

Radiation-Pattern Improvement of Patch Antennas Using a Compact Soft/Hard Surface (SHS) Structure on LTCC Multilayer Technology

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Abstract: A compact soft/hard surface (SHS) structure consisting of a square ring of short-circuited metal strips is employed to surround the patch antenna for blocking the surface-wave propagation, thus alleviating the effect of the edge diffraction and hence improving the radiation pattern. The operating frequency of the SHS is determined by the width of the metal strip, therefore it is suitable for a substrate with arbitrary thickness and dielectric constant. The compact SHS structure is realized on a low temperature co-fired ceramics (LTCC) technology. It is shown that the gain of a patch antenna can be increased to near 9 dBi through the use of the proposed compact SHS structure.

I. INTRODUCTION

Nowadays there is an increasing demand in wireless systems for integration of antennas with RF front-end circuits or even with IF and base-band components [1]. For high-frequency (such as millimeter-wave) applications, the size of a patch antenna may be much smaller compared to the printed circuit board (PCB) substrate, where the analog and digital devices are integrated [2]. When a patch antenna is fabricated on a larger-size substrate, its radiation pattern may be considerably affected by the diffraction of surface waves at the edge of the finite grounded substrate [3]. On the other hand, the excitation of strong surface waves also causes unwanted coupling between the antenna and other components on the PCB, thus degrading the performance of the integrated module [4].

The most popular technique for the improvement of the radiation performance of patch antennas on a large-size substrate is to construct an artificial periodic structure, such as photonic bandgap (PBG) or electromagnetic bandgap (EBG) [5], [6], surrounding the patch antenna to prevent the surface waves from propagating in the substrate. Unfortunately, it requires a considerable area to form a complete band gap structure. Another approach considered has been to use the concept of artificial soft/hard surface (SHS) for the improvement of the radiation patterns [7]. However, the conventional corrugation-based SHS structures require a substrate thickness of one quarter guided wavelength as well as a quite large area. Recently, a modern realization of artificial SHS structures has been described in [8]. The new proposed SHS consists of a number of quarter-wavelength metal strips that are short-circuited to the ground plane. The operating frequency for this SHS is determined by the strip width, not by the thickness of the substrate, allowing for its implementation in arbitrary substrate thicknesses. In this paper, we apply the concept of the modern SHS structure to improve the radiation pattern of patch antennas. A single square ring of the shorted quarter-wavelength metal strips is employed to surround the patch antenna for the suppression of outward propagating surface waves, thus alleviating the diffraction at the edge of the substrate. The effectiveness of the compact SHS structure in terms of radiation pattern improvement is verified by its implementation on LTCC multilayer technology.

II. DESIGN OF THE COMPACT SHS STRUCTURE

Consider a probe-fed square patch antenna on a square grounded substrate with thickness H and a dielectric constant ϵ_r . The patch antenna is surrounded by a square compact SHS

structure, as shown in Fig. 1. The substrate thickness has a lateral size of $L \times L$, much larger than the size the square patch ($L_p \times L_p$). The ideal compact SHS structure consists of a square ring of metal strips that are short-circuited to the ground plane by a metal wall along the outer edge of the ring. The inner length of the SHS ring (denoted by L_s) was found to be approximately one wavelength plus L_p . The width of the metal strip (W_s) is approximately equal to a quarter of the guided wavelength.

III. IMPLEMENTATION OF THE SHS STRUCTURE ON LTCC TECHNOLOGY

To demonstrate the feasibility of the LTCC technology on the implementation of the SHS, we simulated a benchmarking prototype which is shown in Fig. 2. Note that the LTCC substrate is hidden in order to see the SHS structure clearly. The shorting wall of the SHS was replaced on the LTCC process with a ring of vias. The utilized LTCC material had a dielectric constant of 5.4. The whole module consists of a total of 11 LTCC layers (layer thickness=100 μm) and 12 metal layers. To support the vias, on each metal layer a metal pad is required. To simplify the simulation, all pads on each metal layer are connected by a metal strip with a width of 600 μm . The size of the LTCC board was 30 mm \times 30 mm. The design frequency is 16.5 GHz. The optimized values for L_s and W_s were respectively 22.2 mm and 1.4 mm. Fifty vias on each side of the SHS ring were assigned. The total metal strip width for the SHS ring was found to be 1.7 mm. A stacked configuration was adopted for the patch antenna to improve its input impedance performance. The upper and lower patches (3.4 mm \times 3.4 mm) were respectively printed on the first LTCC layer and the seventh layer from top. The lower patch was connected by a via hole to a microstrip line that is on the bottom surface of the LTCC substrate. The ground plane was embedded between the second and third LTCC layers from the bottom.

The simulated 3D radiation patterns of the stacked-patch antennas with and without the SHS are shown in Fig. 3. It is observed that there is a deep drop in the z-direction for the antenna without SHS due to the diffraction of surface waves at the edge of the substrate. The degradation of radiation pattern is significantly improved by the via-incorporated SHS. The radiation patterns measured in the E-plane are compared with simulated results in Fig. 4. We can see good agreement for the co-polarized components. It is confirmed that the radiation at broadside is enhanced and the backside level is reduced. Also the beamwidth in the E-plane is significantly reduced by the SHS. The maximum gain measured for the patch with the SHS is near 9 dBi, about 3 dB higher than the maximum gain and 7 dB higher than the gain at broadside for the antenna without the SHS.

IV. CONCLUSION

The effectiveness of a modern SHS concept on the radiation-pattern improvement of a patch antenna on a large-size substrate has been investigated. The new SHS structure consists of a ring of short-circuited metal strips with a strip width of a quarter guided wavelength, much more compact than typical PBG/EBG structures. The compact SHS structure can be easily implemented in 3D modules, such as those fabricated using LTCC technology. Experimental results show that it is feasible to make use of the via-metallization process on the LTCC technique for realization of a shorting wall required by the compact SHS structure. A maximum gain of near 9 dBi can be achieved for the LTCC module.

Acknowledgement

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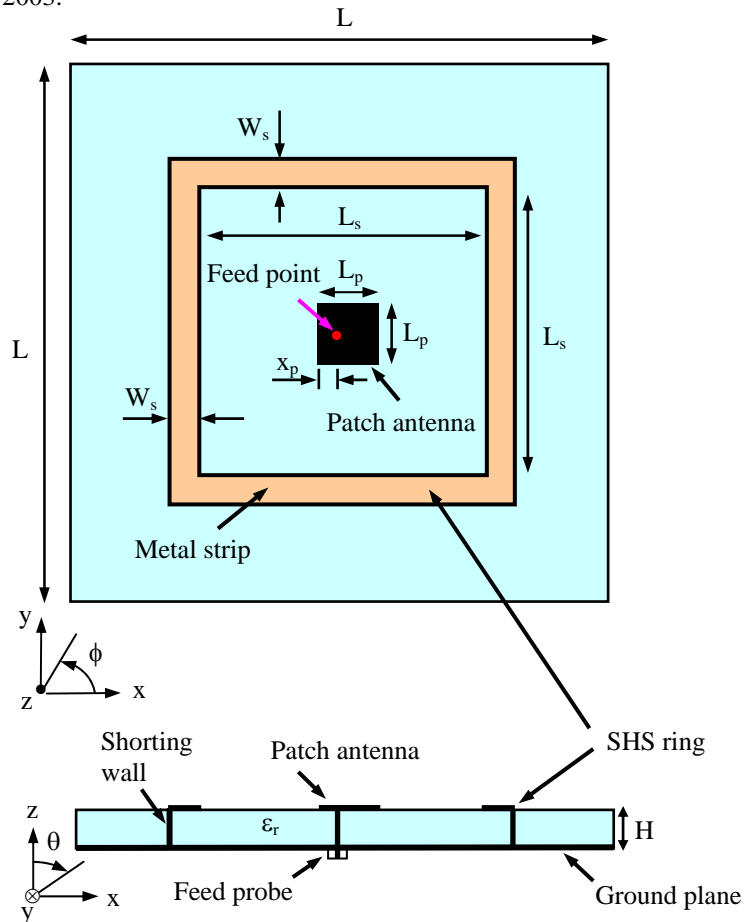


Fig. 1. Patch antenna surrounded by an ideal compact SHS structure.

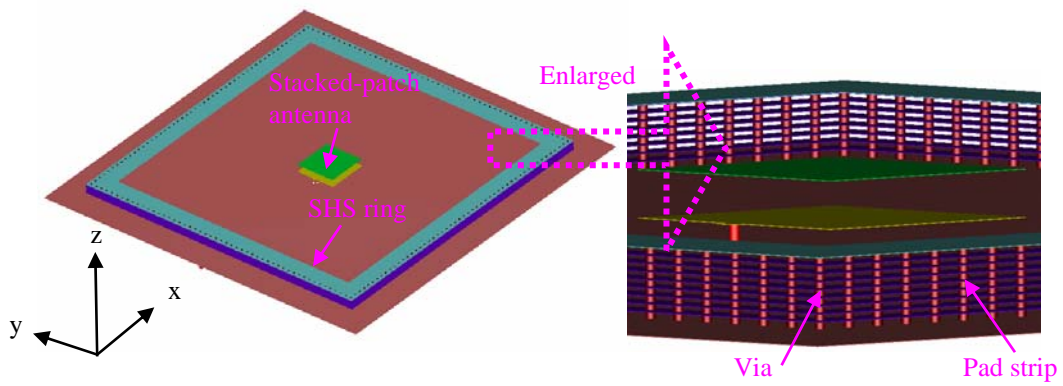


Fig. 2. Patch antenna surrounded by a compact SHS structure on LTCC technology.

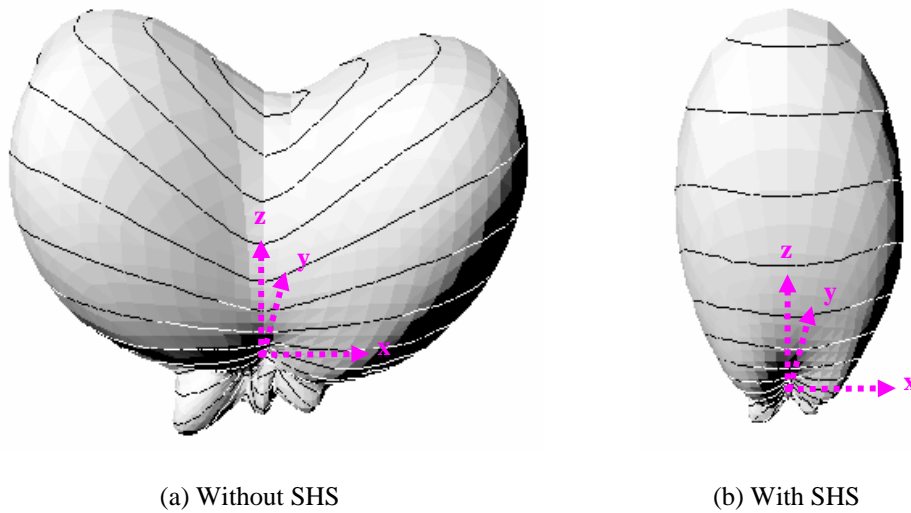


Fig. 3. 3D radiation patterns of the patch antennas with and without the SHS.

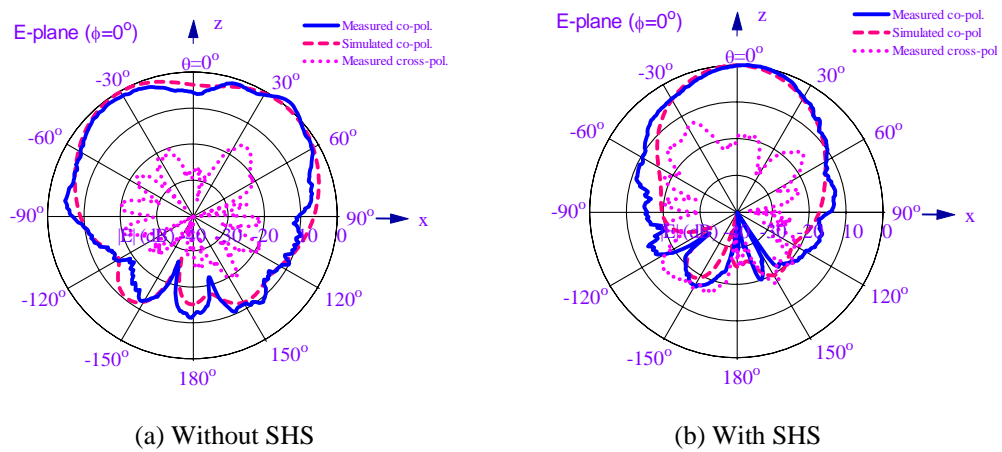


Fig. 4. Radiation patterns in E-plane for the patch antennas with and without the SHS.