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Nature Inspired Fibonacci Sequence Microstrip Patch Antenna for Energy Harvesting Applications

Asha Meena, Anita Garhwal, Kanad Ray

Abstract: ***In this paper, design and simulation of Nature Inspired Fibonacci sequence golden spiral antenna is presented. It is based on the snail's shell structure which is frequently found in nature. The proposed antenna geometry has its unique design and it is used for energy harvesting applications. For energy harvesting applications rectenna is designed which has an antenna, matching circuit, voltage doubler circuit and load. The antenna is designed in CST (computer simulation technology) microwave studio software. Using CST software S-parameter, surface current, E-field, H-field are simulated and results are analyzed. The antenna is simulated in 3 GHz to 10 GHz frequency band and achieves multiband return loss characteristics and positive gain at respective frequencies.***

Keywords: ***Energy harvesting, Fibonacci sequence, golden ratio, rectenna.***

I. INTRODUCTION

In today's world wireless communication system antenna is major component essential to create a communication link. Antenna is a transducer device that converts energy from one from to another. It is an electromagnetic device that both transmits and receives data [1-2]. Microstrip patch antennas are accepted because of they are easy to use as compared to conventional antennas. Patch antennas are low cost, low profile and easily printed on circuit board [3].

In recent years the nature inspired antennas attract the researchers. The natural design concept of plants, flowers petals, tree branches, shells, seeds heads, spiral galaxies, hurricanes and etc. provide interesting research field in microwave, satellite, radar and antenna design. Fibonacci numbers are named by Italian mathematician Leonardo of Pisa, later known as Fibonacci. Fibonacci numbers appear in nature often enough to prove that they reflect some naturally occurring patterns. Application of Fibonacci numbers include computer algorithms such as the Fibonacci search techniques and the Fibonacci cubes used for interconnecting parallel and distributed systems [4].

Several papers have been published under nature inspired concept of antenna designs. An article presents design, simulation, implementation of antenna structure based on Fibonacci sequence found in snail's shell and this super-ultra wideband microstrip antenna (tapered feed is used and half circles are used in ground plane) is used for satellite navigation [5]. A dual band sneezewort plant growth pattern shaped antenna simulated for (UWB, Ku and X-band) triple band [6]. A sunflower shaped microstrip antenna has wideband performance used in Ku band and for satellite application is presented [7]. Koch fractalized compact spiral antenna design based on Fibonacci sequence with miniaturization using fractals. Fibonacci spiral antenna which is fractalized based on Fibonacci sequence, also using Koch curve and second order of iteration [8-9]. A set of two designs octagon and decagon shaped fractal antenna are designed for S, C and X band applications for 8GHz to 12GHz using CST microwave studio software. This antenna is also used in mobile satellite and radio location services, radar and space communication [10]. Two designs circular and elliptical shaped fractal patch antennas are designed and fabricated for c band applications, satellite communication, wireless communication network in frequency band from 1GHz to 12GHz and results are simulated, measured and analyzed [11]. A reconfigurable hexagonal fractal patch antenna is designed for ambient computing application in the frequency range from 2GHz to 10GHz. In this design defected ground plane and fuzzy logic model concept is introduced and used for getting better results [12]. An inscribed Fibonacci circle fractal antenna used for ultra wideband operation with 50% size reduction as compared to conventional antenna [13]. A novel 2.5D frequency selective surface element using fibonacci spiral is presented for radome application [14]. Self-complementary antenna with multi-resonance frequency based on Fibonacci sequence for UWB application and six hexagonal are placed at midpoint to maintain the sequence, feed line is expanded for improving electrical current distribution, self-complementary sequence is inscribed in the ground plane which allows multiple resonating frequencies [15].

This paper has following contents; at first introduction, second is introduction to Fibonacci sequence, third is antenna design, fourth is simulation result, fifth is about rectifier circuit and sixth is conclusion.

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II. INTRODUCTION TO FIBONACCI SEQUENCE

The Fibonacci sequence is related to the golden ratio, a proportion (roughly 1:1.6) that occurs frequently in natural world. When we take any two successive (one after the other) Fibonacci numbers, their ratio is very close to the Golden ratio and it is denoted as "Φ" which is approximately 1.618034…[16]. In fact, the bigger the pair of Fibonacci numbers, the closer the approximation. We can calculate any Fibonacci number using the golden ratio equation (1): -

$$Fn = \frac{\Phi^n-(1-\Phi)^n}{\sqrt{5}} \qquad \ldots\ldots\ldots (1)$$

III. ANTENNA DESIGNS

This paper is designed by the concept of Fibonacci series and golden ratio. The antenna design is inspired from snail's shell [5] which follows the golden spiral as shown in fig. 1. The substrate used is FR-4 epoxy material which has permittivity 4.4 and loss tangent 0.02.

Fig. 1. Nature Inspired Snail's Shell[5]

In fibonacci spiral design first we have to make Fibonacci series squares and then circles which have radii equal to Fibonacci number and in these circles, we have chosen only quarter part and then connect the opposite ends of these circles and combine the spiral for making design. One thing which is different is that normal spiral has equal width (distance between two turn) in each turn but Fibonacci series spiral has increasing width (distance between two turn) in each turn.

A. Design-1 & 2 :- Equal Width Fibonacci Spiral And Increasing Width Fibonacci Spiral Design

Design-1 and 2 are presented in literature in [5]. The antenna dimensions are 23 mm x 23 mm x 1.6 mm and 30 mm x 30 mm x 1.6 mm for first two basic designs which are Equal Width Fibonacci Spiral and Increasing Width Fibonacci Spiral design. Microstrip line feeding is used in each design.

In design-1 (Equal Width Fibonacci Spiral) fibonacci sequence is used 2,3,5,8 for Fibonacci spiral design and it has 1mm of width from starting point to last point. Substrate size is 23 mm x 23 mm, ground is 23 mm x 7 mm, feeding length and width is 10.05 mm x 1 mm.

In design-2 (Increasing Width Fibonacci Spiral) Fibonacci sequence is used 2,3,5,8 for inner part and for outer part Fibonacci sequence is used 3, 5, 8 and 13. It has increasing width of Fibonacci spiral design from starting point to last point. Ground has compact size 30 mm x 30 mm and feeding length and width are 11.1 mm x 1mm. The compared result of S_{11} parameter of Equal width fibonacci spiral (red colour) and incresing width fibonacci spiral design (green colour) are shown in fig. 4. As we can see that increasing width fibonacci spiral design has better and improved result compared to equal width fibonacci spiral design.

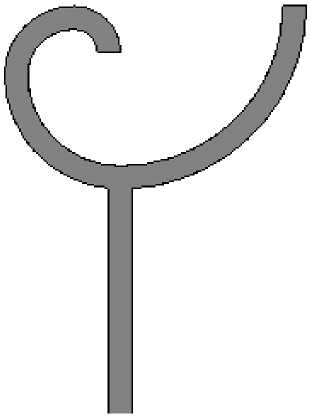

Fig. 2. Equal width fibonacci spiral design[5]

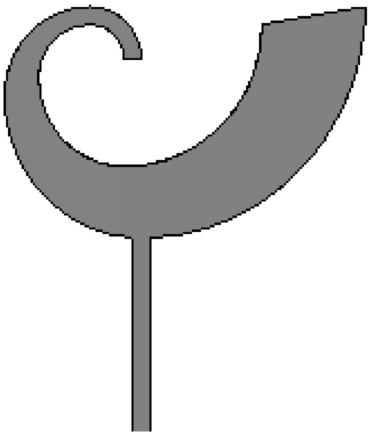

Fig. 3. Increasing width fibonacci spiral design[5]

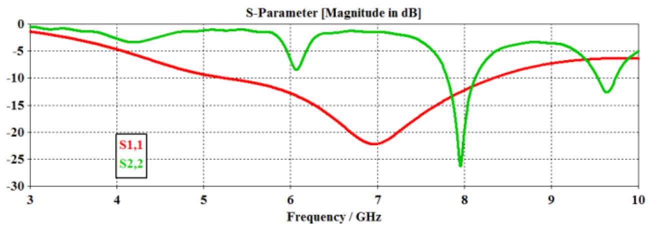

Fig. 4. Comparision of S_{11} parameter of Equal width spiral fibonacci and Incresing width spiral design

B. Proposed Design-3 & 4:-Equal Width Fibonacci Spiral (EWFS) With Triangle And Increasing Width Fibonacci Spiral (IWFS) With Triangle Design

In third design (fig-5) we have used first design (fig-2) as basic design and adding triangle from starting point to the last point in spiral pattern and length of triangles is increased as Fibonacci series spiral is increasing. Ground is 65 mm x 45 mm in size, Substrate dimension is 84 mm x 55 mm, feeding length and width 12 mm x 1 mm. The S_{11} parameter of Equal width fibonacci spiral (EWFS) with triangle design is shown in fig.7 and it has been resonating on different frequencies and achieves better result compared to previous two designs.

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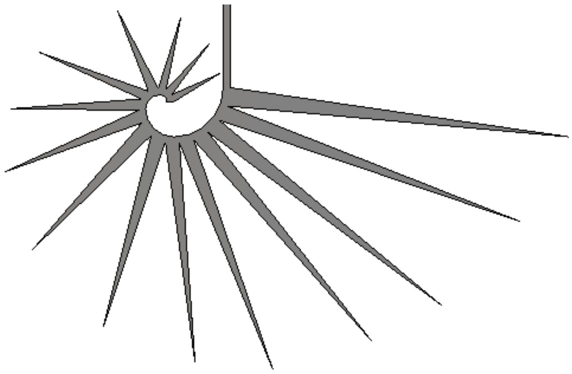


Fig. 5. Equal width fibonacci spiral (EWFS) with triangle antenna design

In fourth design (fig.6) we have used second design (fig.3) as basic design and adding triangle from starting point to the last point in spiral pattern and length of triangles is increased as Fibonacci series spiral is increased. Ground is 65 mm x 45 mm of size, Substrate dimension is 84 mm x 55 mm, feeding is used and length and width are 11.9 mm x 2 mm. The S_{11} parameter of Increasing width fibonacci spiral (IWFS) with triangle design is shown in fig. 8 and it has been resonating on different frequencies and gets better result compared to previous three designs.

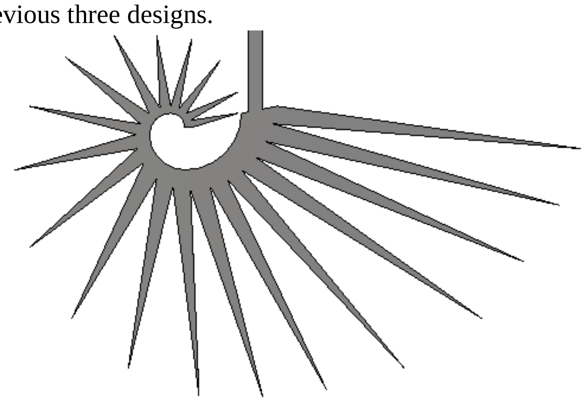


Fig. 6. Increasing width fibonacci spiral (IWFS) with triangle antenna design

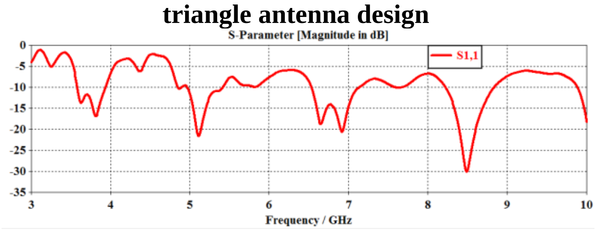


Fig. 7.S_{11} parameter EWFS with triangle design

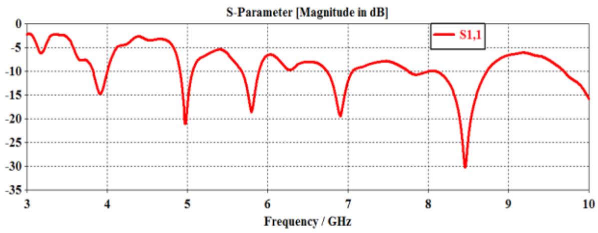


Fig. 8. S_{11} parameter IWFS with triangle design

IV. SIMULATION RESULTS

In this paper Nature Inspired Fibonacci Sequence Microstrip Patch Antenna is simulated and the parameters which are included are S-parameter, surface current, E-field, H-field. Fig.9 shows the surface current distribution at frequency 6.96GHz. In fig.10 show surface current distribution at frequencies 7.95 and 9.63GHz. In this (Equal width fibonacci spiral) design defected ground plane is used and in this (Increasing width fibonacci spiral) design full ground plane is used.

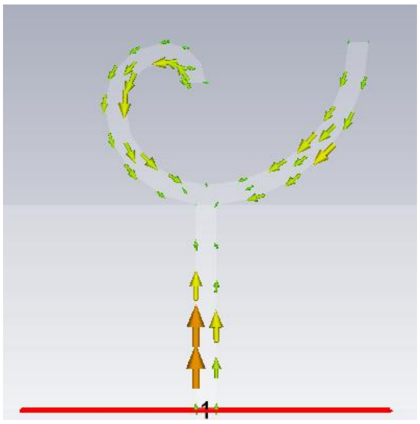
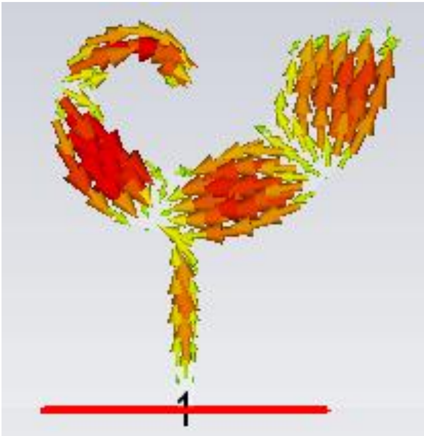
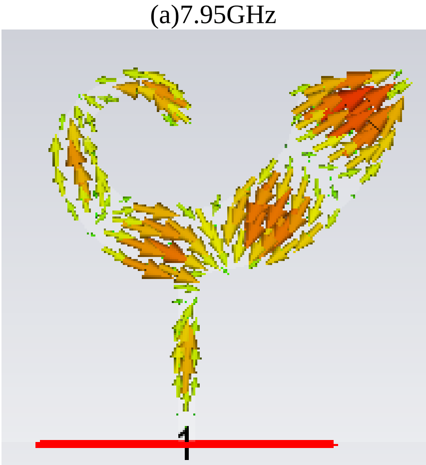


Fig. 9. surface current distribution at 6.96GHz (EWFS)



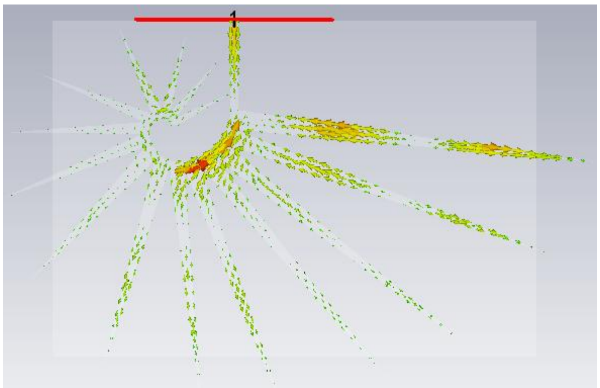
(a)7.95GHz



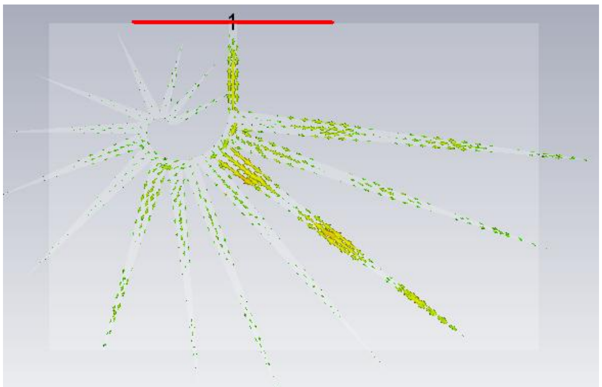
(b)9.63GHz

Fig.10. Surface current distribution at 7.95 and 9.63GHz (IWFS)

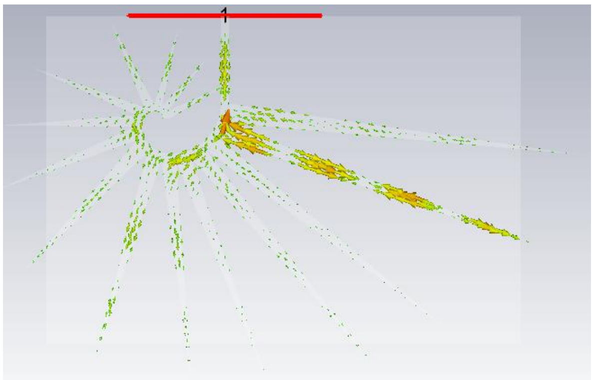
In fig.11 and fig.12 (EWFS with triangle) shows the surface current distribution and radiation patterns of the E-plane and H-plane are shown at different frequencies 3.82, 5.11, 6.65, 6.92, 8.48GHz. At 3.82GHz gain is 4.163dB (maximum gain), 5.11GHz gain is 3.384dB, 6.65GHz gain is 1.081dB (minimum gain), 6.92GHz gain is 3.075dB, 8.488GHz gain is 2.799dB respectively.



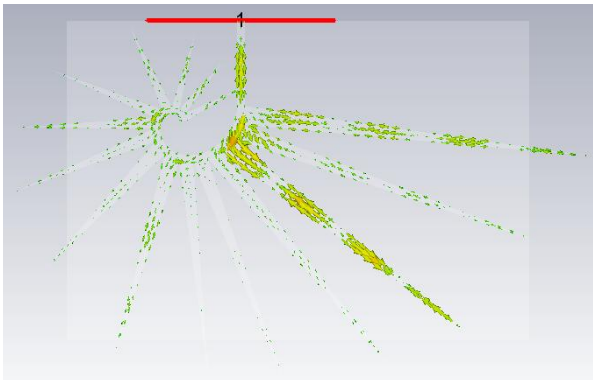
(a)3.82GHz



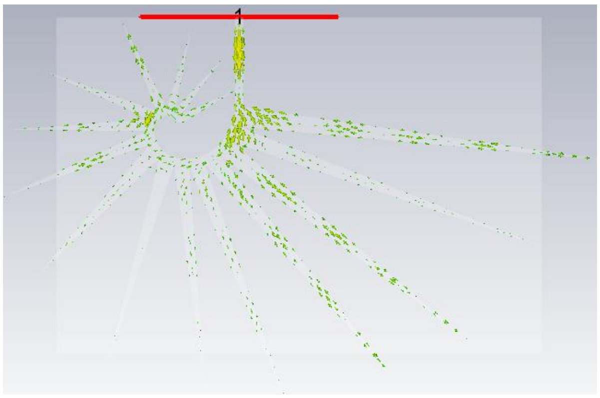
(b)5.11GHz



(c)6.65GHz

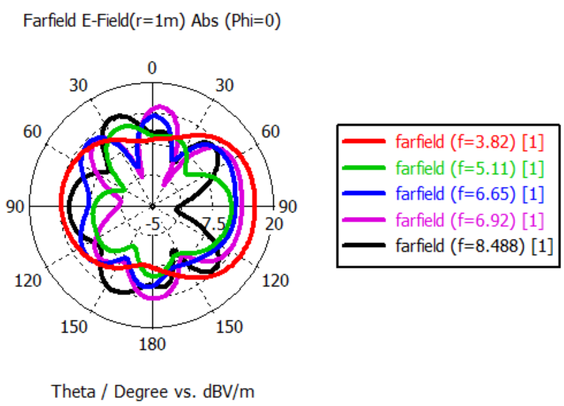


(d)6.92GHz



(e)8.488GHz

Fig .11. surface current distribution at (a)3.82 (b)5.11 (c)6.65 (d)6.92 (e)8.48GHz (EWFS with triangle)



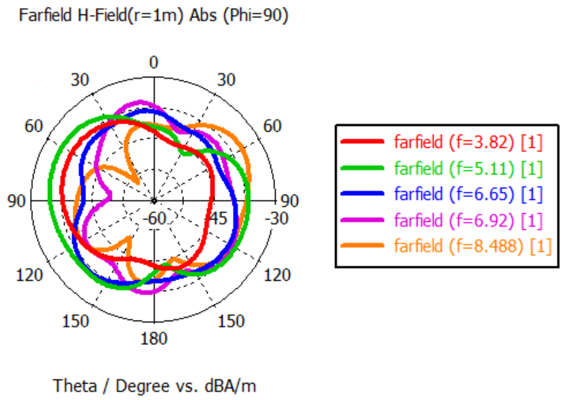


Fig. 12. E and H-field at resonating frequency (EWFS with triangle)

In fig.13 and fig.14 (IWFS with triangle) the surface current distribution and radiation patterns of the E-plane and H-plane are shown at different frequencies 3.91,4.97,5.80,6.90,8.46GHz. At 3.91 GHz gain is 3.701 dB(maximum gain), 4.97 GHz gain is 1.622 dB, 5.80 GHz gain is 2.307 dB, 6.90 GHz gain is 0.1509 dB (minimum gain), 8.46 GHz gain is 2.496 dB respectively.

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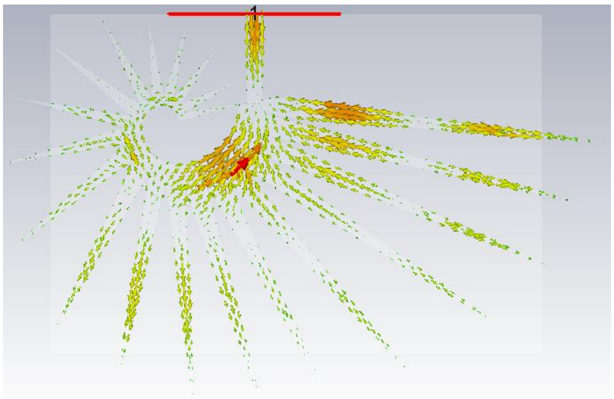
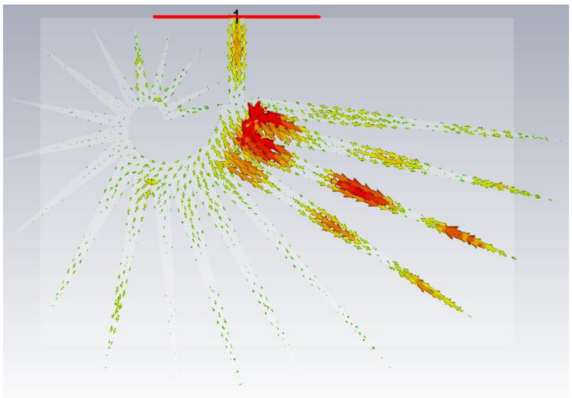
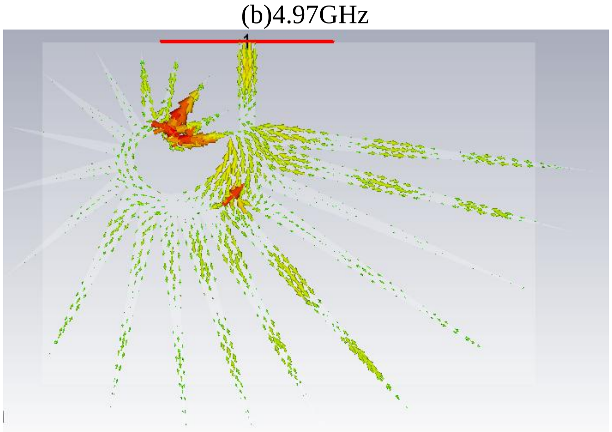


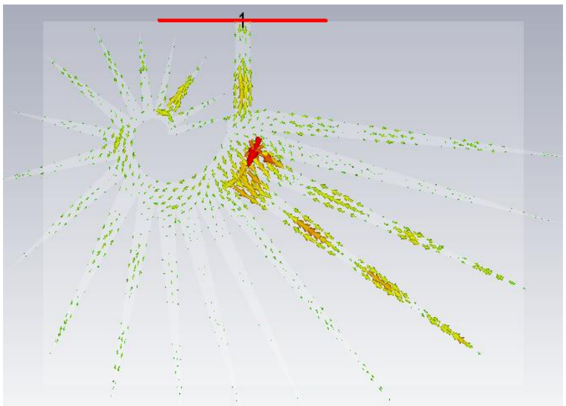
(a)3.91GHz



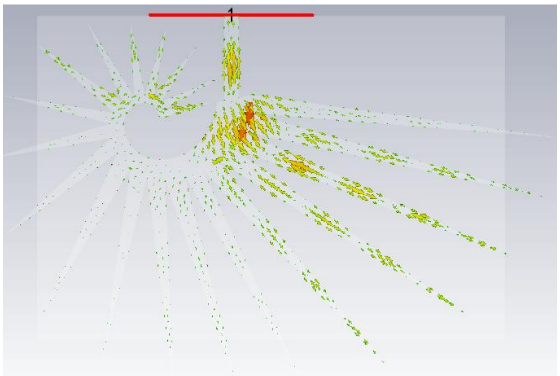
(b)4.97GHz



(c)5.80GHz

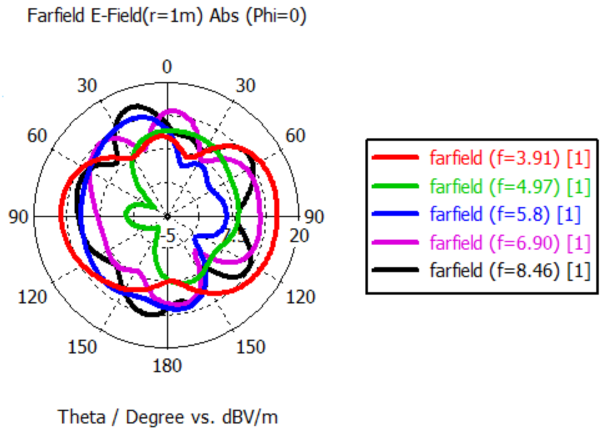


(d)6.90GHz



(e) 8.46GHz

Fig. 13. surface current distribution at (a)3.91 (b)4.97 (c)5.80 (d)6.90 (e)8.46GHz (IWFS with triangle)



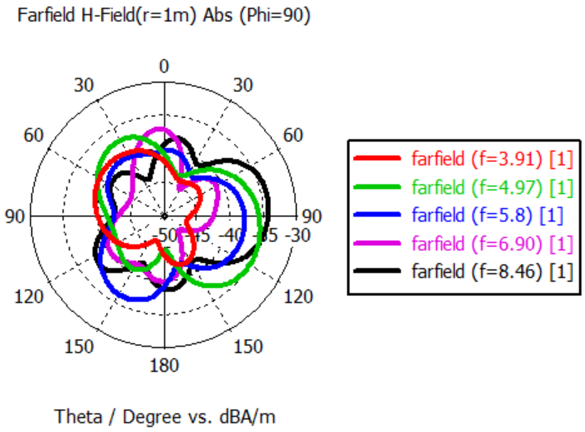


Fig. 14. E and H-field at resonating frequency (a)3.91 (b)4.97 (c)5.80 (d)6.90 (e)8.46GHz (IWFS with triangle)

V. RECTENNA DESIGN

A device which is a combination of antenna and rectifier is called a rectenna. Antenna is the main component in RF energy harvesting device which can receive the ambient energy from environment. Rectifier converts the waves in DC form. Rectifier circuit has qualities like low power consumption, good power, handling capability. Diode is the major key of rectifier circuit where schottky diode or normal PN junction diode is used. There are many types of rectifier circuit like basic rectifier (half wave and full wave rectifier) [17-20], voltage doubler, Villard circuit, Greinacher circuit, Bridge circuit, voltage multipier etc. RF energy harvesting is used in different fields such as medical, wireless sensor network, consumer devices, industrial applications [21-23]. The circuit diagram fig.15 uses an antenna, matching circuit, voltage doubler circuit and load. The voltage doubler circuit can double the applied input values. The chosen values of capacitor and resistor are C_1=C_2=100pf and RL =100KΩ and diode which is used is IN5408RL.

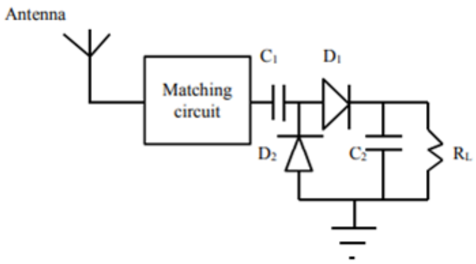
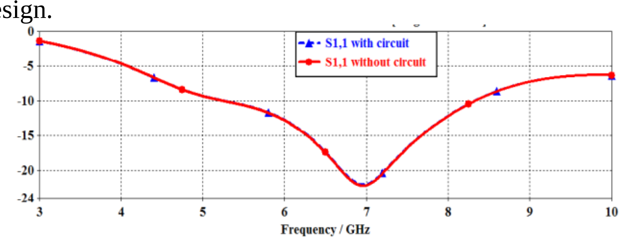
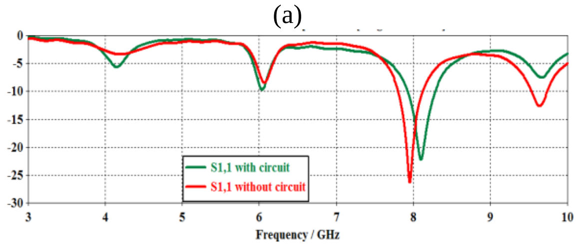


Fig.15. Rectifier Circuit [24]

The S_{11} comparison of the antenna with rectifier circuit shown in figures. Fig.16(a) shows that S_{11} graph of equal width fibonacci spiral design it has close agreement to rectifier circuit. In fig.16(b) we can see that IWFC (without triangle) design has better performance compared to EWFC design.



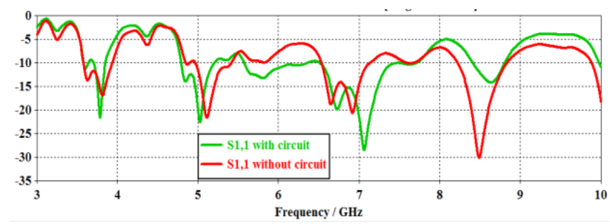
(a)



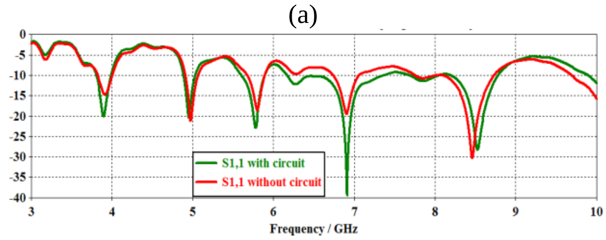
(b)

Fig. 16. Comparison of S_{11} parameter EWFS design

The S_{11} comparison of the antenna design EWFS & IWFS with triangle and with rectifier circuit is shown in fig.17. In fig.17 we can see that IWFS with triangle design has better performance compared to EWFS design with triangle.



(a)



(b)

Fig. 17. Comparison of S_{11} parameter with triangle EWFS and IWFS design

VI. CONCLUSION

In this paper, nature inspired fibonacci sequence microstrip patch antenna for energy harvesting applications is presented. The main thing of this design is that it's inspiration taken from nature. The proposed antenna design working in the range from 3 to 10 GHz. The first two designs are like snail's shape design and the difference between them is width one has equal width and other one has increasing widthand they has been resonating on 6.96GHz &7.95GHz, 9.63GHz respectively. In third and fourth design first two designs are used as basic design and triangles are added from starting point to last point respectivelyand improved results are achieved. Return loss of all the designs is

simulated and most accurate results are achieved in fourth design (Increasing width fibonacci spiral (IWFS) with triangle). The maximum gain achieved in these designs are 3.82GHz gain is 4.163dB (design-3) and 3.701 dB at 3.91 GHz (design-4). The antenna parameters return loss, gain, surface current, E-field, H-field are simulated. This antenna is used for energy harvesting and for this application a rectifier circuit is used and the compared return loss graph are shown above and they have close agreement to each other.

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