Investigations into minimization of mutual coupling between patch antennas with a row of metamaterial cells

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Abstract

A single-negative metamaterial can be used for the purpose of suppressing mutual coupling between adjacent antenna elements in arrays. In the carried out studies, we examined the mutual coupling between two pair of patches with an artificial magnetic row inserted in-between. The studies have been focused on a magnetic wall made with a single line of spiral resonators. The numerical analysis and measurements provided consistent results and confirmed that the mutual coupling can be significantly reduced between both elements. This phenomenon was observed even for substrates featuring dielectric permittivity lower than 2,5. Even though, such magnetic isolators are tiny, they can contribute to further antenna arrays miniaturization without compromising their electrical impedance and radiation properties.

1. Introduction

Improving antenna elements performance and their dense packing is of paramount importance to the advancement in antenna array engineering. These objectives establish great challenges due to the trade-off with mutual coupling phenomenon. One of major advert effects is the undesired perturbation in current distributions and in consequence, the setup of the troublesome limits on antenna designs. Increasing the spacing between elements is not a solution many designs can deal with [4,5]. With these motivations, we have carried out extensive research on overcoming the limitations on the close antenna element meshing by the use of a row of the signal negative metamaterial. The row has the same thickness as the substrate. The considered metamaterial was made with a row of tiny cells.

2. Metamaterial cell made with a spiral printed line

An elementary cell of the metamaterial studied makes use of a narrow printed line wrap-up into a spiral layout (as a solenoid). The electromagnetic properties of the cell circuit vary greatly with the frequency. In particular, it is feasible to establish a bandstop rejection when illuminated by the TEM wave propagating normal to the circuit plane [1 ,2, 3]. Figure 1 displays the geometry and Figure 2 shows the calculated parameters of the 1D metamaterial cell. The signal element has 6x6x0.508 mm size and was manufactured on the RO4003 laminate (ε_r=3,38, tan=0,0021, thickness 20 mils / 0,508 mm and double side copper cladding of 1/2 oz / 17µm). In our studies, the metamaterial wall consisted of a single row that is 55 mm long and comprises of 16 cells arranged side-by-side. The row was inserted in-between two patch antenna elements along the mid line.

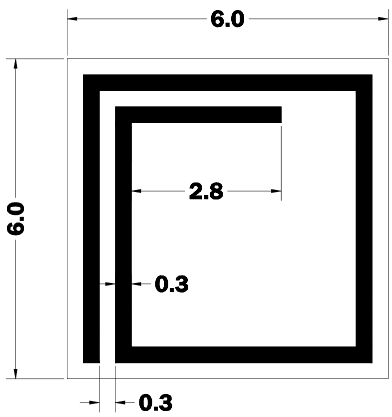

Fig 1. Geometry of the spiral resonator on RO 4003 substrate - thickness 20mils (0,508 mm).

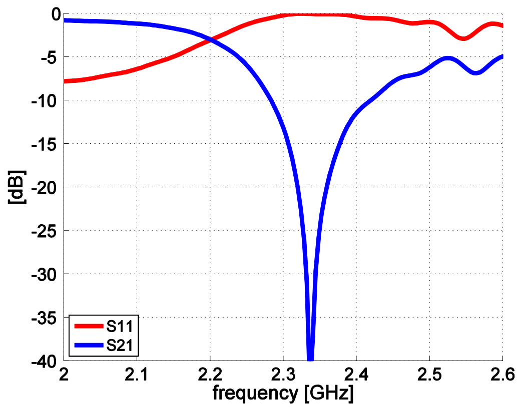

Fig 2. Calculated S11 and S21 parameters of spiral resonator illuminated by TEM wave.

Figure 3 presents the distribution of the magnetic field in the patch antenna element fed with a coaxial probe. In order to work with the highest efficiency, a plane of the coil circuit has to be set normal to the direction of the magnetic field (as it is with loops). Therefore, the plane of coils should be appropriately oriented [1,2]. In our investigations, we have confirmed that removing some cells from the patch edges (making the row of metamaterial sparse), is a measure to simplify the array structure without sacrificing the possibility to further lower the mutual couplings between patches (as shown in Fig. 4).

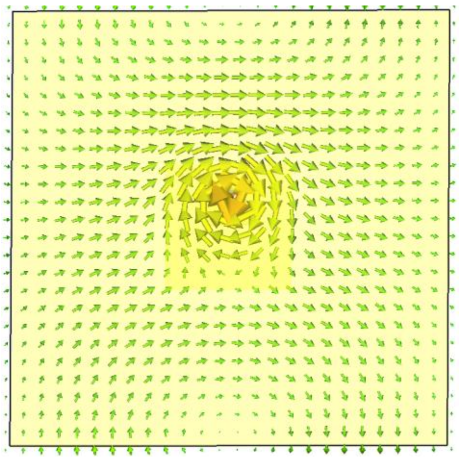

Fig 3. Distributed magnetic field in patch antenna. Antenna probe fed. Size of the patch 37x37 mm. Polypropylene substrate (εr=2.2, tan=0.0003, thickness 6mm).

3. Observed effects of passive metamaterial cells presence

In the reported case, scattering the parameters of the patch pair was measured in the anechoic chamber with four-port network analyzer ZVA50. The design center frequency was 2,35 GHz. Patches were made on a 6 mm thick polypropylene substrate (εr=2.2, tan=0.0003). The numerical analysis was carried out with the FDTD code implemented into the CST Microwave Studio. The distance between the elements was set to 65 mm (λ/2 for 2,35 GHz). Figure 4 plots measured S21 for different configurations for the single metamaterial row applied along the mid line. The red line on the plot represents a case without any metamaterial. The maximum value S21 (-22dB) is for 2,35 GHz. For elements with 16 cells of the inserted metamaterial, the measured mutual coupling takes the minimum values for bandwidth 100MHz. It is much broader than in the case of the antenna with 5 metamaterial cells (50 MHz). If the metamaterial starts to extrude slightly above the top of the substrate surface, the isolation further improves.

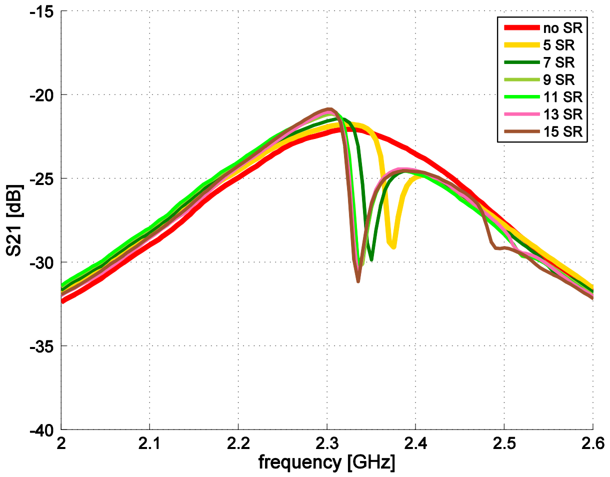

Fig 4. Measured S21 for different number of SR in the row between antenna elements.

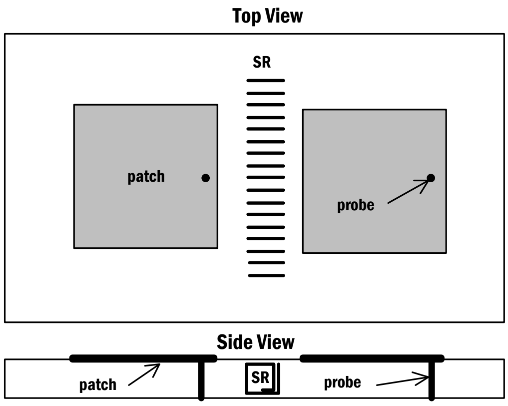

Fig 5. A drawing depicting two patch antenna elements separated with SR. Distance between two adjacent SR was set to 3 mm.

4. Conclusions

It has been shown that the embedded row of the metamaterial SR cells can be an effective measure to suppress mutual coupling over a limited bandwidth for low profile antennas made on the substrate of permittivity around ε_r=3. In the case when the metamaterial is inserted close to the patches, the mutual coupling plot reveals an increase of up to 5÷8 dB. In such a case metamaterial works narrowband. An advantage of that configuration is the straightforward manufacturing. To get significantly reduced mutual coupling, it is sufficient to use 11 SR cells. Directivity, efficiency and also gain increase if the metamaterial isolator is inserted at the edge of the antennas. Such an isolator can be used in larger arrays for improving the parameters and to contribute to a higher degree of the miniaturizations of antennas.

References

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