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Equiangular Spiral Slot Antenna for C- band Applications

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ABSTRACT

In this paper, An Equiangular Spiral Slot Patch Antenna has been designed and simulated at operating frequency range between 4 GHz to 10 GHz. This antenna is modeled on a thin single sided Rogers RO4003C substrate with dielectric constant of 3.38. The proposed design is achieved by cutting a equiangular spiral slot on the circular patch. The modeling and simulation of the proposed Antenna has been done with Finite Element Method (FEM) based software COMSOL Multiphysics. A parametric analysis has been done with variation in geometry of Spiral slot. The results of the proposed Equiangular Spiral Slot Antenna acclaim its use for C-band applications and also demonstrate its wideband operation in the range 4 GHz to 10 GHz.

Keywords: Equiangular Spiral Slot antenna, Finite Element Method (FEM)

1. INTRODUCTION

The Spiral Slot antennas have gained a lot of attention in the last few years due to their characteristics like stable impedance, axial ratio, gain and pattern over wideband [1] and their conformal design. These antennas can be used for communication, sensing, tracking, positioning, Wi-Fi devices, cordless phones and many other applications in different microwave frequency. These antennas operate as a fast wave, leaky wave, and traveling wave antenna. The traveling wave nature of the excited currents on the spiral arms allows for broadband performance of antenna. This wave is fast due to the mutual coupling between neighbouring arms and leaks energy while propagating on the trace to produce radiation. The Spiral Antennas are frequency independent antennas. The design of these antennas is based upon the fact that the impedance and radiation properties of an antenna are linked with the electrical dimensions (expressed in wavelengths) of the structures. So an arbitrary scaling of the antenna structure results in the identical structure, but possibly rotated about the vertex consequently making their electrical properties independent of frequency [2-3]. Frequency independent antennas can be described merely by angular specifications. Antennas, described on conical surfaces and by equiangular spiral curves, satisfy this angle requirement. Theoretically, the structure must be infinite in range and derive from a point vertex. Microstrip antennas are one of the most widely used antennas in the microwave frequency range. These antennas have a very low profile, are mechanically rugged and conformable to the curving skin of a vehicle [4]. So they can be easily mounted on aircraft and spacecraft, or are incorporated into mobile radio communications devices. The major limitations of microstrip antenna are narrow bandwidth and poor radiation efficiency [5]. But it is still a challenging task to attain a better compromise between gain, bandwidth, impedance matching and radiation efficiency of antenna. In order to increase the bandwidth of antennas, to various techniques have been used in literature including increase of the substrate thickness, the use of a low dielectric substrate, the use of various impedance matching and feeding techniques, the use of multiple resonators and slot antenna geometry [6-7] etc. Slotting includes the insertion of narrow shaped slots, wide slots, circular ring slot, U shaped slots on metallic patch. Microstrip Slot antennas have found heavy applications in military aircrafts, missiles, rockets and satellites because of extremely thin profile (0.01 to 0.05 λ), [8-9].

In this paper, an Equiangular Spiral Slot Antenna has been modeled and simulated with Finite Element Method (FEM) based software COMSOL Multiphysics. In Section 2, the design parameters, geometry of the model and equations have been presented. Section 3 discusses FEM modeling of Equiangular Spiral Slot Antenna. Section 4 presents the results and discussions. Section 5 gives conclusion of the paper.

2. EQUIANGULAR SPIRAL SLOT ANTENNA

Spirals can be designed with different numbers of arms. The equiangular spiral has characteristic feature that each line starting in the origin cuts the spiral with same angle; hence it is named as Equiangular Spiral. The Equiangular Spiral has gradually enlarged arm width and separation between the arms as they open toward the outside. This shape can be entirely described by angles and is frequency independent [10]. The Equiangular Spiral Slot Antenna shown in Figure 1, is designed by the equiangular spiral curve

$$\rho = \rho_i \, e^{a\,(\varphi-\varphi i)} \qquad \ldots (1)$$

Where ρ is the radial distance from the vertex in the $\theta = \pi/2$ plane, φ is the angle from the x axis, ρ_i and φ_i are the initial radial distance for each arm of the spiral and initial angular position of the spiral curve, a is flare rate of the spiral. The flare rate is related to the pitch angle of the spiral (ψ) by

$$\tan \psi = 1/a \qquad \ldots (2)$$

The first arm, which originates along the x-axis, is defined by the two edges given in equation (3) and (4) and is shown in Figure 2.

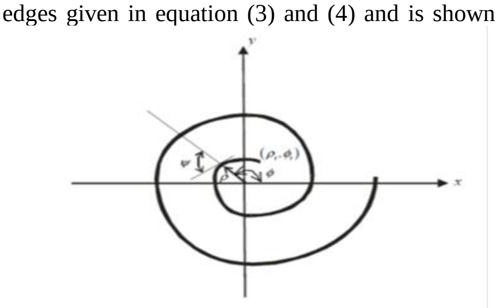

Figure 1: Equiangular spiral curve

Outer edge : $\rho_1 = \rho_0\ e^{a\varphi}$ ….(3)

Inner edge: $\rho_2 = \rho_0\ e^{a(\varphi-\delta)}$ .....(4)

Where $\frac{\rho_2}{\rho_1} = e^{-a\delta} < 1$ … (5)

δ is the area taken up by each arm and is given by $\pi//n$, ρ_0 is the starting radius, φ is the progressive flare angle. The second arm can be realized by simply rotating the first arm by π radians [11].

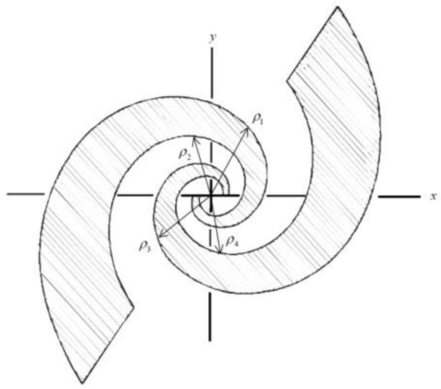

Figure 2: Design of Equiangular Spiral

3. FEM MODELING OF EQUIANGULAR SPIRAL SLOT ANTENNA

In the present work, a spiral slot antenna is built with a two-arm equiangular spiral slot which is patterned on a thin substrate of Rogers RO4003C with dielectric constant 3.38 using parametric curves keeping a = 5. The lumped port is placed at the centre of the Spiral Slot to excite the antenna. The metal surface of Circular patch is modeled as perfect electric conductor (PEC). The antenna structure and air region are enclosed by a perfectly matched layer (PML).

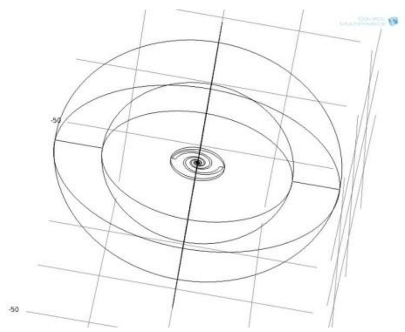

Figure 3: Geometry of Equiangular Spiral Slot antenna

The geometry of equiangular spiral slot antenna has been modeled in the RF module of COMSOL Multiphysics, is shown in Figure 3. Stationary solver has been used to simulate the model. To solve electromagnetic problems with boundaries values, it is essential to formulate the problem in terms of magnetic vector potential A and the electric scalar potential V. The electrical field for the Equiangular Spiral Slot Antenna is solved by the following equation

$$\nabla \times \mu_r^{-1}(\nabla \times E) - k_0^{\ 2}\left(\varepsilon_r - \frac{j\sigma}{\omega\varepsilon_0}\right)E = 0 \qquad \text{…. (6)}$$

Where, E is electric field vector, $k_0^{\ 2}$ is the wave number, ε_r is relative permittivity, μ_r is relative permeability, μ_0 is the absolute permittivity.

4. RESULTS AND DISCUSSION

After modeling the antenna and applying the boundary conditions, meshing of problem domain has been done with mesh statistics detailed in Table 1 and shown in Figure 4. Meshing can be contemplated as the splitting of domains into smaller sub-domains made up of geometric primitives like hexahedrals and tetrahedrals in case of 3D and quadrilaterals and triangles in case of 2D. The number of elements after meshing is 37743.

Table 1: Mesh statistics of generated mesh

Number of degree of freedom	37214
Tetrahedral elements	26311
Prism elements	6390
Triangular elements	3872
Quadrilateral elements	600
Edge elements	570
Vertex elements	32
Minimum element quality	0.003394
Average element quality	0.7492

After initial meshing and refinement, The Equiangular Spiral Slot antenna model is solved to obtain the electric field distribution, Return loss (S_{11}) parameter and radiation pattern.

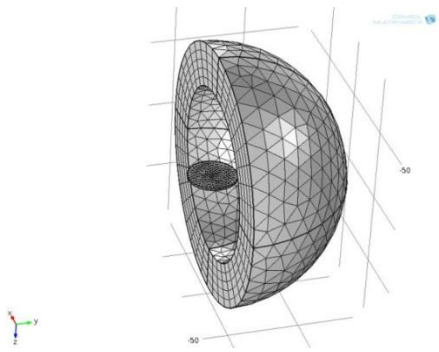

Figure 4: Meshing of Equiangular Spiral Slot Antenna

The solution time for solving this problem is 57 minutes approx. The electric field on top surface of spiral slot antenna is shown in Figure 5. It is perceived from Figure 5 that the intensity of the fields along the slot is stronger than the rest of the surface.

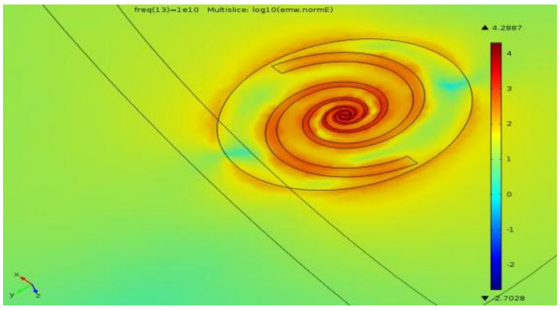

Figure 5: Electric field distribution on XY plane at 10 GHz

The performance of antenna is analysed by Return loss and radiation pattern Half Power Beam width (HPBW). The Return loss and 2D polar plot are depicted with variation in the inner radius of spiral from 0.5mm to 1.5 mm taking 2.5 turns of spiral, in Figure 6 and Figure 7, 8, 9 respectively and corresponding values of parameters are tabulated in Table 2. Then the Return loss and 2D polar plot are plotted with variation in number of turns of spiral from 2, 2.5 and 3 keeping inner radius 0.6 mm, in Figure 10 and Figure 11, 12, 13 respectively and corresponding values of parameters tabulated in Table 3.

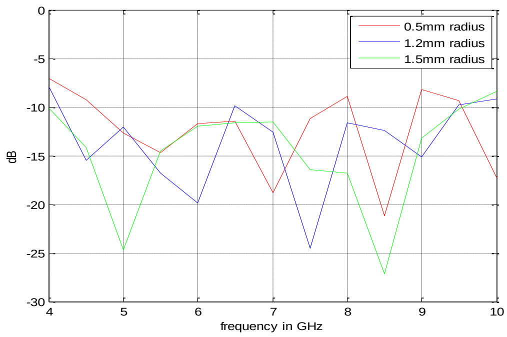

Figure 6: Return loss with different values of inner radius of spiral keeping 2.5 turns of spiral

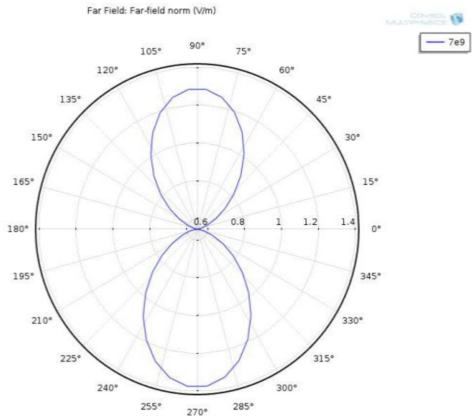

Figure 7: 2D Polar plot on YZ plane with 0.5mm inner radius of spiral and 2.5 turns of spiral

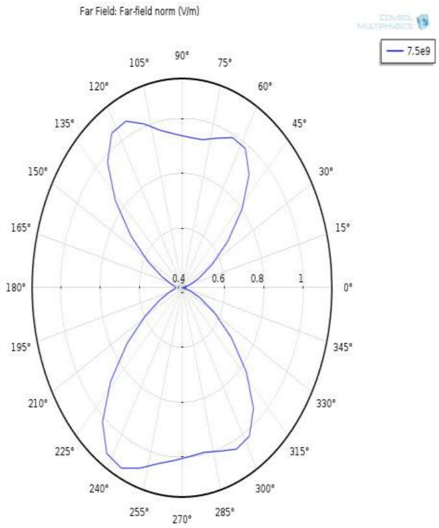

Figure 8: 2D Polar plot on YZ plane with 1.2 mm inner radius of spiral and 2.5 turns of spiral

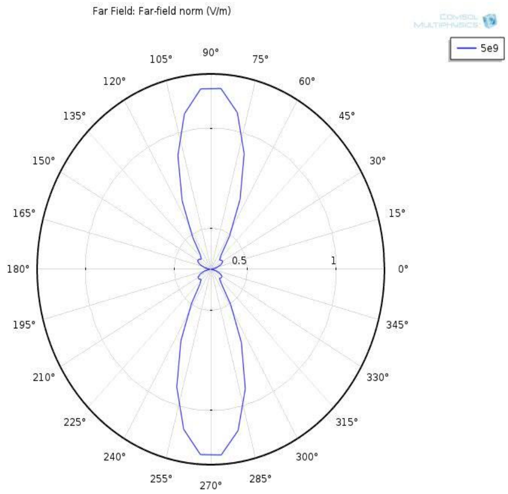

Figure 9: 2D Polar plot on YZ plane with 1.5 mm inner radius of spiral and 2.5 turns of spiral

Table 2: Comparison of Performance parameters of antenna with variation in inner radius of Spiral arm

S. N.	No. of turns	Inner radius(mm)	0.5	1.2	1.5
1.	2.5	Freq. (GHz)	7	8.5	5
		Return loss(dB)	-18.78	-25	-24.74
		Half Power Beam width (deg.)	75	65	55

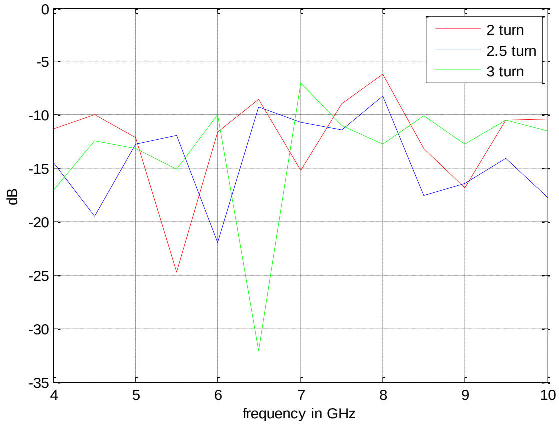

Figure 10: Return loss with variation in number of turns of spiral keeping inner radius of spiral 0.6 mm

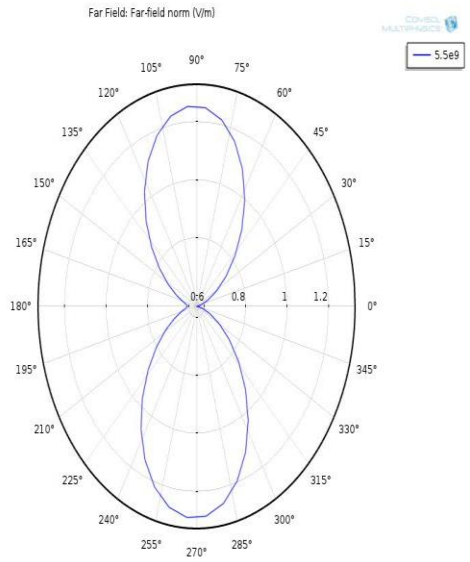

Figure 11: 2D Polar plot on YZ plane with 0.6 mm inner radius of spiral and 2 turns of spiral

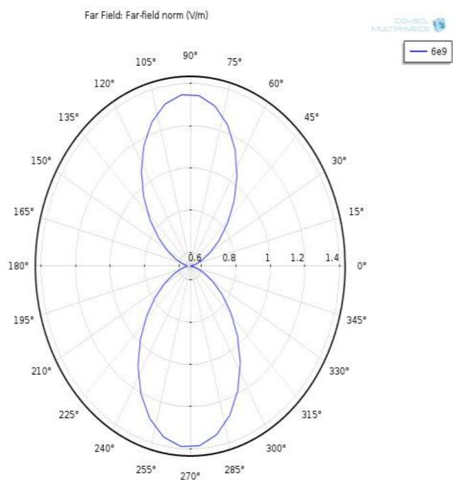

Figure 12: 2D Polar plot on YZ plane with 0.6 mm inner radius of spiral and 2.5 turns of spiral

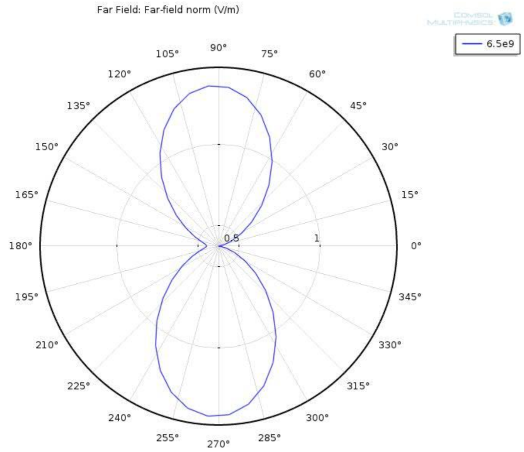

Figure 13: 2D Polar plot on YZ plane with 0.6 mm inner radius of spiral and 3 turns of spiral

Table 3: Comparison of Performance parameters of antenna with variation in number of turns of spiral

S.N.	Inner radius (mm)	Number of turns of spiral	2	2.5	3
1.	0.6	Freq.(GHz)	5.5	6	6.5
		Return loss(dB)	-24.75	-22	-32.15
		Half Power Beam width (deg)	65	62	59

5. CONCLUSION

In this paper, an Equiangular Spiral Slot Antenna has been presented. From the simulated results, it is apparent that the proposed antenna achieves good impedance matching at multiple resonating frequencies. Its directivity get enhanced with increase in inner radius and with more number of turns of spiral and the proposed Antenna is suitable for C-band applications and it also exhibits wideband operation in the range 4 GHz to 10 GHz.

REFERENCES

[1] Kaiser, J. A., “The Archimedean two-wire spiral antenna,” *IEEE Trans. Antennas and Propagation*, Vol. 8, No. 3, 312-323, 1986.

[2] V. H. Rumsey, *Frequency Independent Antennas*, H. G. Booker and N. De Claris, Eds. New York: Academic, 1966, Electrical Science.

[3] Michael McFadden, Waymond R. Scott, “Analysis of the Equiangular Spiral Antenna on a Dielectric Substrate”, *IEEE Transactions on Antennas and Propagation*, Vol. 55, No. 11, pp. 3163-3171, Nov. 2007.

[4] W. He, R. Jin, and J. Geng, “E-Shape patch with wideband and circular polarization for millimetre-wave communication,” *IEEE Trans. Antennas and Propagation*, vol. 56, no. 3, pp. 893-895, 2008.

[5] Ramesh Garg, Parkash Bhartia, Inderbahl, Apisak Ittipiboon, *Microstrip Antenna Design Handbook*, A .V. Title. VI series.

[6] K. Siakavara, *Methods to Design Microstrip Antennas for Modern Applications*, Aristotle University of Thessaloniki, Dept. of Physics, Radio communications Laboratory, Thessalonik, Greece.

[7] K. L. Lau, K. M. Luk, and K. L. Lee, "Design of a circularly-polarized vertical patch antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 54, No. 4, pp. 1332-1335, 2006

[8] F. Yong, X. Zhang, X. Ye, and Y. Rahmat-Samii, "Wide-band E-shaped patch antennas for wireless communication," *IEEE Trans. on Antennas Prop.*, Vol. 49, No. 7, pp. 1094-1100, Jul. 2001

[9] Jen-Yea Jan and Jia-Wei Su, "Bandwidth enhancement of a printed wide slot antenna with a rotated slot," *IEEE Transaction and Antennas Propagation.*, Vol.53, No.6, pp. 2111-2114, June 2005.

[10] John D. Kraus, Ronald J. Marheflka, Ahmad S Khan, *Antennas and wave propagation*, Fourth edition. Constaintine A. Balanis, *Antenna Theory analysis and design*, 2nd edition , John Wiley And Sons