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Design and Analysis of Dual-Reverse-Arrow Fractal Geometry Based Miniaturized Thin Strip Patch Antenna for Ultra-Wideband Applications

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***Abstract**:* The military, radar and satellite systems require ultrawideband antennas. Microstrip patch antenna's serve the purpose for such applications as they are low profile, occupies less volume and mechanically robust when applied on rigid surfaces. Fractals are space filling self similar structures where each sub part is the replica of the whole fractal. Fractal geometry when applied to microstrip patch antenna provides a good way to achieve the desired miniaturization and multiband properties. In this paper a miniaturized, wideband antenna based on novel fractal geometry is presented. The proposed design is a repeated S-fractal microstrip patch antenna. The simulation and optimization are performed using Ansoft HFSS. The results show that the proposed antenna shows multiple resonances at frequencies of 8.08GHz, 9.11GHz and 11.88GHz with the bandwidths of 240MHz, 745MHz, and 7.75GHz respectively. The maximum Gain of antenna at 11.88GHz is 9.25dB and the corresponding directivity is 9.88dB, thus making the antenna 93.62% efficient. To enhance the bandwidth of the antenna, the thickness of the substrate was increased. In order to have minimum reflections the terminal impedance of the antenna should match the characteristic impedance of the coaxial cable. The impedance matching was done by finding the best feed position parametrically, using HFSS.

Keywords: Fractal Geometry, Gain, Microstrip Patch Antenna, Miniaturization, Thin Strip Antenna, Wideband Behaviour

I. INTRODUCTION

Modern communication systems need antenna with small size and wide bandwidth. The geometry of Microstrip patch antenna consists of a substrate sandwiched between a radiating patch and a metallic ground plane. The patch and ground are made of copper and the substrate is made of FR4 (flame retardant). Fractals are self similar space filling structures where the sub part resembles the actual fractal from where it is extracted. Microstrip patch antenna along with fractal geometry is always desirable due to their several properties like low profile, low volume and also the ease in fabricating the antenna. Fractal geometry, when applied to the microstrip patch antenna produces multiple resonances and miniaturization. Multiple resonance behavior of the antenna is due to the self similarity property of fractal. By self similarity it is meant that each sub- part is the replica of the whole structure. Another property of fractal is the space filling which is responsible in attaining miniaturization of antenna. By miniaturization it is meant that the electrical length of the antenna is increased while keeping the surface area constant.
A lot of methods are being used to achieve miniaturization of microstrip patch antenna. Some approaches used in miniaturization of antenna include use of complementary split ring resonator in the ground plane [1]. Applying fractal geometry to the patch antenna results in miniaturization of patch [2]-[3], by the use of array of antennas on a single patch [4], miniaturization was done. By applying two or more fractal geometries on a single patch for designing a hybrid fractal antenna as in [5]. Reference [6] used a combination of split ring and fractal antenna for miniaturizing the patch. The multiband behavior of the antenna is mainly achieved by two methods, either by modification in the main radiating element or by modifying the ground plane. Reference [7] and [8] uses slots on the radiating patch and achieves multiband behavior. Use of complementary split ring resonators and slotted split ring resonators also helps to attain multiband operation[9]-[11].Fractals are very useful in generating multiple resonances and thereby showing multiband and wideband behaviors. Reference [12] uses an octagonal fractal antenna for super wideband operation. Reference [13] applied E-shaped fractal geometry on one of the edges of the patch for multiband applications. Reference [14] used Koch fractal geometry on the patch and split ring resonator in the ground plane for dual band operations. For a triband operation, asymmetrical Koch fractal boundary patch with embedded asymmetrical fractal slot was used in [15] Suspended technique is also favorable in terms of multiband operation [16] where suspended ground plane is used together with Koch snowflake fractal. Use of multiple stacked patches also gives multiband operation [17]-[18].

For modern day communications in X band and Ku band it is desirable to have an antenna of gain 10dB approximately so that the antenna can be used by military and for radar and satellite communication. Miniaturization is an ever ending need for designing antenna. Thus in this study a novel repeated S-shaped fractal microstrip patch antenna, which realizes its miniaturization and attains wideband characteristics with improved gain, is presented. The fractal geometry is used upto 2nd iteration and the results obtained are compared. Further the thickness of the substrate is increased, in order to obtain wideband behavior of antenna.

This communication is arranged in five sections. Section II describes the design of the proposed antenna. Simulated results and prototype of the antenna are presented in section III. Section IV gives the measured results. Conclusion of the article is summarized in section V.

II. ANTENNA DESIGN

The geometry (not drawn to scale) of the proposed repeated S-shaped fractal for the first two iterations is shown in the figure 1. For 1st iteration, the total length of 30mm is divided into three equal parts of length 10mm each and the middle part is further divided into two equal parts, to generate the structure as shown. The same procedure is followed to generate the further iterations of the repeated S-fractal. It is well known that the substrate dimensions should be minimum half-wavelength more from the radiating patch in all directions. The dimensions of the substrate are given by the following formulae.

SUBX= $\lambda/2$+L

where L is the minimum length of the patch to avoid overlapping of the geometry

SUBY= $\lambda/2$+H

where H is the total width containing the patch vertically

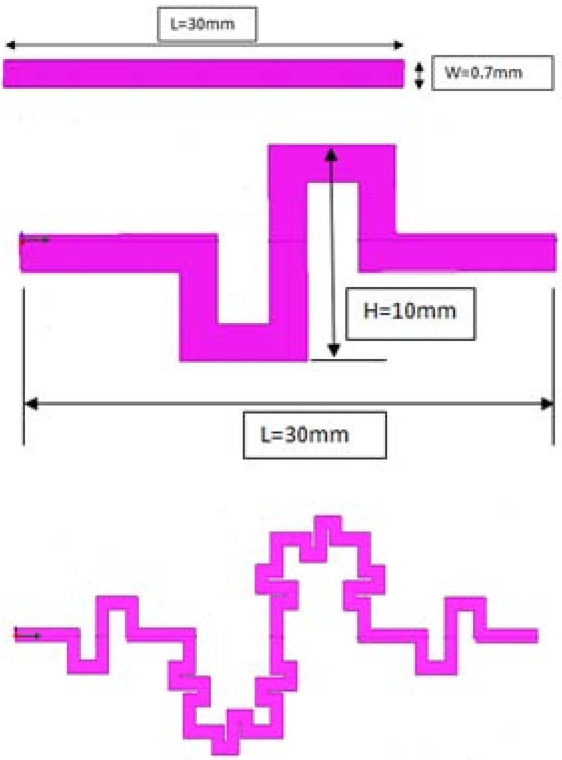

Figure 1 Structure of The Proposed Fractal Antenna

For this antenna the length is 30mm and the total width is 10mm.The substrate used is FR4 (flame retardant) with dielectric constant ε_r =4.4 and loss tangent tanδ=0.02 and thickness=3.2mm.

In this communication, the second iteration of the repeated S-shaped fractal geometry is considered since higher order iterations were difficult to evaluate also the benefits starts decreasing at higher orders, thus not making significant affect on antenna properties.

It is well known that the maximum coupling between the antenna patch and coaxial probe occurs at the point of maximum electric field intensity. The position of the coaxial probe to match the input impedance Z=50Ω is founded by the parametric analysis done by varying the feed position of the probe in horizontal direction only. The best feed position was found at (1.5, 0, 0) mm.

III. SIMULATION RESULTS

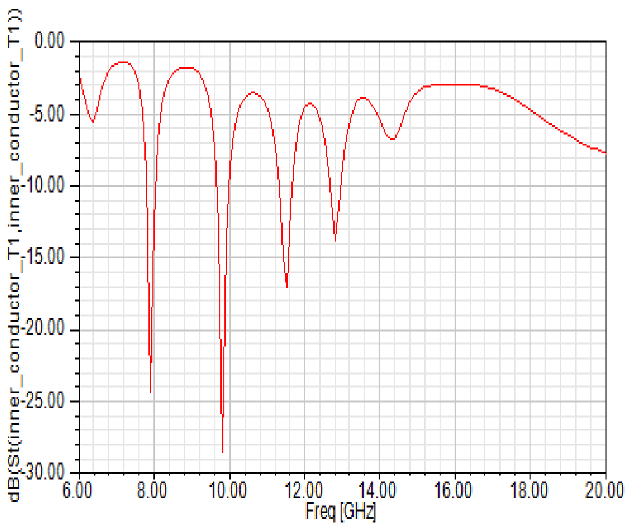

Figure 2 Simulated Scattering Parameter for 1st Iteration

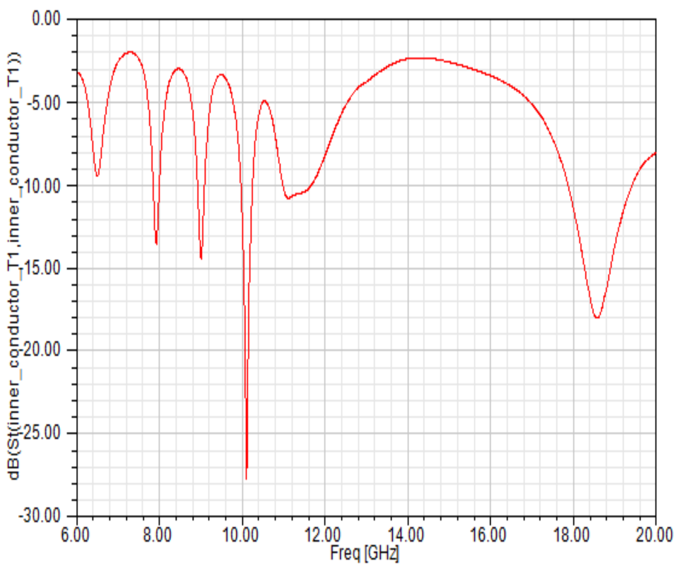

Figure 3 Simulated Scattering Parameter for 2nd Iteration

This microstrip patch antenna is stimulated using HFSS software. The ground plane and all the conductors are assumed perfectly electric and the radiation box is considered to be an infinite sphere. The simulation frequency range is from 6GHz-20GHz. This does not mean that the antenna does not resonate above 20GHz.

Figure2 shows the scattering parameter for the 1st iteration of the repeated S- shaped fractal antenna and figure3 shows the scattering parameter for 2nd iteration of the antenna. According to the results, it is depicted that the resonating frequencies shift to lower sides and also more number of bands get incorporated.

A. *Optimizing Feed Location*

The greatest advantage of using a coaxial feeding technique is that the best feed location can be found parametrically by changing the position of the feed within the patch. The best feed location is the point on the patch where the impedance matching is maximum. The characteristic impedance of the coaxial cable (50ohms) should match the intrinsic impedance of the antenna. To find this position a parametric analysis in Ansoft HFSS was done and the results obtained are shown in figure 4.

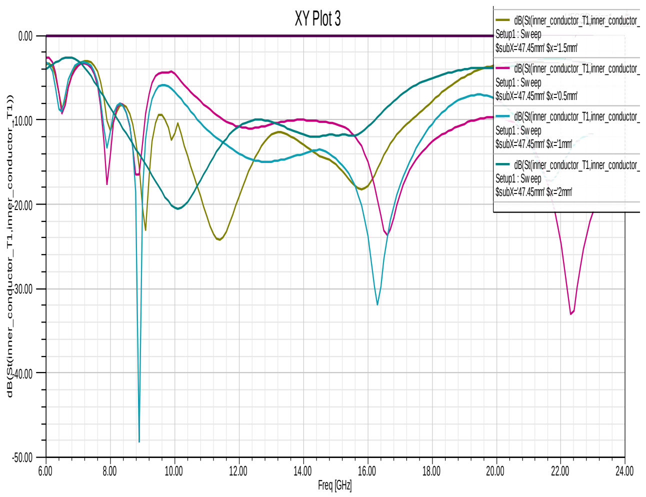

Figure 4 Parametric Study for Finding Optimum Feed Point

B. *Enhancement of Bandwidth*

Though many bands are obtained in the 2nd iteration of repeated S-fractal but the bandwidth is not sufficient for applications in these bands. Thus there is a need to improve the bandwidth of the antenna. This was done by increasing the thickness of the substrate from 1.6mm to 3.2mm. From figure 5, it can be clearly observed that the bandwidth of the antenna has improved enormously. An ultra wideband of approximately 7.75GHz is obtained at a resonating frequency of 11.88GHz. Two other bands are also obtained with considerable bandwidths.

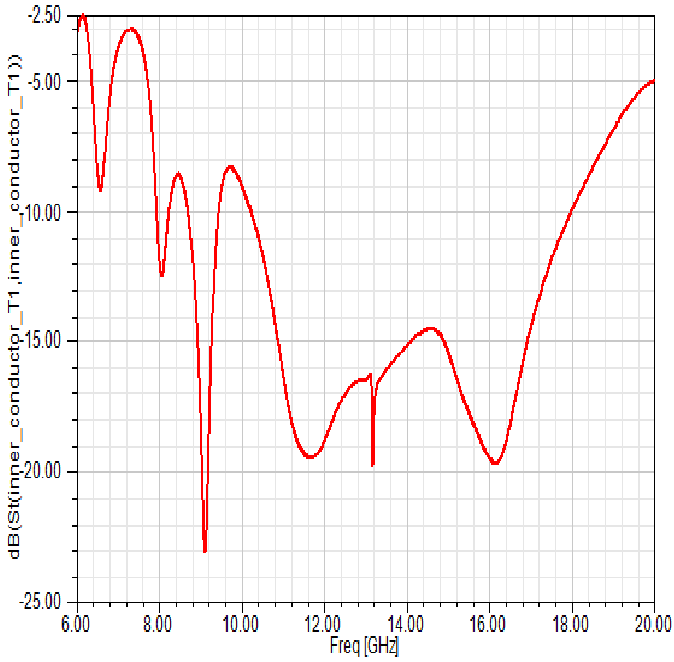

Figure 5 Scattering Parameter at Substrate Thickness of 3.2mm

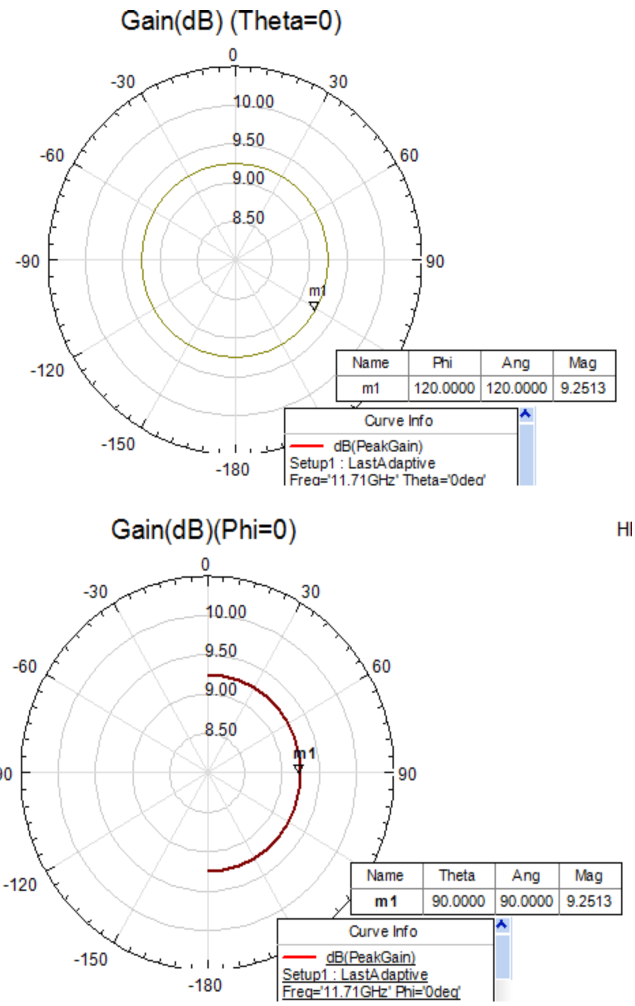

Figure.6 Simulated Gain at Theta=0 and Phi=0 respectively.

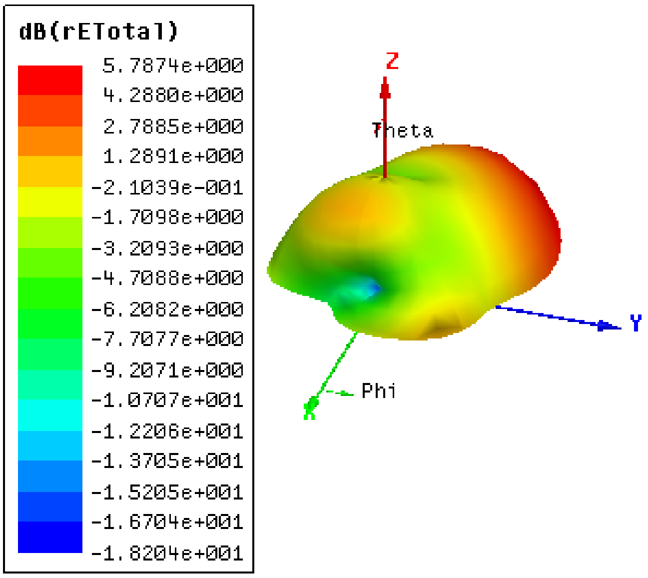

Figure 7 3-D Radiation Pattern

For the applications of antenna in X and Ku band the minimum gain of the required antenna should be approximately around 10dB and the simulated gain of antenna is found to be 9.25dB, which is in proximity to the desired value. Also the directivity of the antenna is 9.88dB, thereby making the antenna 93.62% efficient. Figure 6 shows the gain pattern of the antenna when theta=0 and when phi=0 respectively. The three dimensional radiation pattern of the antenna is shown in figure7 and VSWR versus frequency curve is plotted in figure 8.

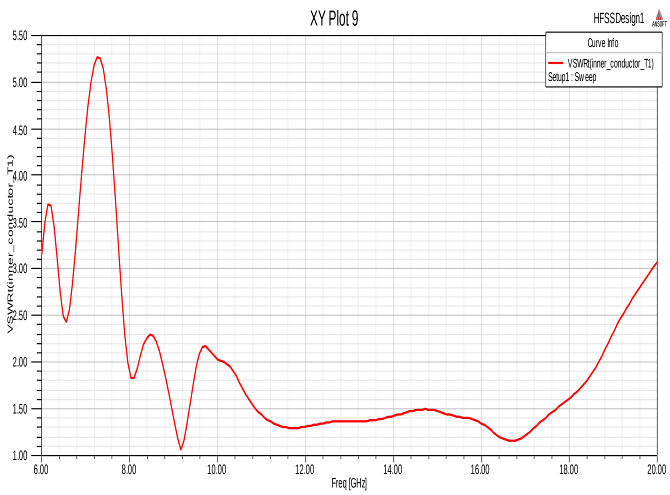

Figure 8 Simulated VSWR of Antenna

For the antenna to have better performance, the maximum tolerable value of VSWR can be 2. The VSWR is found to be 0.57 at a frequency of 9.16GHz.

The prototype of the repeated S-shaped fractal fabricated antenna is shown in figure 9 and figure 10. Figure 9 depicts the top view and figure 10 depicts the lateral view of the fabricated S-shaped fractal antenna.

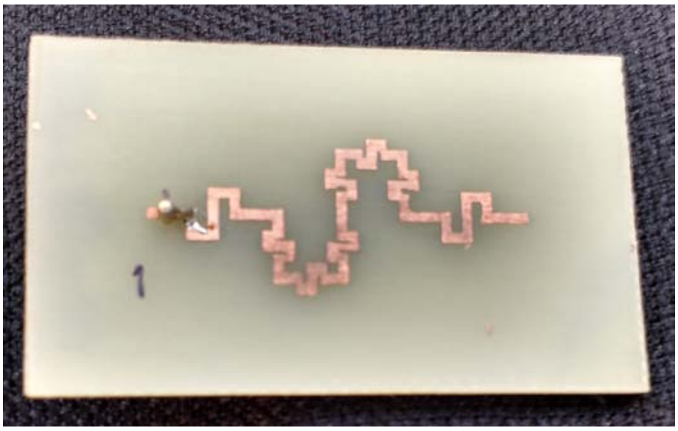

Figure 9 Prototype of Fabricated Antenna (Top View)

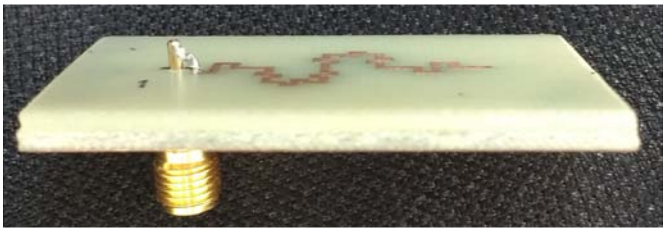

Figure 10 Lateral View of Fabricated Antenna

IV. MEASURED RESULTS

The prototype model the proposed repeated S-shaped fractal antenna is fabricated as shown in figures 9 and figure 10 respectively. The results of the antenna are measured using Vector Network Analyzer. The measured result verifies the desirable characteristics of antenna designed.

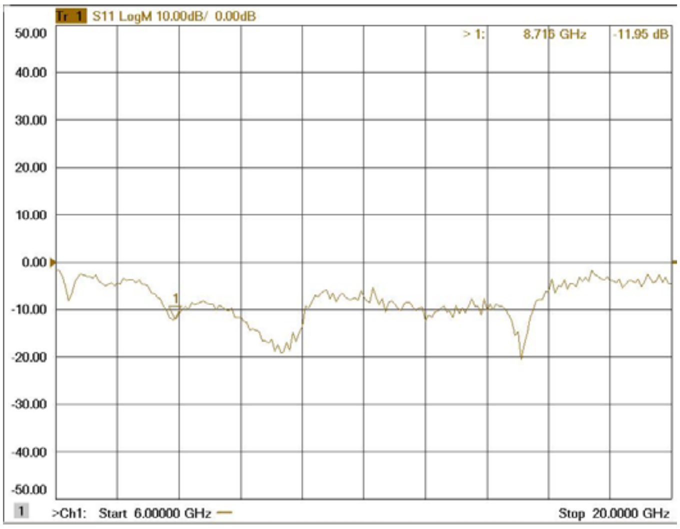

Figure 11 Measured Scattering Parameter versus Frequency

The measure of scattering parameter S11 versus frequency of fabricated antenna is shown in the figure 11 which is comparable to the simulated results obtained.

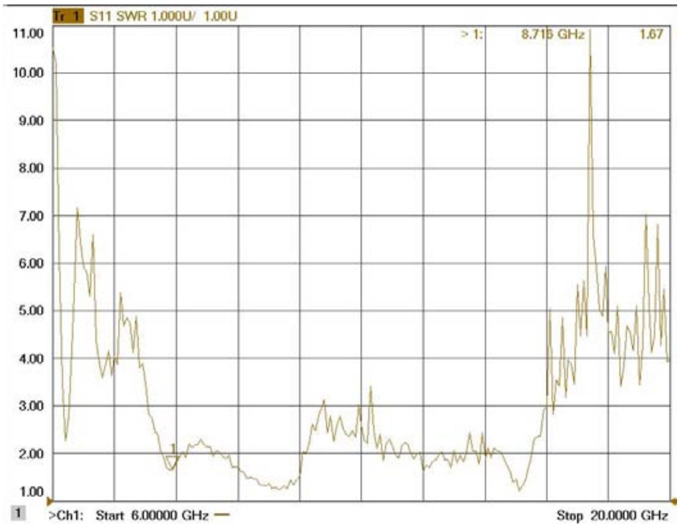

Figure 12 Measured VSWR

The measured VSWR pattern of the antenna and smith chart is shown in the figure 12 and 13 respectively. From the smith chart observation can be made that the maximum impedance matching of the coaxial cable and the antenna is obtained at a value of 40.77 ohms. The results of repeated S-shaped fractal antenna are shown in table 1 as follows.

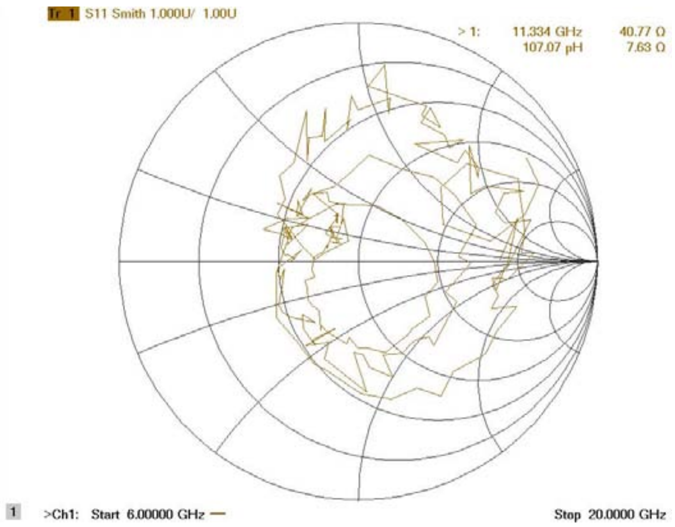

Figure 13 Smith Chart

Table 1 Summary of Simulated Results

Parameter	S-shaped fractal antenna
Resonating frequency	8.08GHz,9.11GHz,11.88GHz
Bandwidth	240MHz, 745MHz,7.75GHz
Gain	9.25dB
Directivity	9.88dB
VSWR	0.57

V. CONCLUSION

A novel repeated S-fractal geometry is introduced and implemented on a microstrip patch antenna to show it is effective in the antenna miniaturization. Furthermore, the thickness of the substrate is doubled in order to enhance the bandwidth of the antenna significantly. The antenna proposed finds suitable applications in military, radar and satellite communications since it has a very good gain. Results show that an ultrawideband of 7.75GHz is obtained and the antenna is highly efficient for radar and military applications.

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