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Comparison between Metamaterial based circular patch antenna and microstrippatchAntenna

ManishKumar Gupta*, Monika Singh #
1. Department of Electronic and communication, student, KIET *
2.Department of Electronic and communication, Asst. Prof. KIET#

Abstract-
The Metamaterial based antenna is designed for some improvement in the performance of directivity gain, return loss and size of circuit area. A patch antenna has been designed and fabricated to operate between 1Ghz.-3Ghz. The aim of the project is to design and fabricate metamaterial antenna and study the effect of antenna dimensions Length (L), Width (W) and substrate parameters relative Dielectric constant (ε_r), substrate thickness on Radiation parameters of Band width. Low dielectric constant substrates are generally preferred for maximum radiation. The conducting patch can take any shape but rectangular and circular configurations are the most commonly used configuration. Other configurations are complex to analyze and require heavy numerical computations. The length of the antenna is nearly half wavelength in the dielectric; it is a very critical parameter, which governs the resonant frequency of the antenna. In view of design, selection of the patch width and length are the major parameters along with the feed line depth. Desired Patch antenna design is initially simulated by using IE3D simulator and Patch antenna is realized as per design requirements.

Keywords:*Circular patch antenna; metamaterial; split-ring structure*

I. INTRODUCTION

One of the remarkable aspects of the human civilization development is the intention to create something that is not available in natural [1]. Metamaterial (MTMs) are artificial media characterized by constitutive parameters generally not found in nature whose values can be engineered to specified values. The "meta" refers to the resulting effective properties whose electromagnetic responses are "beyond" those of their constituent materials. The invention of metamaterial was started in the late 1960s; Veselago has studied theelectrodynamics of substances with simultaneously negative values of dielectric permittivity and magnetic permeability [1-3]. The term of metamaterial was synthesized byRodger M. Walser, University of Texas at Austin, in1999, which was originally defined as "Macroscopiccomposites having a synthetic, three-dimensional, periodic cellular architecture designed to produce an optimized combination, not available in nature, of two or more responses. Actually, a metamaterial is a macroscopic composite of periodic or non-periodic structure, whose function is due to both the cellular architecture and the chemical composition. If the metamaterial is regarded as an effective medium, there is an additional requirement that the cellular size is smaller than or equal to the sub-wavelength. Thematerial with negative permittivity and permeability also known in several name such as left-handed material (LHM) and backward wave material(BWM)[4].Although metamaterial does not present in nature, interesting properties were theoretically predicted for these substances, such as the reversal of the Snell Law, Doppler Effects, Cherenkov radiation and built perfect lenses [3]. Materials may be categorized by their constitutive parameters ε and μ according to the diagram shown in Fig. 1. If both the permittivity and permeability have positive real parts as in the first quadrant of Fig. 1, as most of the materials in nature do, they will be called "double positive (DPS)" media. In contrast, if both of these quantities are negative, as in the third quadrant of Fig. 1, they will be called "double-negative (DNG)." The materials with one negative parameter, quadrants two and four, will be called "single- negative (SNG)." If the permittivity is negative, as in the secondquadrant, these SNG materials will be called "epsilon- negative (ENG)." The ionospheres plasma layer exhibits this behavior at AM radio frequencies while natural plasmonic materials (noble metals and some dielectrics) do at optical frequencies. If the permeability is negative, as in the fourth quadrant, they will be called "mu-negative (MNG)." Ferromagnetic materials exhibit this behavior in the VHF and UHF regimes. If both ε and μ are zero or very close to zero,

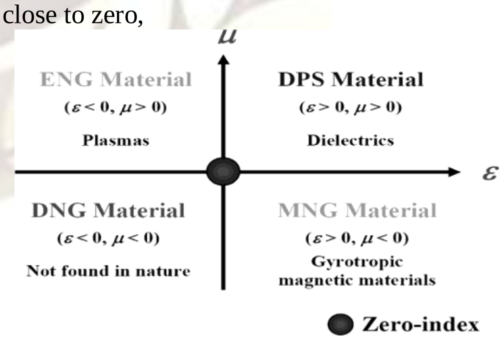

Fig1.Classification ofMetamaterialby the real parts of their constitutive parameters i.e. their permittivity and permeability.

the materials will be called "zero index.".We note that the realization of SNG materials may be relatively easier than that of DNG materials. Therefore, many recent efforts have been aimed at exploring if SNG media can be used to achieve some of the applications originally proposed for DNG media.

The first structure that has been used to prove the existing of metamaterial was a split ring structure invented in 2001 by Shelby Smith and Schultz at the University of California [6]. Three new structures were proposed in year 2005, starting with symmetrical ring structure than omega structure and the latest was S structure [7]. The implementation of metamaterial in microwave is expected to improve the performances of the devices since the material loss is dominant at the radio frequency applications.Applying these concepts to patch antennas is relatively straightforward. The antenna is an important transitional structure between two transmission medium; free space and guiding devices. Microstrip patch antenna has gain extensive application in present scenario of wireless communication due to their light weight, small size, ease of fabrication and integrability with circuitry. However these antennas are less suited to modern communication [8,9] as they efficiently resonate at single frequency and shows narrow bandwidth and low gain especially at lower microwave frequencies. As they are compact in nature and hence are popular structures in modern wireless communication system.

There are varieties of patch structures available but the rectangular, circular and triangular shapes [10] are most frequently used. The performance of antenna is affected by patch geometry, substrate property and feed technique. In circular structure the mode TMz (where z is taken perpendicular to the patch) is supported by circle shape on substrate with height ($h << \lambda$) very small as compared to wavelength. There are different model toanalyze the microstrip patch antenna. The basic model to analyze the patch antenna is the cavity [11] model. This model provides the method that the normalized field within the dielectricsubstrate can be found moreaccurately and does not radiate any power the effective dimension of antennas are greater than the actual dimension due to the fringing[12] [13] field between the patch and the ground plane. With the development of mobile and wireless communication system the demand for broad band, multiband patch antennas are desired.

Thispaperwillfocusoncomparison ofcircularpatchantenna and microstrip patchantenna onasinglecellofMetamaterial.Theproperties of Metamaterialstructure and radiation dimensions of the circular patch antenna and microstrip antenna have been investigated inthis project.

II. METHODOLOGY

A metamaterial is a macroscopic composite of periodic or non-periodic structure, whose function is due to both the cellular architecture and the chemical composition. If the metamaterial is regarded as an effective medium, there is an additional requirement that the cellular size is smaller than or equal to the sub- wavelength. Figure 2 shows two typical metamaterial structures in the microwave regime, in which Fig. 2(a) is a periodic structure that is equivalent to a homogeneous medium and Fig. 2(b) is a non-periodic structure that is equivalent to an inhomogeneous (gradient) medium. The microwave metamaterials are fabricated with printed circuit boards (PCB) by making different metal architectures on PCB. The properties of such metamaterials are mainly due to the cellular architecture, and also dependent on the PCB substrates, which can be FR4, F4B, RT5880 and Rodges.

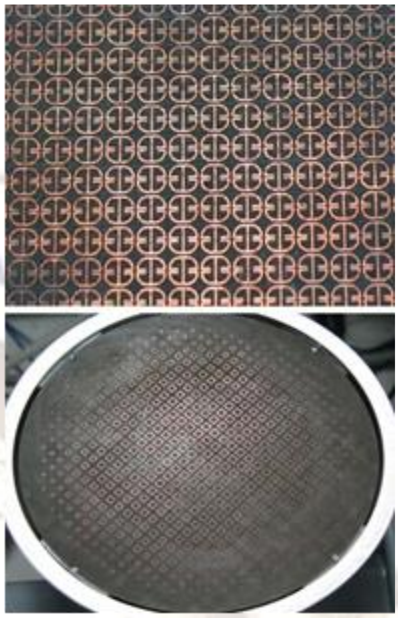

Fig. 2 Two typical metamaterial structures in the microwave regime. (a) A periodic structure, which is equivalent to a homogeneous medium (above). (b) A non-periodic structure, which is equivalent to an inhomogeneous (gradient) medium (below).

The dependence of metamaterial properties on the cellular architecture provides great flexibility to con-trolmetamaterials. One can create new materials which are unavailable in nature but can be realized in practice using metamaterial structures. This is the biggest advantage of metamaterials. This structure since the architecture is only uses a single unit cell to obtain the left-handed material features. This structure is chosen due to the simple assembly construction. The dimensions of the split ring structure are shown in the Figure 3.

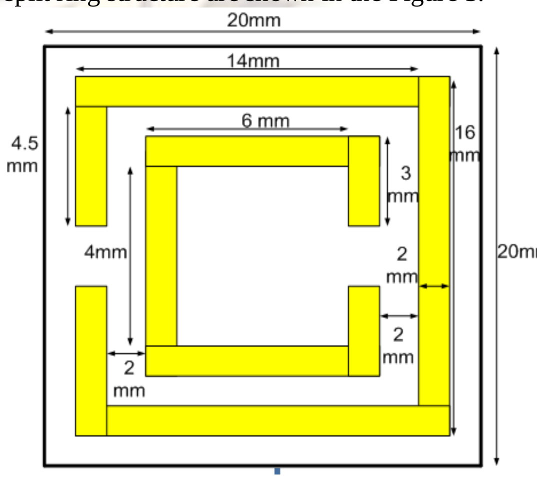

Figure3: Dimensions ofthesingleunitcell construction using split ring structures

Fig. 4 shows a single unit cell of an omega structure, consisting of two parts: the substrate and the omega Perfect Electric Conductor (PEC) structure. Two waveguide ports are set at the top and bottom of the Y-axis, where the wave penetrates into the metamaterial. PEC boundary conditions are implemented on the left and the right of the X-axis, and perfect magnetic conductor (PMC) boundary conditions were placed in front and back of the Z-axis [14].

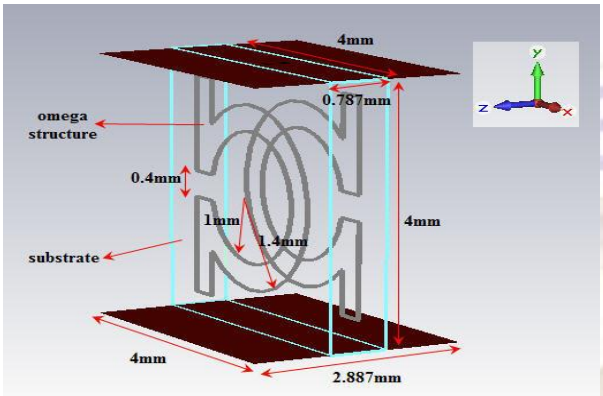

Figure 4: A unit cell of omega structure in a waveguide

The single unit cell substrate is containing of FR-4 and the conductor structures which are constructed from copper. FR-4 is the primary insulating backbone upon which the vast majority of rigidprinted circuit boards (PCBs) are produced. A thin layer of copper foil is laminated to one, or both sides of an FR-4 glass epoxy panel. These are commonly referred to as "copperclad laminates. FR-4 copper-clad sheets are fabricated with circuitry etched into copper layers to produce printed circuit boards. The details properties of FR-4 are shown in Table I.

TABLE I
FR-4 SUBSTRATE PROPERTIES

Properties	Values
Permittivity, ε	4.9
Loss Tangent,L	0.025
Permeability,μ	1
Substrate Height,h	0.25mm

The combination of RT5880 and the omega structure made of Perfect electric conductor (PEC) are used to build up the metamaterial substrate. The PEC is very important for assuming the ideal case during the simulation to obtain the best results from the metamaterial. The detailed features are shown in Table II.

TABLE II
ROGERS RT5880 SUBSTRATE PROPERTIES

Properties	Values
Permittivity, ε	2.2
Permeability,μ	1
Substrate Height,h	0.787mm

IE3D SI simulation is used to simulate the circuit that shown in the Figure 3 and figure 4. IE3D SI's full-wave 3D EM design and verification solution meets the capacity & run-time performance demands of complete package, PCB or circuit-level simulation and modeling. The EM-accurate results enable design and signal integrity (SI) engineers to design and verify their largest designs with confidence.

IE3D SI delivers multiport S-parameter models (Touchstone Format) and broadband RCLK Spice sub circuit models ready to be plugged into your circuit simulations. MDSPICE performs robust, accurate, and efficient time-domain simulations based upon frequency-domain s-parameters. Besides getting the desire output; an optimization process was performed in IE3D simulation software to obtain the best antenna response. In order to maintain the impedance of the transmission line, the width ofthe transmission line was kept constant along the optimization process. The other parameters such as radius and the lengthof transmission linewere continuously varied until achieving the best results.From the simulation results, all S-parameters data will collect and analyzed in order to verify the permittivity of the new material result from the combination of FR-4 and circular split ring structures. There are several methods to verify the permittivity and permeability of a substrate that can be extracted from S-parameters. The most four popular methods are Nicolson-Ross-Weir (NRW), NIST iterative technique, new non-iterative technique and short circuit technique [15]. All methods are based on the S-parameters that obtained from the simulation or measurement results.

A (microstrip and circular) patch antenna is chosen as a case study for antenna performance comparison. One will be designed on FR-4 and another one is on metamaterial substrate. The circular patch antenna on FR-4 is shown in Figure5.

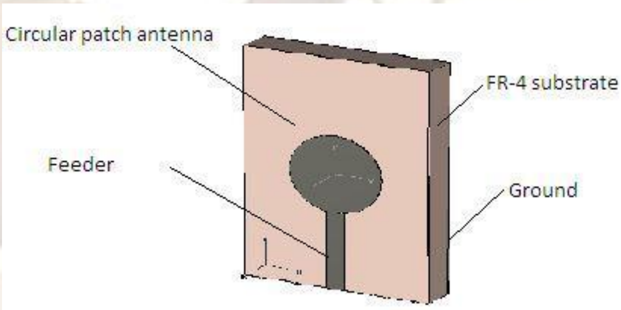

Figure5: AviewofcircularpatchantennaonFR-4substrate.

Copper metal was used to build up the patch and transmission line structures, while a perfect electrical conductor (PEC) as ground plane and FR-4 is considered as the base substrate. The radius of the circular patch is the main parameter that will facilitates to achieve the desire resonant frequency. The width and length of conventional antenna parameters parameters are shown in the Table III

TABLE III
CONVENTIONAL ANTENNA PARAMETERS

Parameter of antenna	Length (mm)
Radius, a	16.0
Transmission line width ,W	0.845
Transmission line length, L	8.419

After constructing the rectangular split ring, a full simulation process will be done in order to obtain S-parameters. A confirmation on the metamaterial substrate is depending on the negative permittivity at the desired frequency that obtained from the calculation before a circular patch antenna will be designed on thenew substrate. The difference between antenna on metamaterial and on FR-4 substrates is the sizeofoverall layout. In the new approach, the FR-4 substrate was replaced by a single unit cell of metamaterial substance. The overall size of the conventional antenna will be reduced pursue to the single unit cell metamaterial layout. Consequently, the size of metamaterial antenna is smaller than the size of the conventional antenna on FR-4 substrate. Figure 3 shows the construction of the antenna on metamaterial substrate.

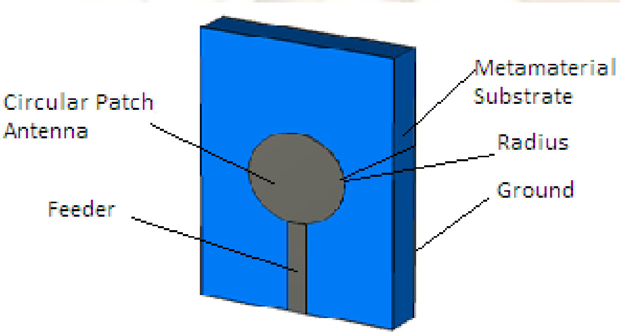

Figure3: Aviewofcircularpatchantennaonmetamaterialsubstrate.

A conventional rectangular microstrip patch antenna consists of several parts such feeder line, radiation patch, ground and substrate. The dimension of tthis antenna is shown in Figure 4. Radiation patch, feeder line and ground plane are made of PEC, while the substrate is RT5880.

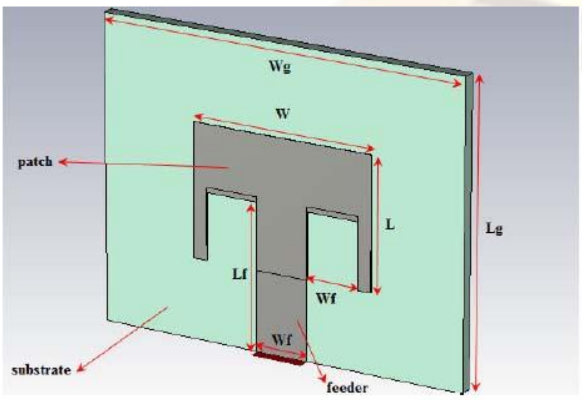

Figure4: Aviewofa conventionalantenna

The ground plane of the antenna is applied using PEC, which is placed at the bottom. The radiator patch and feeder line are constructed on the other side of the RT5880 substrate.the calculated dimension of conventional patch antenna is shown in Table IV

TABLE IV
DIMENSION OF THE PATCH ANTENNA

Properties	Dimensions(mm)
Patch Width,W	11.90
Patch Length ,L	9.7
Substrate Width,W_s	24.9
Substrate Length,L_s	20.5
Feeder Width,W_f	3.50
Feeder Length, L_f	10.25

In construction of metamaterial as a substrate, the construction of conventional antenna on RT5880 substrate is replaced by the metamaterial. The antenna substrate mostly will follow the metamaterial dimension, so the patch and transmission line of this antenna decrease gradually from the conventional antenna.
The first method is a patch that applies the metamaterial as the base substrate, and the second uses a metamaterial slab as a cover over the conventional antenna.

A. Metamaterial as Base Substrate

The use of metamaterial as a base substrate means that the RT5880 was replaced by a single unit cell of the omega structure. As a result, the substrate width and length of the metamaterial antenna were decreased by a ratio of 6.225 and 5.125, respectively. The same ratios apply to the patch and feed line of the antenna. The new calculated antenna dimensions are shown in Table V.

TABLE V
DIMENSION OF ANTENNA WITH METAMATERIAL AS A BASE SUBSTRATE

Properties	Dimensions(mm)
Patch Width,W	1.912
Patch Length ,L	1.892
Substrate Width,W_s	4.00
Substrate Length,L_s	4.00
Feeder Width,W_f	0.562
Feeder Length, L_f	2.00

Fig. 5 shows the patch antenna that applies the metamaterial as a base substrate. During the simulation process, the width and length dimensions of the radiator patch as well as the feeder were continually varied until the required results were obtained.

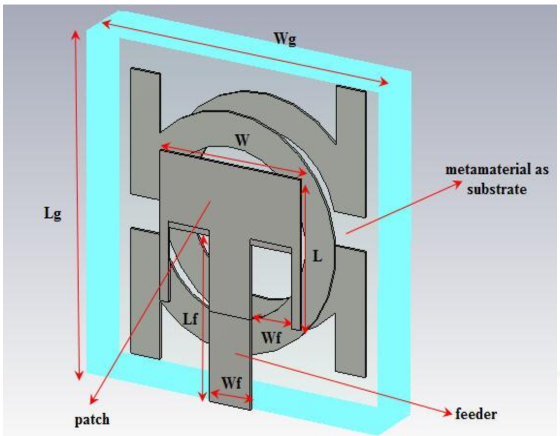

Figure5: Aviewofpatchantennaon metamaterial substrate

B. Metamaterial As a Cover

Thirty unit cells of metamaterial with the same omega structure were combined into a slab to build up a metamaterial cover. The constructed slab was shown in Fig. 6.

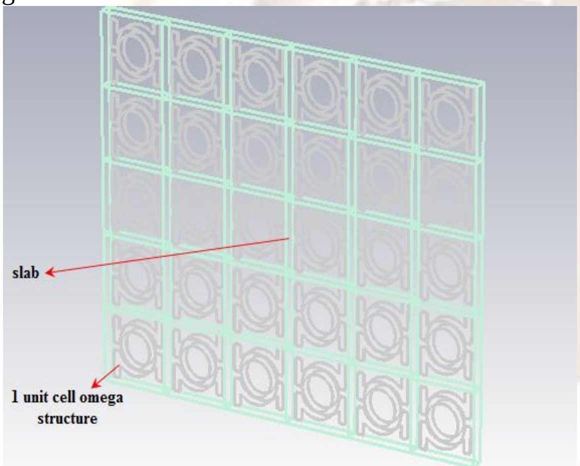

Figure6: Ametamaterialslabfroma combinationof 30 unitcells

The constructed slab was located a distance d from the conventional antenna to act as a cover. The distance d can be varied to obtain the best return loss and radiation pattern. The combination ofmetamaterial slab and conventional antenna was shown in Fig. 7. The best value of d obtained after the optimization process was 17 mm, which is about half wavelength.

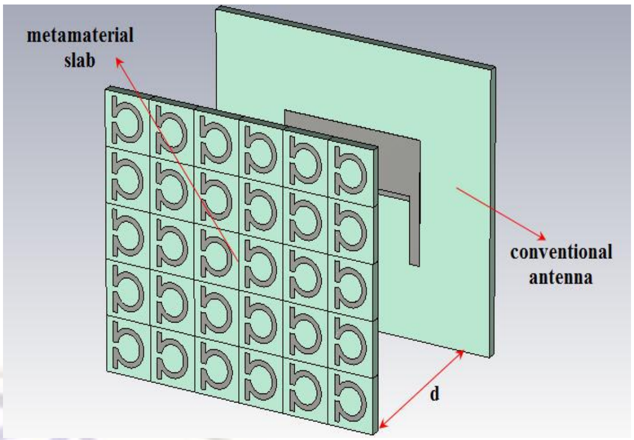

Figure7: Ametamaterialslabactsastheconventionalpatchantennacover

III. RESULTS ANALYSIS

The performance parameters of two antenna i.e. circular patch antenna and the micro strip patch antenna studied under similar condition .The overall performance of circular patch antenna is higher than the micro strip patch antenna.. The negative permittivity appears in the range of frequencies between 1 GHz to 3 GHz. Therefore the antenna on metamaterial must be designed to operate within the range of frequencies. The material that has been confirmed by the feature of LHM from the values of negative permittivity then was applied to the antenna design as a base substrate. Since the size and structure of the split ring could not varied in order to maintain the features of left-handed material. The circular patch antenna on the metamaterial should only be designed for the limited size of the single unit cell. This approach is able to reduce the circular patch antenna but still able to operate at the same resonant frequency. Now a conventional antenna is constructed on FR-4 and RT5880 substrates for the purpose of comparison and analysis.

After both antennas have been studied , the overall results prove that the antenna on metamaterial(FR4) substrates has better performances compared to the design on RT5880 substrates The metamaterial antenna is able to reduce the size.In other word, the size of the new antenna is almost half of the design on FR4. A clear size reduction is shown in Table VI for an obvious comparison.

TABLE VI
PARAMETERS OF FR-4 AND RT5880 SUBSTRATES

Parameters	FR4	RT5880
Permittivity, ε	4.9	2.2
Loss Tangent	0.025	0.009
Permeability,μ	1	1
Substrate Height,h	0.25mm	0.787

Hence, the usage of metamaterial base is able to recover this weakness by focusing the radiation pattern to the desired coordinate.

IV. CONCLUSIONS

In this paper, a circular patch antenna compared to the microstrip antenna with different substrate material is presented. The complete design of circular patch antenna is tested by IE3D software . This design demonstrates a multi- wide impedance bandwidth. These are greatly due to using the substrate (RT5880),and FR4 substrate with suitable dimensions, and a ground plane with an adjusted length. The proposed antenna designed a FR4 epoxy glass substrate based on PCB designed to operate in the UHF range in between 1 Ghz - 3Ghz which is processed easily. The multiple bands of the antenna and its suitable gain enable it for a wideband of applications for the wireless communication systems.

V.RESEARCH WORK

Several improvements to enhance the gain and characteristics of the metamaterial based antenna can be taken into consideration for future research. The metamaterial can be designed using FR4 glass epoxy substrate on PCB sheet . Circular patch antenna and feeding techniques may affect the performance of the antennas and simulate the result with the IE3D SI simulator for their directivity ,gain and bandwidth. Despite of using single unit cell, a combination of a number of unit cells can be applied in designing the antenna on metamaterial substrate.

VI. ACKNOWLEDGEMENT

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