Preparing Generic Spiral Structure using Optimized Design Parameters

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Abstract— *In this paper, frequency reconfigurable spiral patch antenna is designed. Frequency reconfiguration is achieved by changing the electrical length of antenna with the help of PIN diode switch. Design parameters of spiral antenna are optimized to get improved results. After that, a generic spiral structure is designed using these optimized values. This will reduce complexity and simulation time. Now, there is no need to redesign spiral structure for different values of design parameters. Just have to put values of parameter in their respective variable and this generic structure will be converted to desired structure. This will reduce design complexity and simulation time.*

Keywords— FR4 Substrate, Rectangular Spiral Microstrip Antenna (RSMA), Coaxial feeding, PIN diode.

I. INTRODUCTION

Reconfigurable microstrip antenna plays a wider role in wireless communication. Microstrip patch may have many conventional shapes example rectangular, circular, spiral etc [1]. Rectangular spiral structure consist thin spiral pattern printed on substrate and fed from the center. It has advantages like reduced size, low profile and high efficiency. These structures show characteristics of circularly polarization with moderate gain. It can have any number of turns. Spiral structures are broadly classified into two categories- Archimedean spiral and rectangular spiral.

Spiral antennas are basically frequency independent antenna. Frequency independent antennas are those antennas whose radiation pattern, impedance and polarization remain unchanged over wide bandwidth. Frequency pattern of such antennas depends only on its physical dimensions. Spiral antenna's radiation pattern direction is perpendicular to plane of spiral. These antennas have wide half power beam width and it can be used in LAN, GSM, CDMA, RADAR applications etc [2]-[4]. Thus, it can avoid use of different antenna for different services. Numerical analysis of spiral by moment method and this antenna can be mounted over ground plain to attain bidirectional radiation and study of central loading to improve axial ratio[5]-[6].

Frequency Reconfigurability is the property of antenna to change its resonant frequency by changing structure while radiation pattern and polarization remains unchanged. Its operating frequency can be modified by adding or removing some length of the antenna through electrical, mechanical or any other means. The radiation pattern of this new modified length antenna possesses same characteristics as first one because current distribution will remain same.

Effective length of antenna can be changed by MEMS, PIN diodes, optical diodes or by mechanical methods. PIN diode switches are mostly used because they have advantages like fast switching speed, ease of handling capacity, pure resistance at RF frequency, excellent isolation and less power consumption. Also, this switch can easily be placed on spiral structure.

II. THEORY AND DESIGN

The smallest and largest radius of the spiral structure defines their respective upper and lower cut-off frequencies. Band theory defined working of spiral antenna as operating in the region where the circumference of the spiral is equal to its wavelength [7]-[8] as shown in figure 1.

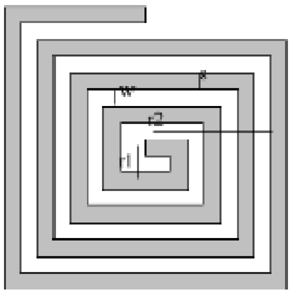


Fig. 1: Basic two wire rectangular spiral antenna

Where
r1: inner radius of spiral antenna
r2: outer radius of spiral antenna
W: width of spiral patch

S: distance between turns

While designing spiral structure, spiral arm is increased by discrete steps in the manner a_0, a_0, $2a_0$, $2a_0$, $3a_0$, $3a_0$, $4a_0$, $4a_0$……$(M-1)a_0$, $(M-1)a_0$ and Sa_0 is designed as shown in figure 2 The value of a_0 set as 0.503λ. The last turn length $4Ma_0=C$ is taken as outer peripheral length of spiral antenna [9].

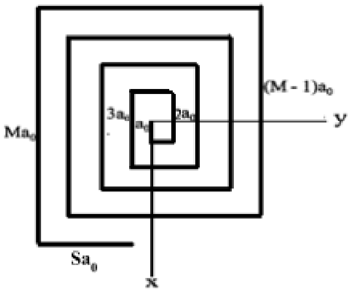


Fig. 2: Spiral patch configuration

Design parameters of spiral antenna are height, length & width of the structure, length and width of the spiral segment and gap between two turns which are calculated below. The design frequency of this antenna is 2.5 GHz.

The operating wavelength of proposed structure is

$\lambda = C/f = 120$ mm (C= speed of light=3×10^8)

1. **Thickness of Substrate**
   h= 0.134λ = 16.2 mm
2. **Length of substrate**
   L=0.6λ = 70 mm
3. **Width of spiral patch**
   w = 0.0135λ = 1.62 mm
4. **First element length of spiral patch**
   $a_0 = 0.0503\lambda = 6.04$ mm
5. **Peripheral length of spiral patch**
   $C = 4Ma_0 = 1.61\lambda = 187$ mm

We got length of the outermost spiral arm (C) is 187 mm which is within the range of $2\lambda g < C < 3\lambda g$ (i.e. 144 mm and 216 mm). This ensures antenna radiates tilted beam of the circular polarization.

This spiral structure is placed on dielectric material which is further backed by conducting ground plane. FR4 type material is selected as dielectric substrate which has dielectric constant of 4.4. This dielectric substrate and ground plane both show same physical dimensions square shape and same side length L which is 70 mm.

Designed spiral patch antenna is excited through coaxial wire feeding. Coax feed is applied at appropriate location of spiral structure. Coaxial connector is attached to lower surface of ground plane. Coaxial wire after passing through substrate is soldered to spiral patch as shown in figure 3. Coaxial feeding is mostly used because of its ease to fabricate, good impedance matching and low spurious radiation advantages [10].

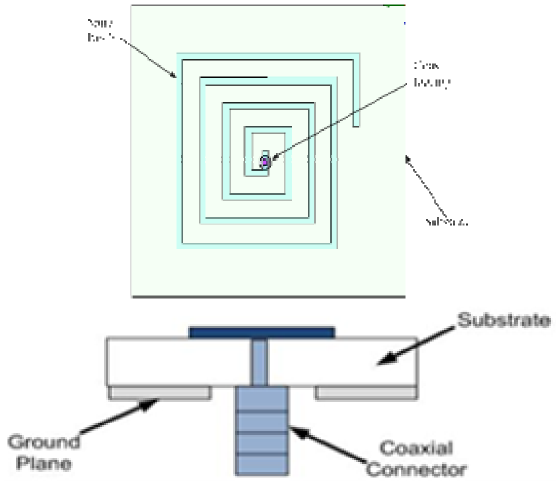


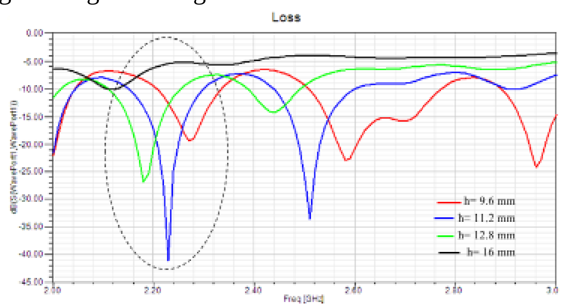
Fig. 3. Coaxial feeding of designed antenna

III. OPTIMIZATION OF THE DIFFERENT PARAMETERS

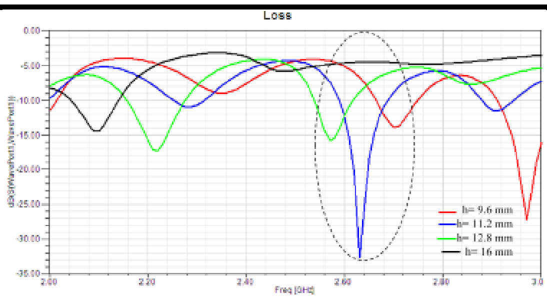
Effect of height of dielectric substrate and last segment length (*l*) of spiral patch on matching characteristics as well as radiation properties is analyzed. Variation of other parameter like the width of spiral is not discussed because it has negligible effect on performance of antenna

A. Substrate height optimization (h)

The thickness of the substrate (H) is calculated 16 mm by using the relation (0.134 λ) from existing literature. For optimization the antenna geometry is analyzed for different values of H in multiple of 1.6 mm. Simulated return loss at both switch ON and OFF state for different substrate heights are given in figure 4.



(a)



(b)

Fig. 4. Return loss for different substrate heights (h) at (a) PIN ON state (b) PIN OFF state

Table.1: Return loss for different substrate heights (h) at pin on and off state

Parameter	**h=9.6 mm**		**h=11.2 mm**		**h=12.8 mm**		**h=16 mm**	
	PIN ON	PIN OFF	PIN ON	PIN OFF	PIN ON	PIN OFF	PIN ON	PIN OFF
Resonant frequency(*f*) (GHz)	2.27	2.7	**2.23**	**2.63**	2.18	2.57	2.11	2.1
Return loss at f_r (in dB)	-19	-14	**-41**	**-32**	-27	-17	-10	-14

From above figures and table, the optimize value of substrate height should be 11.2 mm. FR4 (Glass epoxy) materials of height 1.6 mm is used in seven stacked layers to maintain the height of 11.2 mm is selected as substrate.

B. Last segment length optimization (*l*)

The line segment length has important role in maintaining axial ratio at radiating frequency. This segment length is optimized for $l=2a_0$ (12mm) to $l=5a_0$ (30mm) length. Segment lengths of designed spiral antenna are shown in figure 5.

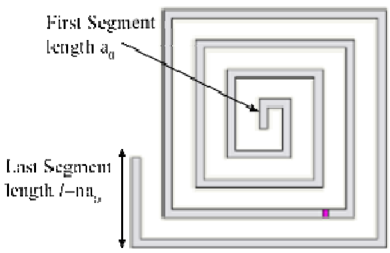


Fig. 5: Segment length representation of designed antenna

The value of last segment length (*l*) is obtained 24mm while designing four turn spiral antenna taking initial segment length 6 mm (a_0=0.0134λ). Thickness of substrate is taken as 11.2 mm. Antenna is analyzed for nearby values of segment lengths (in multiple of a_0=6 mm) to get best results in terms axial ratio. Simulated axial ratio is given in figure 6.

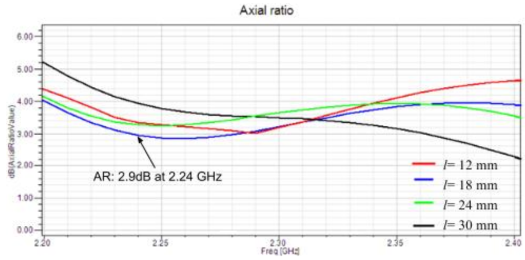


Fig. 6:Axial ratio for different segment length (l)

Table.2:Axial ratio for different segment lengths (l)

Parameters	***l*=12 mm**	***l*=18 mm**	***l*=24 mm**	***l*=30 mm**
Resonant frequency (f_r) (GHz)	2.24	2.24	2.24	2.24
Axial ratio at f_r (in dB)	3.34	2.96	3.27	3.93

From above figure and table, it can be seen that lowest axial ratio (<3dB) is obtained for *l*=18mm at 2.24 GHz. Antenna at other length parameters will not result good circular polarization due to axial ratio>3dB.

IV. PREPARING GENERIC SPIRAL STRUCTURE

Designing of spiral structure is difficult for every simulation for its every parametric variation. When we start modeling this structure in software (HFSS), it is quite difficult to place different size perpendicular segments. It is rigorous to remember the consecutive segments coordinate positions. This conventional process is time consuming as well. We may have to change the dimensions many times. Therefore, variable based generic design is prepared which is used for further simulations.

The design parameters of generic structure are shown in figure 7 below.

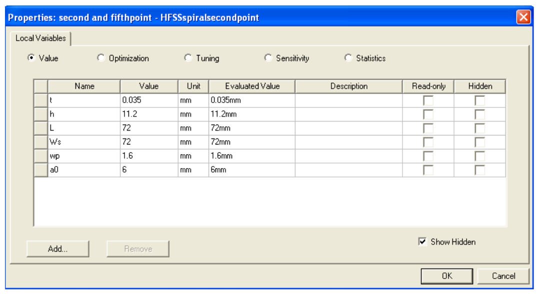


Fig. 7: Design properties of generic spiral structure

Where
L, Ws and h: length, width and height of Substrate
wp, a0 and t: width, first segment length and thickness of Spiral structure
Coordinates and dimensions of all segments of spiral patch are expressed in terms of design parameters. Such preparing of generic structure is shown in figure 8 and explained below.

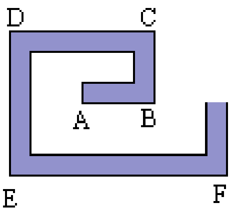


Fig. 8:Preparing generic spiral structure

Coordinates of point A: L/2, Ws/2, h
Length of segment AB: a_0
Coordinates of point B: L/2, Ws/2+a0-wp, h
Length of segment BC: a_0
Coordinates of point C: L/2+a0-wp, Ws/2+a0, h
Length of segment CD: $2a_0$
Coordinates of point D: L/2+a0, Ws/2-a0, h
Length of segment DE: $2a_0$
Coordinates of point E: L/2-a0, L/2-a0, h
Length of segment EF: $3a_0$
Coordinates of point F: L/2-a0, Ws/2+2*a0-wp, h
And so on……..
Prepared generic spiral structure using design parameters which are calculated for 5 GHz and 1 GHz is shown in figure 9 and 10 below.

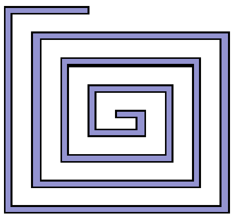


Fig. 9:Small generic spiral structure radiating at 5 GHz

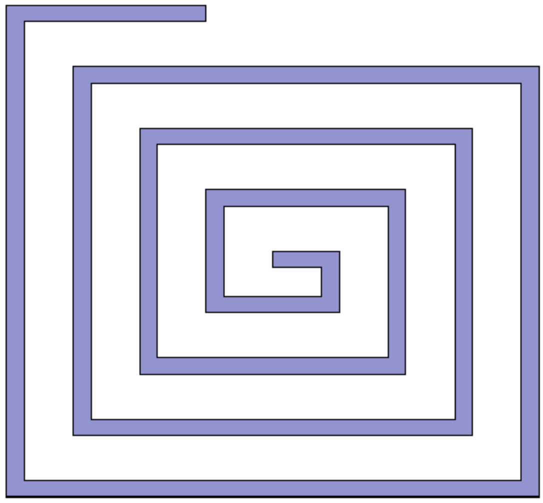


Fig. 10:Large generic spiral structure radiating at 1 GHz

V. CONCLUSION

Rectangular spiral microstrip antenna is designed and it is placed on FR4 substrate which is backed by conducting ground plane along with coax feeding. Different design parameters of antenna are optimized and optimized values of substrate height and last segment length obtained are 112 mm and 18 mm respectively. A universal spiral structure is prepared to avoid designing of spiral structure again and again for different design parameters and thus reducing simulation time and complexity.

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