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Rectangular Microstrip Patch Antenna using Meta-material

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Abstract—*This paper proposes a circularly polarized micro-strip patch antenna which is a set of 7X7 meta-surface based. Patch antenna which is a low profile antenna having low power, efficiency bandwidth etc. is fed by a coaxial feed. With the use of meta-material its improved performance is achieved. The antenna consists of a rectangular, slotted patch radiator, a meta-surface of 7X7 rectangular ring unit cells and a coaxial feed using FR-4 substrate. The final design, with an overall size of (15.65mmX21.9357mmX4.8mm) was fabricated and measured. The antenna has a measured 3dB axial ratio bandwidth of 3.85-4.39GHz (12.85%), a gain of 6.3862dB, bandwidth of 4.1337-4.5072GHz(8.89%) at 4.2GHz. Desired patch antenna design is initially simulated by using ANSYS HFSS Simulator and patch antenna is realized as per design requirements.*

1. INTRODUCTION

Micro-strip antennas received considerable attention starting in the 1970s, although the idea of a micro-strip antenna can be traced to 1953 and a patent in 1955. Some of the benefits of micro-strip patch antennas include small profile, low weight and inexpensive fabrication. Additionally, by changing the shape of the structure, versatility in resonant frequency, polarization, pattern, and impedance can be achieved. Many feeding mechanisms are possible for feeding the micro-strip patch structure, such as probe feeds, aperture feeds, micro-strip line feeds and proximity feeds, where each method has advantages depending on the application.

Despite these advantages, micro-strip antennas present major challenges to the designer due to an inherently narrow bandwidth, poor polarization purity and tolerance problems. Much research has been done to overcome these limitations, notably in increasing the bandwidth. Micro-strip patch antennas have many advantages over conventional antennas which makes them suitable for a wide variety of applications. These antennas are low-profile antennas that has a number of advantages over other antennas: it is lightweight, inexpensive, and electronics like LNA's and SSPA's can be integrated with these antennas quite easily.

While the antenna can be a 3- D structure, it is usually flat and that is why patch antennas are sometimes referred to as planar antennas. There are numerous substrates that can be used for the design of micro-strip antennas, and their dielectric constants are usually in the range of $2.2 \leq \mathcal{E}_r \leq 12$. Linear and circular polarizations can be achieved with either single elements or arrays of micro-strip antennas. Arrays of micro-strip elements, with single or multiple feeds, may also be used to introduce scanning capabilities and achieve greater directivities.

1.1. Circularly Polarized Patch Antenna

The study of polarization of radio waves can be dated back to the experiments conducted by Heinrich Hertz between 1886-1889. From a practical point of view, the polarization can be classified into three categories: linear polarization, two circular polarizations and elliptical polarization. The elliptical polarization is a very general term and radio systems are rarely designed to use explicitly this type, although both linear and circular polarizations can be considered as special cases of elliptical polarization.

Circular polarization: To generate circular polarization, two orthogonal components of electric field are needed. These components need to be equal in amplitude, but shifted in phase by ±90°.

CP antennas are demanding to design, however offer multiple benefits:

• Mitigation of multipath propagation**.** A circularly polarized wave, after reflection from a conducting, flat surface, becomes counter polarized (that is right hand CP wave becomes left-hand CP and vice 2 1. Introduction versa). This allows the antenna to filter out reflected signal and is of huge benefit for navigation systems, especially satellite based. It also offers benefits for high data rate communication in indoor environments, as it decreases interference between direct and reflected signal.

• Polarization losses due to misalignment**.** For linearly polarized communication systems the receiving and transmitting antenna must be aligned to avoid polarization mismatch. For CP this is not required. It is worth mentioning that if ideal CP signal is received by a linearly polarized antenna the loss is 3 dB, regardless of the orientation of the receiving antenna. This property is especially useful for RFID systems, as it ensures the portable tag will be detected regardless of its orientation.

Use of single feed has an advantage of simplicity and smaller feed network, without the need to incorporate phase shifters and power dividers. On the other hand this implies, that the two orthogonal modes and the phase shift required for CP need to be generated internally by the antenna geometry. There are many methods to achieve this, with the most commonly used shown in Fig.-

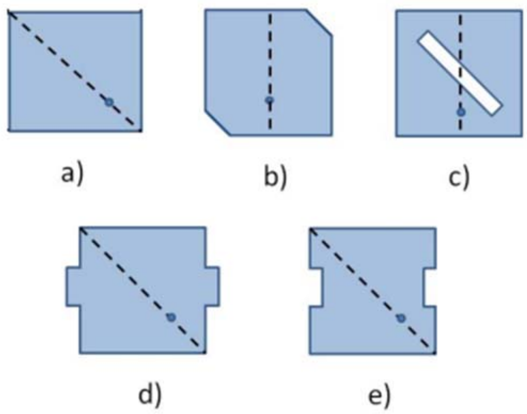


Fig. 1: Geometries of various CP patches. Dashed line shows the line along which the feed point is located.

1.1.1. Methods for circular polarization:

- A nearly square patch with a single feed along the diagonal is one of the simplest micro-strip antenna configurations to generate CP.
- CP can also be obtained by modifying corners of the square MSA. Small isosceles right angle triangular patches or small square patches are removed from the diagonally opposite corners of the square patch.
- Instead of chopping the corners, small square patches could be added at the corners to obtain CP.
- A square MSA with a rectangular slot along its diagonal and the feed along its central axis produces CP. The difference in the resonance frequencies of the orthogonal modes is caused by the rectangular slot, which makes the path lengths of the two diagonals unequal.

Similar to the modified square micro-strip antenna, modified circular and triangular micro-strip antenna configurations with a single feed also generate CP.

2. META-MATERIAL

Recently, the field of material science has shifted its focus from studying the properties of new materials to the engineering of the materials. In the realm of electromagnetism, the field of meta-materials (MMs) has reached significant breakthroughs in their final properties.

Meta-materials (from the Greek word "meta" meaning go to beyond) are smart materials engineered to have properties that have not yet been found in nature. 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, bending waves, to achieve benefits that go beyond

what is possible with conventional materials.

These are artificial metallic structures having simultaneously negative permittivity (ε) and permeability (μ), which leads to negative refractive index. Due to negative index it supports backward waves i.e. inside Meta-material phase velocities and group velocities are anti-parallel. Meta-material doesn't obey Snell's law, Doppler effect, Vavilov-Cerenkov radiation etc. No other material in the world shows the above properties like Meta-material. Due to these unusual properties Meta-material can change the electric and magnetic property of electromagnetic wave passing through it and because of these reasons when Meta-material is used in the fabrication of microwave components and antennas the required properties can be enhanced.

Also miniaturization in the size of the component is possible as the structural cell size of Meta-material is less than one-fourth of the guided wavelength. Using this Meta-material antenna the demerits of ordinary patch antenna like low gain and efficiency can be overcome and is useful in the field of wireless communication.

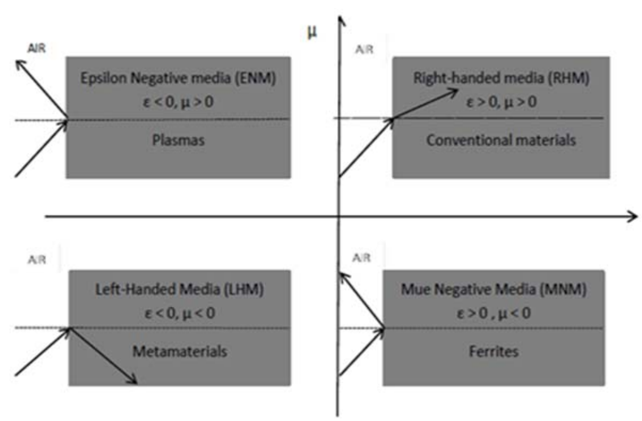
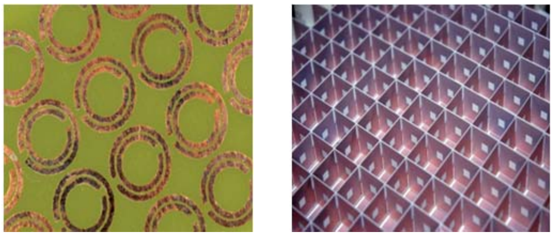
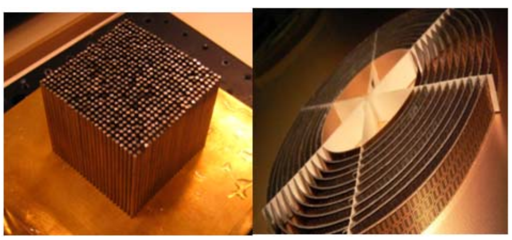


Fig. 2. Ɛ-μ Space

Due to negative refractive index, the group and phase velocities of electromagnetic wave appear in opposite direction such that the direction of propagation is reversed with respect to the energy flow direction. Meta-surfaces constitute a class of thin meta-materials, which are used from microwave to optical frequencies to control wave propagation along the surface, i.e. to enable new radiation and guiding properties.



(a) (b)



(c) (c)

Fig. 3: Different structures for meta-surfaces

3. ANTENNA DESIGN

Based on the simplified formulation that has been described, a design procedure is outlined which leads to practical designs of rectangular micro-strip antennas. The procedure assumes that the specified information includes the dielectric constant of the substrate (Ɛr) the resonant frequency (fr), and the height of the substrate *h*. The procedure is as follows:

For an efficient radiator, a practical length & width that leads to good radiation efficiencies are given as follows-

$$W = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{2}{\epsilon_r+1}} = \frac{\upsilon_0}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}}$$

$$L = \frac{1}{2f_r\sqrt{\epsilon_{\text{reff}}}\sqrt{\mu_0\epsilon_0}} - 2\Delta L$$

Where υ_0 is free space velocity of light.

Values of effective dielectric constant, Ɛreff & ΔL can be given as-

$$\epsilon_{\text{reff}} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2}$$

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

Table 1: Antenna Dimension

S. No.	Antenna Dimensions	Values
1.	Dielectric constant (Ɛr)	4.3
2.	Width (W)	21.9357mm
3.	ΔL	2.0850mm
4.	Leff	0.0190mm
5.	Ɛeff	3.5164mm
6.	Length (L)	15.65mm

Antenna dimension values mentioned in above table are the calculated values by using above equations.

4. SIMULATION RESULTS

In this section improved results of patch antenna in terms of return loss using meta-surface of rectangular ring unit cells have been simulated and presented:

Table 2: Designing parameters of antenna using meta-material.

S. No.	Parameters	Values	Optimized Values
1.	Ground Plane	X=60mm Y=88mm	X=60mm Y=88mm
2.	Substrate1 & Substrate2 height	3.2mm 1.6mm	3.2mm 1.6mm
3.	Outer ring & inner ring radius of slot	2.6, 1.6mm	2.6, 1.6mm
4.	Width of rectangular ring- Inner ring (Sw) Outer ring (Wu)	0.85mm 5.6mm	0.85mm 5.6mm
5.	Length of rectangular ring- Inner ring (S1) Outer ring (Lu)	7.46mm 8.96mm	7.46mm 8.96mm
6.	Length of patch	15.65	15.65
7.	Width of Patch	21.9357	21.9357
8.	Feed location	(3.924,8,0)	(3.924,8,0)

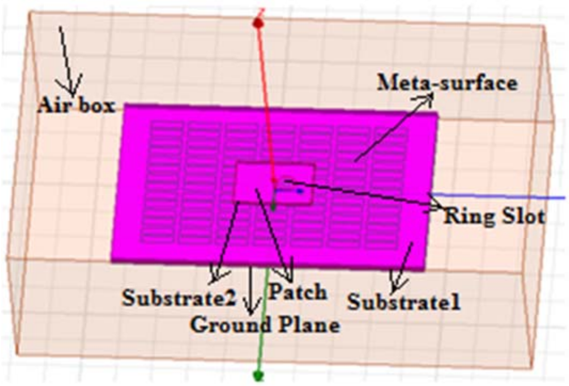


Fig. 4. Patch antenna using meta-material

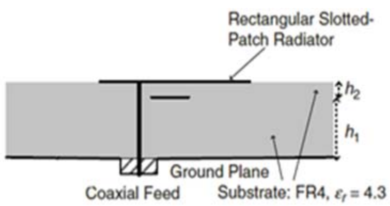


Fig. 5. Cross sectional view of patch antenna

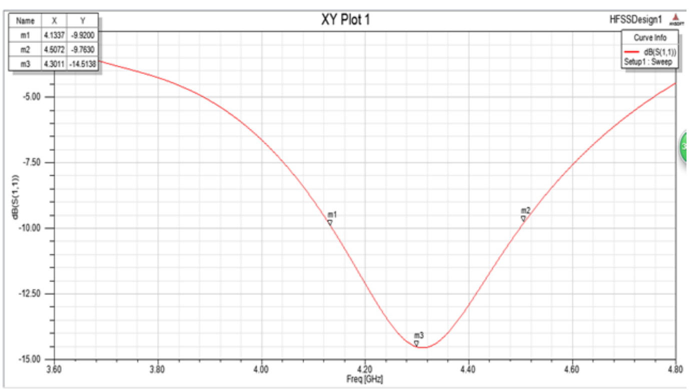


Fig. 6. Plot of return loss

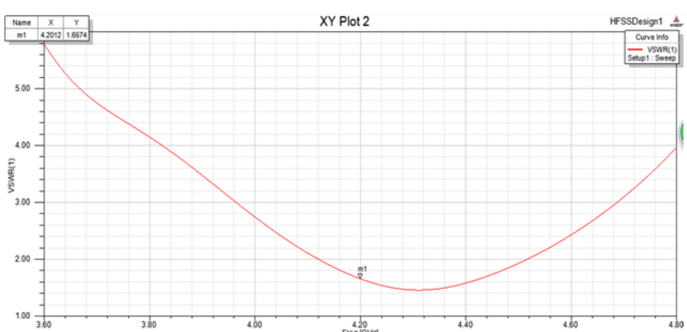


Fig. 7. Plot of vswr

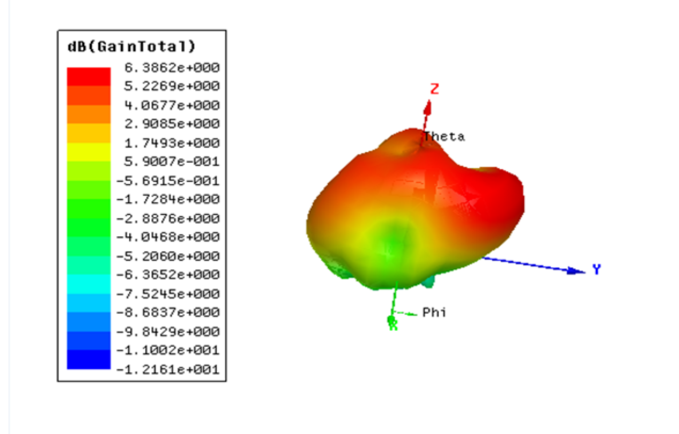


Fig. 8. Plot of gain

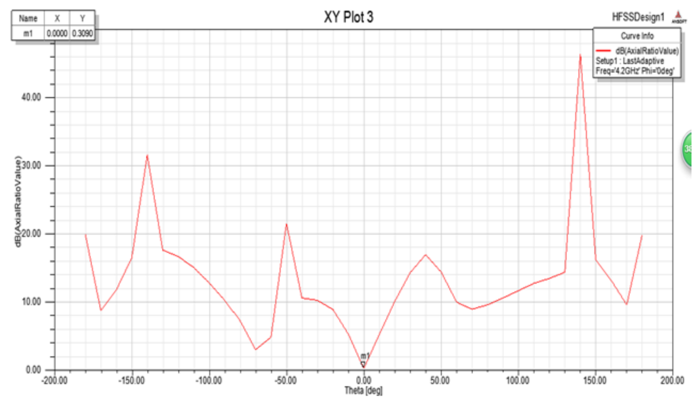


Fig. 9. Plot of axial ratio at boresight

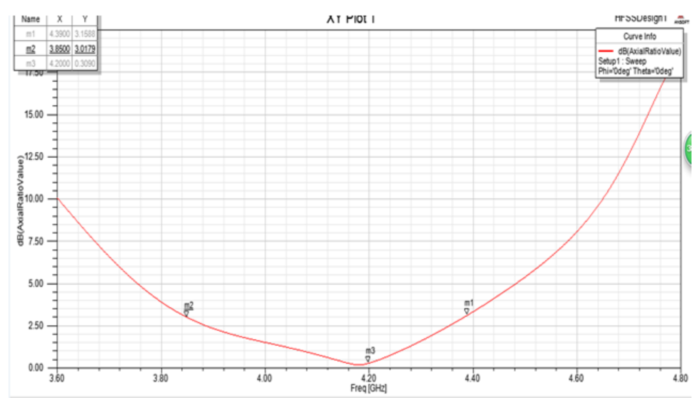


Fig. 10. Plot of axial ratio bandwidth

In this work bandwidth is from 4.1337GHz-4.5072GHz possessing 8.892% percentage bandwidth, gain is 6.3862dB, return loss -14.5138dB, axial ratio bandwidth is in between 3.85GHz-4.39GHz having 12.85% as axial ratio bandwidth. For circularly polarized antenna value of circular polarization should be 1 or 0dB. In this proposed design axial ratio value is 0.3090dB.

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