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Designing Single and Double-Arm Spiral Antenna for RF Energy Harvesting

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ABSTRACT

RF energy harvesting is an important field of study as it has the potential to generate power from ambient sources, which can be further used to run low power devices. In this paper, we propose two distinct designs of spiral slot antenna as 'a single arm' and 'a double arm' spiral antenna for RF energy harvesting systems. Both antennas were designed on a FR-4 epoxy substrate and were simulated to recover wideband energy from sources present in the environment like GSM, WiMax. Next the efficiency of both antennas was analyzed by comparing parameters like return loss.

Keywords: *Spiral Antenna, Theoretical Modelling, Ultra-Wide Band, Wireless Communication.*

1. INTRODUCTION

Battery life is finite and this makes RF energy harvesting a potent field of study. Industries and companies require devices to be independent, in the sense that these devices should be powered wirelessly, while the system is mobile. In this direction the RF energy harvester looks to capture ambient energy and harvest it, so as to charge batteries and activate sensors [1]-[5].

This paper focuses on the spiral antennas to trap the ambient energy present in the environment [6]. While a patch [7] or a microstrip [8] antenna would be able to work at a designed frequency, the spiral antenna has a much larger bandwidth in the range of ultra-wide band and thus can scavenge energy from numerous sources like GSM900, WiMax and WLAN thus making it a perfect antenna for energy harvesting. Moreover the bandwidth of the spiral antenna can be optimized by changing various parameters like the number of turns in the antenna, the feed length, slot width etc. [9].

While prior research has been conducted to validate the use of spiral antenna in energy harvesting, little effort has been put in analyzing the efficiencies of various types of spiral antennas. Here the two specific design types in the category of spiral antennas are: The single arm spiral and the double arm spiral antenna.

These antennas were meant to be utilized to support the GSM900 [10] band communication (IEEE 802.11ah), Bluetooth (IEEE802.15) and to scavenge energy in the WiMax range (IEEE802.16a) and even some high frequency bands.

The arrangement of the paper goes as follows. First we have described the detailed modelling of both the antennas for supporting multi-frequency bands followed by a comparison of their return losses and commenting over the better design.

2. THEORETICAL MODELLING

Both the antennas were independently modelled and optimized to achieve best possible return loss in the desired frequency bands.

While modeling a spiral antenna many design parameters have to be considered [9].The parameters which define the spiral antenna are:

1. Spacing between the turns.
2. Width of arm.
3. Inner Radius of spiral
4. Outer Radius of spiral
5. Feed length.

a. Double arm Spiral Antenna

The inner radius is measured from centre of the spiral to centre of the first turn while the outer radius is measured from centre of the spiral to centre of the outermost turn. The front and the back view of the antenna are given in Fig. 1 and Fig. 2.

We can calculate R_1 and R_2 by using

$$F_{high} = c/2\pi R1 \quad (1)$$

$$F_{low} = c/2\pi R2 \quad (2)$$

Where R2>R1

In this paper spacing between the arms of the spiral and the width is kept constant as 0.3mm. Next the antenna is optimized to get out suitable wide-band.

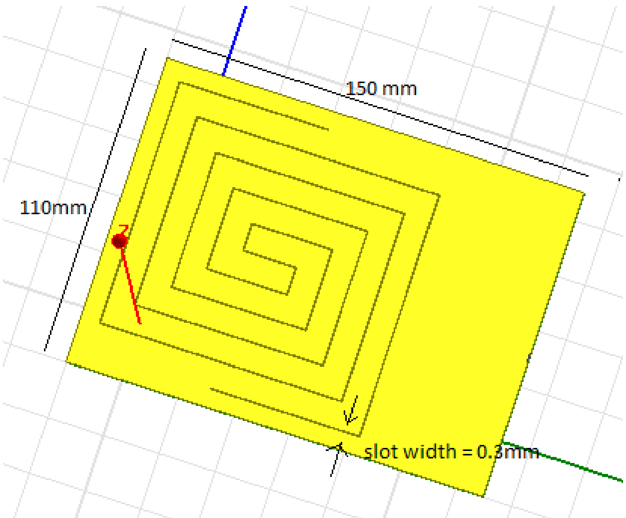

Fig. 1. Top View Of Double Arm Spiral

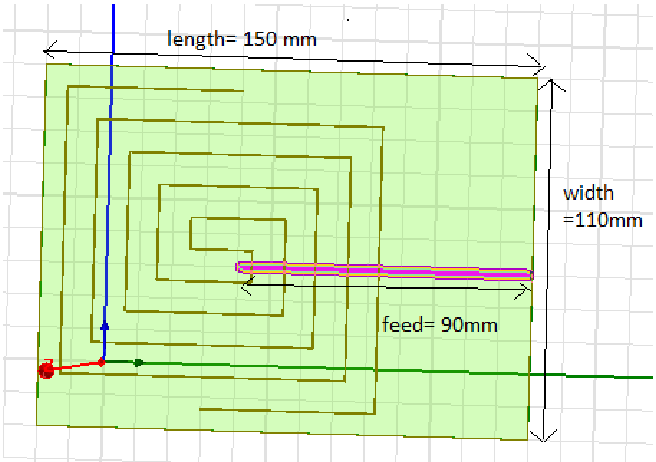

Fig. 2. Feed touching the center of double-arm spiral antenna

b. Single arm Spiral antenna

Here a single spiral arm antenna is designed using a planar feed. The antenna efficiency is optimized by changing various parameters as mentioned before. The design equation [11] which was followed for the design of single arm spiral antenna is as follows:

$D_n = 2(n-1)\, D_1$ where n=2,3,4 etc (3)

Where D_1 is the first arm length and D_n is the nth arm length. Later the lengths were optimized in order to get the desired results. The front and back view of the single arm spiral is given in Fig. 3 and Fig. 4.

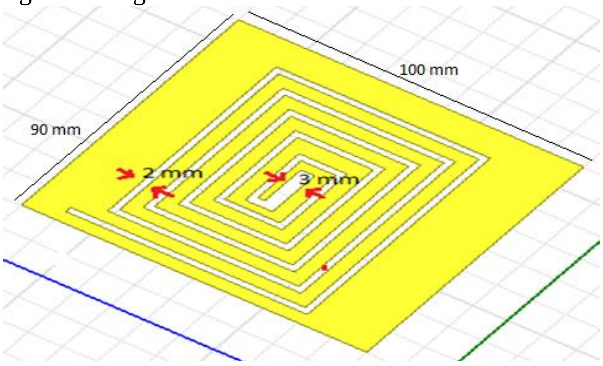

Fig. 3. Top View Of Single Arm Spiral.

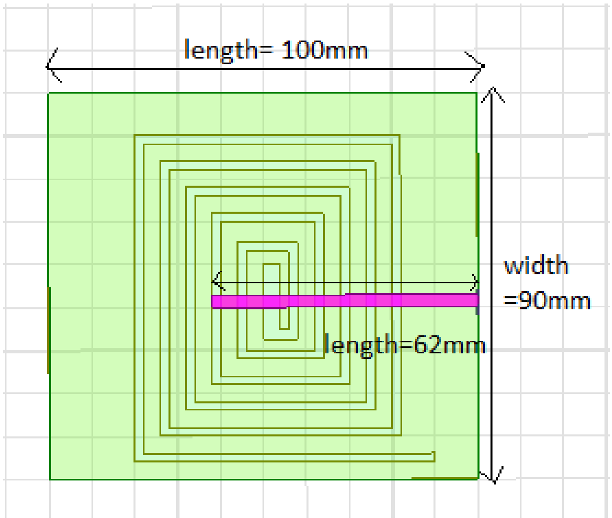

Fig. 4. Single arm spiral antenna with optimized feed length.

c. Feed length and width

Feed length is designed and is taken as the top of our antenna fabricated on the substrate. Fig. 5 shows a typical micro-strip feed line with a patch antenna. The design equations which were utilized to find the feed length and the width are as follows [12]

$$\varepsilon_e = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2\sqrt{1+12\left(\frac{H}{W}\right)}} \quad (4)$$

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r+1}{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23+\frac{0.11}{\varepsilon_r}\right) \quad (5)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \quad (6)$$

$$\frac{W}{H} = \left\{ \begin{matrix} \frac{8e^A}{e^{2A}-2} \\ \frac{2}{\pi}\left[B-1-\ln(2B-1)+\frac{\varepsilon_r-1}{2\varepsilon_r}\left\{\ln(B-1)+0.39-\frac{0.61}{\varepsilon_r}\right\}\right] \end{matrix} \right\}$$

for $Z_0 > 44\text{-}\varepsilon_r$ narrow-strip (7)

Where ε_e is the effective dielectric constant and ε_r is dielectric of the material which is 4.4. While W is the width of the micro-strip feed line and L is its length of the feed line.
H is the height of the substrate which is 1.6mm in this case. A, B are constants and Zo is Impedance which is taken as 50ohms.

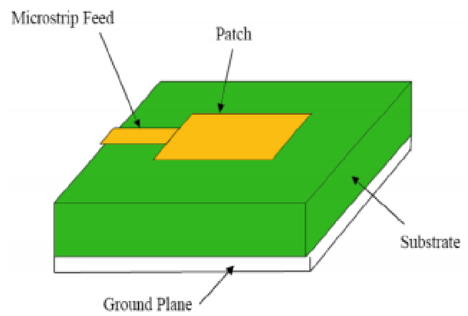

Fig. 5. Microstrip Line Feed

3. ANTENNA DESIGN

The front side of a slot spiral antenna utilizes the planar feed [8]. The structure consists of micro-strip line that wind towards the center of the spiral antenna. The feed is on the top of the substrate while the slotted copper plate is at the bottom and acts as a ground plane. The height of the substrate is 1.6 mm and the impedance of the feed line is 50ohms.

The thickness of the feed is 3.04 mm and has a length of 17.101mm calculated through design formulas at a particular frequency. Next the feed length was changed to a particular value until the optimum results were obtained. Later the other parameters like width, number of turns etc were changed and the design offering optimized result was finalized.

Table 1 and Table 2 mentioned below depicts the change in return loss in dB at different frequencies with the change in the feed line length. For single arm antenna, the optimized feed length was 62mm, while for the double arm antenna it was 90mm ,as at these lengths the return loss has been better.

TABLE 1: Change In Return Loss (Db) At Different Frequencies With Change In Feed Length For Single-Arm Spiral Antenna.

Feed Length	0.945 GHz	1.845 GHz	2.4 GHz	5.8 GHz
25mm	-1.33	-2.84	-4.26	-12.17
40mm	-10.45	-18.24	-13.83	-5.12
50mm	-14.01	-7.19	-12.61	-9.97
62mm	-8.0	-21.84	-20	-13.1

TABLE 2: Change in return loss (dB) at different frequencies with change in feed length for Double-Arm spiral antenna.

Feed Length	945MHz	1845MHz	2.4GHz	5.8Ghz
55 mm	-15.18	-34.67	-19.77	-9.180
62mm	-11.25	-23.40	-31.77	-3.246
71mm	-7.90	-16.55	-14.65	-16.277
90mm	-17.67	-21.50	-24.91	-19.083

4. SIMULATION RESULTS AND DISCUSSION

The return loss of both the antennas were plotted for a frequency sweep of few GHz. Fig. 6 and Fig. 7 shows the significant return losses obtained at various frequencies for single and double arm antenna respectively .The substantial return losses obtained at desired frequencies were also marked in Fig. 6 and Fig. 7.

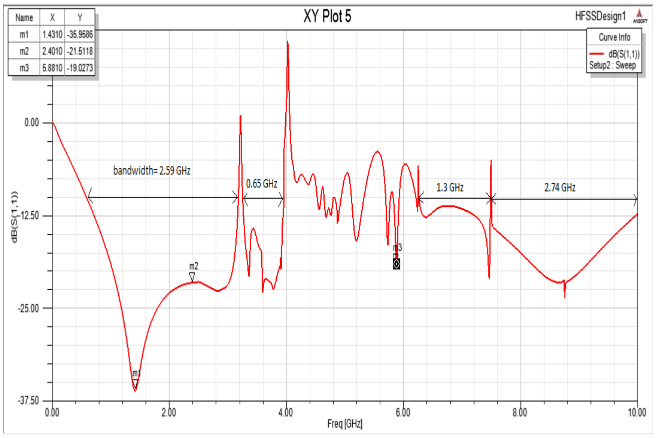

Fig. 6: Return loss vs frequency of double arm spiral slot antenna.

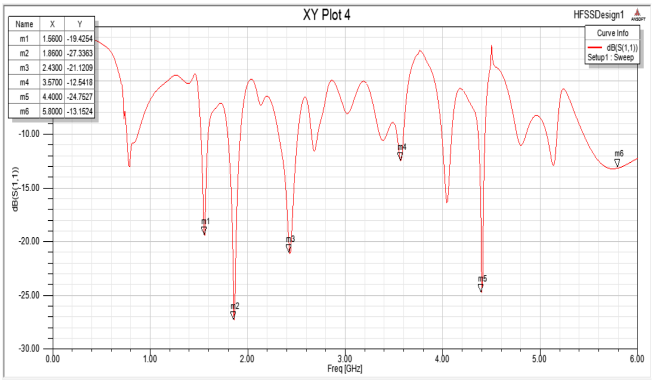

Fig. 7: Return loss vs frequency of single arm spiral slot antenna.

Since this paper focuses over the design which will help to scavenge energy from various bands mainly the GSM 900, WLAN and WiMax bands we will compare the return losses at these particular bands.

From Fig. 6 and Fig. 7 we can see that in the GSM900 frequency range (downlink) the double-arm spiral has a maximum return loss of -17.13dB at a frequency of 961MHz while the single-arm has a return loss of -7dB at a frequency of 950MHz. Similarly in the WiMax and WLAN bands the double arm spiral has better return loss than the single arm spiral antenna. Table 4 and 5 compares the maximum return losses between both antennas WLAN and WiMax range.
Moreover, the double arm spiral also has a continuous wide-band of 2.6GHz from 0.7 GHz to 3.3GHz with an appreciable return loss. The other bandwidths are as 2.74GHz, 1.6GHz and 0.65GHz as mentioned in the figure.

TABLE 3: Comparison Of maximum Return Losses between Single and Double arm Spiral Antenna in GSM900 band (downlink).

Type Of Antenna	Frequency (GHz)	Return loss (dB)
Single Arm Spiral	0.95	-7
Double-Arm Spiral	0.96	-17.13

TABLE 4: Comparison Of maximum Return Loss between Single and Double arm Spiral Antenna in WLAN band.

Type Of Antenna	Frequency (GHz)	Return Loss (dB)
Single Arm Spiral	2.44	-19.8
Double-Arm Spiral	2.46	-21

TABLE 5: Comparison Of maximum Return Loss between Single and Double arm Spiral Antenna in WiMax band.

Type Of Antenna	Frequency (GHz)	Return Loss (dB)
Single Arm Spiral	3.56	-12
Double-Arm Spiral	3.5	-23.11

TABLE 6: Comparison Of maximum Return Loss between Single and Double arm Spiral Antenna in IEEE C band.

Type Of Antenna	Frequency (GHz)	Return Loss (dB)
Single Arm Spiral	4.4	-24.75
Double-Arm Spiral	5.8	-19.11

5. CONCLUSION

In this paper two distinct spiral antennas were designed and the designs were optimized to have an appreciable return loss. In conclusion, it's shown here that a double-arm spiral antenna is a better option to scavenge RF energy as compared to a single-arm antenna as it covers wide band of frequencies and at the same time offers appreciable return loss.

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