DUAL BAND OAM BEAM GENERATION BY A UNIFORM CIRCULAR ARRAY WITH SQUARE PATCHES

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Abstract –In this paper the uniform circular array (UCA) with square patch antennas for generating the orbital angular momentum (OAM) beam is presented. The 8-element microtrip square patch UCA is designed to work for dual band at 5.41 GHz and 5.93 GHz which generates the OAM beam of mode l = -1. In the proposed design the feeding network is designed to eliminate the multi-layer feeding network in the dual band by taking the optimal frequency value for the nearer frequencies applications. The simulation results like VSWR, gain, beam and phase patterns are observed.

Index Terms -- Uniform circular array (UCA), OAM beam, Square patch.

I. INTRODUCTION

Over the last few years, the data rates over the specific bandwidth have significantly increased technologies are shrinking as a result of the ability to send large amounts of data quickly over a small frequency range has become tough [1] [2]. The demand for increased transfer and channel capacity is rapidly growing [3]. The development of various communication multiplexing technologies has increased as a result, and these technologies are based on characteristic differences such as amplitude, phase, frequency, and polarization [4]. However, a modern method based on the use of radio waves with orbital angular momentum (OAM) has recently been researched [5] [6]. After seeing the unique behavior of these beams, it is possible that they have an infinite number of orthogonal states, opening up a new possibility for using these states as channels for communication [7]. A few designs for creating OAM beams were investigated. The Spiral phase plate was originally used for beam generating during the OAM period [8]. OAM beams are produced using later reflector antenna techniques and single microstrip patch antennas with slots. They were ignored because of their poor conversion efficiency [9]. Then the circular phased antenna array entered the scene, which was capable of producing OAM beams and had a great degree of flexibility and ease of processing [10].

Rectangular patches were used as the radiation components in the previously published works on OAM creation using UCA [11] [12]. For mode l= -1, the suggested UCA design comprises eight identical square patches to produce OAM beams. Section II of this study contains the complete report on the uniform circular array design with square patch antennas to generate OAM beam as well as details on the results of the simulation. Section III made the conclusions in the end.

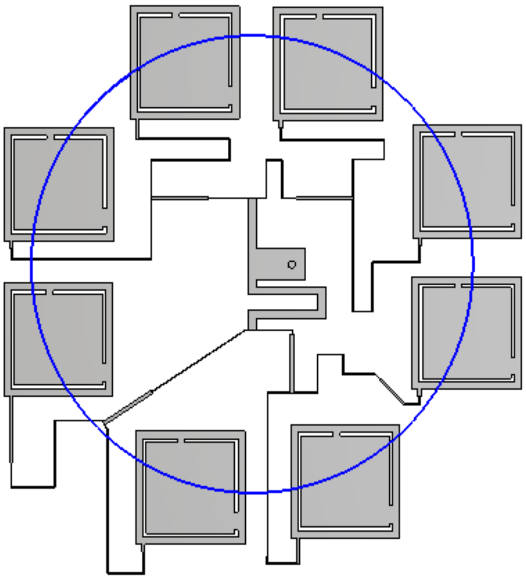


Fig.1: Illustration of the proposed uniform circular array with square patch elements

II. ANTENNA DESIGN

A UCA's structure is made up of N identical triangular patch antenna elements that are placed geometrically in a circle with a radius of r wavelengths and an easy-to-use feed network. Although the amplitude of all the radiating elements is the same, there is an incremental phase shift of

$$\Delta\emptyset_n = \pm\frac{2\pi l}{N}$$

to each element. In this manner, a complete rotation of the rectangular array of antennas yields the overall phase distribution necessary for the creation of the OAM model.

To design a basic patch antenna, parameters such as dielectric constant (ε_r), resonant frequency (fr) should be considered. The design equations used to find the patch dimensions for a specific design frequency are given below.

Length of patch (L) is

$$L = \frac{C}{2f_r\sqrt{\varepsilon_{reff}}}$$

Width of the patch (W) is

$$W = \frac{C}{2f_r}\,X\,\sqrt{\frac{2}{\varepsilon_r + 1}}$$

Effective dielectric constant of antenna (ε_{reff}) is

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\,X\,(1 + \frac{12h}{w})^{-0.5}$$

The extended length (L) of antenna is

$$\Delta L = 0.42\,x\,h\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)}$$

The effective length, add the length L to the extension of the length ΔL is

$$L_{eff} = (L + 2\Delta L_{eff})$$

The characteristic impedance of the microstrip line can be written as:

$$Zo = \frac{120\pi}{\sqrt{\varepsilon reff}\left(1.393+\frac{W}{h}+\frac{2}{3}\ln\left(\frac{W}{h}+1.444\right)\right)}$$

The affective dielectric constant is also a function of frequency *fr* equation is

$$f_r = \frac{\upsilon_0}{2\sqrt{\varepsilon_{reff}}\,(L+2\Delta L_{eff})}$$

As the number of radiating elements increases, the quality of the generated OAM beams also gets better [13]. Each element in the array is excited with an enhanced phase shift of 45° (2l/8 radians), where *l* is the OAM mode number, for the creation of OAM mode *l*= -1, by attaching the appropriate feed lines to the square patch antenna element in a clockwise direction [13] [14]. According to Fig. 1, the lengths of the feed lines for each pair of elements are altered, resulting in the necessary phase delay. The array's radius at 5.41 GHz and 5.93 GHz is set to 0.75λ to reduce mutual coupling while retaining a high-quality OAM beam. The substrate was chosen to be Rogers, which has a relative permittivity of 2.2 and a thickness of 1.6 mm. Each element's input port's input impedance is 150Ω. The elements of the traditional feed network are all matched to the 50Ω coaxial feed using impedance matching techniques to the 50Ω coaxial feed using impedance matching techniques.

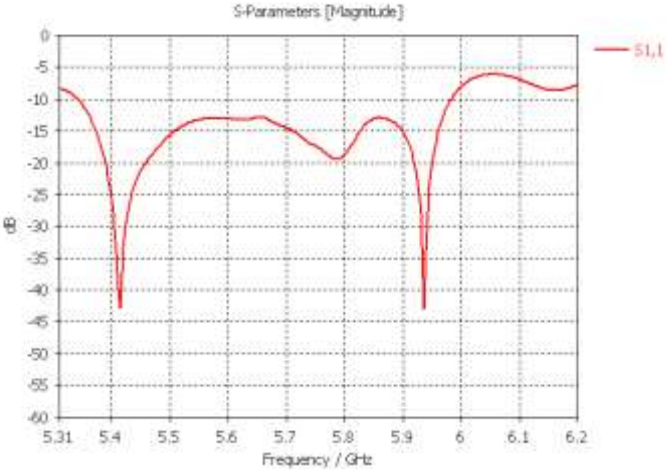


Fig. 2: Simulated array reflection coefficients

An OAM antenna has the unusual ability to output radio beams with a certain number of twists that match the number of OAM modes. Most OAM modes that can be created for an N element array are provided by -N/2<lmax<N/2. As was mentioned above, the array's 45° phase increment, which results in the twisted phase fronts, is necessary for the creation of OAM mode *l*= -1. The resulting array emits the OAM mode of *l*=0 if the phase increment is not added. The eight array elements are thus given a total phase shift of 0° to 360°. This suggests that the phase of the circular patch's initial element is 0° and that it increases until every two components have a 45° phase delay. Extending the feed length provides the necessary phase delay at each element. The UCA is created in the CST Microwave studio suite at 5.41 GHz and 5.93 GHz respectively based on these hypotheses. The

simulated reflection coefficients that are smaller than -30 dB at the target frequency are shown in Fig. 2.

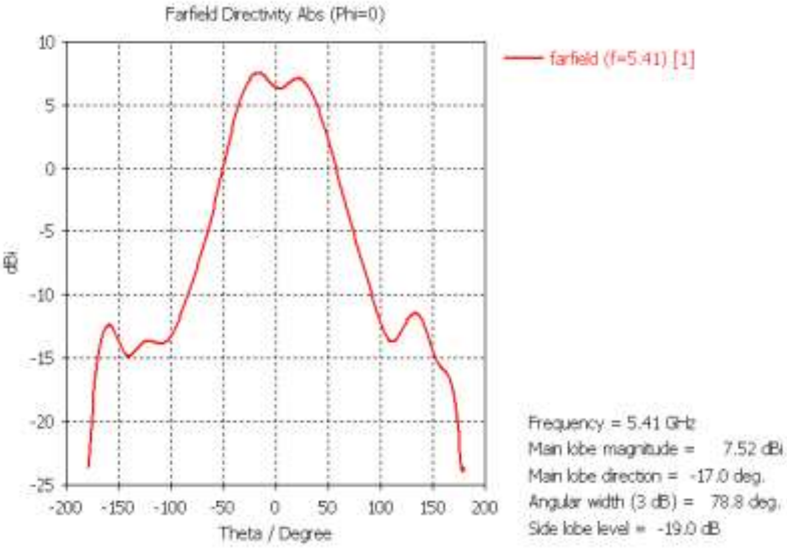


Fig. 3: Simulated 2D radiation pattern of OAM mode *l*= -1 at 5.41 GHz

The radiation pattern created at the resonant frequency in Fig. 3, Fig. 4, Fig 5, and Fig 6 shows sidelobe levels of lesser size and a null in the center along the z-axis in the direction of the boresight, which supports the characteristic of OAM beams. Both at 5.41 GHz and 5.93 GHz, the antenna's maximum gain is 9.84 dBi and 8.87 dBi, respectively.

The farfield elevation phase fluctuation for OAM mode *l*= -1 is shown in Fig. 7 and Fig.8. Fig. 9 and Fig.10 show the phase distribution of the electric field in the z-plane and show that the generated OAM mode is stable.

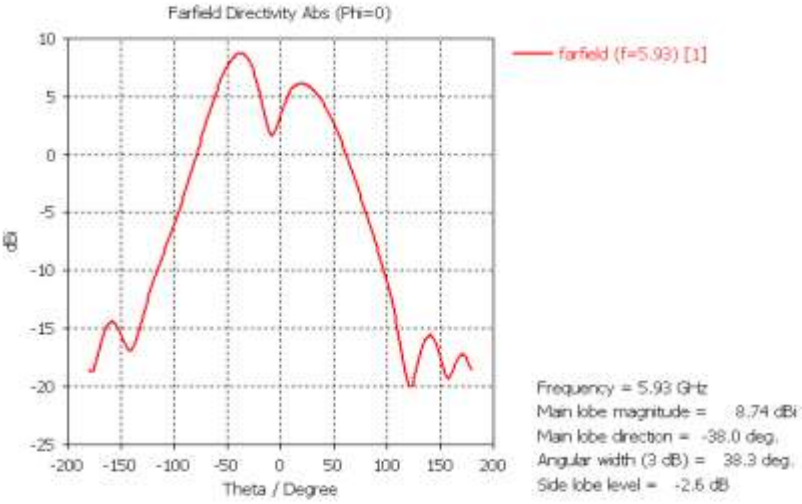
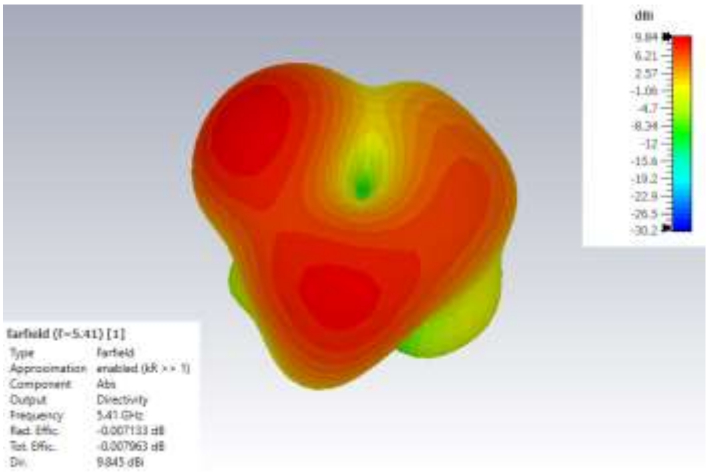
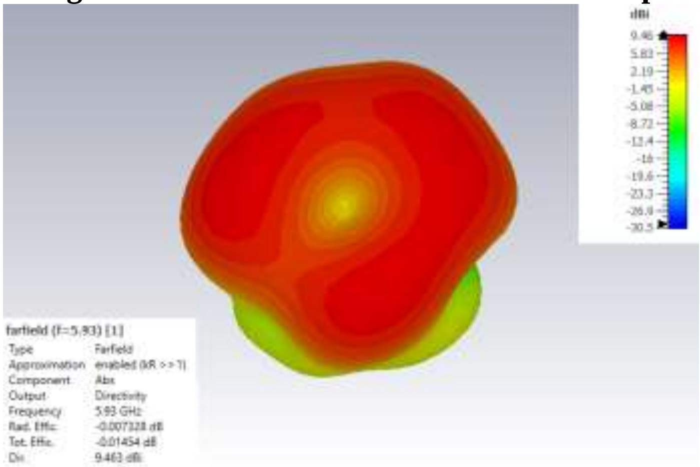


Fig. 4: Simulated 2D radiation pattern of OAM mode *l*= -1 at 5.93 GHz



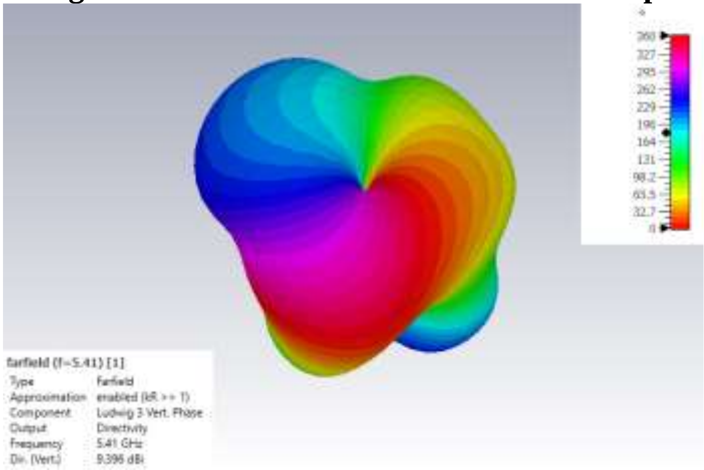
farfield (f=5.41) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Directivity
Frequency 5.41 GHz
Rad. Effic. -0.007133 dB
Tot. Effic. -0.007963 dB
Dir. 9.845 dBi

Fig. 5: Simulated magnitude of OAM mode *l* = -1 3D radiation pattern at 5.41 GHz.



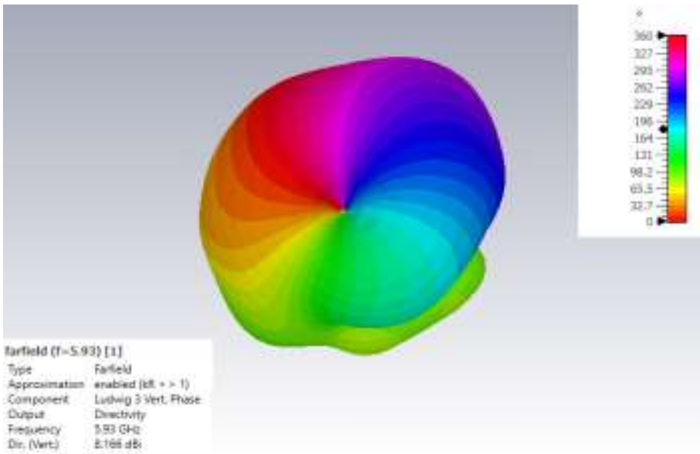
farfield (f=5.93) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Directivity
Frequency 5.93 GHz
Rad. Effic. -0.007328 dB
Tot. Effic. -0.01454 dB
Dir. 9.463 dBi

Fig. 6: Simulated magnitude of OAM mode *l* = -1 3D radiation pattern at 5.93 GHz.



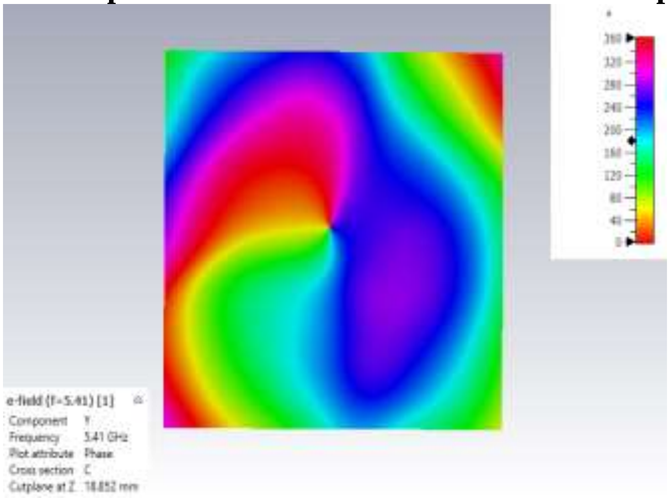
farfield (f=5.41) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Ludwig 3 Vert. Phase
Output Directivity
Frequency 5.41 GHz
Dir. (Vert.) 9.396 dBi

Fig. 7: Simulated elevation phase of OAM mode *l* = -1 3D radiation pattern at 5.41 GHz.



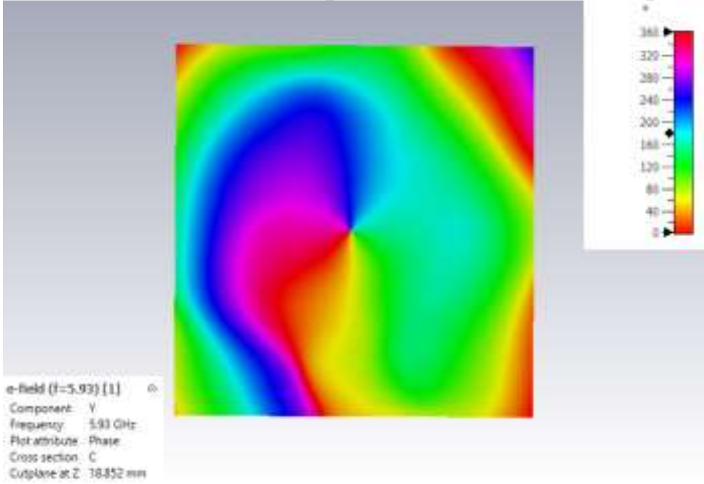
farfield (f=5.93) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Ludwig 3 Vert. Phase
Output Directivity
Frequency 5.93 GHz
Dir. (Vert.) 8.166 dBi

Fig. 8: Simulated elevation phase of OAM mode *l* = -1 3D radiation pattern at 5.93 GHz.



e-field (f=5.41) [1]
Component Y
Frequency 5.41 GHz
Plot attribute Phase
Cross section C
Cutplane at Z 18.852 mm

Fig. 9: Side view of simulated E-field phase distribution in Z plane at 5.41 GHz



e-field (f=5.93) [1]
Component Y
Frequency 5.93 GHz
Plot attribute Phase
Cross section C
Cutplane at Z 18.852 mm

Fig. 10: Side view of simulated E-field phase distribution in Z plane at 5.93 GHz

III. CONCLUSION

An OAM beam with mode *l*=-1, a uniform circular array of square patch antenna elements has been constructed and simulated at dual bands, namely at 5.41 GHz and 5.93 GHz. We obtained the radiation pattern data for both frequencies, including phase patterns, gain plots, magnitude plots, and reflection coefficients. A gain of 9.84 dBi and 8.87 dBi, as well as low sidelobe levels, are recorded for the array's efficient radiative performance.

REFERENCES

[1] A. Benjebbour, Y. Kishiyama, and T. Nakamura, 5G Requirements: Applications, Requirements and Candidate Technologies, 11 2016, pp.9–22.

[2] C.-X. Wang, J. Huang, H. Wang, X. Gao, X. You, and Y. Hao, "6g wireless channel measurements and models: Trends and challenges,"IEEE Vehicular Technology Magazine, vol. 15, no. 4, pp. 22–32, 2020.

[3] A. Gnauck, P. Winzer, S. Chandrasekhar, X. Liu, B. Zhu, and D. Peckham, "Spectrally efficient long-haul wdm transmission using 224- gb/s polarization-multiplexed 16-qam," journal of lightwave technology, vol. 29, no. 4, pp. 373–377, 2011.

[4] J. Reed, M. Vassiliou, and S. Shah, "The role of new technologies in solving the spectrum shortage [point of view]," Proceedings of the IEEE, vol. 104, no. 6, pp. 1163–1168, 2016.

[5] L.Allen,M.W.Beijersbergen,R.Spreeuw,and J.Woerdman, "Orbital angular momentum of light and the transformation of laguerre-gaussian laser modes," Physical review A, vol. 45, no. 11, p. 8185, 1992

[6] S.M.Mohammadi, L.K.S.Daldorff, J.E.S.Bergman, R.L. Karlsson, B.Thide, K.Forozesh, T.D.Carozzi, and B.Isham, "Orbital angular momentum in radio—a system study," IEEE Transactions on Antennas and Propagation, vol. 58, no. 2, pp. 565–572, 2010.

[7] F.Tamburini, E.Mari, B.Thide, C.Barbieri, and F.Romanato, "Ex- ´ perimental verification of photon angular momentum and vorticity with radio techniques," Applied Physics Letters, vol. 99, no. 20, p. 204102, 2011.

[8] P. Schemmel, G. Pisano, and B. Maffei, "Modular spiral phase plate design for orbital angular momentum generation at millimetre wavelengths," Optics express, vol. 22, no. 12, pp. 14 712–14 726, 2014.

[9] E. Mari, F. Spinello, M. Oldoni, R. A. Ravanelli, F. Romanato, and G. Parisi, "Near-field experimental verification of separation of oam channels," IEEE Antennas and Wireless Propagation Letters, vol. 14,
pp. 556–558, 2015.

[10] Q. Bai, A. Tennant, B. Allen, and M. U. Rehman, "Generation of orbital angular momentum (oam) radio beams with phased patch array," in 2013 Loughborough Antennas Propagation Conference (LAPC), 2013, pp. 410–413

[11] Z.-G. Guo and G.-M. Yang, "Radial uniform circular antenna array for dual-mode oam communication," IEEE Antennas and Wireless Propagation Letters, vol. 16, pp. 404–407, 2017.

[12] W. Wei, K. Mahdjoubi, C. Brousseau, and O. Emile, "Generation of oam waves with circular phase shifter and array of patch antennas," Electronics Letters, vol. 51, pp. 442–443, 03 2015.

[13] Q. Bai, A. Tennant, and B. Allen, "Experimental circular phased array for generating oam radio beams," Electronics letters, vol. 50, no. 20, pp. 1414–1415, 2014.

[14] L. Fang and R. M. Henderson, "Orbital angular momentum uniform circular antenna array design and optimization-based array factor," in 2019 IEEE Texas Symposium on Wireless and Microwave Circuits and Systems (WMCS), 2019, pp. 1–4.

[15] W. Wei, K. Mahdjoubi, C. Brousseau, and O. Emile, "Generation of oam waves with circular phase shifter and array of patch antennas," Electronics letters, vol. 51, no. 6, pp. 442–443, 2015.