S11 of the proposed antenna simulated using HFSS software. In addition, the interaction between the driven and parasitic patches has a profound impact on the bandwidth of the antenna.

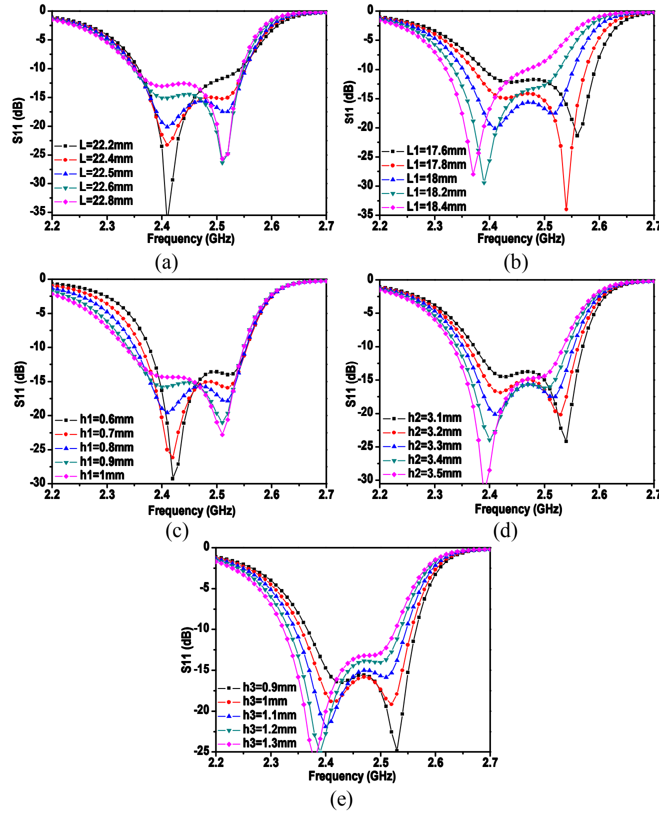


Fig. 4. S11 characteristics, (a) Lower patch L variation, (b) Upper patch L1 variation, (c) Thicknesses of the dielectric substrate under the lower patch of the antenna variation, (d) Separations of the lower and upper patches variation, (e) Thicknesses of the supersubstrate variation

The separation of the lower and upper patches, h_2, has a heavy influence on the antenna performance. The smaller or larger separation strengthens or weakens the coupling of the two patches, which results in a relatively narrow impedance bandwidth. Thus, a proper height should be selected to obtain a wide bandwidth. Simultaneously, a thinner substrate is also necessary to miniaturize the antenna's size. Fig. 4 (d) shows the effect of varying the height of the parasitic patch across the bandwidth of the antenna. The EM coupling between the driven and parasitic patches strengthens as the thickness h_2 increases. In order to enhance the gain and bandwidth of the antenna, a thin supersubstrate, which has a thickness of h_3, is introduced to cover the upper patch. One of its advantages is that the supersubstrate can avoid the abrasion of the antenna. Different thicknesses of the supersubstrate are calculated by HFSS and the results are illustrated in Fig. 4 (e). The characteristics of S11 with different thicknesses of the supersubstrate are similar to that reported simulated S11 for different thicknesses of the supersubstrate show similar results which are obtained with different substrate thicknesses between the lower and upper patches.

In previous description, the thicknesses of the LTCC materials and the patches have an impact on the impedance

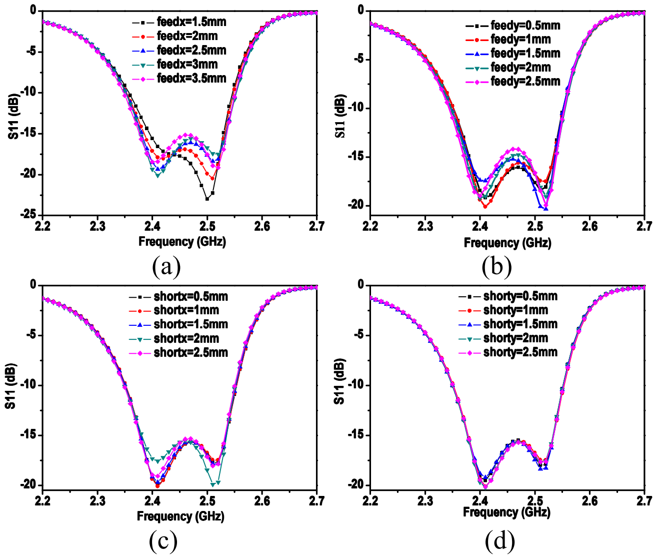


Fig. 5. S11, (a), (b) S11 in different offset of the feed location, (c), (d) S11 with variable position of the shorting pin

match and the bandwidth. Finally, another key factor affecting the antenna performance is the loci of the feeding and shorting pins. Due to the feeding pin placed in the corner of the lower patch without the shorting pin, a 90° phase difference is produced and CP is obtained. Since the desired polarization is LP, a proper position of the shorting pin is necessary and important for achieving the desired polarization state. The results of the proposed antenna with different positions of the shoring and feeding pin are shown in Fig. 5. When the position of the feeding pin is offset in a specific range of a distance *feedx* and *feedy*, from the corner of the patch along *x* and *y* direction, respectively, the stacked-patch antenna can excite two resonant modes with good impedance matching shown in Fig. 5 (a) and (b) and S11 across the frequency band is nearly unchanged. The distances, *shortx* and *shorty* along *x* and *y* direction, are away from another corner of the lower patch. The simulated results are illustrated in Fig. 5(c) and (d). It is observed that the variations of S11 are not sensitive to the movement of the feed position from 0.5mm to 2.5mm for *shortx* and *shorty*.

IV. CONCLUSION

In this paper, a compact and low-profile stacked-patch antenna using low temperature cofired ceramic (LTCC) package technology is designed. Broadband linear polarization radiation is achieved and the two modes together give a fractional impendence bandwidth of 8.16% with respect to the center frequency at about 2.45GHz. The stable radiation patterns are achieved. The total height of the proposed antenna is 4.09mm and the average gain is 5.28dBi across the operating frequency band. The parameters analyses are carefully conducted in this paper for design guidance. The proposed antenna is suitable for integration into the chip package using LTCC package technology.

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