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The Effect of Flare Angle on the Behaviour of Sierpinski Monopole Antenna for Multi Band Applications

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Abstract: *This paper aims to presents the behaviour of Sierpinski monopole gasket for different flare angles. The advancements in the wireless standards demand for the flexibility as well as unobtrusiveness within antenna system design. The most important aspect in the design of antennas for advanced telecommunication systems are the performance in terms of operating range, radiation characteristics and their behaviour at different frequencies, ease of installation, size and cost. One of the efficient methods to solve this difficulty is by the usage of Fractal Antenna structuresas they offer adaptability in terms of low profile, ease of installation, compactness, low cost. The most commonly used fractal structure is the Sierpinski gasket because its performance can be altered by modification of various design factors. One of the prominent features of the Sierpinski gasket design is its flare angle.In this paper, a simple Sierpinskigasket design with different flare angles is presented by using Ansys- HFSS (High Frequency Structure Simulator) simulation software. It was observed that the change in the flare angle alters the operating frequency range as well as the radiation characteristics. As this structure offers multi band characteristics, it finds many applications in the area of wireless communications and especially in the Cognitive Radio (CR) environments by incorporating suitable switching techniques.*

Keywords: *Wireless communications, Fractal Antennas, Sierpinski gasket, Multiband behaviour, low profile, Ansoft-HFSS*

I. Introduction

Modern wireless communication systems require the antennas with smaller dimensions with wider operational bandwidths. The fractal shaped structures offers better performance and flexibility in terms of reduction of size because of theirself-repetitive characteristics and number of iterations are involved in the antenna design. Various fractal geometries have been introduced in recent years by the vast research in this domain such as Sierpinski carpet, Koch Fractal curve, Murkowski Curve, Sierpinski triangle, Cohen-Murkowski Geometry etc. Some of these geometries have been particularly useful in reducing the size of theantenna, while other designs aim at incorporating multi-band characteristics. These structures offers low profile with moderate gain with multi band operation. The multi band operation of the fractal structures is due to their recursive, infinite, space filling and self-symmetry properties. One of the prominent fracture structure considered for study is the Sierpinski gasket. The Sierpinski gasket structure can be obtained by eliminating the central portion of the main triangle by an inverted triangle with its vertices at middle point of the main triangle and the same process can be repeated by applying number of iterations. The performance of this structure can be modified by either changing the substrate material, shape of the ground plane, distance of the ground plane to the antenna structure, number of iterations and the flare angle. The resonant frequency can be calculated by using the formula as reported in [2].

$f_r = K \frac{c}{h} cos\frac{\propto}{2}\delta^n$ -----(1)

Where K = Constant and is 0.152
forSierpinski Gasket for a given substrate
α= flare angle
δ = scaling factor and is 2
n= iteration number

The theoretical analysis of the Sierpinski gasket of the iterative transmission model is presented in section II.

The present study of the paper mainly concentrates on the changing the flare angle of the Sierpinski gasket and their behaviour in terms of its band of operation and radiation characteristics is presented in Section III. The following figures show the Sierpinski gasket with different flare angles. Fig .1 shows the Sierpinski gasket with flare angle $\alpha = 30^0$ and Fig.2 shows the $\alpha = 60^0$ and Fig.3 shows the $\alpha = 90^0$

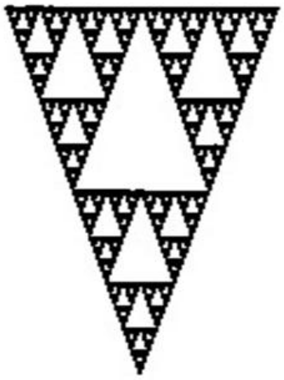

Fig.1. Sierpinski gasket with α = 30^0

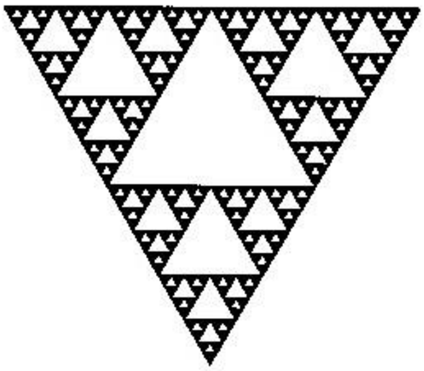

Fig.2. Sierpinski gasket with α = 60^0

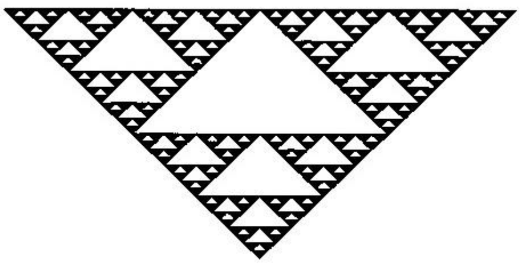

Fig.3. Sierpinski gasket with α = 90^0

The Figures shown above depicts that the change in flare angle will alter the structure in terms of change in the shape of the triangles and the design considerations were discussed as in the Section III.

II. An Overview Of Iterative Transmission Line Model

A simple model of iterative transmission line model for Sierpinski antenna was introduced in this work based on the number of iterations considered for the design. It explains that multiband properties of Sierpinski gasket are inbuilt towards its fractal structure. The model of iterative transmission line provides a good prediction of behaviour of Sierpinski antenna. Validityof the representation is assessed by means of applying the model of iterative transmissionline to three fractal Sierpinski antennas by means of flare angles $\alpha = 30^o$, $\alpha = 60^o$ as well as$\alpha = 90^o$. Using this model of analysis, the initiator for isosceles triangle is considered and by the application of reciprocity, the initiator requires four parameters to represent the matrix and is given by

$$[s] = \begin{bmatrix} \alpha & \beta & \beta \\ \beta & \gamma & \delta \\ \beta & \delta & \gamma \end{bmatrix} \text{----(2)}$$

The simultaneous iterative structures can be built by the given one iteration and the corresponding parameters for the next iterative process can be written as

$$\alpha_{n+1} = \alpha_n + 2\beta_n^2\left(\alpha_n + \frac{\beta_n^2}{1-\gamma_n}\right).$$

$$\frac{1}{1-(\gamma_n-\delta_n)\left(\alpha_n+\frac{\beta_n^2}{1-\gamma_n}\right)} \text{------(2)}$$

$$\beta_{n+1} = \left(1+\frac{\delta_n}{1-\gamma_n}\right)\frac{\beta_n^2}{1-(\gamma_n+\delta_n)\left(\alpha_n+\frac{\beta_n^2}{1-\gamma_n}\right)} \text{--(3)}$$

$$\gamma_{n+1} = \gamma_n + \frac{\beta_{n(E_nH_n+G_n)+\delta_n(G_nB_n+H_n)}}{1-B_nE_n} \text{--(4)}$$

$$\delta_{n+1} = \frac{\beta_{n(E_nC_n+F_n)+\delta_n(B_nF_n+C_n)}}{1-B_nE_n} \text{---(5)}$$

And given the auxiliary parameters B, C,D,E,F,G,H are defined as

$$B = \left(\gamma + \frac{\delta\alpha+\gamma\beta^2}{1-\alpha\gamma}\right)\frac{\beta}{1-\gamma^2-\frac{\beta^2(\delta+\gamma^2)}{1-\alpha\gamma}} \text{--(6)}$$

$$c = \frac{\left(\delta+\frac{\beta^2\gamma}{1-\alpha\gamma}\right)}{1-\gamma^2-\frac{\beta^2(\delta+\gamma^2)}{1-\alpha\gamma}} \text{----(7)}$$

$$E = \beta\frac{\gamma+\frac{\delta(\delta\alpha+\gamma)}{1-\alpha\gamma}}{1-\alpha\gamma-\frac{\delta(\delta\alpha^2+\beta^2)}{1-\alpha\gamma}} \text{---(8)}$$

$$F = \frac{\frac{\beta\delta}{1-\alpha\gamma}}{1-\alpha\gamma-\frac{\delta(\delta\alpha^2+\beta^2)}{1-\alpha\gamma}} \text{---(9)}$$

$$G = \frac{\beta\gamma+(1+\alpha)\frac{\beta\delta^2}{1-\alpha\gamma}}{1-\alpha\gamma-\frac{\delta(\delta\alpha^2+\beta^2)}{1-\alpha\gamma}} \text{---(10)}$$

$$H = \frac{\delta\gamma+(1+\gamma)\frac{\beta^2\delta}{1-\alpha\gamma}}{1-\gamma^2-\frac{\beta^2(\delta+\gamma^2)}{1-\alpha\gamma}} \text{---(11)}$$

The reflection coefficient of the input for three port network when port 2 and 3 are loaded is given by

$$K_{in} = \alpha + \frac{\beta^2}{D1}\tau_2\left(1+\frac{\delta\tau_3}{1-\gamma\tau_3}\right) + \frac{\beta^2}{D2}\tau_3\left(1+\frac{\delta\tau_2}{1-\gamma\tau_2}\right) \text{---(12)}$$

Where D1, D2 are given as

$$D1 = 1-\gamma\tau_2-\frac{\delta^2\tau_2\tau_3}{1-\gamma\tau_3} \text{---(13)}$$

$$D2 = 1-\gamma\tau_3-\frac{\delta^2\tau_2\tau_3}{1-\gamma\tau_2} \text{----(14)}$$

For equilateral triangle with the flare angle $\alpha=60^0$ can be put in to matrix form as

$$[S] = \begin{bmatrix}\alpha & \beta & \beta\\ \beta & \alpha & \beta\\ \beta & \beta & \alpha\end{bmatrix} \text{----(15)}$$

And when the relations from 2-5 are simplified as

$$\alpha_{n+1} = \alpha_n + \frac{2\beta_n^2\left(\alpha_n+\frac{\beta_n^2}{1-\alpha_n}\right)}{1-(\alpha_n+\beta_n)\left(\alpha_n+\frac{\beta_n^2}{1-\alpha_n}\right)} \text{---(16)}$$

$$\beta_{n+1} = \frac{\beta_n^2\left(1+\frac{\beta_n}{1-\alpha_n}\right)}{1-(\alpha_n+\beta_n)\left(\alpha_n+\frac{\beta_n^2}{1-\alpha_n}\right)} \text{---(17)}$$

The simple iterative model can predict the working of the Sierpinski gasket for different iterations. The model considered was lossy transmission line model and the length of each line is calculated using the height of the antenna, flare angle, and number of iterations. The load resistance can be approximated as

$$R_l \cong \left(\frac{h}{c}f\right)^2 \text{---(18)}$$

Where h= height of the antenna

c= velocity of the light

f= frequency

This indicates the dependence of the termination resistance is small compared to the lower frequencies. This affect is because of the load becomes open so antenna currents not enter the edges.

III. Antenna Design

The Antenna is printed over the Rogers Substrate (εr = 2.2, h= 1.6 mm) and placed over a circular ground plane of 15.6 cm diameter. The Antenna structure is fed through a coaxial connector using SMA connector in accordance with the impedance matching. The antenna is designed for four number of iterations and it is assumed that it can resonate over four different frequencies. The considered scaling factor was two, so that the antenna structure resonates by a factor of multiples of two. The entire structure was simulated using Ansys-HFSS with different flaring angles viz for $\alpha = 30^{0,}$ $\alpha = 60^{0}$ and for $\alpha = 90^{0}$ and the same was shown in the below Figures. The below Fig.4 gives the simulated structure for $\alpha = 30^{0}$, the Fig 5 shows for $\alpha = 60^{0}$ and Fig.6 shows the structure for the flare angle $\alpha = 90^{0}$.

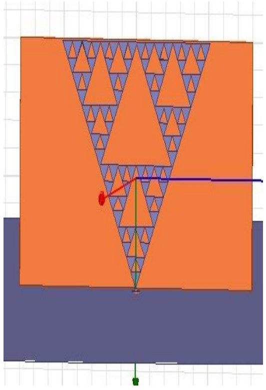

Fig.4. Sierpinski gasket with $\alpha = 30^{0}$

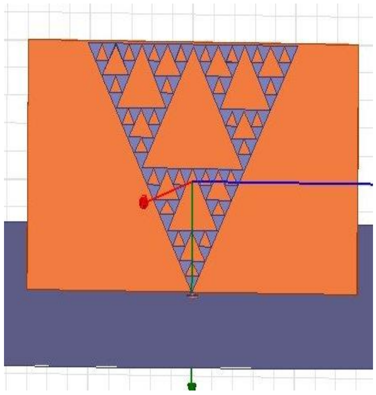

Fig.5. Sierpinski gasket with $\alpha = 60^{0}$

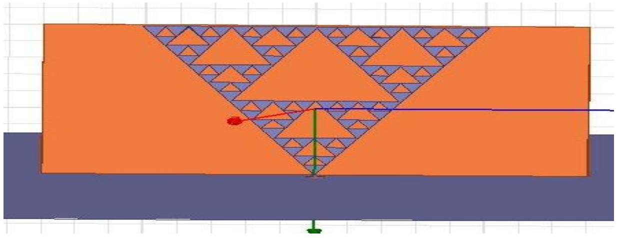

Fig.6. Sierpinski gasket with $\alpha = 90^{0}$

The log-periodic performance of antennasis evinced when we consider the resonant frequency at each band. Exclusive of first band, resonant frequenciesfor monopole Sierpinski antenna are computed in which we consider the speed of light;height of monopole;flare angle;log-period as well as band number.The initial band is referred as bowtie mode of antenna.At initial resonance, truncation effect is noticeably dominantin Sierpinski antenna and etched holes are not important because of their size when compared to wavelength. Two important facts were evidenced concerning Sierpinski gasket antenna, log-periodic behaviour, and the resonant frequencies are connected to gasket edge length to a certain extent than to its height. With the increase of frequency, pattern has agrowing number of lobes and this behaviour resembles more to a linear monopole than multiband behaviour of fractal antenna. Animprovedunderstanding of the behaviour of antenna is gained from present distribution.The current distribution of three antennas was computed by means of FEMscheme. For the cases where $\alpha = 30^o$, $\alpha = 60^o$ as well as$\alpha = 90^o$the current distribution has a related pattern from band to band, exclusive of scale factor.The antennas include an active region whose size decreasesby means of a factor of two every time frequency is improvedby means of a factor of two. In contrast, in the situation where current distribution is not limited to active region however it is distributed all along whole geometry of the antenna. The explanation was to be found in short length of edges of triangular clusters for angles $\alpha = 30^o$ andin thissituation,antenna turns into a poor radiator and current distributionis not limitedtowards an active region however it reaches antenna end. This information was already anticipated by means ofantennas input parameters. Fordouble resonances predicted by means of iterative transmissionline representation and really measured, recommends a doublemode of procedure of this antenna. One of them is Sierpinski mode which is associated with initial resonanceof matching scale of fractal. The secondary mode symbolizes harmonic resonances of huge scalesof fractal. The superposition of both modes causes current distribution on the antenna to extend to the wholestructure. The result is observedwithin the antennas radiation patterns. The appropriateinterpretation of this result illustrates thatSierpinski fractal antenna is interpreted as a series of resonators which are embedded in each other. In this situation, each of the resonatorscontains a reduction in scale of two;thus, basic resonant frequency doubles for each of the resonator [4].For huge flare angles just basic resonant modes of one resonator is excited. However for smaller flare angles and because of small radiation losses harmonic modes of larger resonators aremoreover excited. The simulated resonant frequencies for different flare angles were shown in Fig 7 and similarly the radiation patterns for the same was depicted in Fig.8 (8a-8f) and the 3dB gain was shown in Fig.9.

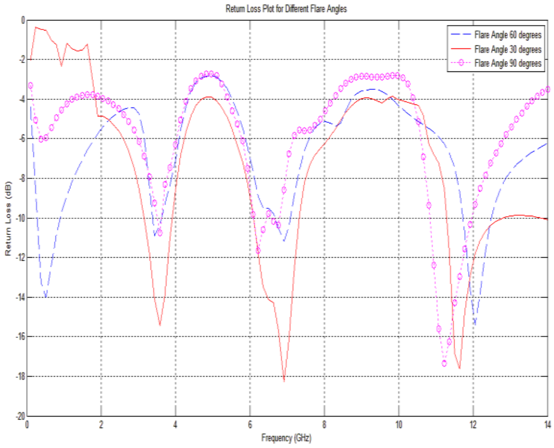

Fig.7. The Simulated Return Loss plot for

Different Flare angles

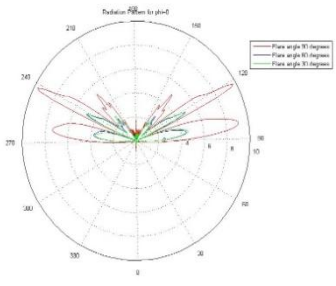

Fig.8a. The Simulated Radiation pattern for $\phi=0^0$ fordifferent Flare angles.

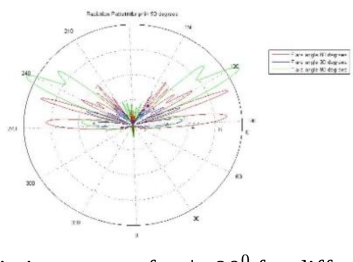

Fig.8b. The Simulated Radiation pattern for $\phi=90^0$ for different Flare angles

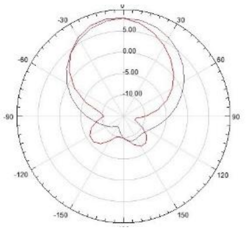

Fig.8c. The Simulated Radiation pattern for $\phi=90^0$ for different α = 60^0

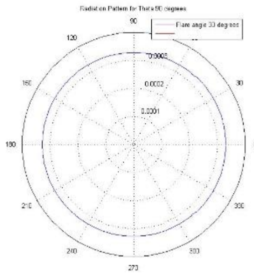

Fig.8d. The Simulated Radiation pattern for $\Theta=90^0$for α =30^0

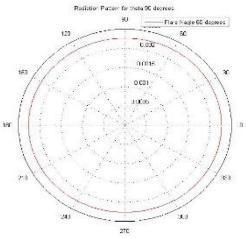

Fig.8e. The Simulated Radiation pattern for $\Theta=90^0$ for α =60^0

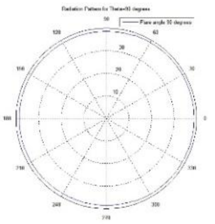

Fig.8f. The Simulated Radiation pattern for $\Theta=90^0$ for α =90^0

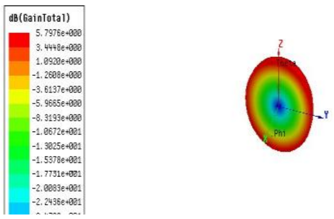

Fig.9a. The Simulated 3 dB gain pattern for α =30^0

Fig.9b. The Simulated 3 dB gain pattern for α =60^0

Fig.9c. The Simulated 3 dB gain pattern for $\alpha = 90^0$

IV. Discussion Of The Results

From the above Figures is it is visible that the Antenna structure is resonating at different frequencies for different Flare angles. For the flare angle $\alpha = 30^0$, it is seen the structure is resonating in the frequency range 0.5 -12 GHz with different operating frequencies.The gain of the antenna ranges from 4.56dB- 5.56d B and the number lobes in the radiation pattern are increased by increasing with the flare angle. Number of resonant frequencies is predicted and shown that with the increase of flare angle, the resonant frequencies shift towards lower frequencies. The results that are simulated are in good harmony with predictions that are made by model. It is probable to alter the input impedance of triangular antennas for instance bow-tie antenna by means of changing flare angle of antenna. A similar conclusion is reached for Sierpinski antenna. It is believed that initiator of Sierpinski gasket is an isosceles triangle; as a result, as a result of symmetry as well as reciprocity properties of initiator, four parameters are essential to completely explain the network [2]. This simple recursive representation permits to expect input parameters behaviour of Sierpinski antenna for any iteration stage. Any symmetrical, reciprocal three-port network capable to store up electric as well as magnetic energy could be used to model the initiator. We consider a symmetrical junction of lossy lines and the length of Transmission lines is just determined by means of height of whole gasket, number of iterations, as well as flare angle. To account for radiation losses a fixed factor was considered by means of introduction of an attenuation factor within transmission lines. This representation does not build a fine prediction of antenna impedance at lower frequencies. The accuracy of model may be improved when the second and third ports of complete Sierpinski network are loaded to consider radiation resistance at lower frequencies that come into view as underestimated by means of the lossy transmission model. The parabolic dependence as function of frequency considers the radiation resistance behaviour of small antenna. At high frequencies, effect of terminating loadis negligible for two reasons such as initially, with the increase of frequency, load tends to be open circuit, and secondly because of radiation losses of antenna current does not attain tips of the antenna; as a result, at higher frequencies, terminating load value is inappropriate. The antennas were simulated with a monopole configuration. The model of iterative transmission line provides a good prediction of behaviour of Sierpinski antenna. As height of the antenna is similar for three cases, increase of flare angle involves longer edges of triangles. The transmission line model accurately predicts frequency down shifting supports the assumption that current distribution on the antenna is mostly supported on edges. The model of iterative transmission line does not imagine any mutual effects among different antenna clusters; on the other hand, model is precise enough to predict overall behaviour of the antenna.

V. Conclusion

In the modern times, possibility of designing antenna that utilize properties of fractals to attain the goals, has gained a lot of consideration.In this model a simple iterative transmission line for Sierpinski antenna was introduced in thiswork which is based on the model of iterative transmission line which has already been effectively applied for prediction of Sierpinskimicrostrip networks behaviour. The model of iterative transmission line provides a good prediction of behaviour of Sierpinski antenna. The transmission line model accurately predicts frequency down shifting supports the assumption that current distribution on the antenna is mostly supported on edges. The proposed model moreover shows that log-period nature of antenna is inherent to its fractal structure that is somehow replicated by the model of iterative transmission line. It has moreover been focuses that a self-similar structure has by its very own log-periodic behaviour; however this behaviour is masked in certain situations by presence of harmonic resonances within structure.

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