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Design of Compact Circular Microstrip Patch Antenna by Using Metamaterial Structure

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A B S T R A C T

In today's modern communication industry, antennas are the most essential components required to create a communication link. Micro strip antennas are the most suited for aerospace and cellular applications because of their low cost, light weight and low power handling capacity. The paper provides a detailed study of the design of compact circular microstrip patch antenna by using metamaterial structure.The metamaterial antenna is designed in FR4 Epoxy substrate with dielectric constant of 4.4, height of the substrate is 1.6 mm with a circular patch.
Metamaterial analysis and simulation was done using HFSS 2022 R2 Software yields a best results of gain at their operating frequency (f_r) and return loss. Desirable voltage standing wave ratio between 1 and 2 is achieved, after introducing artificial magnetic unit cell metamaterial on the circular patch antenna. Hence multiband antenna is obtained used for Sub-6 GHz 5G applications, operates in S, C, X, Ku bands.

Keywords:Metamaterial, -μ, -ε.

1. Introduction

By using metamaterials in the design of circular micro strip patch antenna, size can be, minimized and other parameters like gain and return loss are increased with VSWR between 1 and 2. Metamaterial has an rare and unique kind of properties such as negative permeability ($\mu<0$) and negative permittivity ($\varepsilon<0$) due to this the electric field, magnetic field, and the propagation vector form left-handed medium materials in a double-negative region. Since the mu-negative material, the unit cell split-ring resonators are most used structure used as metamaterial.

The classification of metamaterial was first proposed by Veselago scientists by considering the permittivity ε, and the permeability μ. Meta materials can be classified as:

a) In the quadrant I, both parameters ε and μ are positive, and are called Double Positive (DPS) or right-handed medium (RHM). These materials can be found in nature, such as dielectric materials.
b) In the quadrant II, the parameters are ε is negative, and μ is positive, and such material is called as epsilon negative (ENG) medium, and is represented by a plasma.
c) In the quadrant III, parameters ε is negative, and μ is negative, this region is called double-negative (DNG) or left-handed medium (LHM), and such material could not be find in nature.
d) The quadrant IV ε is positive, and μ is negative, and such material is called μ—negative (MNG), represented by ferrite materials. Such medium has below plasma frequency.

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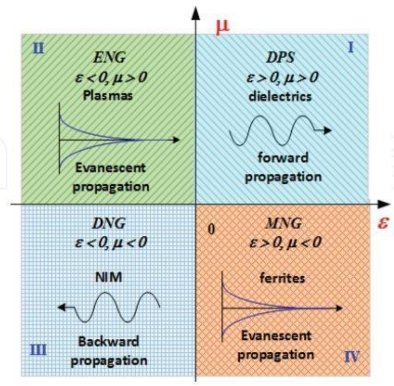


Fig 1. The classification of electromagnetic MTMs based on signs of the ε and μ

2. The effect of applying metamaterial in antenna design

Using metamaterials in antenna design may lead to reduced size, improve gain, enhance bandwidth or to create multiband antenna. Depending on the technical requirements of the designed antenna, the metamaterials will be used as different functions of the antenna.

a) Metamaterial improves the gain of antenna:

In this case, the used metamaterials are applied as the environment of the antenna in such a way as to arrange the unit cells of the metamaterials adjacent radiated elements of the antenna.

b) Metamaterial to obtain multiband:

By changing the position or by increasing the number of unit cells the resonating frequencies varies, and the multiband antenna can be obtained. Due to this multi band, one part of antenna remains active at one band and other part remains active at another band.

c) The metamaterials in reducing the size of antennas:

For the designing of compact microstrip antennas, shorting pins, shorting walls, inserting some disturbances into antenna structure, etc. However, there are some difficulty such as narrow bandwidth and low gain using these technics. The use of electromagnetic metamaterials are helpful to decrease the size of the antenna.

3. Unit cell of metamaterial

The metamaterials applied in the antenna design can be in the form of a unit cell or even multiple unit cells. Hence, the first step in designing the antenna metamaterials is to design and analyze the main factors affecting the resonance frequency, permittivity, and permeability of its unit cell. The design of unit cells of metamaterials is based on the calculation of size and simulation of unit cells, so that the parameters ε and μ of these unit cells will satisfy the requirements at the expected resonant frequency.

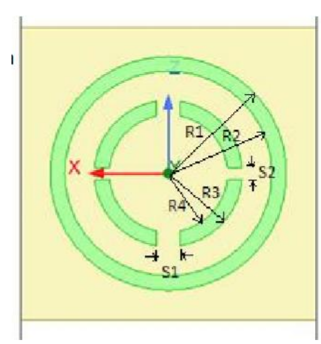


Fig 2. Top view of Metamaterial Unit cell.

In Ansys HFSS software, we can use the optimization methods to save time.Split ring resonator type unit cell of dimensions 10×10 mm. metamaterial was designed. Here outer circular ring has inductive nature whereas inner has a more capacitive nature compared to outer ring as it has more number of slots.So, by combing these two rings, we achieved –ε,-μ as shown in below graphs

Table 1 - Design parameters of unit cell.

Symbol	Description	Value(mm)
R1	Radius of the circle 1	4
R2	Radius of the circle 2	3.5
R3	Radius of the circle 3	2.5
R4	Radius of the circle 4	2
S1	Gap1 between circles	0.5
S2	Gap2 between circles	0.2

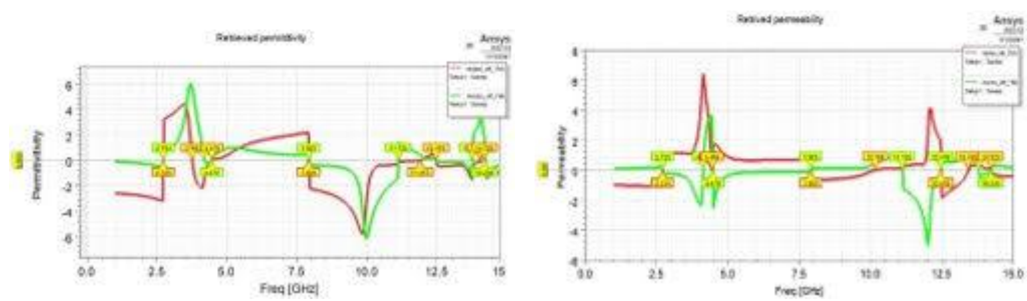


Fig 3. (a) Permittivity of Unit cell, (b) Permeability of Unit cell.

4. Proposed antenna design

4.1 Antenna design 1

A 40x 45x 1.6 mm Circular patch antenna, with rectangular notch on top side and has two small slots in right and left plane respectively consists of FR4 Epoxy substrate with dielectric constant of 4.4 .Micro strip feeding technique was used during the antenna design. The antenna design is shown in the fig 4 using Ansys HFSS software**.**

Fig 4.Top view design of 40x 45x 1.6 mm microstrip circular patch antenna

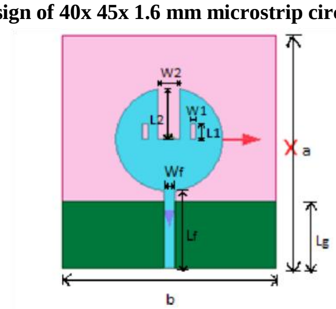


Table 2: Design parameters of Antenna 1 circular patch

Symbols	Description	value (mm)
a	Substrate length	45
b	Substrate width	40
h	Substrate thickness	1.6
r	Radius of antenna	10
Lg	Length of the ground	10
Lf	Microstrip line-feed length	12
Wf	Microstrip line-feed width	2
L1	Length of the Vertical Slot 1	1
W1	Width of the Vertical Slot 1	3
L2	Length of the Vertical Slot 2	4
W2	Width of the Vertical Slot 2	10

Below are the stimulated results for the proposed of 40x 45x 1.6 mm microstrip circular patch antenna. The stimulated SParameter plot shows the dual band with operating frequencies at 6.45 GHz and 13.08 GHz. Hence the antenna works between 2.64 GHz – 9.84GHz and 11.6GHz – 14.6GHz frequencies. The VSWR (Voltage Standing Wave Ratio) of this antenna design is 1.92.

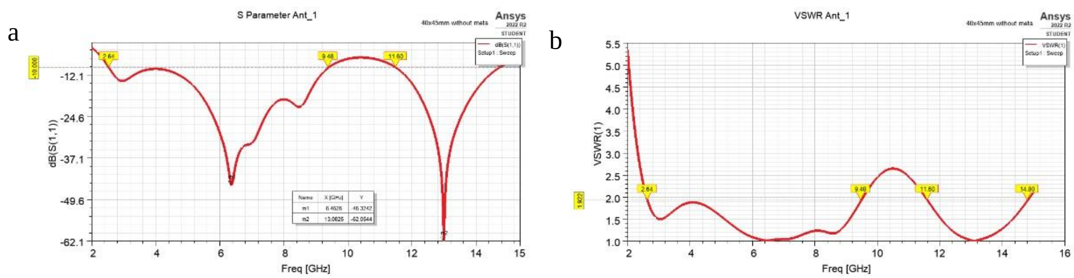


Fig 5. (a) Stimulated S-Parameter Plot, (b) VSWR plot has a VSWR is 1.92of 40x 45x 1.6 mm circular patch antenna without unit cell.

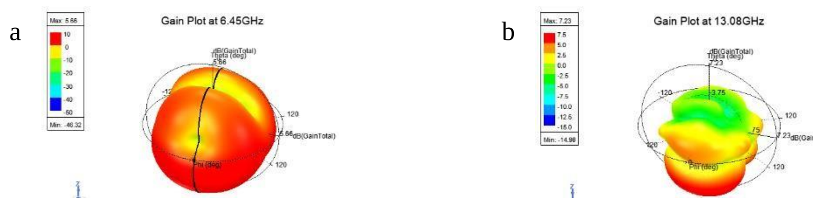
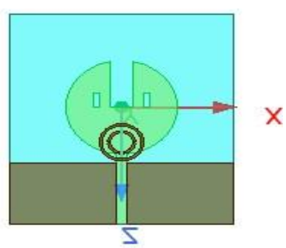


Fig 6. Gain plot of Circular patch Antenna without unit cell (a) Gain at 6.45GH is5.66dB, (b) Gain at 13.08GHz is 7.23dB.

4.2 Antenna design 2



A 40x 45x 1.6 mm Circular patch antenna, consists of a metamaterial structure unit cell to enhance the performance characteristics of the design.

Fig 7. Top view design of 40x 45x 1.6 mm microstrip circular patch antenna with single unit cell.

Below are the stimulated results for the proposed of 40x 45x 1.6 mm microstrip circular patch antenna with unit cell. The stimulated S-Parameter plot shows the triple band with operating frequencies at 3.07GHz, 5.44GHz, 9.18GHz and 12.36GHz. The VSWR (Voltage Standing Wave Ratio) of this antenna design is 1.92.

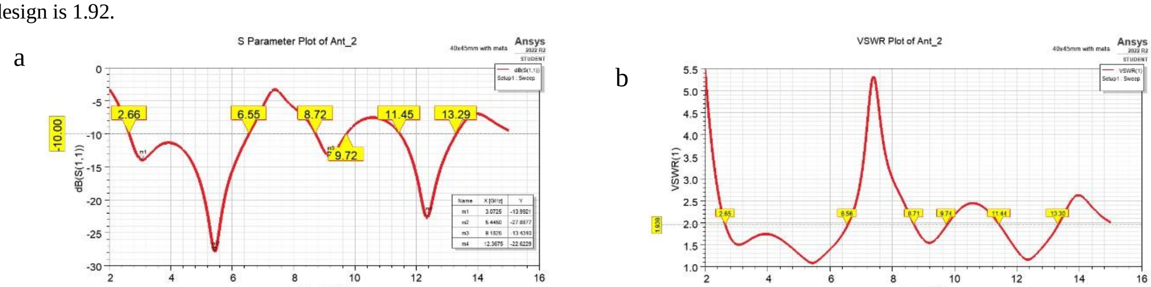


Fig 8. (a) Stimulated S-Parameter Plot, (b) VSWR plot has a VSWR is 1.92of 40x 45x 1.6 mm circular patch antenna with unit cell.

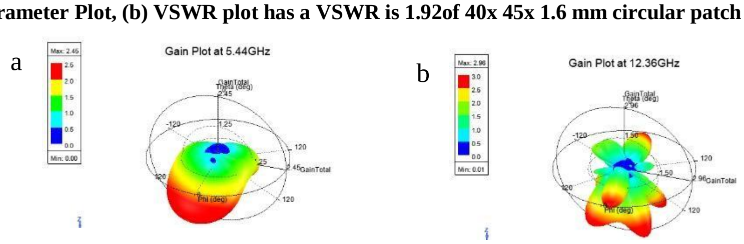


Fig 9. Gain plot of Circular patch antenna with unit cell, (a)Gain at 5.44GHz is 2.45dB, (d) Gain at 12.36GHz is 2.96dB.

4.3 Antenna design 2

A 40x 45x 1.6 mm Circular patch antenna, consists of a metamaterial structure unit cell which is placed towards the left hand side to enhance the performance characteristics of the design.

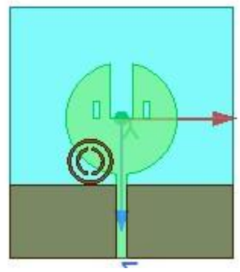


Fig 10. Top view design of 40x 45x 1.6 mm microstrip circular patch antenna with single unit cell moved towards left side.

Below are the stimulated results for the proposed of 40x 45x 1.6 mm microstrip circular patch antenna with unit cell placed towards the left side. The stimulated S-Parameter plot shows the triple band with operating frequencies at 4.89GHz, 10.12GHz and 12.62GHz. The VSWR (Voltage Standing Wave Ratio) of this antenna design is 1.9.

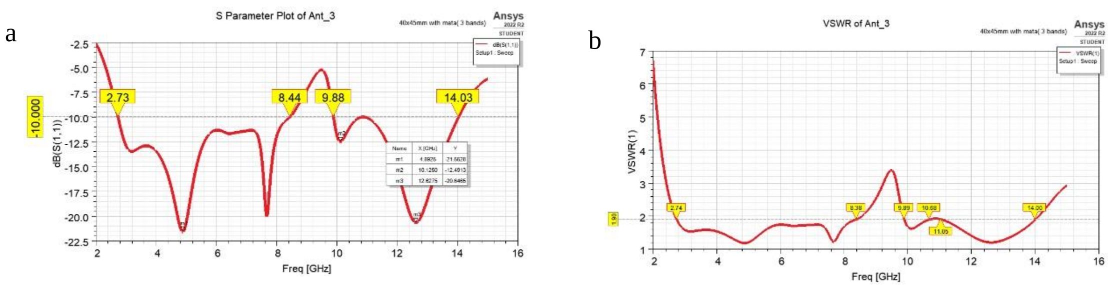


Fig 11. (a) Stimulated S-Parameter Plot, (b) VSWR plot has a VSWR is 1.92of 40x 45x 1.6 mm circular patch antenna with unit cell moved towards left side.

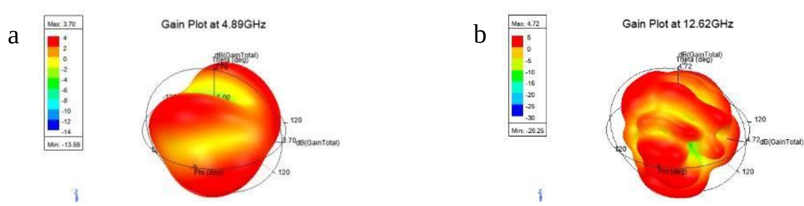


Fig 12. Gain plot of antenna when unit cell position is shifted to left, (a) Gain at 4.89GHz is 3.7dB, (b) Gain at 12.62GHz is 4.72dB.

5. Discussion

In this proposed antenna designs split ring like unit cell metamaterial structures have been used to reduce the size of antenna and to produce multiple bands. From the above results, we can say that antenna performance has been increased by considering various parameters like Gain, VSWR, Reflection coefficient at their operating frequencies to observe the effect that was being caused on the circular patch antenna due to metameterial. The simple microstrip feeding technique was applied during the antenna design which makes these antennas a good choice in many communication systems.

6. Conclusion and Future scope

The metamaterials are useful to improve power gain, to create multifrequency-band and maintain the Voltage standing wave ratio should be between 1 and 2 of antennas. The proposed metamaterial-based design of multi-band microstrip circular patch antenna is effectively designed and executed, hence operates in S, C, X, Ku bands. Also applicable for 5G wireless technology.

Future research is to work on a linear MIMO array or circular MIMO array at the same operating frequency for enhancing the gain. Additionally, improvement in the gain at other frequencies and increase in the bandwidth can be done by changing the various metamaterial structures.

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