60 GHz High-Gain Aperture-Coupled Microstrip Antennas using Soft-Surface and Stacked Cavity on LTCC Multilayer Technology

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Abstract- In this paper, an aperture-coupled patch antenna integrated with a soft surface and the stacked cavity has been demonstrated on LTCC multilayer technology. A higher gain (~ 7.6 dBi) is achieved by stacking the cavity underneath the soft surface, which is 2.4 dB improvement compared to the patch antenna with the soft surface. It is also confirmed that the back radiation is significantly reduced by about 2.5 dB by stacking cavity to the patch antenna with the soft surface. The compact antenna with the soft surface and the stacked cavity can be easily integrated into 3-D 60 GHz modules and be easily extendable to array configuration for point-to-point applications in short-range indoor wireless personal area network (WPAN).

Introduction

The growing interest in using unlicensed spectrum around 60 GHz for high-data rate applications, such as high-speed internet access, has motivated the development of highly integrated compact antennas into RF front-end modules using LTCC multilayer technology [1]. However, because of the high path loss at 60 GHz, such antennas should be easily extendable to array configurations to achieve the high gain and to help direct the electromagnetic energy to the intended target/user. A microstrip patch antenna can be one of the candidates for the integrated antennas due to its low-cost, lightweight and planar structure but can suffer from the diffraction of surface wave at the edges of finite substrates with a high dielectric constant, such as LTCC [2].

To improve the radiation performance of patch antennas on large-size substrates, periodic techniques such as photonic bandgap [3] or electromagnetic bandgap [4] have been employed to suppress the surface waves from the propagating in the substrate. However, those techniques are not suitable for integrated modules because of their large size. The advanced technique of the artificial soft-surface consisting of a single square ring of metal strip shorted to the ground has been recently proposed with the advantages of compact size and excellent improvement in the radiation pattern of patch antennas [2]. In this paper, we further improve this technique by adding cavity based feeding structure on the bottom LTCC layers (Substrate 4-5 in Fig. 1 (c)) of an integrated module to increase the gain and to reduce future the backside radiation. The back radiation is significantly reduced, and the maximum gain for the patch antenna with the soft surface and the stacked cavity is approximately 7.6 dBi which is 2.4 dB higher than 5.2 dBi for the “soft-enhanced” antenna without the backing cavity.

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Antenna Structure Using a Soft-Surface and Stacked Cavity

The 3-D overview, top view and cross-section view of the topology chosen for the micostrip antenna using a soft-surface and a vertically stacked cavity are shown in Fig. 1 (a), (b) and (c), respectively. The antenna is implemented into 5 LTCC substrate layers (layer thickness = 117 μm) and 6 metal layers (layer thickness = 9 μm). The utilized LTCC is a novel composite material of high dielectric constant (ε_r~7.3) in the middle layer (substrate 3 in Fig. 1 (c)) and slightly low dielectric constant (ε_r~7.0) in the rest of the layers (Substrate 1-2 and 4-5 in Fig. 1 (c)). A 50Ω strip-line is utilized to excite the microstrip patch antenna (metal 1) through the coupling aperture etched on the top metal layer (metal 4) of the cavity as shown in Fig. 1 (c). In order to realize the magnetic coupling by maximizing magnetic currents, the slot line is terminated with a $\lambda_g/4$ open stub beyond the slot. The patch antenna is surrounded by a soft surface structure that consists of a square ring of metal strips that are short-circuited to the ground plane (metal 4 in Fig. 1 (c)) for the suppression of outward propagating surface waves [2]. Then, the cavity (Fig.1 (c)) utilizing the via fences of the "soft-surface" as sidewalls is stacked right underneath the soft-surface structure to improve the gain and to reduce backside radiation. The operating frequency is chosen to be 61.5 GHz. The optimized size ($P_L \times P_W$) of patch is 0.54×0.88 mm^2 with the rectangular coupling slot ($S_L \times S_W$ = mm^2). The size (L×L) of the square ring of metal strip and the cavity is optimized to be 2.6×2.6mm^2 to achieve the maximum gain [2]. The width of metal strip (W) is found to be 0.52 mm to serve as an open circuit for the TM_{10} mode, alleviating the surface current flowing outward. The ground planes are implemented on metal 4 and 6.

Results

The antenna structure is analyzed with the aid of a FEM-based full-wave simulator (HFSS). The simulated result for the return loss is shown in Fig. 2. The excellent impedance matching property is observed around the design frequency. The radiation patterns simulated in E and H planes of patch antennas with the soft surface and with the soft surface/stacked cavity are compared in Fig. 3 (a) and (b), respectively. It is confirmed that the back radiation is significantly reduced by about 2.5 dB by stacking cavity to the patch antenna with the soft surface. The simulated gains at broadside at the operating frequency of 61.5 GHz are also investigated. A 7.6 dBi gain is obtained from the patch with the soft surface/stacked cavity which is 2.4 dB improvement compared to with the soft surface.

Conclusion

A patch antenna integrated with a soft surface and the stacked cavity has been investigated on LTCC multilayer technology. A higher gain is achieved by stacking the cavity underneath the soft surface, and the significant reduction of the backside radiation is observed as compared to the patch antenna with the soft surface. The compact antenna with the soft surface and the stacked cavity can be easily integrated into 3-D 60 GHz modules. An antenna array using the proposed antenna as a unit cell will be investigated to achieve the higher gain and directivity for point-to-point applications in short-range indoor wireless personal area network (WPAN).

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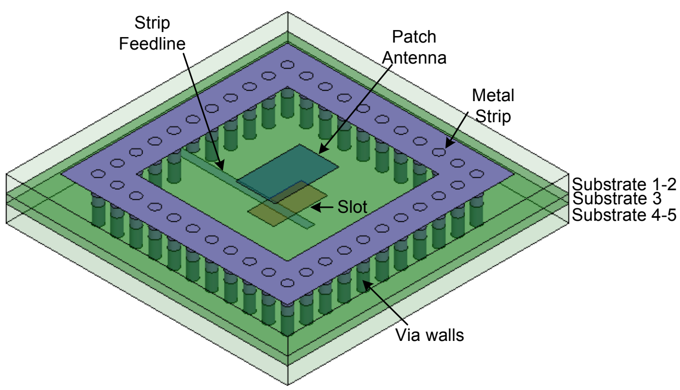
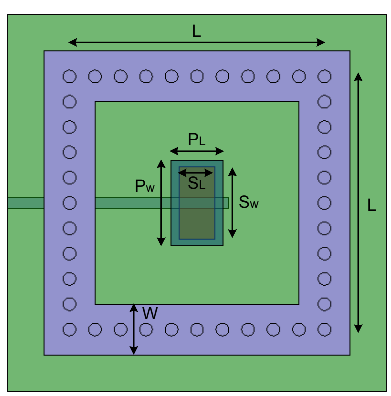
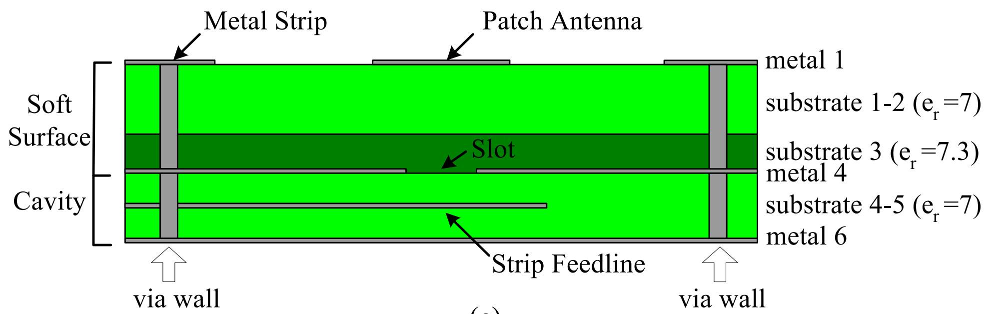


(a)



(b)



(c)

Figure 1. (a) The 3D overview (b) cross-section view (c) cross-section view of a patch antenna with the soft surface and sacked cavity.

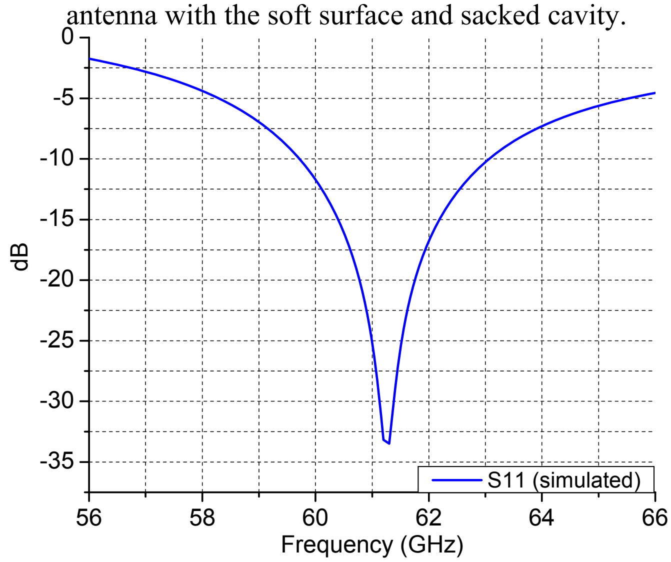
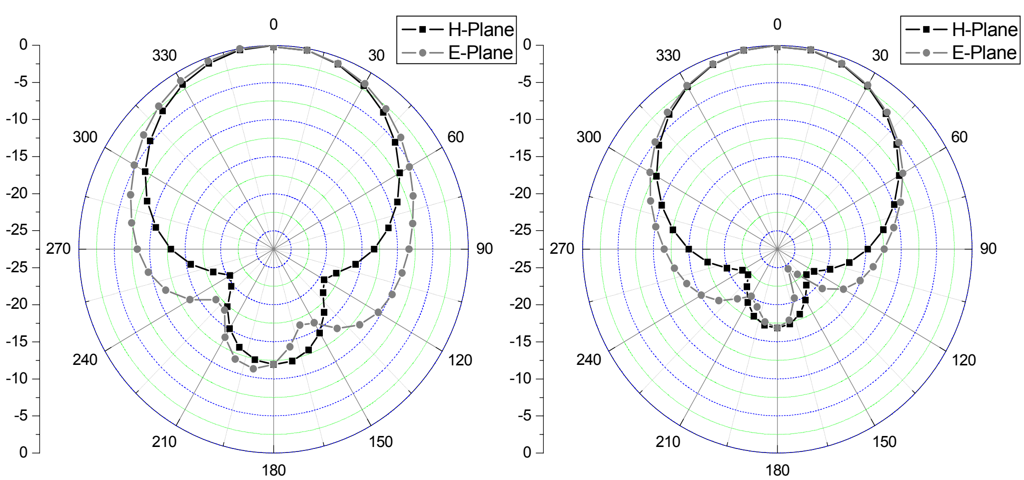


Figure 2. The simulated return loss (S11) of a patch antenna with the soft surface and the stacked cavity.



(a) (b)

Figure 3. The radiation characteristics at 61.5 GHz of patch antennas (a) with the soft surface and (b) with the soft surface and the stacked cavity