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# SQUARE SLOTTED POLARIZATION RECONFIGURABLE MICROSTRIP PATCH ANTENNA

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**Abstract –** *In this paper, a dual band, polarization reconfigurable, circular patch antenna, using dual coaxial feed technique, has been presented. The antenna simulated, works on resonant frequency of 10 GHz with RogersRO 3003 as substrate, having εr=3 & height of the substrate as 100mil (1 mil= 0.0254mm). The antenna is providing approximate gain of 2.9dBi at 10 GHz in both linear as well as circular polarization case with maximum gain ranging up to 8dBi, with multiple bands in the S11 plot, well below -10dB line. High axial ratio bandwidth & impedance bandwidth (S11 bandwidth) are other plus points of this antenna.*

***Key Words*: Polarization Reconfigurable, Coaxial Feed, Circular, Axial Ratio**

## 1. INTRODUCTION

Antenna plays an important role in a communication system. It is used in both the transmission & reception of electromagnetic waves. Microstrip patch antennas are very useful in wireless communication at microwave frequencies, for their inherent features like low profile, low cost, light weight, adaptability with RF circuitry & easy fabrication. [1]

Antennas are sensitive to the polarization of electromagnetic waves & this is an important aspect of their operation. The most common types of antenna polarization are linear & circular polarizations, both of these can be further subdivided in to vertical, horizontal & right hand circular, left hand circular polarizations respectively. The polarization of an antenna is based on the E plane orientation of the electromagnetic energy radiated or received by the antenna. [2]

Antennas with linear polarization are widely used for low frequency microwave applications, but it contains some losses due to multipath interference, atmospheric losses due to weather conditions & antenna orientation problems. To mitigate these drawbacks, circularly polarized antennas are used as it is free from orientation problem, polarization mismatch losses & multipath interference. [5]

A dual circularly polarized antenna can realize the right & left hand circular polarizations, generating polarization diversity. A member of dual circularly polarized antennas have been realized in the literature based on slotted apertures, such as the dual circularly polarized antenna presented in [4], excited by four cross slots via a Microstrip line with multiple matching segments below the ground plane.

For circular polarization, two orthogonal modes with 90-degree phase difference have been generated by the seven coupling points in a serial manner. Wide axial ratio has been achieved through multiple feed schemes [4]. However, its complex design makes its fabrication process difficult & its attributes makes it specific in terms of applications.

In [5], an aperture coupled circular patch antenna is presented for dual circular polarization at Ka-band. Two Microstrip lines are used to excite a circular patch through two slots, to generate a broadband RHCP & LHCP with high isolation between them. However, use of three metallic layers, with complicated geometry, makes it highly specific.

A dual circularly polarized antenna based on the field transformation (FT) method is presented in [6]. The antenna consists of a dual linearly polarized feeding patch antenna & an FT wave plate as a reflector. The FT wave plate enables the realization of a circularly polarized antenna with wide bandwidth & unidirectional radiation pattern. However, use of FT wave plate limits the use of this antenna to specific applications.

Polarization reconfigurable circular patch antenna with a C- shaped slot is proposed in [7]. It is demonstrated that by introducing a reconfigurable C-shaped slot in a circular patch, the polarization, can be switched effectively. The polarization reconfigurable characteristic is realized by controlling the states of the two switching diodes (PIN diodes). However, by using PIN diodes extensively, antenna fabrication process becomes critical.

In [8], a novel partially reflective surface (PRS) antenna is proposed, which can electronically alter its polarization. In it a reconfigurable Wilkinson power divider is used as the feed network. In the design, 4 PIN diodes are used to change electrical lengths of the patch. Multiple diodes, power dividers & complex biasing network makes the design critical as well as limited in case of applications.

A novel probe fed single layer circular patch antenna with dual band dual polarization is proposed in [9]. By modified mushroom structure, dual mode circular polarization characteristic is realized. Loading structure including four curved patches added around the circular radiating patch, providing new resonant points & wide impedance bandwidth. By directing curved branches clockwise & anticlockwise, left hand & right hand circular polarization is achieved, respectively. However, dependency on changing the design, by directing curved patches, makes it specifically useful, limiting its applications.

An octagon star shaped circularly polarized patch antenna with conical radiation pattern is proposed in [10]. It contains a simple design & coaxial feed, making it easy to fabricate. A slight size difference between the two square patches enables the radiator to excite two degenerated orthogonal TM11 modes with slightly different resonant frequencies, providing circular polarization at specific resonant frequency. However, it is designed to provide either right hand or left hand circular polarization.

In this paper, a simple & easy to fabricate, square slotted dual band polarization reconfigurable antenna is presented. For simulation purpose Ansys' High Frequency Structure Simulator (HFSS) version 13 has been used. The patch has circular shape & using two coaxial feed, to generate polarization re-configurability.

## 2. DESIGN PRINCIPLE & CONFIGURATION

At first, a circular shaped patch antenna, based on cavity model for TM110 mode has been designed. For design purpose, the resonant frequency is taken as 10Ghz, substrate used is RogersRO 3003 having relative permittivity (*$\varepsilon r=3$*) & height of the substrate as 100 mil (1 mil = 10^-3 inches). Figure 1, drawn below, shows the circular Microstrip patch antenna.

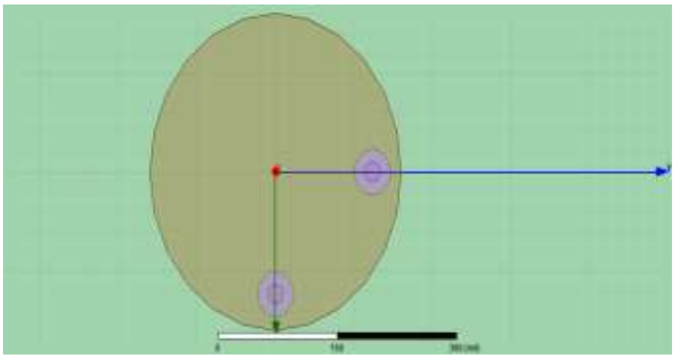

Figure 1: Dual feed circular patch antenna

A patch antenna is a resonator with magnetic walls around boundary. Any patch lying in xy-plane supports only TM mode. If we imagine that under the patch, we have only the z-component of electric field, Ez, then it results that H under the patch have x, y components only & because xy is the transversal plane, modes are called transverse magnetic mode (TM). [2]

In TMmnp, P=0 for Ez not equal to 0. Hence TMmn0 cavity mode can exist. In case of circular waveguide, m= no. of full wave patterns along the circumference, n= no. of half wave patterns along the diameter. For circular waveguide, the dominant mode is TM110 mode, in cavity model. [2]

At first, a dual coaxial feed circular patch antenna has been designed. For this purpose, following formulas are used for the taken values of Fr, $\varepsilon r$ & h.

Radius of the circular shaped patch is given by,

$$a = F/\left(1 + \frac{2h}{\pi\varepsilon rF}[\ln\left(\frac{\pi F}{2h}\right) + 1.7726]\right)^{1/2}$$

Here, F is in cm& is given by,

$$F = (8.791*10^\wedge9)/ \, \mathrm{Fr}(\varepsilon)^{1/2}$$

The effective radius or the electrical radius, is calculated as,

$$ae = a\left(1 + \frac{2h}{\pi\varepsilon ra}[\ln\left(\frac{\pi a}{2h}\right) + 1.7726]\right)^{1/2}$$

Here, h = height of the substrate in cm,

εr = relative permittivity of substrate,

a = radius of the patch,

Fr = resonant frequency,

ae = effective radius of the patch,

Here Fr = 10 GHz, for RogersRO3003 as substrate having εr as 3, height of substrate h = 100 mil = 2.54mm, or h = 0.254cm, (since 1 mil = 0.0254 mm), radius of the patch is, a = 160 mil = 4.064mm = 0.4064cm.

Dimensions of ground & substrate are taken on the basis of the idea that it should be larger than the dimension of the patch. Hence, length & width of the patch is taken as 2000*2000 mil.

Here, coaxial feed method is used, for the antenna supply. To calculate a proper position for the feed, parametric analysis is performed & by testing in different positions, a proper feed position is selected, providing proper impedance matching.

The diameter of the inner conductor of the coaxial cable is 20mil & of the outer dielectric is 46.046mil. Two symmetric coaxial feeds are given at x-axis & y-axis, equating for TE & TM mode, at a distance 123 mil from the center of the patch.

Both the sources are given same amplitude of supply voltage with 90 degree phase shift to generate circular polarization. First a circular patch with coaxial feed is designed, which provides a linearly polarized wave output at 2.4 & 10Ghz, making the antenna useful in ISM band or S-band(2-4Ghz) & X-band(8-12Ghz).

By providing 90 degree phase difference between the two sources, circular polarization is achieved. In HFSS, this phase difference is simulated by editing source option in HFSS menu. After validation check & then running the simulation, results for impedance matching, which is S11 parameter, is checked. In this case the S11 plot is showing poor return loss, by passing through -10 dB line of S11 plot providing -10dB return loss as shown in figure 2. Hence, for proper impedance matching, slotting is performed in the patch.

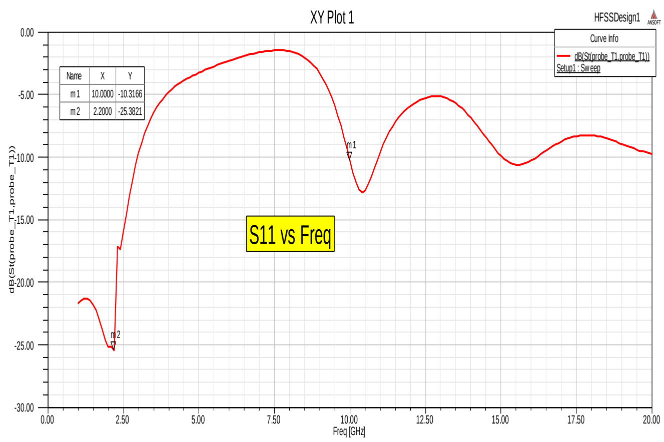


Figure 2: S11 of circular patch antenna without slotting

To perform slotting, first the current density plot of the patch is studied. In current density plot, areas of low current density have been slotted. Slotting is performed in square shape as shown in figure 3. After slotting the patch, better return loss is achieved at resonant frequency, which is 10 GHz as shown in figure 4. In figure 4, S11 at 2.4 GHz is -20 dB & at 10 GHz it is -21 dB, with impedance bandwidth of more than 1 GHz, making the designed antenna an efficient dual band antenna. Improvement in return loss indicates that slotting in the patch has helped in impedance matching, giving better S11.

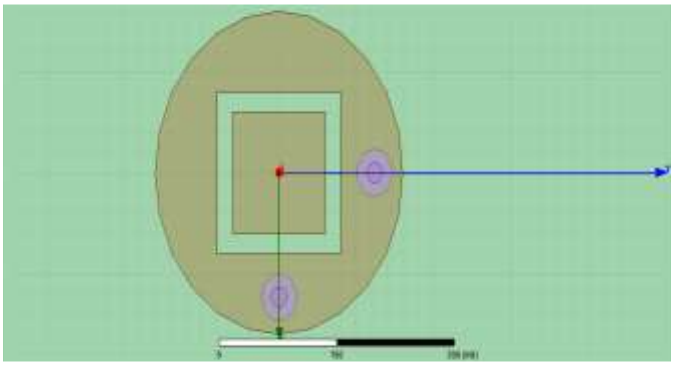

Figure 3: square slotted dual feed circular patch antenna

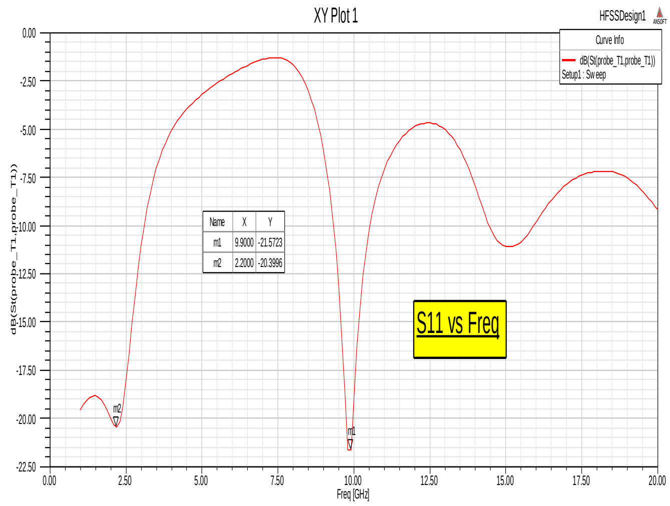


Figure 4: S11 of the slotted circular patch antenna

After getting better S11, calculation of axial ratio is required. For this purpose, calculation of values of phi & theta is required, at which antenna is circularly polarized with proper gain. To perform this, at first the plot of Gain total vs. theta at 10Ghz is calculated for all values of phi, as shown in figure 5 drawn below.

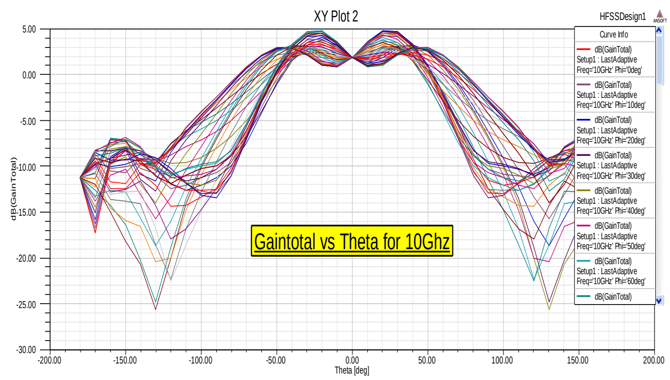


Figure 5: Gain total vs. theta plot of slotted circular patch for theta & phi calculation

Figure 5 indicates the range of values of theta, for which gain is high (approx 5dBi), which is for values of theta from -40 degree to 40 degree. Now to find value of phi, axial ratio vs. theta plot is calculated at 10 GHz, as shown in figure 6.

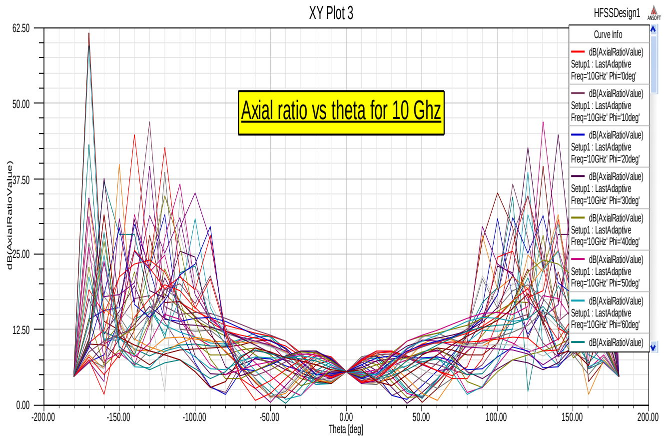


Figure 6: Axial ratio vs. theta plot of slotted circular patch for theta & phi calculation

The value of axial ratio should be below 3 dB for antenna to generate circular polarization. Now, in the range of theta from -40 degree to 40 degree, that value of phi is selected in figure 6, for which axial ratio is well below of 3 dB. Figure 5 & 6 indicates that at phi = 10 degree & theta = 30 degree, the antenna is circularly polarized having axial ratio around 1 dB & high gain, at 10 GHz. Now, the plot of Gain RHCP vs. freq. is calculated under far field analysis, at phi = 10 degree & theta = 30 degree, as shown in figure 7.

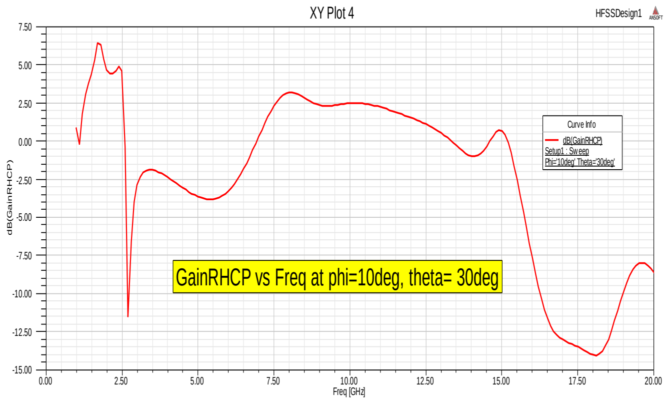


Figure 7: Gain RHCP vs. freq. plot of the slotted circular patch for phi=10 degree & theta= 30 degree; port 2 (in y-axis) is 90 degree offset from port 1, generating RHCP.

Figure 7 indicates that the right hand circular polarized gain at 10 GHz is approx 2.5dBi, while the left hand circular polarized gain is below -20dBi, indicating that the antenna is acting as a right hand circularly polarized antenna. Here, antenna polarization can be switched between right hand circular & left hand circular polarization by making offset phase 90 degree, for port 1 giving RHCP or for port 2 giving LHCP, by editing source using HFSS.

Now, to calculate axial ratio bandwidth, axial ratio vs. freq. plot is calculated at phi = 10 degree & theta = 30 degree, as shown in figure 8. The plot shows that the axial ratio bandwidth is around 3.5 GHz around center freq. 10 GHz.

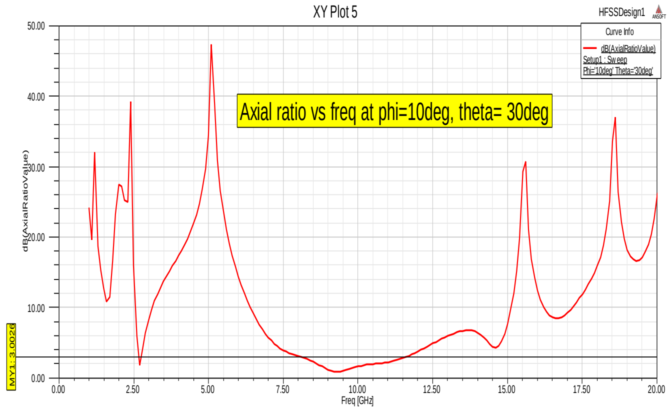


Figure 8: Axial ratio vs. freq. plot of the slotted circular patch for phi=10 degree & theta= 30 degree; port 2 (in y-axis) is 90 degree offset from port 1, generating RHCP.

The antenna works as a left hand circularly polarized antenna, when port 2, which is placed on y-axis, is having 90 degree offset angle, as phase difference with respect to port 1. For LHCP, the value of phi & theta for axial ratio value calculation, is calculated as phi = 70 degree & theta = 30 degree. Hence, for these values of phi & theta, LHCP Gain vs. freq. plot is calculated as shown in figure 9. It indicates that the antenna is providing left hand circular polarization gain of 2.75dBi.

For axial ratio bandwidth calculation, axial ratio vs. freq. plot has been calculated as shown in figure 10, by using the same values of phi & theta. Figure 10 shows the axial ratio bandwidth as 2.5 GHz at center freq. of 10 GHz.

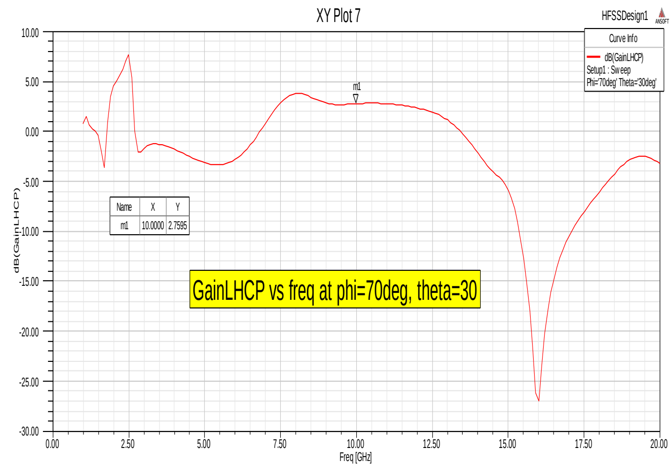


Figure 9: Gain LHCP vs. freq. plot of the slotted circular patch for phi=70 degree & theta= 30 degree; port 1 (in x-axis) is 90 degree offset from port 2, generating LHCP.

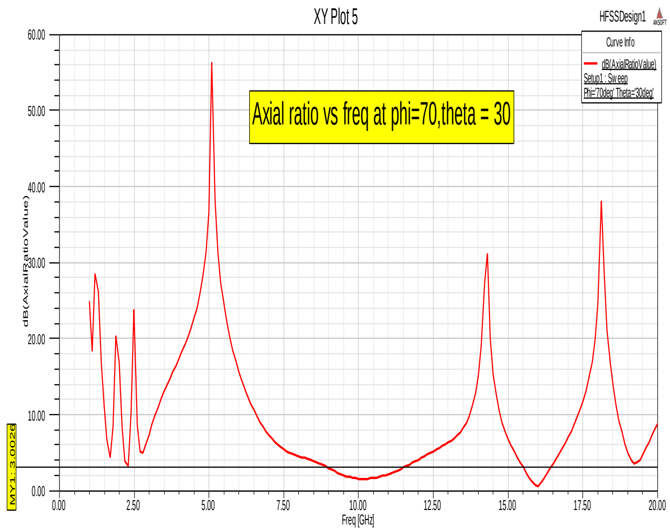


Figure 10: Axial ratio vs. freq. plot of the slotted circular patch for phi=70 degree & theta= 30 degree; port 1 (in x-axis) is 90 degree offset from port 2, generating LHCP.

The antenna simulated, works as a linearly polarized antenna, when only one port, either port 1 or 2, is acting as source & the other is idle. Hence, it is a single antenna, containing simple design geometry, which performs as a linearly polarized antenna, when either of the port is on or both ports are on without 90 degree phase shift between them. For circular polarization, 90 degree phase shift has been provided between the two ports with same amplitude, with square slotting in patch for proper impedance matching, making it an easy to fabricate, polarization reconfigurable antenna.

## 4. COMPARISION WITH REFERENCES

| Ref. | Bands covered | Peak gain (dBi) | No. of PIN diodes | Polariza-tions possible | Remark |
|---|---|---|---|---|---|
| [4] | S- band (3.7 GHz) | 9.6 | zero | LHCP-RHCP | Not easy to fabricate, useful only for specific applications |
| [5] | Ka-band (30GHz) | 5 | zero | LHCP-RHCP | Multilayer, complex, limited & specific applications |
| [6] | S- band (2.4 GHz) | 7.7 | zero | LHCP-RHCP | Low axial ratio bandwidth, poor impedance matching |
| [7] | S-band (2.45 GHz) | 8 | 2 | HP-VP/ LHCP-RHCP | Single band, low bandwidth |
| [8] | C-band (4.7 GHz) | 11 | 8 | LP, LHCP, RHCP | Complex geometry, poor bandwidth |
| [9] | C-band (4.42 GHz, 5.74 GHz) | 7.1 | zero | RHCP-LHCP | Poor axial ratio bandwidth, single band |
| [10] | L-band (1.58 GHz) | 3.9 | zero | LHCP or RHCP | Not polarization reconfigurable, single band |
| [11] | C-band (5.35 GHz, 6.75 GHz) | 7.45 | zero | LHCP or RHCP | Not polarization reconfigurable, single band |
| Proposed antenna | S-band (2.4 GHz) X-band (10GHz) | 6.5 | zero | HP-VP, LHCP-RHCP | Dual band, high axial ratio bandwidth, easy to fabricate |

## 5. CONCLUSION

A dual coaxial fed, circular shaped, easy to fabricate, polarization reconfigurable antenna is simulated using HFSS version 13. S11, return loss is lower than -20 dB, indicating proper impedance matching. The peak gain of the antenna is well above 2.5dBi & axial ratio bandwidth achieved is 3.5GHz.

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