Comparison of Antennas for Radio Frequency Energy Harvesting in 0.2- 2.4 GHz Range

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Abstract—**Broadband Radio Frequency Energy Harvesting is a lucrative area of research nowadays. In this paper, we analyze various antennas for Radio Frequency Energy Harvesting in terms of broadband gain, return loss and packing conformality. Use of hexagonal spiral antenna which can provide excellent broadband characteristics without putting any bound on packing conformality is particularly emphasized. Analysis is based on simulation of various antennas using Method of Moments in IE3D Software.** *(Abstract)*

Keywords-hexagonal spiral; packing conformality; rectenna (keywords)

I. INTRODUCTION

The use and development of planar antennas for Radio frequency Energy Harvesting has been done by various researchers like Sim [1], Hagerty [2], Bouchouicha [3]. Progress in this field has been made by designing rectangular patch antennas, spiral antennas and rectennas (rectifying antennas). The drawback of using rectangular patch antennas is their inherently narrow bandwidth [4]. On the contrary spiral antennas posses radiation pattern over wide range of frequencies [5]. However spiral antennas have much lesser packing conformality when built on printed circuit boards. A conformal antenna is an antenna that conforms to do something [6]. In our case it shall conform to high density planar packing. Use of a spiral antenna causes a large fraction of area of printed circuit board to remain uncovered. Optimizing the antenna cover area on printed circuit boards would have given us much higher amount of power as we could have placed greater number of antenna patches. However the optimization method should be such that nearly same characteristics as spiral antennas are obtained.

An ultimate solution to this problem could be use of a hexagonal spiral antenna [7]. In the subsequent sections rectangular patch antenna, Archimedean spiral antenna, square spiral antenna and hexagonal spiral antenna are analyzed and their performance in terms of broadband gain, return loss and conformality has been compared. The frequency range 0.2-2.4 GHz is selected taking the consideration that most of the radiation for domestic appliances including Television [8], Mobile [9] [10], Bluetooth etc) lies in this range and hence the antennas can be used for capturing broadband radiation.

II. RELATIONSHIP BETWEEN HEXAGONAL SPIRAL AND ARCHIMEDEAN SIRAL GEOMETRIES

An Archimedean spiral is represented by [11]

$$r = r_0 + a\phi \qquad (1)$$

Where, r_0 is the initial radius and a is the growth rate. If $a = 0$, the spiral will not grow and hence will form a circle.

In the very similar way we can relate a hexagonal spiral with a hexagon. In order to simplify our calculations and understanding we would use a circle for representing an Archimedean spiral and a hexagon for representing a hexagonal spiral. A circle is a limiting case of a many sided polygon [12]. From the above lines we conclude that a hexagonal spiral should give approximately the same characteristics as an Archimedean spiral. The use of a square spiral antenna was suggested by Minhong [13] and Mickle [14]. However a hexagonal spiral tends to approach a circular shape better than a square spiral and hence is expected to generate better characteristics in terms of broadband gain. Moreover the hexagonal spiral would be efficient to maintain packing conformality which could also be maintained in square spiral antenna.

III. COMPARISON OF UNCOVERED AREA IN ARCHIMEDEAN SPIRAL AND HEXAGONAL SPIRAL GEOMETRIES

We have already mentioned relationship between circle and Archimedean spiral and also between hexagon and hexagonal spiral. So in this analysis we deal with simple hexagons and circles and try to find the percentage of uncovered area if circular or spiral patches are used in a panel.

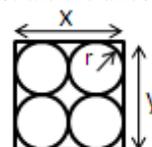"Fig. 1" would demonstrate the uncovered area:

Figure 1. Uncovered area calculation

The percentage of uncovered or wastage area (%U) is represented by (2)

$$\%U = \frac{xy - n\pi r^2}{xy} \times 100$$

(2)

Where, x and y are the length and breadth of the area to be covered, n is the number of circles covering the area and r is the radius of each circle. For a hexagonal spiral panel theoretically this area would be zero but practically for routing and proper placement a fraction of area would still be uncovered. This routing and placement area is required for any antenna panel design and will be approximately equal for any antenna panel designed. So while comparing the uncovered area it would not be necessary to calculate this area considering it as a general wastage.

IV. PROPOSED GEOMETRY AND PLACEMENT OF HEXAGONAL SPIRAL

The idea of placement of hexagonal spiral antennas has been inspired from hexagonal cell structure arrangement found in mobile communications [15]. The proposed placement to get the highest packing conformality is shown in "Fig. 2" and "Fig. 3"
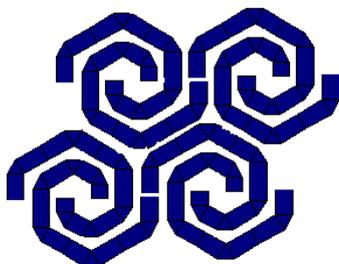

Figure 2. Hexagonal spiral antenna

Figure 3. Array of Hexagonal Spiral Antenna

An Archimedean spiral antenna is shown in "Fig. 4". The array for this spiral antenna is shown in "Fig. 5"

Figure 4. Archimedean spiral antenna

Figure 5. Array of Archimedean spiral antenna

A square spiral antenna is shown in "Fig. 6". The 4-element array for this spiral antenna is shown in "Fig. 7"
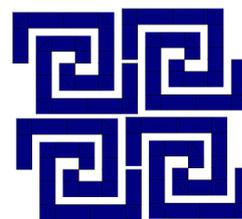

Figure 6. Square spiral antenna

Figure 7. Array of square spiral antenna

V. COMPARISON OF SIMULATION RESULTS

The antennas are designed on Rogers RT/duroid 6010.2LM substrate having dielectric constant 10.2 [16]. The designed antennas are simulated in IE3D Software which uses Method of Moments (MoM) [17] for finding the solution. The total field gain and the return loss of the antennas were simulated and compared. We have concentrated only on these two parameters as these are the most important parameters when an antenna is to be used for radio frequency energy harvesting applications. The total field gain plot for a rectangular patch antenna with resonant frequency of 1.2 GHz, an Archimedean spiral antenna, a square spiral antenna and a hexagonal spiral antenna having an effective bandwidth of 0.2-2.4 GHz are shown through "Fig. 8" to "Fig. 11"
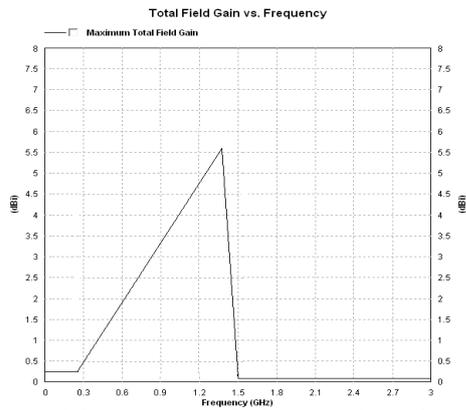
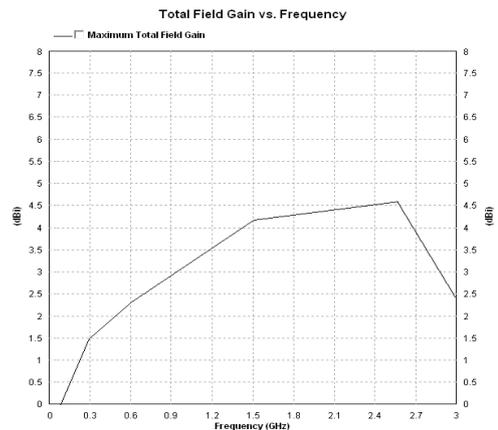Figure 8. Gain vs Frequency plot for rectangular patch antenna

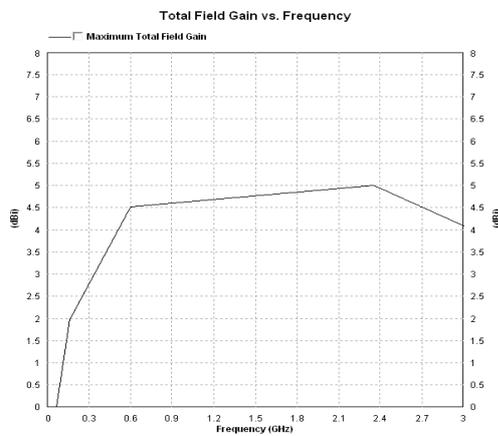Figure 9. Gain vs frequency plot for Archimedean spiral antenna

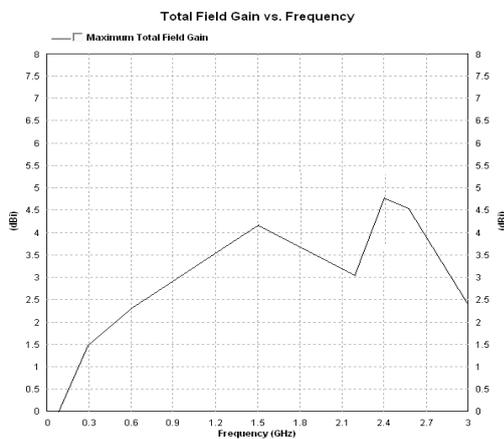Figure 10. Gain vs frequency plot for square spiral antenna

Figure 11.   Gain vs frequency plot for hexagonal spiral antenna

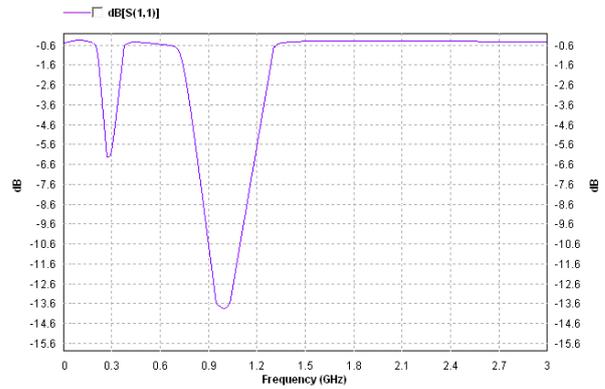The return loss plots for these antennas are shown through "Fig. 12" to "Fig. 15".

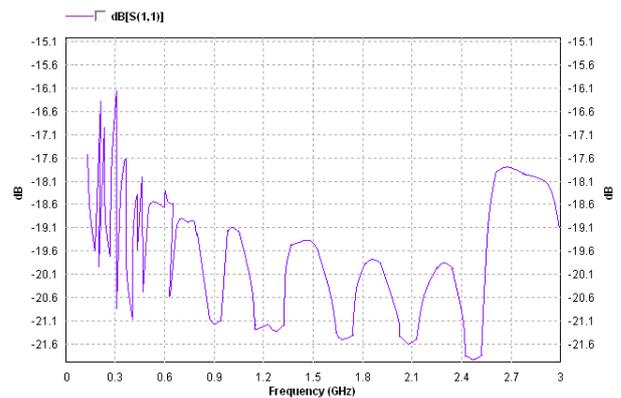Figure 12. Return loss vs frequency plot for a rectangular patch antenna

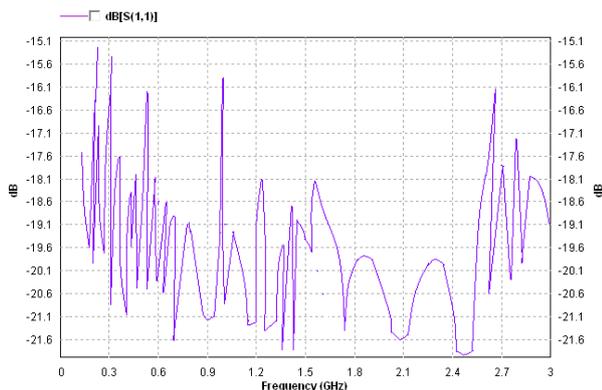Figure 13. Return loss vs frequency plot for Archimedean spiral antenna

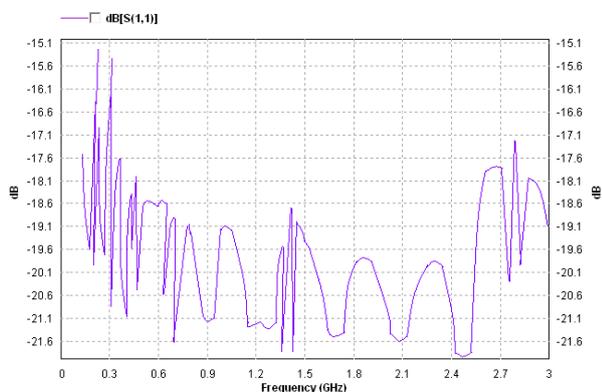Figure 14. Return loss vs frequency plot for square spiral antenna

Figure 15. Return loss vs frequency plot for hexagonal spiral antenna

VI.   PRACTICAL DESIGN ASPECTS

From the above plots we observe that a hexagonal spiral and an Archimedean spiral antenna have almost similar characteristics. In the initial stage of our fabrication process we have found the savings in printed circuit board area. Theoretically the area wasted can be given by the formula $xy - n\pi r^2$, where x and y are the dimensions of Printed Circuit Board, r is the radius of the spiral if an Archimedean spiral was used and n is the number of such spirals. For example if a square board of side 200 mm is used and each Archimedean spiral has a radius 20 mm then we can accommodate twenty five such spirals as shown in "Fig. 16". The area wasted using the formula is 8584.073 mm^2. This area would be enough to accommodate more than six such Archimedean spirals.

Thus more number of spirals could be accommodated if we use hexagonal spiral instead of Archimedean spiral (considering the area required for separation between the antennas in both cases are same).
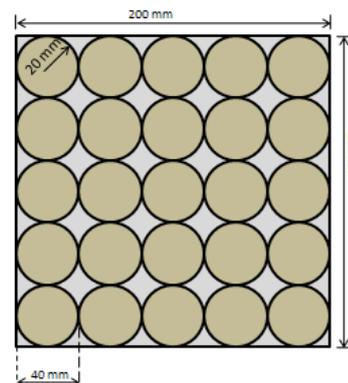

Figure 16. Wastage area calculation for Archimedean spiral array

VII.   CONCLUSION

From the above calculations, observations and results we can conclude that a hexagonal spiral antenna is much more advantageous than an Archimedean spiral or square spiral antenna. Advancements in printed circuit board technology with inherent high dielectric constant substrate will definitely make hexagonal spiral antenna arrays a need for the future.

VIII.   FURTHER WORK

The practical design of hexagonal spiral antenna is under progress. After the practical design of the panel on Rogers Duroid Laminate is over, a hybrid logarithmic hexagonal spiral antenna would be designed which combines the properties of a hexagonal spiral and a logarithmic spiral.

REFERENCES

[1]   Z.W. Sim, R. Shuttleworth, M.J. Alexander and B.D. Greive, "Compact patch antenna design for outdoor RF energy harvesting in wireless sensor networks," Progress in Electromagnetics Research, vol. 105, pp. 273–294, 2010.

[2]   Joseph A. Hagerty, Tian Zhio, Regan Zane and Zoya Popovic, "Efficient broadband RF energy harvesting for wireless sensors," Proceedings of The Government Microcircuit Applications and Critical Technology Conference, Lag Vegas, pp. 1-4, April 2005.

[3]   D. Bouchouicha, F. Dupont, M. Latrach, L. Ventura, "Ambient RF energy harvesting," International Conference on Renewable Energies and Power quality, Granada, Spain, 2010.

[4]   Rodney B. Waterhouse, Printed Antennas for Wireless Communications, John Wiley and sons, ISBN: 978-0-470-51069-8, 2008, pp. 230-232.

[5]   John L. Volakis, Antenna Engineering Handbook, 4th ed, McGraw-Hill, ISBN: 978-0-071-47574-7, pp. 374-376, 2007.

[6]   Lars Josefsson, Patrik Persson, "Conformal array antenna theory and design," Wiley Interscience Publication, pp.1-2, 2006.

[7]   Richard J. Barton, Peter J. Collins, Paul E. Crittenden, Michael J. Havrilla, Andrew J. Terzuoli, " A compact passive broadband hexagonal spiral antenna array," Antennas and Propagation Society International Symposium, IEEE, pp. 4401-4404, June 2007.

[8]   J.S. Chitode, Consumer Electronics, Technical Publishers Pune, 2nd reprint ed., ISBN: 81-8431-207-5, pp. 264-265, March 2007.

[9]   Kumar, Sanjeev, Wireless and mobile communication, New Age International (P) Limited Publishers, ISBN: 978-81-224-2354-9, pp. 9-10, 2008.

[10] Thomas A. Miligan, Modern Antenna Design, Wiley Interscience Publication, 2nd ed., pp. 526-528, 2005.

[11] Wendy Middleton, Mac E. Van Valkenburg, Reference data for engineers: radio, electronics, computer and communications, Newnes, 9th ed., pp. 1-118, 2002.

[12] Susan Ball, Sue Briggs, Margaret Mackenzie, Folen Maths Programme, Folen Publishers, pp. 22, 2003.

[13] Mi Minhong, M.H. Mickle, C. Capelli, H. Swift, "RF energy harvesting with multiple antennas in the same space," Antennas and Propagation Magazine, IEEE, vol. 47, issue 5, pp. 100-106, Oct. 2005.

[14] Marlin H. Mickle, Christopher C. Capell, Harold Swift, "Energy harvesting circuits and associated methods," United States Patent US 2004/0085247 A1, May 2004.

[15] Hideichi Sasaoka, Mobile Communications, IOS Press, pp. 119-120, 1997.

[16] Rogers Corporation, Data sheet of RT Duroid 6006/6010 LM high frequency laminates.

[17] Y.K. Singh, S.Ghosh, A. Chakrabarty, S. Sanyal, G. Sahoo, "Comparison of IE3D and FIDELITY simulators for planar circuit design," Proceedings of the international conference on Electromagnetic Interference and Compatibility, pp.33-36, 2002.