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A Novel Singly Fed Wideband Circularly Polarized Rectangular Dielectric Resonator Antenna Using Hook-Shaped Metal Strip

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Abstract: A unique hook-shaped conformal metal strip is used to excite the rectangular dielectric resonator antenna (DRA). The excitation by this unique feed produces circular polarization having a broad bandwidth of ~ 9.2% and the impedance matching band of ~ 10%. However the overlapped bandwidth is ~ 8.3%. The design is further optimized by changing the relative permittivity of DRA material and feed dimensions to enhanced the axial ratio bandwidth to ~ 13% and the impedance matching band to ~ 23.4%. However the overlapped bandwidth in this scenario is enhanced to ~ 11%. The rectangular DRA has been successfully designed and excited by using computer simulation technology (CST), a 3D simulation tool. The calculations are made accurately and the results are validated by using another software tool called High Frequency Structure Simulator (HFSS). The results from HFSS show the same pattern which grantee the validity of the proposed design.

1. INTRODUCTION

The dielectric resonator antenna (DRA) has been broadly concentrated on in the course of recent decades, because to its appealing features, like small in size, less loss, simple excitation and comparatively broad bandwidth (Luk, *et. al,* 2003.), (Petosa, *et. al,* 2007). The circularly polarized (CP) systems are much more popular as compared to linearly polarized (LP) systems because of their many advantages in different applications. The circularly polarized (CP) systems are more susceptible to multipath distortion and polarization mismatch losses. Therefore, the researchers are focusing on different single and dual feeding techniques to achieve the circular polarization (CP) of dielectric resonator antennas (DRAs). The circular polarization with broad bandwidth is achieved by using the dual-feed technique to excite the DRA (Mongia, *et. al,* 1994), (Leung, *et. al,* 2000), (Wong, *et. al,* 2001). But dual techniques have their own restrictions such as their feeding network is complex and this technique increases the overall antenna size. Whereas single feeding technique is much more popular because of simple feeding network and overall size of antenna is small. The circular polarization of DRA achieved by different single feeding techniques has been reported in literature. The CP of a rectangular DRA achieved by an outer-fed and 7% axial ratio bandwidth has been reported (Sulaiman, *et. al,* 2010). A circularly polarized rectangular DRA excited by single-slot feed has been demonstrated (Oliver, *et. al,* 1995) and 1.8% axial ratio (AR) bandwidth was achieved. The CP with a 3.5% bandwidth of an elliptical DRA was achieved by a single-probe feeding technique (Kishk, *et. al,* 2003). The CP with a 2.4% bandwidth of a hemispherical DRA (Leung, *et. al,* 2003) and a 2.7% bandwidth of a rectangular DRA (Li, *et. al,* 2005) has been reported by using a parasitic patch. CP with much higher bandwidth of 10% of a circular sector DRA has been reported by using a single feed in which a coaxial probe has been used for excitation (Tam, *et. al,* 2000).As demonstrated in (Lee, *et. al,* 2015), a CP bandwidth of 5.17% of a semi-eccentric annular DRA is achieved by a compact single-feed using a coaxial probe. A CP with a bandwidth of 6.1% I reported in (Guo, *et. al,* 2016) in which DRA with compact ground plane is excited by a microstrip line. In all these research articles the CP bandwidth and impedance matching bandwidths of antennas achieved at same frequency.

In this article the circular polarization of rectangular DRA is achieved by exciting it through a unique *hook-shaped* conformal metal strip. The bandwidth computed for circular polarization is 9.2 % which is greater than that was reported in literature before for single-fed rectangular DRAs. At the same frequency range the proposed antenna provides the impedance-matching bandwidth of 10%. However the overlapped bandwidth is ~ 8.3%. All these bandwidths are further optimized to ~ 13%, 23.4% and 11% respectively and have been reported in the same article. The return losses, AR, and gain been have been measured and demonstrated.

2. MATERIAL AND METHODS

(Fig 1). illustrates a rectangular DRA that has been excited using a hook-shaped feed. The configuration has been modeled using the computer simulation technology (CST). The frequency range used is 2 to 6 GHz. The boundary conditions for Z_{min} was set at Electric ($E_t = 0$) to simulate the infinite ground plane. A rectangular DRA prototype has been designed with a

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relative permittivity of ϵ_r= 9.3.The dimensions of the DRA are the same as those given in (Li, 2005): a = 26.1 mm, b = 25.4 mm and c = 14.3mm. The design has been simulated using hexahedrons meshing. The rectangular dielectric has been mashed using Cells per wavelength = 40, Cells per max model box edge = 20 and Number of Cells = 532918. The hook shape has been constructed using five individual metal strips. The lengths and widths of metal strips has been optimized based on numerous simulations with the help of different parameter sweeps. The optimized dimensions of the individual strips lengths are found to be l_1= 5.5 mm, l_2 = 5 mm, l_3 = 4.25 mm, l_4 = 6.5 mm and l_5 = 2.25 mm. The width of l_1, l_2 and l_3 is 1 mm while the width of l_4 and l_5 is 1.5 mm. The discrete edge port is used to excite the model. The transformed command is used along with parameter sweep to vary the feed positions. The best results were computed at centre point that is at Y = 0 position. The design is further optimized by changing the relative permittivity of DRA. Based from the results, the optimum relative permittivity is found to be ϵ_r= 7.4. The dimensions of the individual metal strips is retained except for the length of l_2, l_3 = 4.75 mm and the width of l_1, l_2 = 1.5 mm.

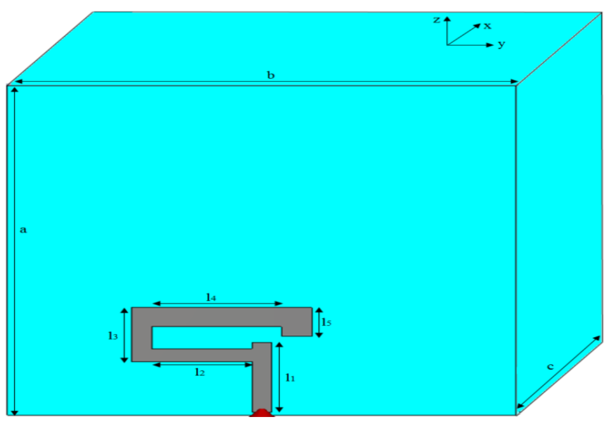

Fig.1.Rectangular DRA excited by a hook-shaped strip

The same antenna with identical parameters has been designed and simulated in HFSS for the validity of the proposed model. The CST uses Finite Difference Time Domain (FDTD) while HFSS uses Finite Element Method (FEM) to compute the results (Jmai, B., *et. al,* 2014).

3. RESULTS AND DISCUSSION

3.1 Design Validation

The antenna designing and simulation is performed in CST. The identical antenna is designed and simulated in HFSS to validate the simulation results obtained from CST. A comparison between the return losses computed by CST and HFSS is shown in Fig. 2, where it is quite obvious that the return losses of the designed antenna follow the same trend both in CST and HFSS.

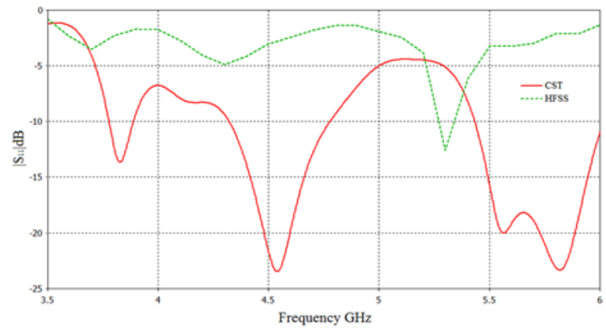

Fig.2. Return losses of a Rectangular DRA excited by a hook-shaped strip

The $|S_{11}| \leq 10$ dB, that is (VSWR) of ≤ 2, has been achieved over a bandwidth of 10%. The minimum S_{11} measured at 4.5 GHz in CST and 5.3 GHz HFSS. The shift observed because of software limitations (Jmai, *et. al,* 2014).

AR has also been computed with both CST and HFSS. The calculation of AR is performed at the boresight direction, $\theta = 0$. The change in AR is plotted against frequency as shown in Fig. 3 and it is obvious from the graph the result of CST and HFSS shows the same trend which confirms the validity of proposed model.

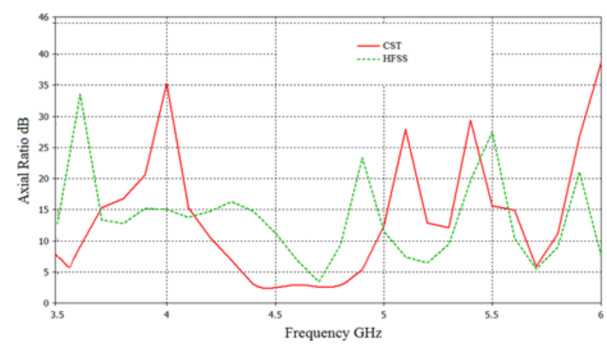

Fig.3. Axial Ratio of a Rectangular DRA excited by a hook-shaped strip

It can be observed from the result that bandwidth of 3dB AR extends from 4.4 GHz to 4.8 GHz. Moreover it can also be observed that the minimum value of AR occurs at 4.46 GHz in CST and 4.7 GHz in HFSS. The small variations are due to different simulation atmosphere of two softwares(Jmai, B., *et. al,* 2014). The figures show that the circular polarization having a bandwidth of 9.2% and the impedance matching band of 10% and the overlapped bandwidth is 8.3%, which greater than that has been achieved in literature by single outer-fed CP rectangular DRA. The AR achieved depends on the lengths and widths of the strips and any change in the dimensions can cause the standing wave current distribution that affects the circular polarization as shown in **(Fig. 4).**

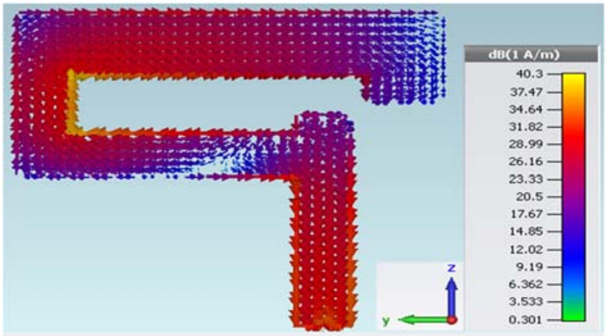

Fig.4. Current Distributions in the hook-shaped feed

3.2 Design Optimization

The proposed antenna design is further optimized by varying the relative permittivity of dielectric and few parameters of metal strips. The **(Fig 5).** shows the comparison between the return losses of proposed design before and after optimization. As it is clear that before optimization the $|S_{11}| \leq 10$ dB, that is (VSWR) of ≤ 2, bandwidth extends from 4.32 GHz to 4.77 GHz with minimum value at 4.54 GHz and gives a bandwidth of ~ 10%. While in optimized design $|S_{11}| \leq 10$ dB, extends from 4.17 GHz to 5.34 GHz with minimum value at 4.97 GHz and provides a bandwidth of ~ 23.4%. A clear enhancement has been observed in optimized design.

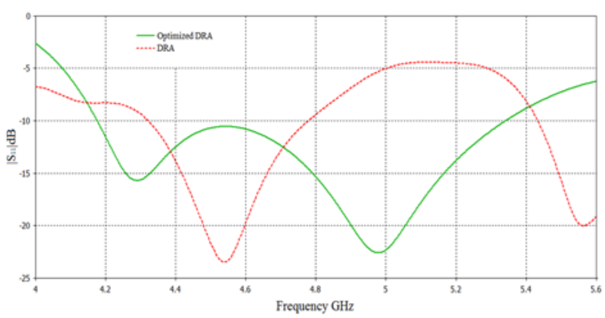

Fig.5. Return losses of the Rectangular DRA before and after Optimization

The **(Fig 6).** shows the comparison between the AR of proposed design before and after optimization. It is has been demonstrated clearly that the bandwidth of 3dB AR of before optimization extends from 4.4 GHz to 4.8 GHz with minimum value is at 4.46 GHz which gives a bandwidth of ~ 9.2%. On the other hand in the optimized design 3dB AR bandwidth extends from 4.79 GHz to 5.43 GHz with minimum value is at 4.89 GHz which gives a bandwidth of ~ 13%. However the overlapped bandwidth before and after optimization is 8.3% and 11% respectively. A considerable improvement has been observed in the optimized design.

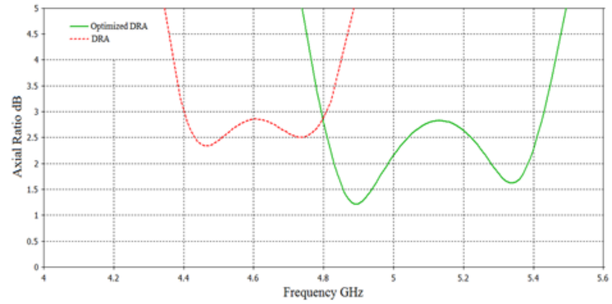

Fig.6. Axial Ratio of the Rectangular DRA before and after Optimization

The **(Fig 7).** shows the comparison between the beamwidth of the design before and after optimization. In the $\phi = 0^{o}$ plane, the circular polarization offered by the DRA over useful beam width of 33° and after optimization has been enhanced to 37°. The achieved beamwidths are comparable to those reported in (Tam M.T., *et. al,* 2000).

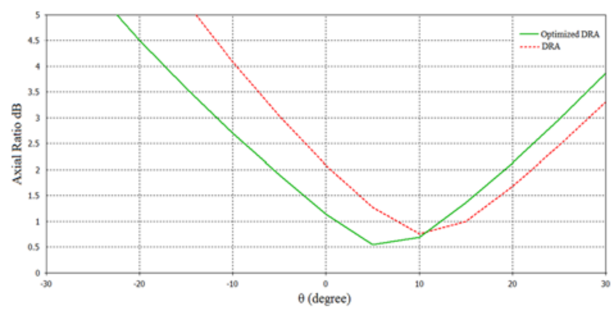

Fig.7.Beam width of the Rectangular DRA before and after Optimization

(Fig 8). is the representation of the comparison of gain before and after optimization. Gain in dBi is plotted against frequency in GHz. The optimum AR frequencies before and after optimization are 4.46 GHz and 4.89 GHz respectively. So it can be seen that the antenna provides a gain of 3.9 dBi and after optimization it has been improved to 4.1 dBi.

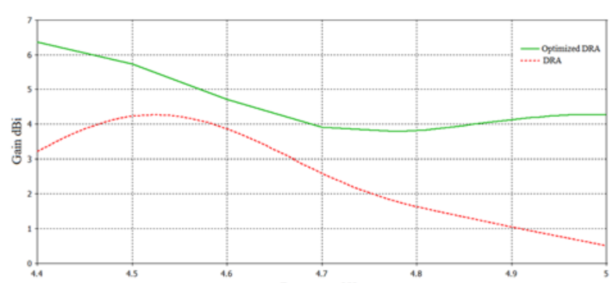

Fig.8. Gain of the Rectangular DRA before and after Optimization.

4. CONCLUSION

A rectangular dielectric resonator antenna providing circular polarization has been designed. Antenna has been excited by *hook-shaped* monopole. The antenna achieved 3dB Axial Ratio bandwidth of ~ 9.2 %, which is a considerable enhancement as compared to those reported in early research studies singly outer-fed CP DRA. The impedance matching bandwidth (VSWR ≤ 2) provided by the antenna is 10% and overlapped bandwidth is 8.3%. The design is further optimized to enhance the performance. The optimized DRA offered 3dB Axial Ratio bandwidth of ~ 13 %, the impedance matching bandwidth of ~ 23.4% and overlapped bandwidth of ~ 11%. The enhancement in the beam width is confirmed as well by the far-field pattern. The optimized DRA provides circular polarization over a beam width of 37^{o}. The optimized DRA offers a gain of 4.1 dBi at optimum AR frequency. Moreover, the feeding technique is quite simple and good resemblance in the trends of the results has been observed between CST and HFSS.

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