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Design and Simulation of ∏ (Pi) Shape Meta-material in Micro-strip Patch Antenna

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Abstract— The advancement in the field of micro-strip patch antennas has made great progress in recent years. Compared with conventional antennas, it has more advantages and better prospects. These are lighter in weight, low volume, low cost, low profile, smaller in dimension and ease of fabrication and conformity. Moreover, the micro-strip patch antennas can provide dual and circular polarizations, dual-frequency operation, frequency agility, broad band-width, feed-line flexibility, beam scanning Omni-directional patterning. Metamaterials can be defined as artificial electromagnetic structures based on the assemblies of multiple elements fashioned from composite materials such as metals or plastics and it is basically an infinitely long metal rod at sub wavelength scale, which have the negative permittivity and the negative permeability simultaneously in a specific frequency range. However it enhances the performances of the antenna.

A rectangular micro-strip patch antenna along with the meta-material structure is studied in **C band**. This work is mainly focused to analyze the behaviour of patch antenna with a **∏ (Pi) shape of meta-material.** The proposed antenna is designed to resonate at 9.29 GHz frequency with -40.1766 dB return loss using meta-material. We have assigned a new meta-material which is placed 3.2 mm from the ground plane with relative permetivity of -66.53 and relative permeability of -77.628 in the rectangular microstrip patch antenna. Without metamaterial the resonating frequency is 4.4 GHZ and the return loss is -26.3533 db in our antenna. The impedance bandwidth of the patch antenna along with the proposed meta-material structure will be observed. For simulation purpose **Ansoft HFSS Software** has been used.

Index Terms— Ansoft HFSS, C band, Meta-material, Micro-strip, Omni-directional, Patch Antenna, Return loss, ∏ shape.

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1 INTRODUCTION

The most common type of micro-strip antenna is the **patch antenna**. Antennas using patches as constitutive elements in an array are also possible. A patch antenna is a narrow-band, wide-beam antenna fabricated by etching the antenna element pattern in metal trace bonded to an insulating dielectric substrate, such as a printed circuit board, with a continuous metal layer bonded to the opposite side of the substrate which forms a ground plane. Some patch antennas do not use a dielectric substrate but these are made of a metal patch mounted above a ground plane using dielectric spacers; the resulting structure is less rugged but has a wider bandwidth. Because such antennas have a very low profile, are mechanically rugged and can be shaped to conform to the curving skin of a vehicle, they are often mounted on the exterior of aircraft and spacecraft, or are incorporated into mobile radio communications devices. To obtain the effective electromagnetic parameters of the structure, a theory of homogenization is used.

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1.1 RECTANGULAR MICRO-STRIP PATCH ANTENNA (RMPA)

The most commonly employed micro-strip antenna is a **rectangular** patch which looks like a truncated micro-strip transmission line. When air is used as the dielectric substrate, the length of the rectangular micro-strip antenna is approximately one-half of a free-space wavelength. The resonant length of the antenna is slightly shorter because of the extended electric "fringing fields" which increase the electrical length of the antenna slightly. The micro-strip antenna is a section of micro-strip transmission line with equivalent loads on either end to represent the radiation loss.

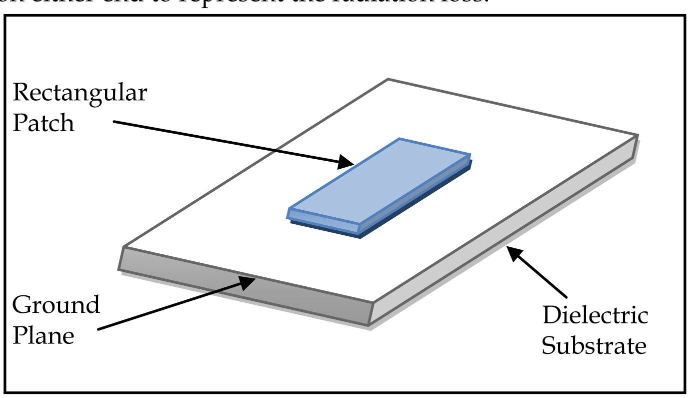


Fig1. Rectangular Micro-strip Patch Antenna

1.2 META-MATERIAL:

A **meta-material** (coined from the Greek word *meta*, meaning "beyond") is a material engineered to have a property that is not found in nature. They are made from assemblies of multiple elements fashioned from composite materials such as metals or plastics. The materials are usually arranged in repeating patterns, at scales that are smaller than the wavelengths of the phenomena they influence. Meta-materials derive their properties not from the properties of the base materials, but from their newly designed structures. Their precise shape, geometry, size, orientation and arrangement gives them their smart properties capable of manipulating electromagnetic waves: by blocking, absorbing, enhancing, or bending waves, to achieve benefits that go beyond what is possible with conventional materials.

Appropriately designed metamaterials can affect waves of electromagnetic radiation or sound in a manner not observed in bulk materials. Those that exhibit a negative index of refraction for particular wavelengths have attracted significant research. These materials are known as negative-index metamaterials.

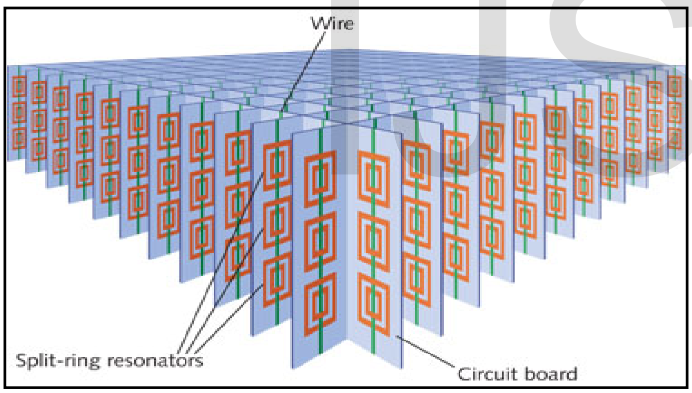


Fig2: Meta-Material

2 METHODOLOGY

2.1 FEEDING TECHNIQUE:

A feedline is the cable or other transmission line that is used to excite to radiate by direct or indirect contact.

There are many different methods of feeding. Four most popular methods are microstrip line feed, coaxial probe, aperture coupling and proximity coupling. Here in our design, we have used microstrip line feeding technique to fabricate the antenna.

2.1.1 MICROSTRIP LINE FEEDING:

Microstrip line feeding is one of the easier methods to fabricate as it is a just conducting strip connecting to the patch and therefore can be considered as extension of patch. It is simple to model and easy to match by controlling the inset position.

- However the Disadvantage of this method is that as the substrate thickness increases, surface wave and spurious feed radiation increases which limits the bandwidth.

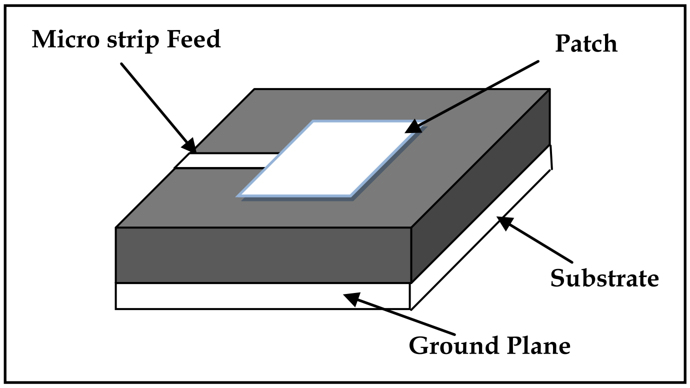


Fig3. Microstrip Line Feeding

2.2 DESIGN SPECIFICATIONS:

For calculation antenna parameters following formulae are used.

I. Calculation of Width (W):

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{C}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$$

Where,

c = free space velocity of light i.e, 3×10^8 m.s^{-1}

ε_r = Dielectric constant of the substrate

II. The effective dielectric constant of the rectangular micro-strip patch antenna:

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{w}}}\right)$$

III. The actual length of the Patch (L):

$$L = L_{eff} - 2\Delta L$$

Where,

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}}$$

IV. Calculation of Length Extension:

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}$$

3 Analysis of Patch Antenna and Meta-Material Structure with Simulated Results

To design the Rectangular Microstrip Patch Antenna we have used **Material4** as substrate. The parameter specifications of rectangular microstrip patch antenna are mentioned in table 1. These are calculated from the above discussed formulae.

Table 1: Rectangular Microstrip Patch Antenna Specifications

PARAMETER	DIMENSIONS	UNIT
Relative Permittivity	2.33	-
Relative Permeability	1	-
Thickness (h)	1.6	mm
Dielectric Loss Tangent (tan ∂)	0.001	-
Lande G Factor	2	-
Length (L)	70	mm
Width (W)	70	mm
Cut Width	1.575	mm

- Without using meta-material the antenna construction is given below:

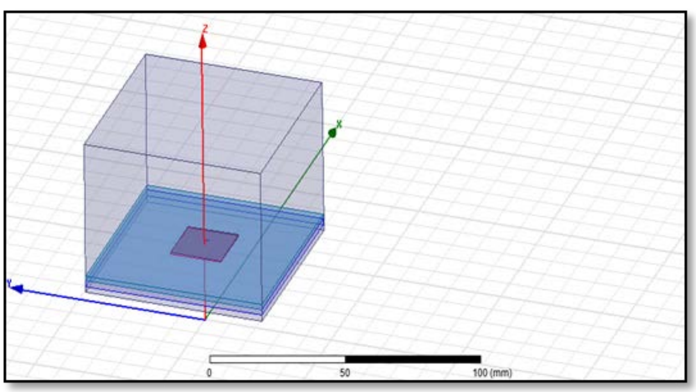


Fig4: Design of Rectangular Microstriop patch Antenna

3.1 META-MATERIAL DESIGN:

We have designed a ∏ (**Pi**) shape meta-material which is employed at 3.2mm from the **ground plane** of the antenna. To design the metaimaterial we have used the following parameters which are mentioned in Table 2.

Table 2: Meta-material Specifications

PARAMETER	DIMENSIONS	UNIT
Relative Permittivity	-66.53	-
Relative Permeability	-77.628	-

- The design of meta-material of the rectangular microstrip patch antenna is given below:

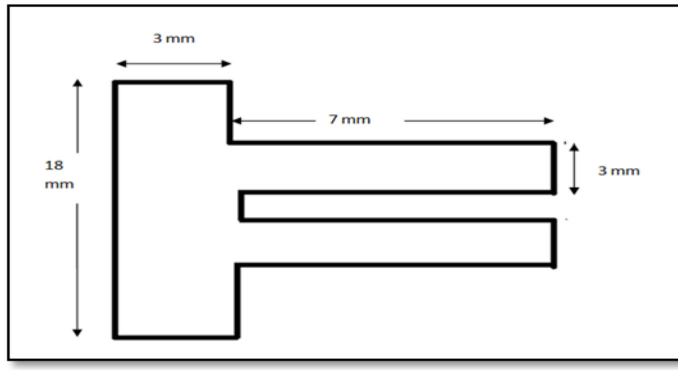


Fig5. Design of ∏ (Pi) meta-material

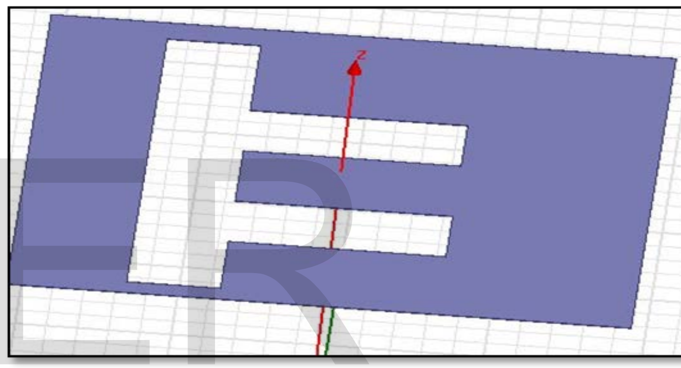


Fig6. Overview of designed meta-material

- **The side view of the design:**

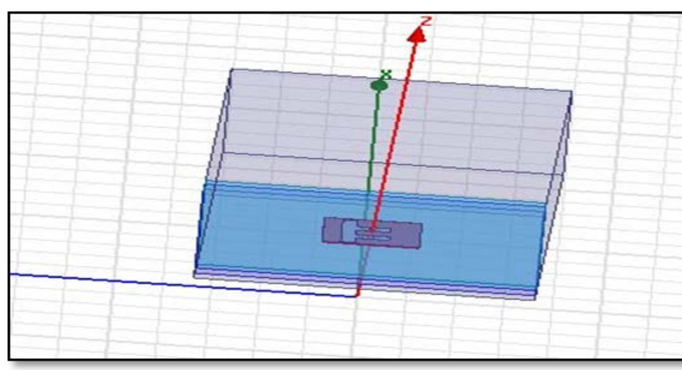
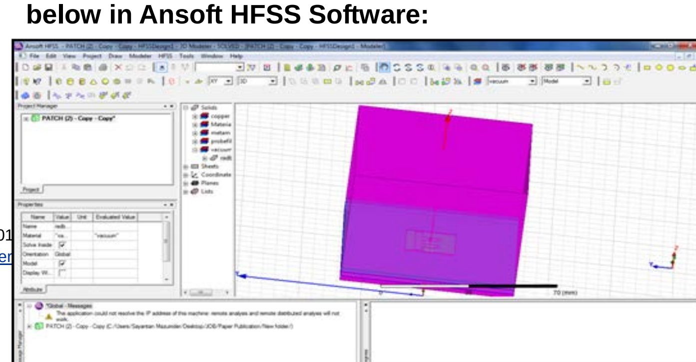


Fig7. Side view of the meta-matirial

- **The designed antenna with meta-material is given below in Ansoft HFSS Software:**



3 Fig8. Final design of Patch antenna with meta-material

We have simulated the above design in **Ansoft HFSS** software. Without meta-material the resonating frequency is 4.4 GHZ and the return loss is -26.3533 db in our antenna. But when we implement the meta-material in the proposed antenna, it resonates at 9.29 GHz frequency with -40.1766 dB return loss. The simulated result is shown below:

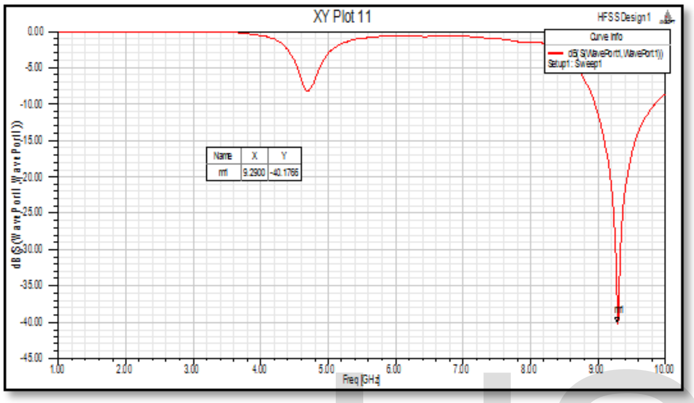


Fig9. Simulated Result

- To compare between designed Pi Shape meta-material and without meta-material, we have plotted the results in Rectangular plot which is shown below:

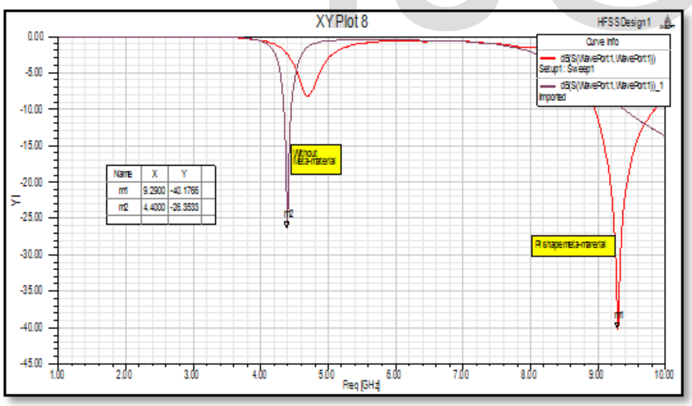


Fig10. Comparision between Pi Shape and without meta-material

3.3 Radiation Pattern:

When we have simulated the designed antenna we have got the radiation patterns as shown below:

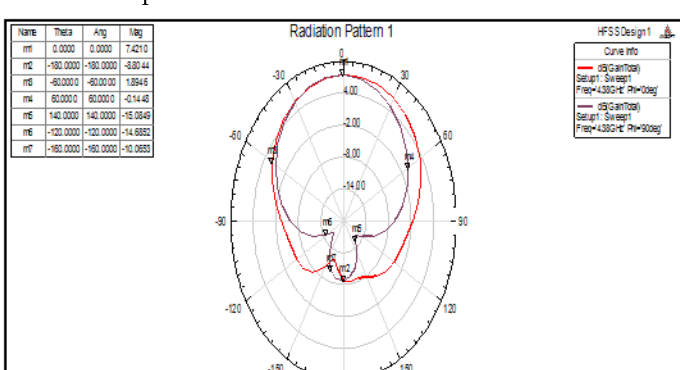


Fig11. Radiation Pattern 1

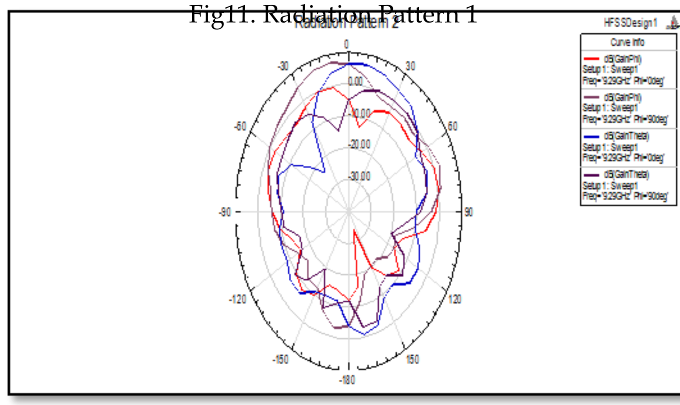


Fig12. Radiation Pattern 2

3.4 Smith Chart:

The Smith chart plot represents that how the antenna impedance varies with frequency.

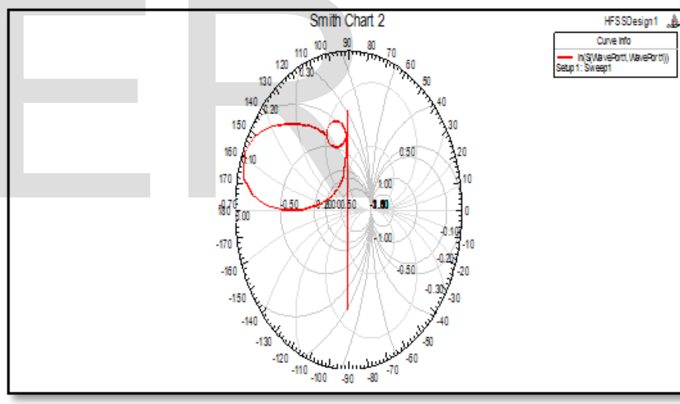


Fig13. Smith Chart

- **Co-polarization** means when the polarization of both the transmitting (test antenna) and receiving antenna (reference horn antenna) is the same and **cross polarization** means when the polarization of both the antennas are different. First, we have found that in which plane of the coordinate system and where our antenna is placed contains the E or H field. Once this is known then we can easily check the co and cross polarization. Generally the Co polarization is very high as compare to Cross polarization.

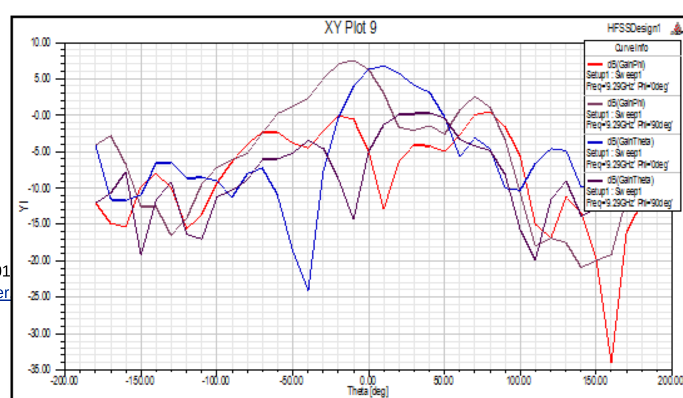


Fig14. Design of Co-polarization and Cross- polarization

4 Simulated Result & Discussion

After designing and simulating the Antenna, ensuring that it operates at the desired frequency and recording its Return loss, we have designed a rectangular micro-strip patch antenna along with the ∏ (**Pi**) shaped meta-material structure at 3.2mm from the **ground plane**, which is studied in C band.

Without meta-material the resonating frequency is 4.4 GHZ and the return loss is -26.3533 db in our antenna. But when we implement the meta-material in the proposed antenna, it resonates at 9.29 GHz frequency with -40.1766 dB return loss. The newly assigned metamaterial has relative permetivity of -66.53 and relative permeability of -77.628.

This structure satisfies Double Negative property within the operating frequency ranges. The impedance bandwidth of the patch antenna along with the proposed meta-material structure is observed. We have also observed the Smith Chart which is shown above. The above results states that the quality of simulated antenna using meta-material structure is improving without making variations in other parameters.

5 Conclusion

The main drawback of Patch Antenna is less impedance bandwidth. For this purpose, Design and analysis of patch antenna using Meta-material structure has been proposed and analyzed in this paper. The simulated results provide bandwidth and directivity improvement, which encourages fabricating the structure. That's why we have designed a newly ∏ (Pi) shaped meta-material structure in the rectangular microstrip patch antenna.

It improves the gain as well as reduces return loss of this Patch Antenna. The proposed antenna provides the better improvement in the impedance bandwidth and reduction in the return loss at 9.29 GHz frequency with -40.1766 dB.

As the main drawback of Patch Antenna is impedance bandwidth so to remove this problem we have loaded the metamaterial structure in the rectangular microstrip patch antenna using **Ansoft HFSS** software in this paper. On making some variations in antenna parameter gain can be improved up to desired limit.

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