DESIGN OF SPIRAL ANTENNA WHICH COVERS GHz FREQUENCY RANGES

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1 INTRODUCTION

Over the past few years there has been an increasing interest in the development and use of efficient antenna systems that have certain desirable characteristics and can be easily integrated into the various shaped bodies, conforming their outer surfaces. Equal attention has been given to the need for reducing the size of antennas, especially in cases where there are space limitations and the antennas must be conformal to the surfaces. At first glance, satisfying these requirements would appear to be a formidable task because, despite the difficulties involved in achieving these goals in most antenna systems there can be no sacrifice in electrical performance. However, antenna systems that can be designed to include these features can solve many problems and have numerous applications.

In microwave systems, a spiral antenna is a type of RF antenna. It is shaped as a two-arm spiral, or more arms may be used. Spiral antennas were first described in 1956. Spiral antennas belong to the class of frequency-independent antennas which operate over a wide range of frequencies. Polarization, radiation pattern and impedance of such antennas remain unchanged over large bandwidth. Such antennas are inherently circularly polarized with low gain. Array of spiral antennas can be used to increase the gain. Spiral antennas are reduced size antennas with its windings making it an extremely small structure. Lossy cavities are usually placed at the back to eliminate back lobes because a unidirectional pattern is usually preferred in such antennas. Spiral antennas are classified into different types; Circular spiral, Rectangular spiral and star spiral etc.

E.M. Turner has introduced the spiral antenna in 1954. The spiral antenna is class of frequency independent antenna under angle concept. The spiral is a planar structure that is fabricated by photo etching a two-arm spiral on copper clad substrate. When the composite spiral is fed, the spiral radiates circularly polarized energy in bi-directional beam perpendicular to the plane. Only the physical dimensions of the spiral limit the frequency band of radiation. To obtain unidirectional beam, the spiral is mounted at the open end of a closed back metallic cavity which, when in the region of λ/4 deep, redirects this half of the energy constructively to form a single beam. However the energy within the cavity is absorbed to achieve broadband radiation. The spiral radiator, being a balanced device, needs to be fed from a balanced transmission line. This necessitates the incorporation of a balun transformer. A traditional two arm spiral antenna radiates by exciting a traveling wave along the arms of the spiral with each arm having opposite polarization at the feed point [23]. Radiation occurs when the current of adjacent arms is in phase creating constructive interference in the far-field. This leads to the concept of radiation bands within the spiral antenna where each band creates a loop that is λg in circumference. This shows that the high frequency limit is created by the resolution of the inner turns and the low frequency limit is controlled by the outer circumference of the antenna. When applying miniaturization to a spiral antenna it is desirable to decrease the wave velocity in the low frequency portion of
the spiral while leaving the high frequency portion unmodified. Ideally this will decrease the low frequency operational point of the antenna while leaving the high frequency operational point intact. Traditionally this is done by designing a tapered substrate that increases in height as it approaches the outer portion of the spiral, concentrating higher levels of dielectric loading at the low frequency region of the spiral. The Periodic Spiral Antenna is created by orienting each arm normal to the plane containing the spiral and oscillating the arms in the same dimension with the amplitude as a function of angular distance. Spirals are extensively used circularly polarized wideband antennas [17]. The wideband features of spiral antenna brought it to the limelight in recent literature, particularly for miniaturization. The fundamental inspiration for miniaturization is to slow down the wave traveling within the antenna structure. Numerous approaches have been pursued to achieve it, which includes dielectric or magnetodielectric loading, artificial materials, spiral arm shaping, distributed reactive loading and arm orienting vertically [12]. Conversely, when using the popular dielectric loading approach, the input impedance is also lowered. On the other hand, when the wave velocity is reduced by meandering of metalized arms, the axial ratio also deteriorates [17]. It has been established that coiling of the spiral arms provides for impedance control [12, 18]. The vast majority of circuits fabricated on PCB use FR-4 [19–22]; thus this volumetric design or miniaturization is weighty, whereas PET is commonly found in RFID inlays and tags. Furthermore, both FR-4, which is a ceramic-based material [23], and polyethylene terephthalate (PET) are nonbiodegradable substances that may take decades to decompose in landfills largely contributing to the bulk of annually generated electronic waste. A spiral antenna is known to have wide bandwidth, i.e., good spectral efficiency compared to other planar antennas [1]. Spiral antennas are based on Archimedes principle for a spiral, which can have many shapes depending on design goals. Theoretically a spiral antenna with an infinite number of turns with optimal spacing between arms has infinite spectral efficiency and bandwidth. Practically we need to deal with the fact that the unlimited size is not possible, and the turns cannot be too close to each other or the gain will suffer. The antenna is intended for a module design in which other components will be placed on the backside of the module. Thus a ground plane is used to shield components from the antenna radiation. Therefore the antennas should be integrated on a multilayer PCB (Printed Circuit Board). UWB has been specified in the frequency range 3.1 to 10.6 GHz [2]. No matter which UWB solution is implemented a spectral-efficient antenna is required. To use more than one single antenna is one possibility if the multiband technique is used [3]. If a wide single-band system, or the solution to change pulse-width within a multi-band system, is desired, an antennaa system that covers the entire frequency band is required.

Thus the spiral antenna consists of three main components
1. The spiral radiator
2. The backing cavity
3. The balun transformer

![Spiral antennas](image)

Fig1 Conventional Circular and rectangular Spiral antennas

2 CONCEPT OF FREQUENCY INDEPENDENT ANTENNAS
An antenna with primary electrical characteristics that vary insignificantly with frequency over an extremely wide range; the various types of such antennas constitute a group of broadband antennas of which the ratio of maximum operating frequency to minimum
ranges to 20:1 or more. The theoretical and technological foundations for frequency-independent antennas were established between 1957 and 1965 by the American scientists V. H. Rumsey, D. Dyson, and others.

The weak dependence of the antennas’ characteristics (the shape of the directive pattern, the front-to-rear ratio, the input impedance and so on) on frequency stems from the fact that the radiation field is created by currents distributed over a finite portion of the antenna surface, known as the active region, beyond whose limits the currents decrease sharply; as the frequency varies, the active region changes in such a way that its relative dimensions expressed in terms of the wavelength $\lambda$ corresponding to the frequency remain unchanged. The lower wavelength limit $\lambda_{\text{max}}$ of the antenna’s operating range is determined by the frequency at which the active region is shifted to the edge of the antenna. The antenna’s operating range can, in principle, be extended toward the shorter wavelengths as far as desired, but in practice the limit is determined by a number of incidental factors, such as the cross-sectional dimensions of the power feeder that are acceptable for given values of the losses introduced, the breakdown, the transmitted power, and so on.

The most common frequency independent antennas are in the form of two-arm spiral and conical helical antennas, log-periodic antennas, and sickle-shaped dipoles. There are also multiarm spiral and helical antennas that have several independent inputs; a well-known type is in the form of a conical dipole with an ultra-wide range of input impedances.

Frequency independent antennas are used for shortwave radio communications, telemetry, and radio astronomy. During the 1970’s lightweight types of relatively simple design were developed for various frequency ranges: log periodic wire antennas were developed for decametre waves, and spiral and helical antennas were created for centimetre and millimetre waves from strip conductors deposited on a fibreglass substrate by a photochemical process. Highly directional frequency independent antennas are being designed as horn antennas with walls having transverse ribs and antenna arrays composed of log-periodic or conical helical radiators positioned along radii in a specific sector of a circle.

Researchers recognized early that the two arm spiral could be excited in two distinct modes while at least half the energy or gain is lost, the spiral remains a useful device for many applications and high quality results over band widths exceeding five octaves, 32:1 are quite common.

Early investigators recognized that two distinct modes were possible for the two arm spiral. The Normal Mode or Sum Mode that excited the two arms out of phase and a difference mode that excited the two arms with equal amplitude, but within phase currents. It was thought this mode would also be frequency independent with nearly constant impedance and null on axis, but attempts to utilize it were unsuccessful. The problem of feed line radiation due to the in-phase currents was recognized and seemed unsolvable. A number of people attempted to use hybrid rings to feed a two arm spiral. The two ring outputs used to feed the spiral were brought into the centre of the ring and attached to two coaxial lines placed side by side that went up through the cavity centre and attached to the spiral terminals. Various means were tried to suppress the feed line radiation. Surrounding the feed lines with absorber, which was needed in the cavity anyway for broad band operation helped, but did not allow the quality of results being obtained in normal mode operation.

The problem of operating the spiral in two or more modes simultaneously was simply and elegantly solved in 1960 when Paul Shelton of Radiating Systems Incorporated, suggested the use of a spiral with three or more arms. Shelton recognized that the number of useful modes on a spiral would be one less than

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the number of arms on the spiral (i.e., a three arm spiral would have two useful modes; a four arm spiral would have three useful modes). Rumsey introduced concept of frequency independent antennas. There are two concepts 1) Angle concept 2) Ratio concept (scaling concept).

3.2.1 ANGLE CONCEPT
A structure, which can be entirely defined in terms of angles (without any characteristic length dimension) will have characteristics that are independent of frequency. Frequency independent means that the observable characteristics of the antenna such as input impedance, radiation pattern vary negligibly over band of frequencies within the design limitations. Such antennas have unlimited bandwidth, in the sense that the upper and lower frequency limits of useful performance may be independently specified by the designer.

Ex: Equi angular spiral antenna

2.2 RATIO CONCEPT
The second idea is that if a structure becomes equal to itself by a particular scaling by 1/ω of its dimensions, it will have the same properties at frequencies at frequencies f and ωf. The antenna characteristics are a periodic function, with a period of |log ω| of the logarithm of the frequency. Antennas obtained from this principle are called log periodic antennas. By choosing ω to 1, the variations of the properties can be made very small.

3 CONCEPT OF ACHIEVING CIRCULAR POLARIZATION:
For achieving circular polarization the following are required.
1. Two linear components of equal amplitude.
2. 90º phase difference of one component relative to the other i.e. the two components should be in phase quadrature.
3. The two components should be orthogonally spaced i.e. space quadrature.

Fig3.2 Circular polarization
The radiation from square spiral can be explained from the band theory of Burdine. The theory is in good accordance with experimental observation. Dual arm spiral can be considered a two-wire transmission line transformed into a radiating structure. Two radiation bands exist, one which produces a single lobe radiation pattern with a maximum along the axis of the spiral, while the second produces a split beam pattern with null on-axis. These are known as fundamental or split beam modes respectively.

3.1 FUNDAMENTAL OR NORMAL MODES
Consider an isolated, tightly wound, dual arm spiral antenna in which two arms are excited by equal amplitude and 180º out of phase. In the vicinity and for some distance from the origin, the currents in the adjacent conductors are out of phase so that little or no radiation takes place. As one proceeds further away from the origin along the curves, the phase relationships between the currents in adjacent arms become random so that the net radiated energy in the region is small. In the neighbourhood of the region where the width= λ/4, the currents in the adjacent arms become random so that the net radiated energy in the region is small. In the neighbourhood of the region where the width= λ/4, the currents in the adjacent arms are in phase and efficient radiation takes place. In square spiral, there are number of apparent discontinuities. Within the radiation band the discontinuities are spaced very nearly one-quarter wavelength apart so that the reflected
components cancel. Two arm spiral antenna in normal mode is shown in fig 3.4.

The spiral is fed by a two wire transmitter wire at the high frequency end, at feed points A and B as shown in the figure 3.3. Any signal with a 180° out of phase current applied by the transmission line to the antenna will seek out the dipole pair antenna that resonates or brings the currents in phase, at the signal frequency passing from the highest frequency antenna pair d₁-d₁ toward the lowest frequency antenna pair dₙ-dₙ. By resonance, we mean the point where the original out of phase current flows in phase as a result of the phase change caused by propagation over the differential distance between the dipole pair and the feed point.

This differential distance assumes that one arm of the pair excites an adjacent arm, which when compared to the first arm can be evolved into a circular spiral by bending the finite dipoles, eliminating the d chords, and replacing them with an Archimedean spiral with an increasing radius as shown above. This illustrates the fundamental mode of operation of the round spiral antenna.

Let A and A₁ are two different current elements at opposite points on the same conductor such that the arm diameter AA₁ is λ/π. Current vectors A & A₁ are in phase since vector A₁ is directed opposite to the vector A by virtue of geometry plus an additional 180° due to (arm) path length AA₁. Corresponding to A & A₁ on first arm, there exist another set of current vectors B and B₁ on second arm. To each group of different current elements lying within the radiating band on the round diameter there exist a corresponding group which is in time and space quadrature to the first. Therefore the radiation is circularly polarized. The radiation patterns will have a maximum value along the axis normal to the plane of the spiral.

1. Fig 4 Radiation Pattern of a Spiral Antenna Operating In Normal Mode

The following are the steps to design the rectangular spiral antenna:

STEP 1:

After installation of this software in the PC, just we have to click on the “Start button” option and then click on “All Programs”. Different folders are available in that click on “Mentor Graphics SDD”. Hyper Lynx 3D EM folder is opened. Click on that, different applications are available, in that click on “Program manager” option.

After that a new window is opened which is shown in figure 5.1.
STEP 2:
In the “Hyper Lynx 3D program Manager” window click on “Hyper Lynx 3D Designer” Option. After that different applications are displayed such as MGRID, PATTERN VIEW, MODUA and so on.

STEP 3:
Run MGRID. Select File->New command. MGRID shows you the Basic Parameters dialog as shown in fig 5.2. In the Length group, select the Unit as “mil”. In the Meshing Parameters group, change the Highest Frequency (F max) to 18 GHz and the Cells per Wavelength (N cell) to 20. Double click the “No.1 Grid Size…” in Layout and Grids group. Change it to 0.25 mils and select OK when you are prompted to edit the Grid Size.

STEP 4:
MGRID is ready for geometry input. After that, we have to click on predefined rectangular antenna structure available in the top of the window. After that rectangular type structure is displayed in the window as shown in fig 5.4 after giving the specified values such as spiral width value is 12, strip width is 0.4, spiral height value is 12, and gap width value is 0.2.

STEP 5:
Click on “port” option available in the window for finding out the different parameters of an antenna. Different options are available after doing that. In that select “port for edge group” option and then a new window is displayed. In that window click on “Advanced extension” option and click ok to continue. After that just drag by using
the mouse on edges of the structure. Different port numbers are displayed after doing the process. Structure with port numbers as shown in fig 5.5

Fig: 5.5 Structure with port numbers window

5. SIMULATION PROCESS AND RESULTS FOR RECTANGULAR SPIRAL ANTENNA

After declaring the ports again go to port option and click exit port option and then save the geometry. For finding out the different antenna parameters we have to follow the following steps.

STEP 1:
Select Process->Simulate command. The Simulation Setup dialog comes up (see Figure 5.6). We would like to simulate the Structure from 0.5 to 18 GHz with 4 frequency points. Select the Enter button in Frequency Parameters dialog. MGRID prompts you for the frequency range. Enter Start Freq = 0.5, End Freq = 18, and Number of Freq = 4. Select OK to add the frequency parameters into the list box. We don’t need to use MODUA to display the s -parameters normally. We are going to use the integrated visualization on MGRID. Select the Define Graphs button (Figure 5.6). It brings up the “S-Parameters and Frequency...” dialog. Select Add Graph button. You are prompted for the Graph Type. Select S-Parameters. You will be prompted for Display Selection for the Graph. Select dB[S (1, 1)]. Select OK. Continue to go back to the Simulation Setup dialog. You will see “graphs are defined” next to the “Define Graphs” button. What we want to do is to jump into s-parameter visualization directly by pre-defining the graphs. Select OK to continue. MGRID will invoke IE3D to perform the simulation in the background. It takes seconds to finish. After simulation, IE3D will create graphs for the s-parameters dB plot.

Fig: 5.6 Simulation setup

STEP 2:
Click on “current distribution file” option and "radiation pattern file” option available in the window, a new window is displayed, just enter the elevation angle values as well as azimuth angle values for the purpose of radiation pattern display and then click OK to continue the process and previous window is displayed .click OK.

STEP 3:
Go to “window” option available at the top in the “polygon editor window”. Just click on that, different options are available as shown in fig 5.7 .We have to select our required parameters.

Fig 5.7 Polygon editor window

STEP 4:
From the available options click on “3D current distribution” to know current flow of an antenna, which is shown in the fig 5.8.

**STEP 5:**
From the available options click on “3D radiation pattern” parameter. 3D radiation pattern of rectangular spiral antenna is displayed and as shown in the fig 5.9.

**STEP 6:**
From the available options click on 2D radiation pattern. 2D radiation pattern window is displayed as shown in fig 5.10. In that window select the required elevation and azimuth angle values. After selecting required values click OK to continue. Then 2D radiation pattern graph is displayed as shown in fig 5.11. In that graph PG represents the power gain of an antenna, AG represents the antenna gain. Expressions for this PG, AG is given as

\[
\begin{align*}
PG & = (\text{Directivity}) \times (\text{antenna efficiency}) \\
AG & = K \times (\text{Directivity}) \quad (K = \text{reference value})
\end{align*}
\]

**STEP 7:**
Go to step 3 and click on “Directivity vs. Frequency” display option and then a new window is displayed for selecting the required elevation angle and azimuth angle values. After that click on OK. Directivity vs. Frequency graph window is displayed as shown in fig 5.12.

**STEP 8:**
Go to step 3 and click on Gain vs. Frequency display option and then a new window is displayed for selecting the required elevation angle and azimuth angle values. After that click on Ok. Gain vs. Frequency graph window is displayed as shown in fig 5.13

Fig 5.13: Gain vs. Frequency display window

6. CHARACTERISTICS OF SPIRAL ANTENNAS

The following are the characteristics of spiral antennas:

1. Frequency independent
2. Wide band width
3. Circular polarization
4. Consistent gain and impedance

5.1 ADVANTAGES

The following are advantages of spiral antenna

1. Excellent direction finding or tracking capability
2. Compact size, lightweight & less complex structure
3. Easy mounting capability on any surface
4. Wide beam width
5. Reduced aerodynamic drag
6. Retaining radar cross section

5.2 DISADVANTAGES

In spite of several advantages this antenna will have the following disadvantages

1. More than below half of the power is absorbed in the backing cavity resulting in low efficiency.
2. Shortening the arm length results in poor radiation characteristics.
3. Low gain

6.3 APPLICATIONS

The following are advantages of spiral antenna

1. Mainly used for Direction Finding (DF) systems mounted on aircrafts, missiles and ships
2. Military surveillance
3. Satellite tracking systems

In this chapter basic theory of spiral antennas is discussed. The concept of frequency independent antennas, concept of achieving circular polarization. Different types of spiral antennas, spiral antenna characteristics, advantages, disadvantages, applications are discussed clearly.

7. CONCLUSION

The design of spiral antennas has been successfully simulated in the IE3D tool and the design analysis has been studied. This design can also be analysed by varying the dielectric constant, substrate materials. This software also helps in physical realization of spiral antennas with the help of PCB circuit board. Different spiral antennas can be designed for different frequencies using this software. Simulated results of the antennas are compared and observed that rectangular spiral antenna is better as compared to circular spiral antenna based on gain value of the antennas. Since gain is inversely proportional to bandwidth.

8. FUTURE SCOPE

Further scope of this project is recommended in the following areas:

1. Circular polarization is important characteristic of EW antennas.
2. Further reduction in size and improvement in performance can be taken up by modulated rectangular spiral antennas with gradual modulation.
3. Further DF systems are going to be extended up to 40GHz. Hence an ultra-broadband antenna can be designed over the frequency range of 0.5-40 GHz by extending techniques described in this project.
1. A project on Designing and Simulation of Composite Spiral Antenna using Network Analyzer tool.


5. A.W.Rudge, K.Milne, A.D.Olver, P.Knight,”The Handbook of Antenna Design” volumes1&2, 1892.


7. www.mentor graphics IE3D.com website for information about tool.


13. D. Kim, J. Kim, J. Kim, W.-S. Park, and W. Hwang, “Design of a Multilayer Composite-Antenna-


