Microstrip Patch Antenna Design with Criss-Cross Metamaterial Based Radome Cover

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Abstract— A high gain microstrip patch antenna with a metamaterial cover over it has been proposed in this paper. A new design namely Criss-Cross metamaterial is being used here. The Criss-Cross unit cell comprises of a cross printed on one face of dielectric substrate and the same cross rotated by 45° is being printed on the other face of the same substrate. The DNG behavior, i.e., both ε and μ are simultaneously negative for this metamaterial is obtained at 6 GHz; the patch also operates on the same frequency. The radome cover is constructed by stacking three layers made up of a 3×3 Criss-Cross metamaterial array. A 3×3 array of Criss-Cross metamaterial unit cell is printed on Duroid substrate. This arrangement of radome cover increases the gain of a simple patch antenna up to 3.66 dB. The radome cover over the antenna is used to protect the structure from environmental hazards. However due to use of conventional dielectric materials as radome, the performance of the antenna degrades. When a metamaterial in printed on such dielectric material, its properties and behavior changes. This leads to improvement of performance of patch antenna along with its physical protection. The directivity of the proposed patch antenna also improves due to the lens behavior of the radome cover over the patch. A conventional radome cover will scatter the EM radiations emitted by the patch antenna. But the metamaterial cover acts as a lens which focuses the EM radiations. This action is once again due to the unusual properties of the metamaterials.

1. INTRODUCTION

Patch antenna consists of a patch of metallization on a grounded substrate. These antennas are low-profile, lightweight and most suitable for aerospace and mobile applications. However, patch antennas also have some limitations such as lower gain, lower efficiency and narrow bandwidth. There has been a lot of study published on the improvement in the performances of patch antennas. Most of the solutions proposed were to use an array of several antennas. The particular disadvantage of this method comes from the feeding of each antenna and also from the coupling between each element. Other solutions have been suggested to make use of a substrate of either high permittivity or permeability [1]. However, this result in big loss of the material and high cost. In the past few years, left-handed metamaterials (LHMs) composed of split-ring resonators (SRRs) and wires have attracted considerable attention because of their unusual electromagnetic properties and can be applied to antennas reflectors, filters, perfect lens and so on [2–4]. Burokur et al. [5] numerically studied the influence of LHMs on the performances of the antenna and found the performance of the antenna can be improved using the focusing effect in the LHMs. Enoch et al. [6] investigated the properties of metallic composite metamaterials and demonstrated that monopol's directivity can be improved greatly using a very low refractive index of metamaterials. Chen et al. [7] theoretically investigated the controllable LHMs based on a varactor-loaded S-shaped resonator structure which can realise continuous scanning capability. In this paper, we study numerically the performances of a patch antenna when Double negative (DNG) is placed above.

2. DESIGNING OF DNG COVER USING CRISS-CROSS METAMATERIA

The design of a metamaterial-radome for a patch antenna operating in a specific frequency band requires the entire determination of its electromagnetic characteristics around the operating frequency with well defined properties. The composed multi-layered media should have an effective index of refraction near zero with low losses to not modify the antenna performances. In this study, the metamaterial radome is made by aligning the layers of the Criss-Cross resonators alternately with layers of air. Since the metamaterial radome is a 3D periodic structure of Criss-Cross, the effective permittivity and permeability of a metamaterial-slab are computed with Ansoft-HFSS software by using both the perfect electric conductor (PEC) and perfect magnetic conductor (PMC) boundaries. This method allows the microwave characterization of a semi-infinite effective homogeneous slab with an infinite periodic array structure. For a plane wave incident normally on the homogenous slab of thickness d, we compute the effective permeability from the reflection (S_{11}) and the transmission (S_{21}) coefficients of the simulated structure.

Here we study the effect of a DNG MM cover over a patch antenna. The MM cover was made of a 3×3 array of Criss-Cross MM [8]. The Criss-Cross structure gives negative ε and μ in the frequency band of 5–7 GHz. Thus a 6 GHz patch antenna was designed in order to match the resonating frequency. The functioning of a MM cover over the patch is explained in Fig. 1 where the scattered radiations from the patch are focused due to the MM cover over it. This action helps

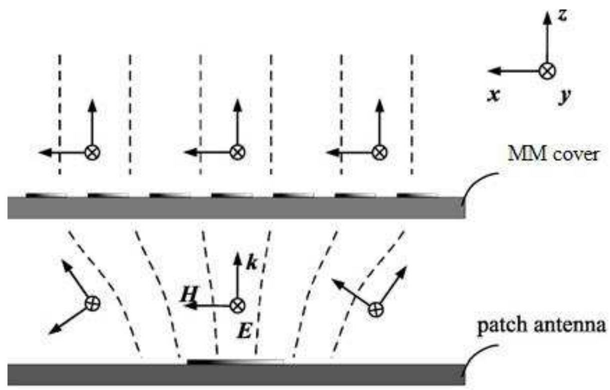

Figure 1: Lensing phenomenon by radome cover using MM over the patch antenna.

Table 1: Summary of different trials applied for radome cover.

TYPE	FREQ (GHz)	S_{11} (dB)	GAIN (dB)	DIRECTIVITY (dB)
Single layer				
i) ag = 10 mm	5.5	−15.49	2.51	3.48
ii) ag = 15 mm	5.8	−15.82	3.21	3.55
iii) ag = 20 mm	6.4	−16.12	4.61	4.68
iv) ag = 25 mm	6.6	−16.19	4.64	4.74
Double layer				
i) ag1 = 25 mm ag2 = 6.25 mm	5.5	−37.97	4.65	4.75
ii) ag1 = 25 mm ag2 = 10.25	6.2	−15.82	2.55	3.26
Triple layer				
(ag1 = 25 & ag2 = 6.25)				
i) ag3 = 6.25	6.3	−15.38	3.69	3.66
ii) ag3 = 10.25	6.4	−16.08	3.66	3.66

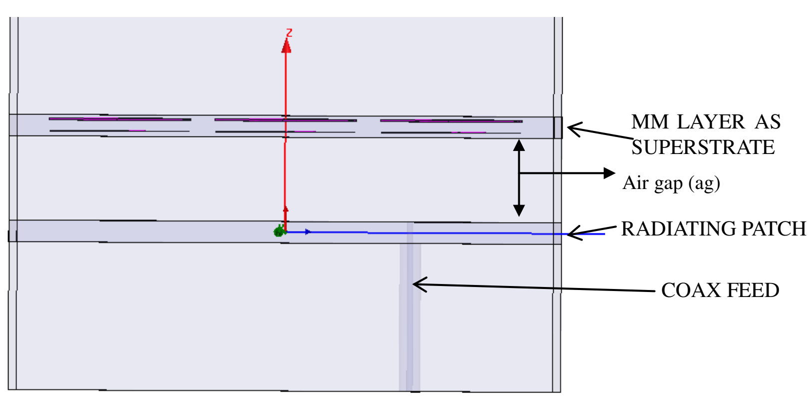

Figure 2: Criss-Cross MM based radome cover made up of single layer over the patch.

in improving gain and directivity of the patch antenna.

Figure 2 shows a single layer radome structure above the 6 GHz radiating patch. The dimensions of the radome optimized with the Ansoft-HFSS software. In order to form the radome cover, a layer consisting of 3×3 array of Criss-Cross MM being printed over Duroid substrate with $\varepsilon_r = 2.2$ was used. The thickness of the substrate is 1 mm. The dimensions of Criss-Cross unit cell are same as in [8]. The distance between the patch and the cover is defined as 'ag'. 'ag' has been varied in steps so as to see its effect on results.

Table 1 summarizes the different optimization trials applied to the radome structure. It has been noticed that the gain and directivity improved as the number of MM layers in the radome structure are increased.

3. CONCLUSION

Use of a conventional dielectric radome cover adds losses and disturbance to the radiation pattern of the patch antenna. But the use of MM for radome cover improves the gain and the directivity of the patch. The results show that under proper conditions the energy radiated by the MM cover antenna is concentrated, and a more directional and higher gain antenna is obtained. MM has the merits of simple structure, compact size, prepared convenience and the most important is that it can improve the performances of the patch antenna greatly. Furthermore, MM cover can also be used to the other antennas such as monopoles, dipole antennas, leak-wave antennas and aperture antennas.

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