LTCC Multilayer Based CP Patch Antenna Surrounded by a Soft-and-Hard Surface for GPS Applications

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Abstract — A circularly polarized (CP) patch antenna is designed for GPS applications. The soft-and-hard surface (SHS) is utilized for reducing the backside radiation. LTCC multilayer technology is employed to realize the SHS structure by surrounding the patch antenna with a number of rings of metal vias that can be easily fabricated in this process. It is found that the backlobe level can be reduced by more than 14 dB (front-to-back ratio > 20 dB) by using six rings of vias. The SHS-surrounded CP patch antenna has a broad coverage (directivity >0 dBi over θ=0-75°), a low cross-polarized level (axial ratio <2 dB over the upper hemisphere), and a good input impedance match (return loss <-10 dB).

I. Introduction

Microstip patch antennas are becoming increasingly attractive as receiving antennas in a variety of applications of the Global Position System (GPS) due to their advantages (e.g. lightweight, low profile and low cost) over other conventional antennas, such as quadrifilar helix antennas [1]-[3]. For high-precision GPS applications, such as differential GPS, GPS-based spacecraft altitude determination or geometric surveying, the receiving antenna with a low-level backlobe radiation pattern is essential for the significant rejection of multipath signals. This property is particularly important for patch antennas because their backside radiation usually appears as a cross-polarized component. The multipath distortion results from the reflection of the GPS transmitted signal, which usually comes from the backside of the receiving antenna. As the GPS transmitted wave is right-hand circularly polarized (RHCP, or co-polarized), the directly reflected wave is left-hand circularly polarized (LHCP, or cross-polarized). Therefore, the patch antenna must have a lower cross-polarized component in the backside direction to eliminate the multipath effects.

A simple way to reduce the backlobe level is to mount the patch antenna on a relatively large ground plane with respect to the size of the patch antenna (e.g., 6-7 times bigger for a 20-dB front-to-back ratio [4]). In some applications, such as laptops or mobile handheld terminals, however, there is not enough space left for a bigger ground plane. Hence, it becomes interesting to search for an alternative solution to suppress the backside radiation. Recently, it has been demonstrated that a soft-and-hard surface (SHS) can be used to decrease the backlobe level by surrounding with it a microstrip patch antenna [5]. In practice, nevertheless, an SHS is generally realized using corrugations, which has a high manufacturing cost and results in a bulky structure.

In this paper we propose an SHS-surrounded configuration for the GPS patch antenna based on the LTCC (Low Temperature Co-fired Ceramics) multilayer technology that is becoming more and more popular for the production of highly integrated, complex multilayer modules, circuits, and integrated antennas [6]-[7]. On one hand, the corrugated structure can be easily realized in LTCC using arrays of metal vias (with a single manufacturing process). On the other hand, LTCC materials typically possess a high dielectric constant, thus helping to reduce the size of the antenna module (including the corrugated structure as well as the patch) and guaranteeing the radiation pattern in order to have an adequate hemispherical coverage.

II. Configuration of Antenna Module

The antenna module based on the LTCC multilayer technology consists of a stacked patch antenna and a surrounded SHS, as shown in Fig. 1. The antenna module is designed at the GPS civilian frequency (f_c=1575.42 MHz). The LTCC material used in the design is Kyocera's LTCC GL660 which has a high dielectric constant of ε_r=9.6 and a dielectric loss tangent of 0.0017. The layer thickness is chosen to be 0.5 mm. The SHS is realized using six square rings of metal vias. The via diameter is 0.2 mm and the via to via space in each ring is 2 mm. The distance between two adjacent rings is w=2 mm, thus leading to an SHS width of 5w=10 mm. The dimensions of the

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outer and inner rings are respectively L_{outer}= 70 mm and L_{inner} =50 mm. The length of the vias (the height of the SHS walls) must be approximately equal to $d=\lambda_0/(4\varepsilon_r^{0.5})$ (λ_0=the wavelength in free space), required by the soft surface boundary condition. Therefore we choose the total thickness of the antenna module as d=32 layers. Under the soft surface boundary condition, the surface waves originated from the patch antenna are prohibited from propagating outside along the surface, thus reducing the backside radiation of the patch antenna. A stacked-patch configuration is adopted here for reducing the cross polarization over the upper hemisphere and for matching the input impedance of the patch antenna to a 50-ohms feed port through a simple adjustment of the position of the lower patch [7]. We leave a cavity with a thickness of 11 layers beneath the patch antenna for burying the GPS RF front-end integrated circuit chipset (RFIC), thus leading a total thickness of h_2=21 layers for the stacked patch. The stacked patch antenna is fed at the lower patch by a feed probe that is placed on the diagonal axis of a square area W×W (see Fig. 1 where x_f=2 mm, y_f=4 mm). The length L and width W of the lower and upper patches (both have the same size) are adjusted to achieve the best circular polarization performance at f_c, which results in L=28.6 mm and W= 22.6 mm. The height of the lower is optimized to be h_1=16 layers for a good input impedance match.

III. Results

The above antenna module was simulated using the TLM (Transmission-Line Method) based software-Microstripes 5.6. Fig. 2 shows the polar amplitude and phase properties at f_c of the LTCC multilayer based patch antennas with and without the SHS. We can see that the backlobe level (LHCP, E_L) of the patch antenna with SHS is about -15 dBi, about 13 dB lower than that without SHS. The directivity gain (RHCP, E_R) is more than 0 dBi up to 15° elevation, much larger than the requirement of –5 dBi for maritime GPS applications [4]. Also the radiation pattern over the upper hemisphere ($|\theta|<90°$) shows very low cross polarization and good symmetry with respect to the z direction. The upper-hemisphere phase change (about 50°) of the patch antenna with SHS is bigger than that for without SHS (about 30°), but is slightly smaller than those for typical quadrifilar helix antennas [8]. The axial pattern for the patch antenna with SHS is shown in Fig. 3. It is observed that the axial ratio is less than 2 dB over almost the entire upper hemisphere. The frequency responses of the front-to-back (F/B) ratio, axial ratio and the return loss are shown in Fig. 4. We see that the use of the SHS can improve the F/B ratio by more than 14 dB over a bandwidth of 2%. It is also observed that the introduction of the SHS results in a reduction in the bandwidth of axial ratio (from 2% to 1% for the 3dB criterion) due to the undesirable contribution from the currents on the SHS. The bandwidth of the –10-dB return loss is found to be about 4%.

IV. Conclusion

It has been demonstrated that the LTCC multilayer technology can be applied to the realization of an SHS for the reduction of the backside radiation of a patch antenna. A CP patch antenna has been designed based on the LTCC-realized SHS for GPS applications. There are two major advantages for the application of the LTCC technology in the realization of SHS. First, the SHS can be easily realized with the help of the via-array process. Second, the high dielectric constant of the LTCC materials can be used to reduce the size of the SHS structure. It has been found that a 14-dB improvement of the F/B ratio can be achieved for an SHS width of less than half of the patch length (or width).

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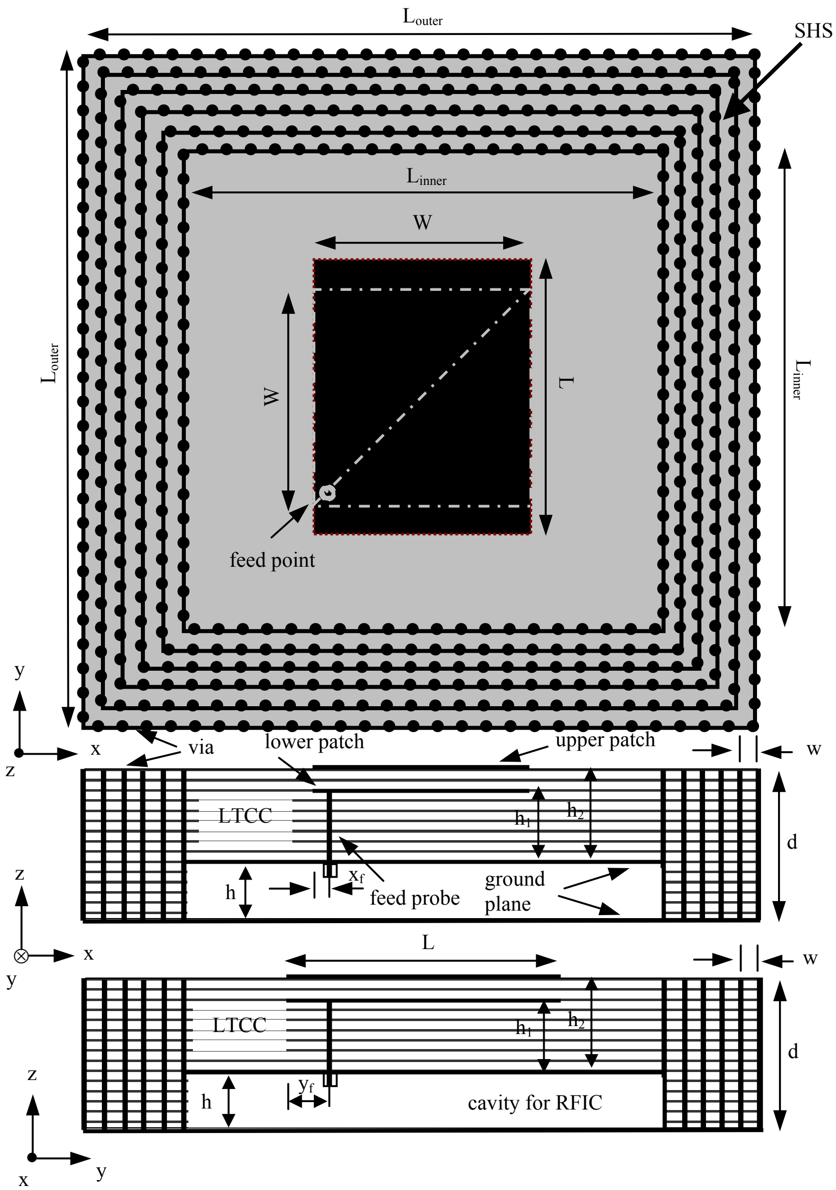
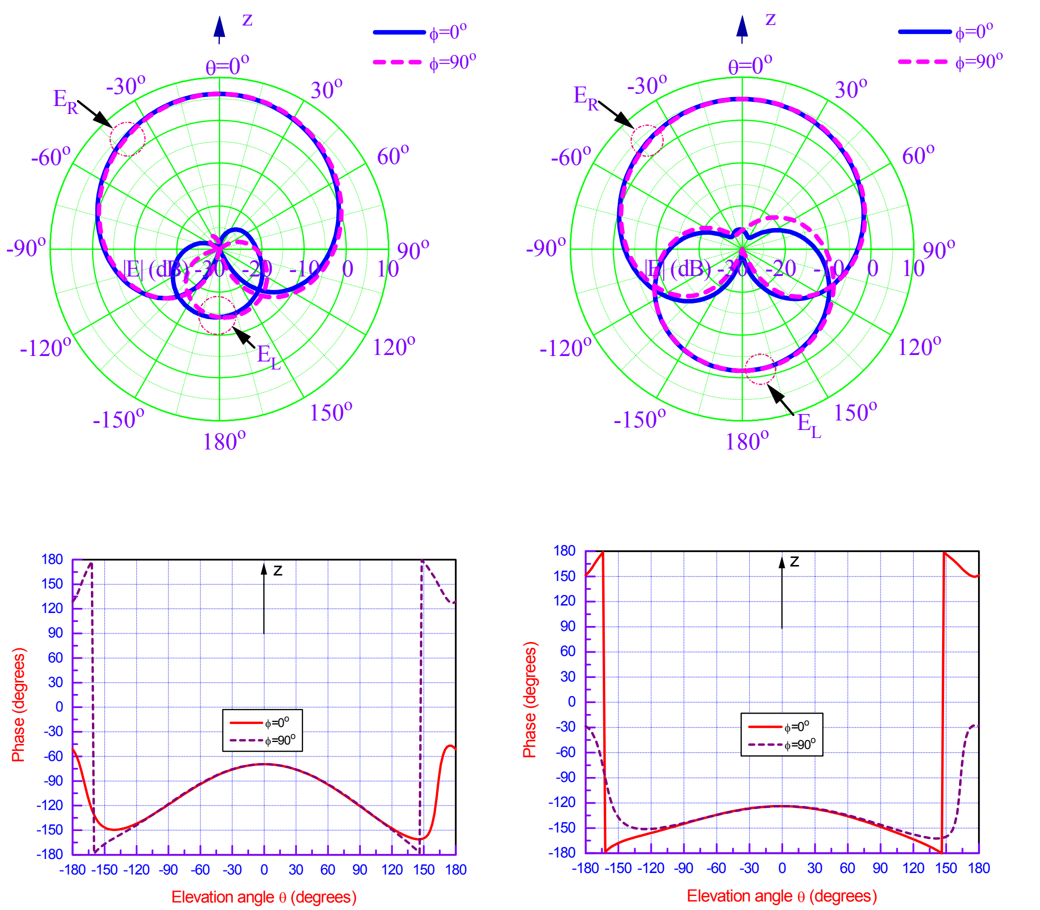


Fig. 1. LTCC multilayer based stacked patch antenna surrounded by an SHS.



(a) with SHS (b) without SHS

Fig. 2. Comparison of amplitude and phase response patterns between patch antennas with and without SHS.

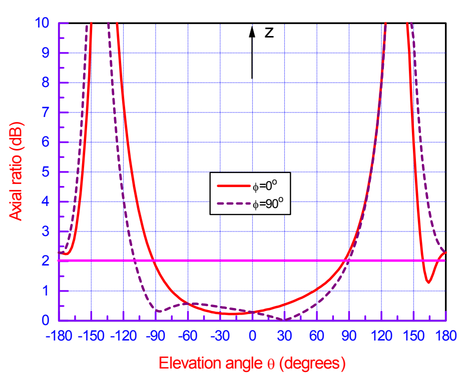


Fig. 3. Axial ratio pattern of the patch antenna with SHS.

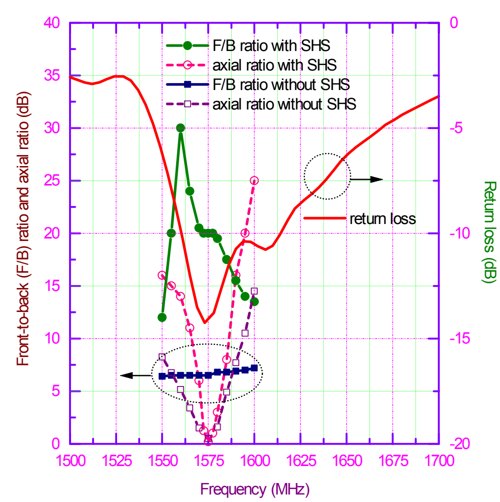


Fig. 4. Frequency responses of front-to-back ratio, axial ratio and return loss.