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Design of Enhanced Gain Micro-Strip Antenna using Square Loop Shaped Meta-Material Substrate

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Abstract - *Inherently, the gain of a microstrip antenna is less. Metamaterials have been shown to enhance specific performance parameters of low profile and high-profile antennas. Our focus in this paper on specifically increasing the gain of low-profile microstrip patch antenna. By placing a metamaterial slab below a microstrip patch antenna (as a substrate below the substrate), we show that the gain of the antenna can be enhanced appreciably. The key advantage of using the metamaterials is to maintain the low-profile advantage of microstrip patch antennas. In various works, different types of superstrates were proposed to enhance the gain of microstrip antennas. The metamaterial structures when used along with the patch antenna to enhance gain are called as Electromagnetic Band gap (EBG) structures in many literatures. Electromagnetic band gap structures consist of periodic metal patches on a dielectric substrate. EBG structures can also be made by combination of dielectric only. EBG structures have properties such that, in a particular frequency band they stop the propagation of surface waves and also reflect back any incoming wave with no phase change. The above properties of EBG structures can be used to get improved characteristics of an antenna. The gain of an antenna can be improved by using EBG structure in two different ways; EBG structure as a superstrate and EBG structure as a ground plane. EBG is also use to improve the isolation and diversity gain in MIMO systems. EBG is also used to get notched characteristic in ultra wideband antenna. EBGs are also used to suppress the noise and reduction of EMI in high speed circuits.*

This dissertation enhances the gain of a basic microstrip antenna by placing a metamaterial substrate beneath the ground plane. Unit cell of the metamaterial is also separately designed and its performance is analyzed. Various parameters of Microstrip antenna like gain, bandwidth, and return loss and radiation pattern are compared with and without the EBG structure.

Key Words: *Microstrip antenna, Metamaterial, EBG structure, Gain.*

1. INTRODUCTION

Microstrip antennas are promising candidates for microwave and millimeter wave application. A microstrip patch consists of a radiating patch of any planar geometry (e.g. square, rectangular, Circular, Ellipse and ring) on one side of a dielectric material substrate backed by a ground plane on the other side.

A microstrip patch antenna consists of a very thin patch that placed a small fraction of a wavelength above a conducting ground plane. The patch and the ground plane are separated by a dielectric. The patch conductor is normally copper and can assume any shape but for this project square patch is used and this simplifies the analysis and performance prediction. The patches are generally photo etched on the dielectric substrate and the substrate should be non-magnetic. The relative permittivity of the substrate is an important parameter to consider. It is because relative permittivity will enhances the fringing fields that account for radiation.

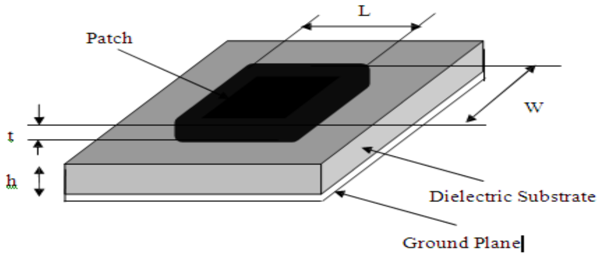
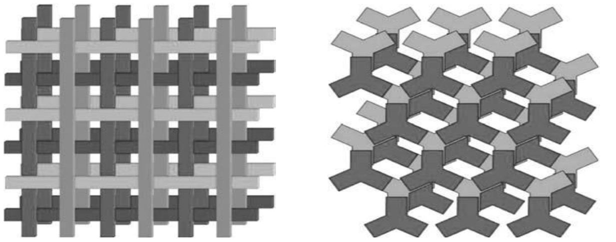


Fig -1: Microstrip antenna

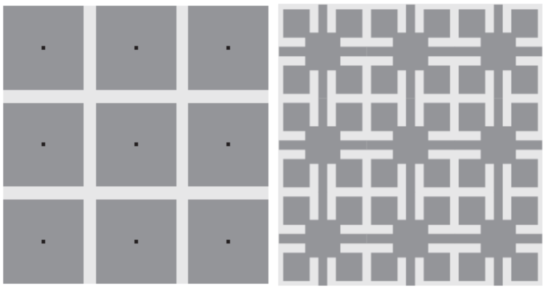
2. METAMATERIALS EBG STRUCTURE-DEFINITION

Periodic structures are abundant in nature, which have fascinated artists and scientists alike. When they interact with electromagnetic waves, exciting phenomena appear and amazing features result. In particular, characteristics such as frequency stop band, pass band, and band gap could be identified. Reviewing the literature, one observes that various terminologies have been used depending on the domain of the applications. These applications are seen in filter designs, gratings, frequency selective surfaces (FSS), photonic crystals and photonic band gaps (PBG), etc. They all are classified under the broad terminology of "Electromagnetic Band Gap (EBG)" structures. Generally speaking, electromagnetic band gap structures are defined as artificial periodic (or sometimes non-periodic) objects that prevent/assist the propagation of electromagnetic waves in a specified band of frequency for all incident angles and all polarization states. EBG structures are usually realized by periodic arrangement of dielectric materials and metallic conductors. In general, they can be categorized into three groups according to their geometric configuration: [1] three-dimensional volumetric structures, [2] two-dimensional planar surfaces, and [3] one-dimensional transmission lines. Fig 2 shows two representative 3-D EBG structures: a woodpile structure consisting of square dielectric bars and a multi-layer metallic tripod array. Examples of 2-D EBG surfaces are plotted in Fig 3: a mushroom-like surface and a uni-planar design without vertical vias. This paper focuses more on the 2-D EBG surfaces, which have the advantages of low profile, light weight, and low fabrication cost, and are widely considered in antenna engineering. The planar electromagnetic band gap (EBG) surfaces exhibit distinctive electromagnetic properties with respect to incident electromagnetic waves:



(a) a woodpile dielectric structure (b) A multi-layer metallic tripod array.

Fig -2: Three-Dimensional EBG Structures



(a) a mushroom-like surface (b) a uni-planar surface

Fig -3: Two-Dimensional EBG Surfaces

METAMATERIALS: Almost at the same time, another terminology, "*metamaterials*," also appeared and has become popular in the electromagnetics community. The ancient Greek prefix, *meta* (meaning "beyond"), has been used to describe composite materials with unique features not readily available in nature. Depending on the exhibited electromagnetic properties, various names have been introduced in the literature, including:

Double negative (DNG) materials with both negative permittivity and permeability;

Left-handed (LH) materials inside which the electric field direction, magnetic field;

Negative refractive index (NRI) materials that have a negative refractive index;

Magneto materials with artificially controlled high permeability;

Soft and hard surfaces that stop or support the propagation of waves;

High impedance surfaces with relatively large surface impedances for both TE and TM waves;

Artificial magnetic conductors (AMC) that exhibit the same properties as a perfect magnetic conductor.

It is worthwhile to point out that some of these interesting electromagnetic characteristics are related to each other. For example, the DNG materials always exhibit both the left-handed property and the negative refractive index. A corrugated metal surface can be a soft surface for wave propagation in the longitudinal direction and be a hard surface for wave propagation in the transverse direction. Furthermore, a periodic composite transmission line structure may exhibit the left-handed property in one frequency region and band gap property in another frequency region. Thus, it is an exciting area for researchers to explore these unique properties and their relations for different metamaterials and apply them in various electromagnetic and antenna applications. Due to their unique band gap features, EBG structures can be regarded as a special type of metamaterials. Besides the band gap feature, EBG also possesses some other exciting properties, such as high impedance and AMC. For example, a mushroom-like EBG surface exhibits high surface impedances for both TE and TM polarizations. When a plane wave illuminates the EBG surface, an in-phase reflection coefficient is obtained resembling an artificial magnetic conductor. In addition, soft and hard operations of an EBG surface have also been identified in the frequency-wave number plane. These interesting features have led to a wide range of applications in antenna engineering, from wire antennas to microstrip antennas, from linearly polarized antennas to circularly polarized antennas, and from the conventional antenna structures to novel surface wave antenna concepts and reconfigurable antenna designs.

In summary, electromagnetic band gap structures are an important category of metamaterials.

3. DESIGN OF A UNIT CELL OF METAMATERIAL FOR 9.5 GHz

The proposed metamaterial consist of a board of Rogers RO3003 (with permittivity of 3 and loss tangent 0.0013). The thickness of the substrate is 0.782 mm. Size of the square shaped board is 7×7 mm. The metamaterial contain a square loop with inner length 6 mm and outer length of 6.5 mm on one side of the board. The loop lies on only lower side of the board (Side 2 shown in Fig 4). The mentioned dimension resonates at 9.5 GHz. For the sake of analysis the dimension of the square loop is varied keeping the thickness of the loop as 0.5 mm, resonance shifts elegantly as expected. Symmetrical circular patches on top and bottom makes the shape a bidirectional filter. Fig 4 shows the 3D view and Fig 5 shows the top view of the unit cell.

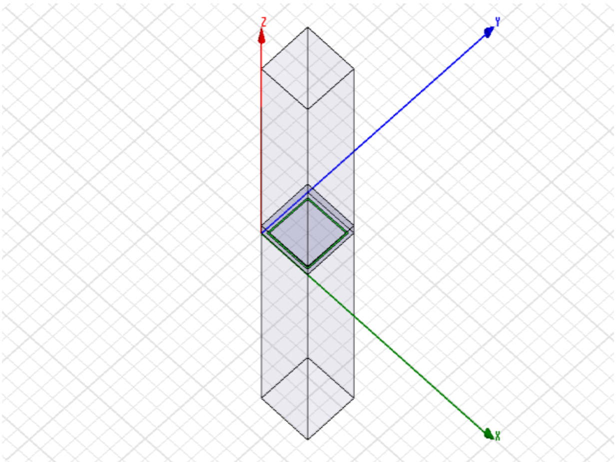


Fig -4: 3D View of the Designed Unit Cell

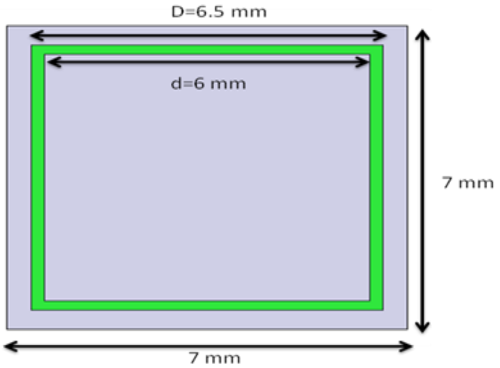


Fig -5: Top View of the Unit Cell

FLOQUET PORT IN HFSS: The Floquet port in HFSS is used exclusively with planar-periodic structures. Chief examples are planar phased arrays and frequency selective surfaces when these may be idealized as infinitely large. The analysis of the infinite structure is then accomplished by analyzing a unit cell. Linked boundaries most often form the side walls of a unit cell, but in addition, a boundary condition is required to account for the infinite space above. The Floquet port is designed for this purpose. The Floquet port is closely related to a Wave port in that a set of modes ("Floquet modes") represents the fields on the port boundary. Fundamentally, Floquet modes are plane waves with propagation direction set by the frequency, phasing, and geometry of the periodic structure. Just like Wave modes, Floquet modes too have propagation constants and experience cut-off at low frequency. When a Floquet port is present, the HFSS solution includes a modal decomposition that gives additional information on the performance of the radiating structure. As in the case of a Wave port, this information is cast in the form of an S-matrix inter-relating the Floquet modes. In fact, if Floquet ports and Wave ports are simultaneously present, the S-matrix will inter-relate all Wave modes and all Floquet modes in the project. For the current version, the following restrictions apply:

Currently, only modal projects may contain Floquet ports.

Boundaries that are adjacent to a Floquet port must be linked boundaries.

Fast frequency sweep is not supported. (Discrete and interpolating sweep are supported.)

4. SIMULATION RESULTS OF UNIT CELL OF METAMATERIAL (9.5 GHz)

REFLECTION COEFFICIENT: The reflection coefficient of a unit cell of metamaterial is shown in Fig 6. It shows that if an EM wave of 9.5 GHz enters from port 1 how much of it is reflected back. It can be seen that the designed cell reflects most of the energy at 9.5 GHz if the inner length (d) of the loop is 6 mm and outer length (D) is 6.5 mm. All other sizes of the loop show their responses at other frequencies.

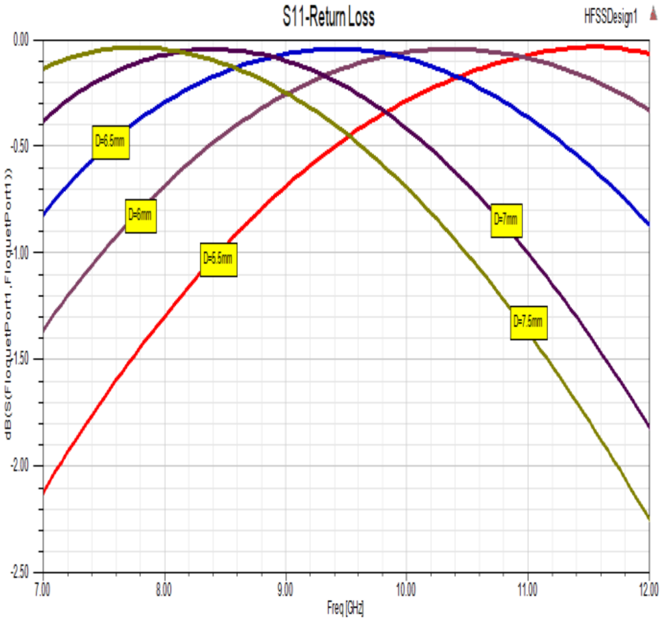


Fig - 6: Reflection coefficient of Unit Cell for various loop dimensions

TRANSMISSION COEFFICIENT: The transmission coefficient of the unit cell of metamaterial is shown in Fig 7. It shows that if an EM wave of 9.5 GHz enters from port 1 how much of it is transmitted to port 2. It can be seen that the designed cell does not allow frequencies at 9.5 GHz if the inner length (d) of the loop is 6 mm and outer length (D) is 6.5 mm. If the dimension of the loop is changed transmission coefficient curve is moved to other frequencies.

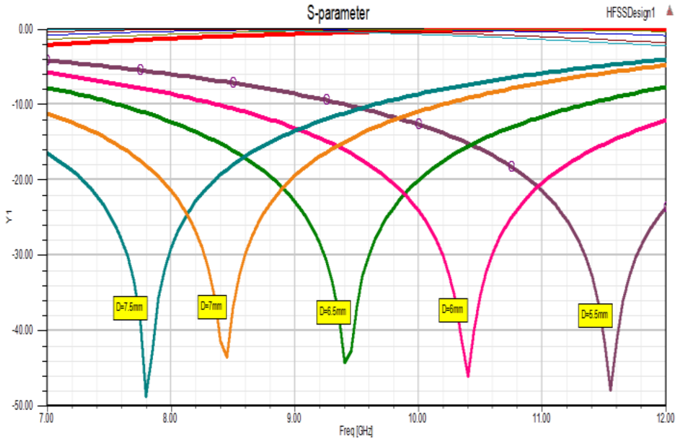


Fig -7: Transmission Coefficient of Unit Cell for Various Loop Dimensions

Above results show that if an array of above unit cell is designed, it will reflect 9.5 GHz. That is why the array of this metamaterial is placed behind the ground plane of the designed microstrip patch antenna.

ARRAY OF SQUARE LOOP UNIT CELL: Fig 8 shows the 5 × 5 array of square loop unit cell forming an EBG substrate. This substrate is expected to reflect frequencies of 9.5 GHz exactly and pass all other frequencies. As a result, if this substrate is placed below the ground plane of a Microstrip patch antenna it should reflect the radiation of 9.5 GHz. This should in turn improve the front to back ratio of the antenna. Unit cells are joined along with their 7 × 7 mm board; hence the spacing between each loop is 1 mm.

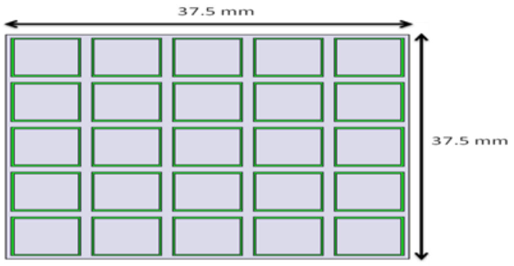


Fig -8: Array of Unit Cell of Square Loop

DESIGN OF GAIN ENHANCED MICROSTRIP PATCH ANTENNA: Fig 9 shows the final designed microstrip antenna. Patch antenna resonant at 9.5 GHz is backed with a 0.782 mm thickness substrate with square loops in an array of 5 × 5.

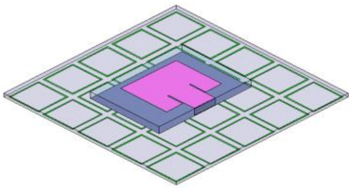


Fig -9: Microstrip Patch Antenna with Metamaterial Substrate

5. SIMULATION RESULTS OF ENHANCED GAIN ANTENNA

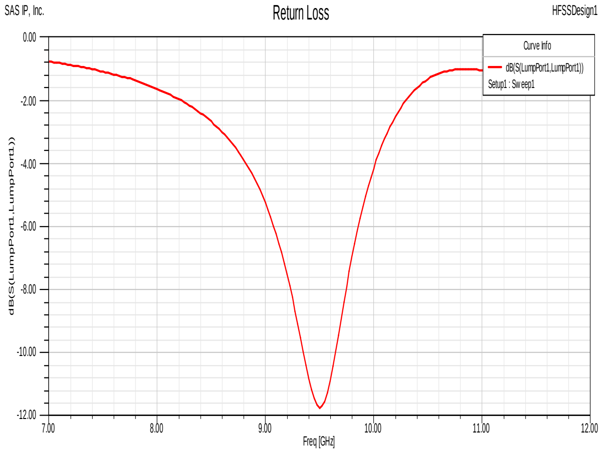


Fig -10: Return Loss of EBG based Microstrip Antenna

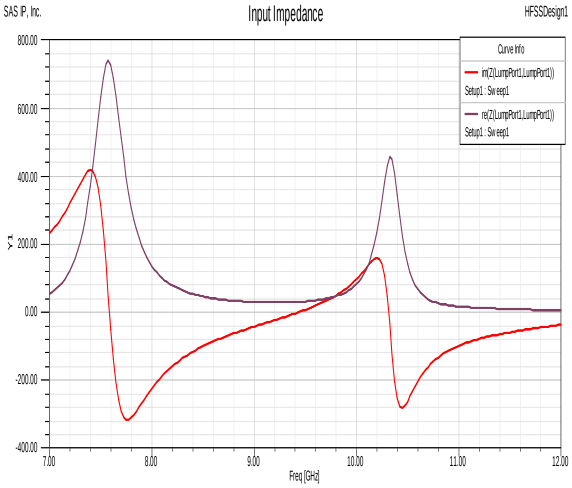


Fig-11:1 Input Impedance of EBG based Microstrip Antenna

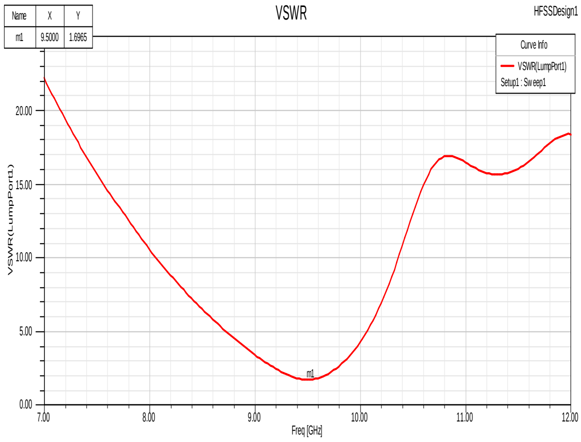


Fig -12: VSWR of EBG based Microstrip Antenna

COMPARISON AND DISCUSSION: Fig. 13, 14 and 15 show the return loss, VSWR and radiation pattern respectively with (blue) and without metamaterial (red). From the Fig 13 and 14 it is evident that antenna characteristics, like operating frequency, input impedance, VSWR and return loss. This is a good sign because theoretically the behavior of antenna changes when another structure is introduced in its vicinity. We have used here a substrate below the antenna in its invisible region rather than putting a superstrate directly in its radiating region as in [1]. This is the main reason that other than providing its reflection characteristics metamaterial is not changing the behavior of microstrip antenna. From Fig 15, it can be seen that the back lobe which was present in the radiation pattern of microstrip antenna is now not present after it is backed with a metamaterial substrate. Gain of the simple microstrip antenna was around 6 dB. After using metamaterial the gain is increased upto 9.5 dB. (Fig 12 and Fig 15 show the gain of antenna without and with metamaterial)

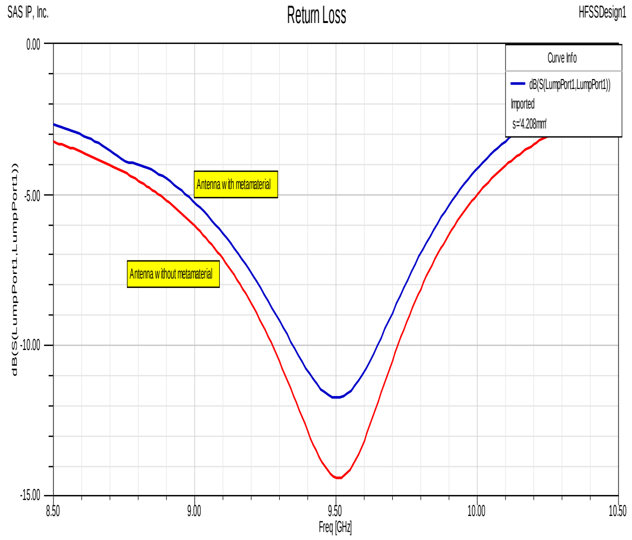


Fig-13: 2 Return Loss with and without Metamaterial

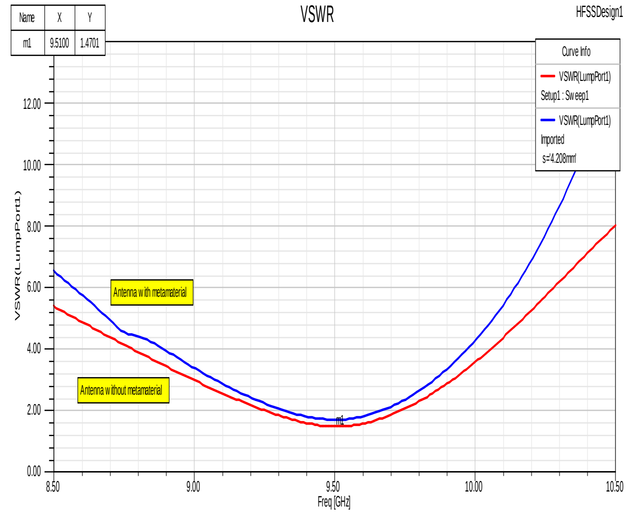


Fig-14:3 VSWR with and without Metamaterial

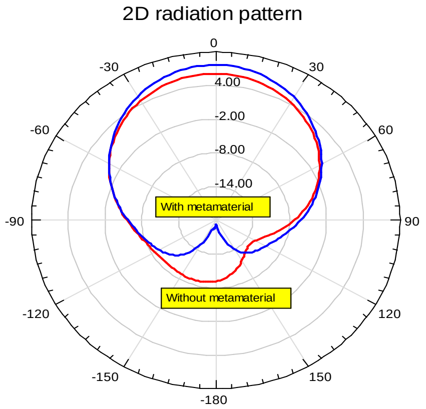


Fig-15: Radiation Pattern with and without Metamaterial

When compared with the referred papers, [2] has managed to get a gain of around 7.3 dB but in the presented work 9.5 dB gain is achieved. Front to back ratio is also improved.

6. CONCLUSION

The dissertation designed a rectangular microstrip patch antenna with inset feed with operating frequency of 9.5 GHz. Then a unit cell that reflects a frequency of 9.5 GHz is also designed. After making an array of the designed unit cell it's positioned behind the ground plane of the microstrip antenna. This design, as expected, increases the gain of the patch antenna significantly. Moreover, it also improves the radiation pattern by increasing the directivity and front to back ratio. The transmission coefficient of the FSS shows that it blocks X-band at 9.5 GHz. This behavior is test at different angle of incidences. The FSS is also analyzed with variable substrate thickness and different dielectric material. When the angle of incidence is changed up to some extent then also the meta-material works as expected.

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