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BACK RADIATION REDUCTION IN PATCH ANTENNAS USING PLANAR SOFT SURFACES

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Abstract—In this work, we propose to use a type of periodic structures, the soft surfaces in their planar version, to reduce the back radiation of patch antennas. A key aspect of these surfaces when compared to other periodic structures is their anisotropy which provides different behaviour for different field polarization (horizontal or vertical). This make them especially convenient for this application, as the soft surfaces force the field intensity for any polarization to be zero on the surface for waves propagating along the surface. In this paper, a design example is presented and the back radiation reduction by using planar soft surfaces is demonstrated.

1. INTRODUCTION

Periodic structures have been extensively used to suppress surface waves propagation in a given frequency range. The cancellation of such waves is desired in many applications such as for instance, to reduce mutual coupling in arrays [1], to increase the antenna efficiency or to reduce the antenna back radiation among others. This last application has deserved only little attention in the literature, however it is one of the important requirements when the antennas are placed in terminals and also to avoid interferences.

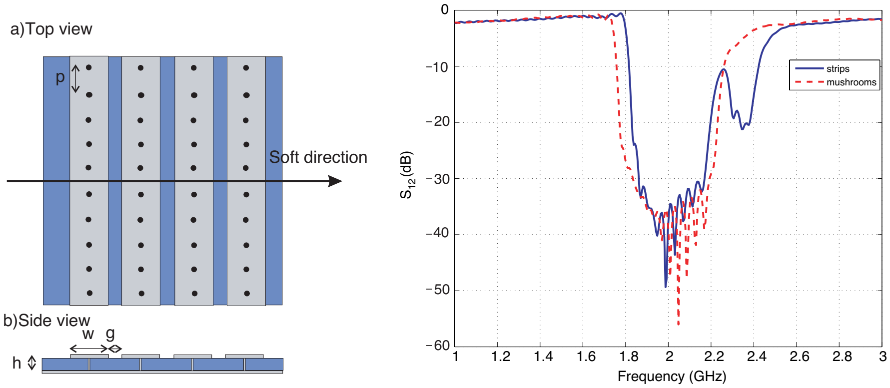
There exist many different types of periodic structures which can provide the required filtering effect for the surface waves, from the typical EBGs (which stop surface wave propagation in all directions in a surface) to anisotropic surfaces such as the soft surfaces [2] which provide the mentioned filtering only in one direction.

From the point of view of the designer, the use of simple geometries with a limited number of parameters which control the position and the width of the forbidden or stop band is always an advantage, even if more sophisticated designs can also find application in particular problems with special requirements. In this sense, the planar soft surfaces [3] can be as well convenient as its design is simple. Moreover, they have an additional characteristic derived from their above-mentioned anisotropy; within the frequency band where they suppress the surface waves, they behave differently for the two polarizations, namely vertical and horizontal with respect to the surface. For vertical polarization, they behave as a Perfect Magnetic Conductor (PMC) whilst for horizontal polarization they do as a Perfect Electric Conductor (PEC). Consequently, they cancel the two polarizations at the same time and this happens for all angles of incidence in the antenna surface (see [4]). This is a main difference with EBGs as, a EBG surface behaves as a high impedance surfaces, i.e., as PMC for both polarizations and it only exhibits a different behaviour for each polarization for grazing incidence, where they behave as PEC for horizontal polarization, thus, cancelling it [4]. However, in a general radiation problem such as the radiation of a patch antenna, the waves will incide on the ground plane with arbitrary angles. This fact has been previously highlighted by some of the authors of this paper in [5] and was also demonstrated for the mutual coupling reduction of two monopole antennas in [6]. Moreover, the back radiation phenomenon is not only caused by the surface waves, otherwise it would be enough with using a cavity backed patch antenna to suppress them. The problem is more complex as it strongly depends on the surface surrounding the antenna.

In this work we will show how to use a simple planar soft surface to reduce the back radiation of a circular patch antenna. There is a previous work in the literature [7] where a planar soft surface was combined with a patch antenna to enhance antenna directivity. On the other hand, corrugations, which are the traditional non-planar implementation of soft surfaces, have been successfully used to reduce back radiation of different antennas [8].

2. DESIGN OF THE SOFT SURFACE

In the proposed example we have selected an arbitrary work frequency of 2 GHz and a conventional substrate for antennas, PVC ($\epsilon_r = 3$) that will be shared by both the antenna and the soft surface. The planar soft surface will be implemented with metal strips and grounded vias as it is shown in Figure 1(a). In order to design it, to suppress surface waves at the desired frequency, there are four key parameters to play with, namely, the strip width w, the substrate height h and the period p and position (across the strip) of the vias. In this example a central



(a) (b)

Figure 1. Planar soft surface design. (a) Planar soft surface. (b) Transmission coefficient.

position of the vias has been selected. The use of vias in other positions will provide a more compact structure if required [3].

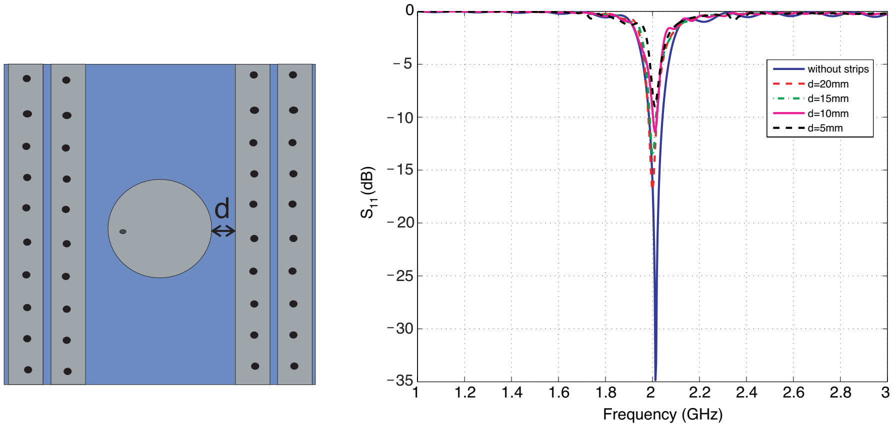
To select the structure parameters it is necessary to perform simulations of the structure to see where (at which frequency) the stop band or bandgap occurs. There are two possibilities to this aim. The first one is to compute the dispersion diagram of the infinite structure in the "soft" direction as in [3]. Another simpler option is to compute the transmission coefficient S_{12} of a finite structure composed of a few periods and see at which frequency the stop band is located. This second technique is much faster and somehow more realistic to what we will find in practice as the dispersion diagram assumes infinite structure without excitation.

The result of this design (assuming a thickness of 3 mm for the substrate (h parameter)) is a surface with strip width w of 20 mm, period of the vias $p = 23$ mm and a gap g of 3 mm. The transmission coefficient S_{12} for such surface, taking 7 periods of the structure is represented in Figure 1(b) (solid line) where a minimum in the transmission around 2 GHz is clearly observed.

It is noted that the resulting structure is relatively compact but if desired, the strip width could be further reduced by modifying other parameters [3], such as further increasing the period of the vias p or placing the vias at the edge of the strips instead of in the middle.

3. APPLICATION TO BACK RADIATION REDUCTION

Once the structure has been designed, it will be used to reduce back radiation of a patch antenna. The strips will be placed only in the antenna E-plane, as it is known that it is in this plane where surface waves are mainly excited [9]. The final structure is described in Figure 2(a). The antenna is a circular patch with a 46 mm diameter, printed on the same PVC substrate. The antenna working frequency is 2 GHz and in this case only two periods of the soft surface at each side of the antenna in E plane have been introduced. Ground plane is squared with a 178 mm side.

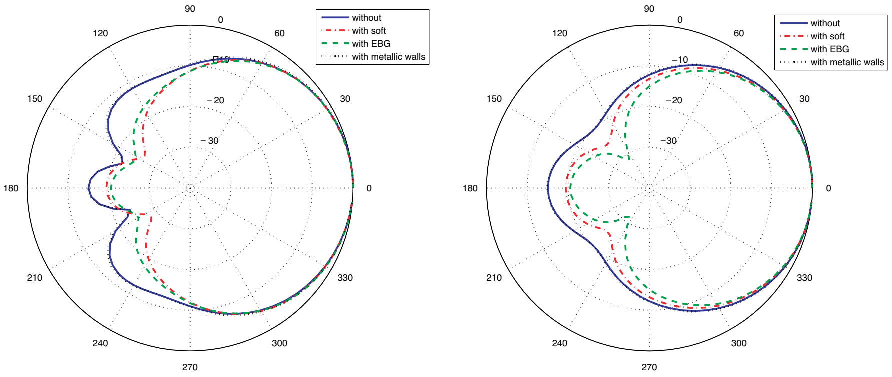


(a) (b)

Figure 2. Proposed patch antenna with two strips to reduce back radiation. (a) Proposed design. (b) Antenna matching as a function of distance d.

Firstly, the effect of introducing the soft surface in the antenna matching was studied as a function of the distance d from the antenna edge to the first strip. A summary of that study is presented in Figure 2(b). It can be concluded that as the strips approach the antenna edge, the matching becomes worse, but still in most cases it is below the required −10 dB.

An important fact related to antenna back radiation is that the increase of the ground plane size does not necessary guarantee a reduction in the back radiation, as it could be expected. This has been explored in [5] for ideal sources and it is a consequence of resonances due to the different electrical sizes of the ground plane as well as propagation of waves along it.



(a) E plane (b) H plane

Figure 3. Back radiation reduction using planar soft surfaces. Simulation results.

Figure 3 contains the simulation results of the radiation pattern in E and H plane for the proposed structure. In both cases, the same antenna with a ground plane with identical size but without the soft surface was simulated for comparison purposes. According to the figure, the reduction in back radiation when the soft structures are added (red dot-dashed lines in the polar graphs) is, approximately, 5 dB in the back lobe but goes up to 10 dB in other directions within the back angular range. Moreover, the soft structure has no negative effects on H-plane.

It is noted that the reduction in the back radiation is caused by the effect of the complete soft surface and not only because the vias could behave as a electrical wall (emulating a cavity backed case). This has been checked in the radiation pattern of the same antenna without the strips and keeping the pins. No back radiation reduction was observed in that case. Furthermore, the case in which the substrate is ended with vertical metallic walls has been simulated and the results are also included Figure 3 (black dotted line, which is almost totally overlapped with the reference case), where almost not effect of this change is observed. We can then conclude that the back radiation is not only caused by the surface wave propagation (of the surface waves excited by the edges of the antenna) to the edge of the substrate but also by the diffraction of the radiated field.

To further complete the study, the performance of the employed anisotropic structure when compared to the use of mushroom-type EBG [10] for the same purpose was explored. To design the EBG surface the same procedure than for the soft surface was followed.

Initially, the dimensions of the mushrooms in the antenna dielectric have been calculated by computing the transmission coefficient (as in the case of the soft surface) to have filtering properties at 2 GHz. This result is included in the previous Figure 1(b) represented by dashed lines. To achieve the same stop band frequency than with the strips, a larger size was required for the mushrooms ($w = 22\,\mathrm{mm}$, i.e., a 10% wider than the strips). As in the previous case, two rows of the designed mushrooms-type EBG were placed at each side of the antenna in E-plane and the back radiation was computed. This radiation pattern is also included in Figure 3 (green dashed line). In E-plane the back radiation is slightly less reduced than with the soft surface whilst in H-plane is more reduced in some directions. The reason for this similar performance is that we are placing the periodic structures only in E-plane and in that plane the patch antenna radiates a field polarized with $\hat{\theta}$ direction, i.e., perpendicular to the antenna surface and both types of surfaces behave the same for that polarization.

Another important issue is the number of periods of the soft surface that has been considered. We have verified that when the number of strips is increased to 3 or 4 the relative back radiation reduction is almost the same than with only two strips. The reason for the latter being related to the mechanism that is effectively reducing the back radiation. Such mechanism is more related to the type of surface that the radiated waves see as ground plane surface (especially at the edge of the ground plane) and not only to the filtering or suppression of the surface waves created by the antenna itself in grazing direction, otherwise the number of periods should have produced a larger reduction of the back radiation.

Finally, the achieved reduction in the back radiation compared to the initial one without soft surface is presented in Table 1 for some ground plane sizes (always using two periods of the soft surface). This table shows how, independently of the ground plane size, the soft surface always reduces the back radiation and how the larger ground plane not always provides a lower back radiation. In the table, the shown back radiation parameter is defined in terms of the maximum

Table 1. Back radiation reduction for different ground plane sizes with and without the soft surface.

GP size (mm)	148	158	168	178
Back radiation (dB)	−17.2	−16.3	−15.7	−15
Back radiation (with soft) (dB)	−20.9	−22.5	−17.7	−20

radiated level achieved in the rear direction, assuming normalized radiation patterns.

4. CONCLUSION

A planar version of soft surfaces has been used to reduce back radiation in a patch antenna. Not only this goal has been achieved, also further information on the better way of reducing such radiation has been obtained. The important factor is the surface surrounding the antenna, especially near the edges. This surface has to be able to cancel waves with arbitrary polarization impinging from any direction. Consequently, it is more related to this fact than to the surface wave propagation by itself. In this sense, soft surfaces have demonstrated to be a good option as they are able to cancel both polarizations due to its inherent anisotropy, and, at the same time, they suppress the surface wave propagation, both effects happening at the same frequency.

In the presented example the planar realization of soft surfaces have been placed only in E-plane as this is the most critical plane in this aspect for patch antennas, but if required they can be easily designed to be rotationally symmetric around the antenna [11] in the same way as it was previously made with corrugations.

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