Gain Enhancement of Patch Antenna Using Double Negative Superstrate Realized by a High Dielectric with Triangular Lattice of Holes

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Abstract

There are many methods for size reduction of microstrip antennas most of which come at the expense of the gain. Amongst techniques for gain enhancement, one method uses double negative material (DNG) as superstrates. In this paper, the DNG material developed in [1] has been used as a superstrate. From an analysis of different configurations of the antenna and the DNG superstrate, gain enhancement of 3.5 dB and radiation patter beam shaping have been achieved.

Introduction

In the recent years, size reduction techniques such as genetic algorithm and particle swarm optimization implemented to obtain relatively high size reduction rates, making small antenna resonate at lower frequencies. However, a significant drop in the gain is associated with size reduction achievement. This drop in the gain could be addressed by left handed materials (LHM). LHM materials, or metamaterials, have a negative refractive index, which could be used to focus the beam and consequently increase the gain. Of interest is the DNG developed in [1-2] which is a high dielectric material with triangular lattice of holes drilled along its length. In the present work this structure has been implemented as a superstrate on a patch antenna that resonates within the same frequency range at which refractive index of the structure is negative. An exhaustive analysis for optimizing the gain and improving the radiation pattern has been done with some very encouraging results.

DNG Material

All nature materials obey Senll's law with positive indices. However, in the recent years it has been shown that some artificially repaired metamaterials and photonic crystals exhibit negative refractive index [1]. Most of work with DNG have been with periodic structures such as metal rods or split ring resonators (SRR) etc. Of interest is the one developed in [1], where the DNG is realized by drilling holes in a high dielectric slab as a triangular lattice structure. The center-to-center spacing of the holes is equal to 2.3 mm and diameter of the hole as 1.6 mm, as shown in Fig. (1). In [2], it has been shown that at 31GHz this structure has a phase velocity opposite to its group velocity, which ensures a negative permittivity and permeability of the structure. The calculated effective permittivity (ε_{eff}) and permeability (μ_{ff}) as shown in [2], are - 3.823 and - 0.294 respectively, thus the refractive index n= -1 according to (1).

$$n_{eff}= \sqrt{\varepsilon_{eff}}\ \sqrt{\mu_{ff}} \qquad (1)$$

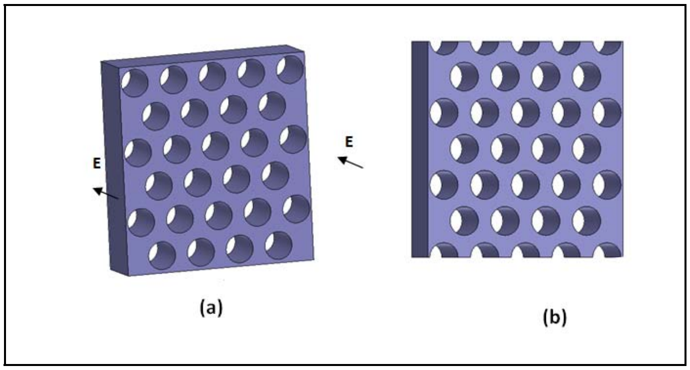


Figure 1: DNG Martial Structure (a) Flat Edges (b) Curvy Top and Bottom Edges

In the present work several versions of this structure have been analyzed using Ansoft's High Frequency System Simulator (HFSS). The first model is 11mm x 3.7mm x11.9 mm. and flat along all the edges; as shown in Fig. 1 (a). The excitation applied from top and bottom edges did not yield good results. However when the edge is cut half way across the holes, Fig. 1(b), and the excitation is along these curvy edges the results are good. Simulation results for the magnitude of reflection and transmission coefficients plot (S11 and S21) is shown in Fig. 2. S21 (thick line) = 0.999 at 31.46 GHz.

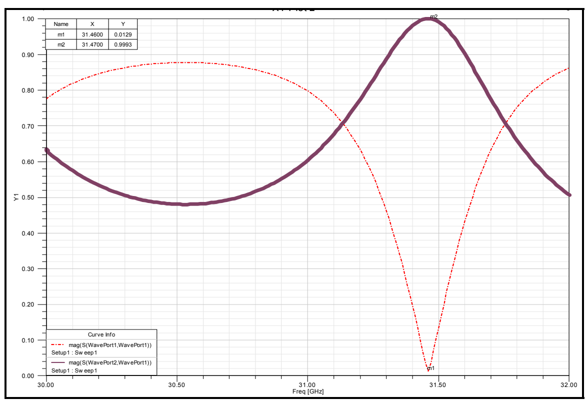


Figure 2: S11 and S21 of the DNG Material in Fig.1 (b)

Results - DNG as Superstrate

After optimizing the DNG material for low reflection coefficient at 31.5 GHz it is implemented as superstrate at different heights from the patch. The radiation pattern of the antenna, Fig. 3(a), without superstrate is used as reference for pattern and gain comparison. When the DNG material is used as a superstrate directly touching the patch, the refection coefficient increased to 0.235 at 31.7 GHz and radiation pattern distorted as shown in Fig 3(b). However, at a height equal to the substrate thickness (0.793mm), the reflection coefficient at 30.85 GHz is 0.018. All results later are obtained at this height. An analysis of the DNG material as superstrate in different configurations has been performed in order to examine its effect on the gain and radiation pattern of the antenna.

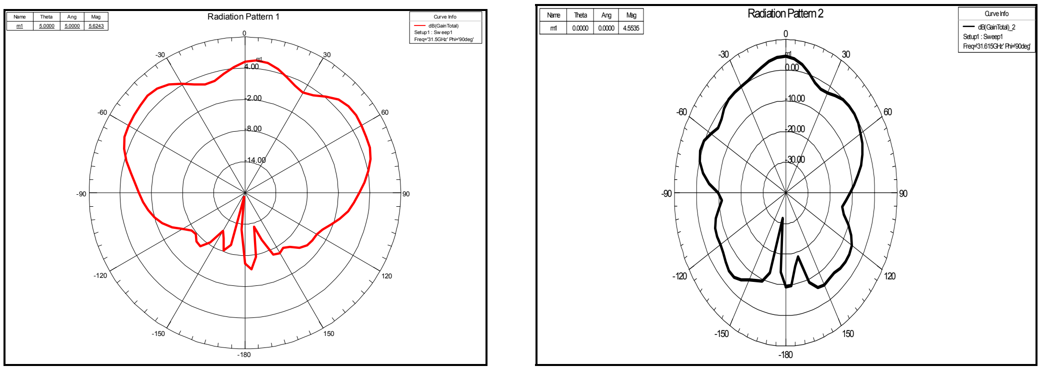
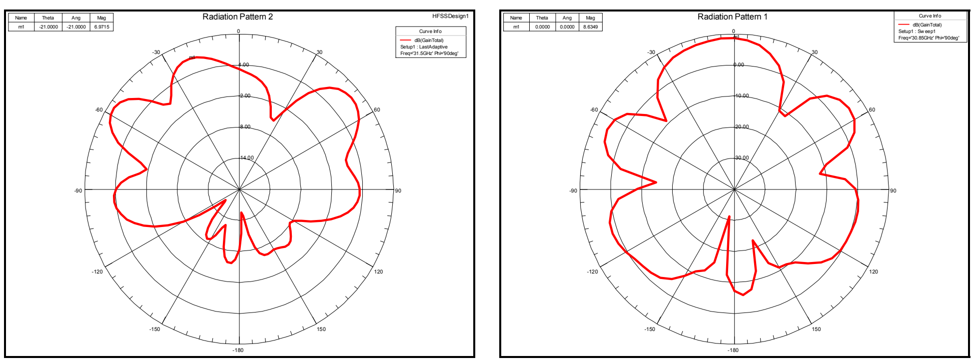


Figure 3: (a) Radiation Pattern at 31.5 GHz without DNG material total Gain 5.62 dB.
(b) Radiation Pattern at 31.7 GHz DNG material touching the patch total Gain 4 dB.

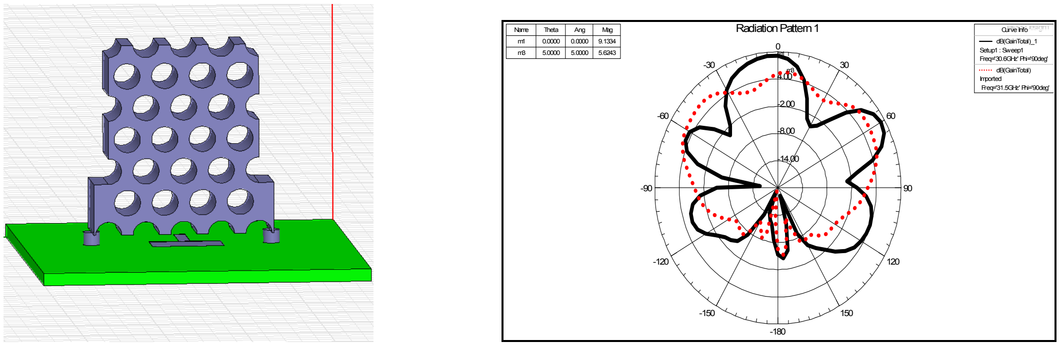
A configuration using the dielectric material of dimension 11x3.7x11.9 mm and without holes has been tried. A result of this configuration reveals a change distortion in the pattern, the maximum forward gain equals to 4 dB as shown in Fig.4 (a). Another configuration is using the same material of the same dimension but with holes. Results of this configuration show a gain of 8.6 dB. This result indicates that the dielectric material with holes does indeed behave as a DNG material providing a focusing effect and hence an increase in gain.



(a) (b)

Figure 4: Radiation Pattern in dB of the Antenna: (a) with High Dielectric Material without Holes as Superstrate. (b) with Holes.

The radiation pattern with DNG material as superstrate shown in Fig. 4(b) has deep nulls at 30^0 and 315^0 In order to improve the pattern we utilized the experience gained earlier from usage of curvy edges. With the superstrate having curvy edges all around, the radiation pattern improved significantly with an enhanced gain of 9.15 dB and nulls dropping to only - 4dB instead of -13dB as before. Fig. 5 (a) shows the enhanced shape of the DNG; note that not only the top and bottom edges are curvy shaped. DNG structure is mounted on pedestal from the same dielectric material for practical implementation. We have tried to mount the DNG material on a slab form the same dielectric but it affected the gain and radiation pattern. The radiation pattern after enhancement is show in Fig. 5(b), along with the patch only pattern (dashed line) for the sake of compassion.



(a) (b)

Figure 5: (a) Enhanced DNG Structure with a Pedestal Mount. (b) Radiation Pattern: Solid Thick Line for Enhanced Shape DNG, and the Dashed Line for the Patch without DNG.

Conclusion

In this paper, the DNG material developed in [1] has been used as a superstrate. From an exhaustive analysis of different configurations of the antenna and the DNG superstrate, gain enhancement of 3.5 dB and radiation pattern beam shaping have been achieved. An exhaustive analysis for optimizing the gain and improving the radiation pattern has been done with some very encouraging results. Future work will include an optimization of the DNG material by varying the hole dimensions and spacing and extracting the permittivity and permeability by the method described in [3]. Also experimental validation will be performed.

References

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