Sierpinski Carpet Fractal Antenna (SCFA) For RFID Applications

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Abstract—**This work presented the design, simulation and analysis of Sierpinski carpet fractal antenna (SCFA) for Radio Frequency Identification (RFID) application. This prototype antenna was fabricated on RT Duroid 4350 of dielectric constant, ε_r = 3.48 with thickness of 1.524 mm while the center frequency was 5.8 GHz and using microstrip line feed. The commercial electromagnetic simulator, CST Microwave Studio was used to carry out the design and simulation. The prototype SCFA was realized and the measurement and analysis was carried out using Vector Network Analyzer (VNA) and Antenna Training System (ATS). Simulated and measurement values of the parameters of the antenna were compared. It was observed that the measured and simulated values of the parameters of the antenna were closed with each other and the omnidirectional radiation pattern was realized. The result shows that the fractal antenna is very small in size while keeping high radiation efficiency.**

Keywords – Radio Frequency Identification (RFID), Computer Simulation Technology (CST), Vector Network Analyzer (VNA), Antenna Training System (ATS), Sierpinski Carpet Fractal Antenna (SCFA).

I. INTRODUCTION

The RFID system is an automatic identification system using radio waves to transfer data between reader units and movable objects called a transponder or tag [1]. It is used to identify, track or categorize a product, documents, electronic devices, luggage, people or pets.

An RFID system has two main components: the RF reader (known also as the base station or interrogator) and the RF tag (or transponder) [2]. At the reader, it is a handheld or fixed unit that can interrogate nearby RFID tags and obtain their identification number (ID) numbers using radio frequency (RF) communication. The tag consists of two main components. There is a small silicon chip or integrated circuit which contains a unique ID and an antenna that can send and receive radio waves.

An antenna for an RFID-tag must satisfy some of the following requirements [3]:

1. The antenna element should be thin
2. It should be flexible with a simple shape
3. The impedance bandwidth should be wide
4. The antenna should provide omnidirectional radiation pattern

Fractal antenna is a new member in the family of antennas. They have peculiar properties that make them suitable for applications where wideband and multiband are important parameters of the overall performance. Fractal technologies allow designing miniature antennas and integrating multiple telecommunication service such as cellular, wireless LAN, GPS, and hiperLAN2 into a single device.

By using fractal antenna, it allowed the antenna to be compact and match with the chip impedance in the RFID frequency range and to provide omnidiectional performance in the plane perpendicular to the axis of the antenna.

Lots of work had been done on fractal antenna [1], [2], [4], [5], [6]. Noorsaliza [4] had developed a SCFA for cellular applications at 1.575 GHZ and 2.4 GHz. FR4 with permittivity, ε_r = 4.5 and thickness, h = 1.6 mm was used as a substrate. Microstrip line feed method was used for the design.

Mircea Rusu etc all [5] had develop a dual band antenna at the center frequency of 868 MHz and 2.45 GHz. RT Duroid (5870 and 4003) and 1.575 mm thickness was used as a substrate.

Sierpinski gasket patch and monopole fractal antenna was designed by Abd Shukur [6] and the substrate material used is FR4 with permittivity, εr = 4.7 and thickness of 1.6 mm. This antenna was operating at 1.8 GHz by using microstrip line feed. Multiband fractal antenna was realized.

I.I. SCOPE OF WORK

In this paper, the work is limited to design a second iteration of Sierpinski carpet antenna using CST Microwave Studio. The microstrip patch antenna was designed and fabricated using RT Duroid 4350 with dielectric constant of 3.48 and thickness of 1.524 mm respectively. The antenna was designed at center frequency of 5.8 GHz. Finally, the parameters of the microstrip antenna were measured by using VNA and ATS. The measured values were compared with the simulated values. The design and the performance of the SCFA were optimized for RFID-tag applications with the specifications as indicated by Table I.

TABLE I. SPECIFICATION OF PERFORMANCE FOR RFID

Parameters	Specification
Center frequency	5.8 GHz
VSWR	< 2
Return Loss	< -10 dB
Bandwidth	< 500 MHz

II. METHODOLOGY

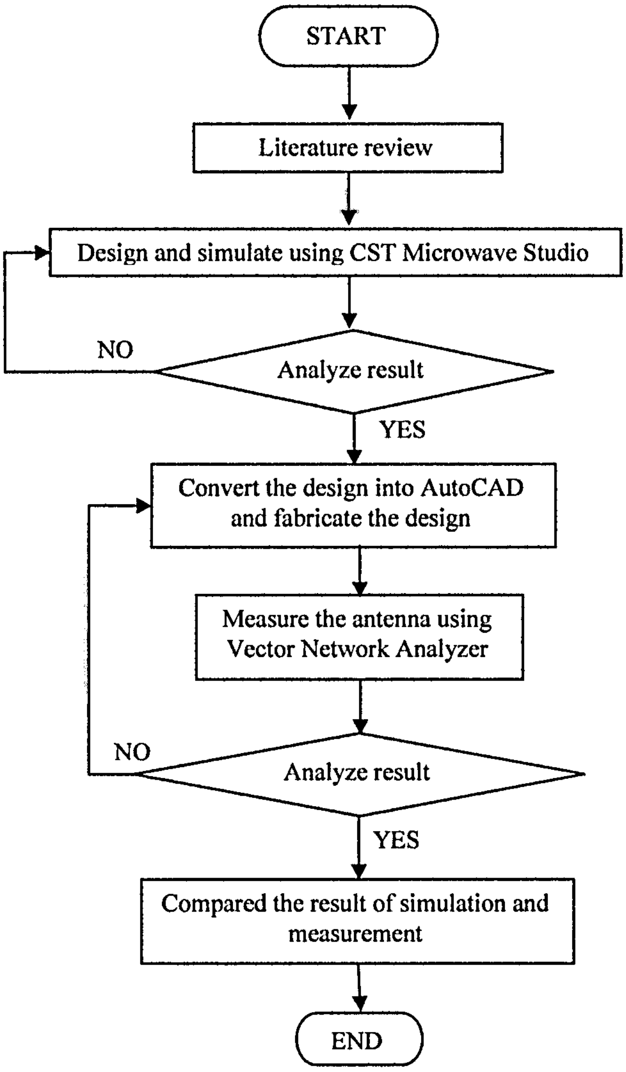

Figure 1. Research flow chart

Figure 1 shows the flowchart of the workflow from the starting to the end and summarizes all the work done to complete the designing of SCFA.

First of all, literature review was carried out then followed by designing and simulation of the antenna using CST Microwave Studio. The optimization procedure was carried out to obtain the best performance of the antenna. Then, the antenna was fabricated on the RT Duroid 4350 as a substrate, with specification as indicated by Table II.

TABLE II. SPECIFICATION OF SUBSTRATE

Frequency	5.8 GHz
Substrate	RT Duroid 4350
Dielectric Constant, $\varepsilon\varepsilon_r$	3.48
Loss Tangent	0.0031
Substrate Height	1.524 mm
Conductor Thickness	0.035 mm

Typical values of dielectric constant for microstrip antenna are in the range of $2.2 \leq \varepsilon_r \leq 12$. By using the lower end of the range of the dielectric constant better efficiency, large bandwidth, and loosely bound electric field for radiation pattern into space can be achieve [4]. This work requires a small size antenna hence RT Duroid 4350 was chosen to achieve the best response at 5.8 GHz.

III. SIERPINSKI CARPET FRACTAL ANTENNA DESIGN

The Sierpinski carpet is a deterministic fractal which is a generalization of the Cantor set into two dimensions [4]. To construct this fractal, it must begin with a square in the plane, subdivide it into nine smaller congruent squares of which drop the open central one, then subdivide the eight remaining squares into nine smaller congruent in each of which drop the open central one.

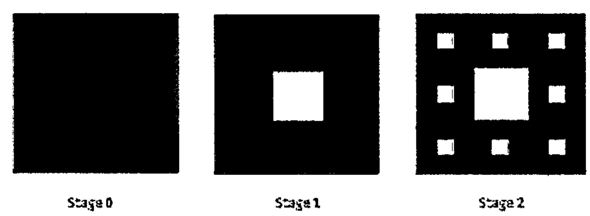

Figure 2. The three stages in the construction of SCFA

Let N, be the number of black boxes, L_n is the scale factor for length of a side of white boxes, A_n is the scale factor for fractional area of black boxes after the nth iteration [4].

$$N_n = 8_n \qquad (2.1)$$

$$L_n = \left(\frac{1}{3}\right)^n \qquad (2.2)$$

$$A_n = L_n^2 N_n = \left(\frac{8}{9}\right)^n \qquad (2.3)$$

The design of the SCFA was starts with the single basic square patch operating at 5.8 GHz. The length, L is slightly less than a half wavelength in the dielectric [4]. The width, W and length, L of the square patch were calculated using 2.4 and 2.8.

$$W = \frac{c}{2f_o\sqrt{\frac{(\varepsilon_r+1)}{2}}} \qquad (2.4)$$

For f_o = 5.8 GHz and $\varepsilon_r = 3.48$, this yields the value of W = 18.462 mm. Then, compute the ε_{eff} for microstrip line, with $\frac{W}{h} \geq 1$, by means of equation for square antenna.

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{L}}}\right) \quad (2.5)$$

By using (2.6), it is found that $\varepsilon_{eff} = 2.622$. With this value of ε_{eff} now the fringe factor, ΔL and effective length L_{reff} can be calculated by using (2.7).

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{reff}}} \quad (2.6)$$

$$\Delta L = 0.412h\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.262\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.813\right)} \quad (2.7)$$

The value of ΔL turns to be 0.7648 mm and $L_{reff} = 15.9715\ mm$, then obtain the improved value of L by using (2.8).

$$L = L_{reff} - 2\Delta L \quad (2.8)$$

By using (2.8), the value of L is 14.4419 mm. The simulation for the basic structure with transmission line feeding resulted in an antenna size of 14 mm x 14 mm. The single structure antenna with transmission line feeding is shown in figure 3.

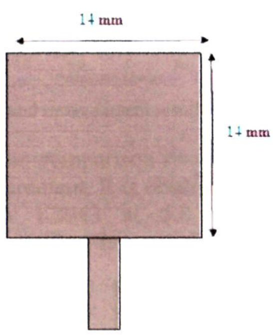

Figure 3. Square patch antenna

Then, the first iteration for SCFA structure was designed by dividing the basic square patch antenna into 9 smaller squares and removes the square at the center, so the remaining square is 8 [4]. The scale factor for the first iteration, L_1 = 0.33. Then, multiply L_1 with 14.4419 mm and equal to the length of small square is 4.7658 mm. The first iteration of SCFA shows in figure 4. From equation (2.1) and (2.2), the value of the L_1 and N_1 was calculated.

$$L_1 = \left(\frac{1}{3}\right)^1 = 0.33$$

$$N_1 = 8^1 = 8$$

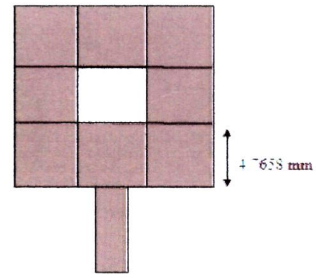

Figure 4. First iteration of SCFA

Lastly, the second iteration of sierpinski carpet structure was designed by divided each remaining eight square into nine smaller square and drop all the center square for each remaining square. For this state, the remaining smaller square is 64 [4]. Then, multiply L_2 with the 14.4419 mm and will get the length for this remaining smaller square is 1.6031 mm. L_2 is the scale factor for the second iteration. It also has been calculated using equation (2.1) and (2.2). Figure 5 is shown the second iteration for SCFA.

$$L_2 = \left(\frac{1}{3}\right)^2 = 0.111$$

$$N_2 = 8^2 = 64$$

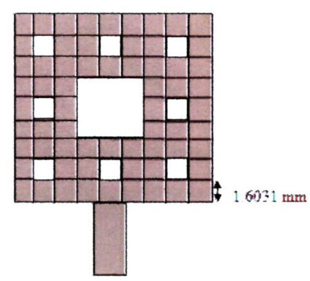

Figure 5. Second iteration of SCFA

IV. RESULT AND DISCUSSION

The first consideration that must be taken in the simulation process is the determination of input impedance from the impedance locus of the proposed antenna. The return loss was maintained below -10dB. The return loss, the impedance bandwidth can be determined which indicates the performance of the simulated antenna.

Table 3 describes the performance of SCFA. It shows that the performance of the SCFA at center frequency of 5.8 GHz in term of return loss, VSWR and percentage bandwidth. All the values were very close with each other.

TABLE III. SIMULATION AND MEASUREMENT RESULT AT RESONANT FREQUENCY OF 5.8 GHZ

	Simulation result	**Measurement result**
Return Loss, S11 (dB)	-20.662	-15.927
VSWR	1.2043	1.38
Percentage Bandwidth	1.724%	2.069%

Figure 6 highlights the measurement and simulated values of the return loss. It is observed that the return loss for the simulation result is -20.662 dB at the resonant frequency of 5.8 GHz while for the measurement result is -15.927 dB. There was slight discrepancy due to many reasons, such as flaw in fabrication or the actual value of the dielectric constant of the substrate.

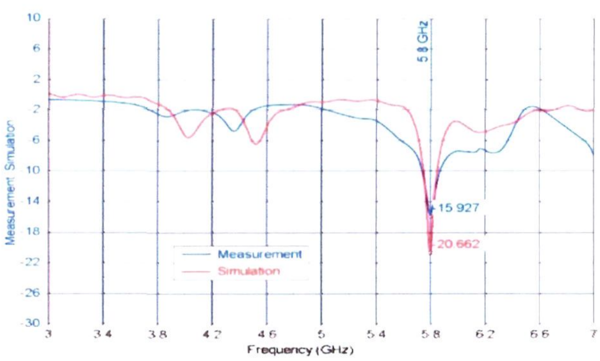

Figure 6. Simulation and measurement results of return loss for SCFA

Figure 7 shows the comparison results of VSWR between simulation and measurement. It is observed that VSWR for the simulation result is 1.2043 at 5.8 GHz while for the measurement result is 1.38 at the same frequency.

VSWR is an indication of how good the impedance matching is. Higher VSWR shows greater mismatch. The antenna has a good performance as the value of VSWR is less than 2.

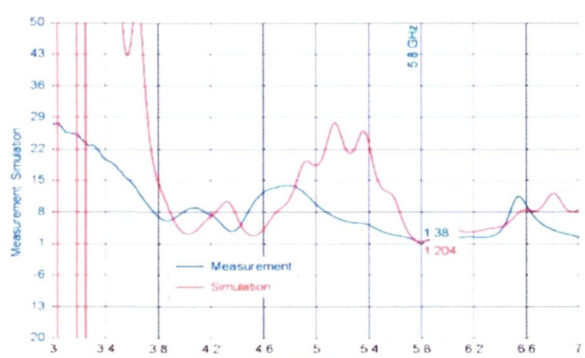

Figure 7. Simulation and measurement result of VSWR for SCFA

The simulation result of input impedance for this antenna is 50.08 ohms at center frequency of 5.8 GHz while the measured result of input impedance was 51.052 ohms at the same frequency.

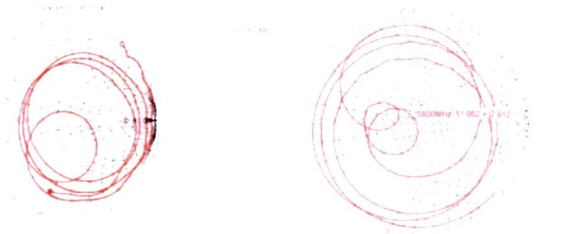

Figure 8. Simulation and measurement result of input impedance for SCFA

The radiation pattern is obtained in farfield region. Figure 9 and 10 shows radiation pattern of the SCFA based on the simulation and measurement results respectively. The different in pattern may be due to many reasons as the measurement was not carried out in anechoic chamber.

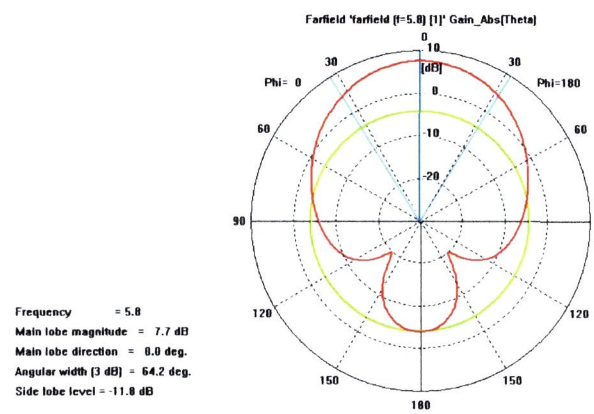

Figure 9. Radiation pattern of the simulated result for SCFA

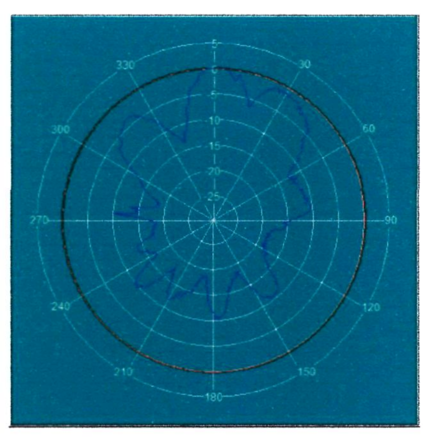

Figure 10. Radiation pattern of the measured result for SCFA

Figure 11 shown the 3D radiation pattern and which gives better illustration of the field strength surrounding the antenna. The simulated antenna radiation pattern indicated that the maximum directive gain is 9.454 dB at the center frequency 5.8 GHz.

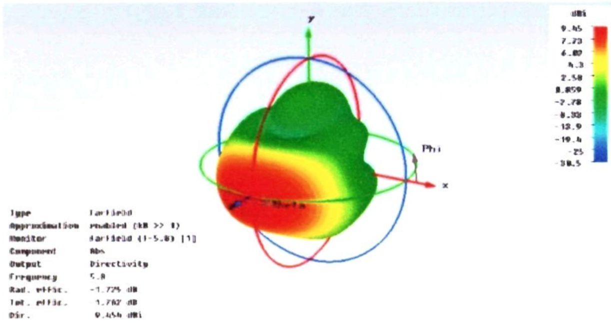

Figure 11. 3D radiation pattern of the directive gain for SCFA

Figure 12 show the prototype antenna after the antenna designed and by using CST Microwave Studio and being optimized to achieve the best response. The total dimension of this designed antenna is 54 mm x 54 mm.

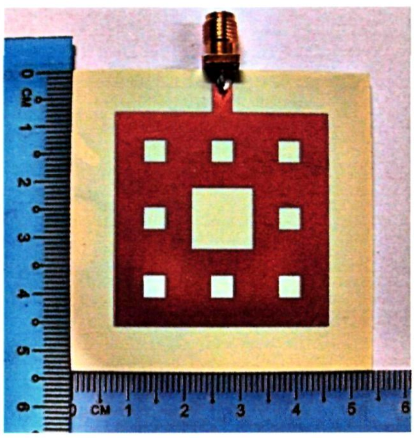

Figure 12. The prototype of SCFA

V. CONCLUSION

This paper presented the design of the SCFA for RFID application with good return loss, gain, directivity and wide bandwidth. The simulated values of return loss are -20.662 dB and VSWR is 1.2043 at the resonant frequency of 5.8 GHz, while the measurement results of the return loss is equal to -15.927 dB and VSWR of 1.38 at the same frequency. This fractal antenna also resulted in wide bandwidth and multiband as well as compact in size.

VI. FUTURE DEVELOPMENT

The results can be improved in future using many ways. To gets better the performance of this antenna, a few recommendations of future works are suggested as follows:

1. Modify the dimension of the antenna to make it can operate for other application based on frequency ratio.
2. Use another type of substrate that has great electrical characteristics and offers great performance like Roger, alumina or silicon.
3. Fabrication process should be précised in order to get the same size with proposed antenna.
4. The improper soldering of SMA connector will cause losses and affect the measurement result. So, the soldering must be done carefully to get a good result.

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