

Design of Compact Triangular Microstrip Patch Fractal Antenna Array for MIMO Applications

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Abstract. A Microstrip fed fractal antenna array of two antennas (with equilateral triangle shapes on the triangular patch) to achieve the good bandwidth in the frequency range between 5.45 – 5.72 GHz for the wireless applications (WLAN band) has been proposed. Proposed antenna is simulated using CST Microwave Studio which is based on the Finite Integration Technique. Simulation results for this proposed antenna are presented in terms of bandwidth, gain and S parameters, which indicates the desired performance of antenna for wireless applications. The antenna array has been proposed for MIMO applications, so the capacity calculations for an ideal MIMO environment of a system with 1 x 2 diversity are also presented.

Keywords: Triangular patch, fractal, MIMO, channel capacity

1. Introduction

When a multiple-element antenna array is used for the wireless applications to increase capacity, these should be small as much as possible. Also, there are some additional requirements which should be met, e.g., good isolation (low mutual coupling) and diversity performance for multiple antennas besides the usual requirements such as compact structure, light weight, low profile and robustness [1]. Therefore, in designing the antenna for the MIMO applications, it is important to balance the trade-off between size and performance [2]. In MIMO (multi-input-multi-output) systems, multiple antenna elements are required at both transmitter and receiver. The multiple antennas at the both ends of the systems provide independent paths to signals in the multipath fading environment [3]. Therefore, the designing of two or more antennas for the MIMO systems is more challenging compared to the design of a conventional single antenna [4]. So, the current paper focuses on the design and development of a Sierpinski gasket fractal antenna array for MIMO systems.

A fractal is a self-similarity structure, which means that a small part of the structure is a scaled-down copy of the original structure. The term fractal means irregular or broken fragments to describe complex shapes that possess an inherent self-similarity or self-affinity in their geometrical structures. These fractal antennas can be used for obtaining a multiband behavior or broadband and sometimes for size reduction too. Literature review presents several other kinds of miniaturization and broad banding techniques, such as use of high dielectric substrates [5], increasing the electrical length of the antenna by optimizing its shape [6], use of notches and short circuits on the patch antenna [7], and use of magnetic substrates have been proposed and applied to microstrip patch antennas [8].

The application of fractal geometry to conventional patch antenna structures modifies the shape of the antennas to increase its effective electrical length while reducing their overall geometrical size and leads to a multiband behavior too. Two resonant bands excited close to each other can give a broad band behavior from the antenna. The current paper focuses on a sierpinski gasket fractal applied to an equilateral triangle geometry, it is found that the resonance frequencies become lower than those of the zero iteration as the iteration number increases, which represents a conventional equilateral triangular patch. Thus, a smaller sized antenna is available for a lower frequency of operation. Next section presents the system model and the antenna requirement in a MIMO system.

2. System model

Figure 1 represents the system model for implementation of a MIMO system for wireless applications with a single antenna at the transmitter and two antennas at the receiver. The 'H' that represents the H matrix for this system with one TX and two RX and is given as

$$H = [h_{11} \ h_{12}]$$

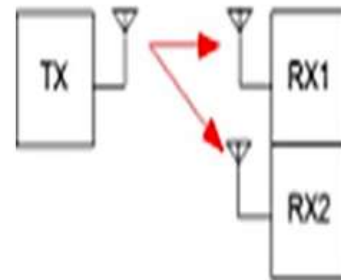


Fig.1. System model of MIMO implementation on receiver side.

The theoretical capacity of a narrow band MIMO channel for this case is given by

$$C = E [\log_2 (\det \{IN, + pHH + IN\})] \quad (1)$$

where, p is the average signal to noise ratio on both receiver and H is the $N_r \times N_t$ channel matrix. $N = \min(N_t, N_r)$.

N_t and N_r are the number of transmitting and receiving antennas respectively. Also, each element of H is taken as a complex Gaussian distributed random variable which signifies that each pair of transmit and receive antennas experiences independent fading. Since the current paper deals with proposing of the fractal antenna array for the given system model; a triangular patch fractal antenna array with two antenna elements is proposed and its design details are mentioned in the next section.

3. Antenna design

The proposed Sierpinski gasket wideband fractal antenna array is which that has a bandwidth from 5.45 – 5.72 GHz is shown in Figure 2. It consists of triangular shape fractals on two triangular patches which are placed on the same substrate layer with $\epsilon_r = 4.4$, with a thickness of $t = 1.57\text{mm}$, tangent loss of $\tan \delta = 0.0024$ and copper thickness of 0.035mm . The length and width of the ground plane and substrate is $13.6\text{cm} \times 13.6\text{cm}$. All the parametric details of the antenna are mentioned in Table 1 for reference.

The antenna is fed using microstrip line feeding method. The next section presents the simulated results of the antenna in terms of its bandwidth, gain, diversity gain, radiation pattern and correlation coefficient.

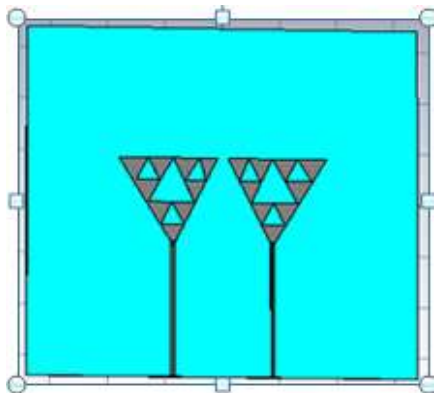


Fig. 2. Triangular patch fractal antenna of second order

Table 1: Calculated parameters of the triangular fractal antenna

Ground plane length (Lg)	136mm
Ground plane width (Wg)	136mm
Side dimensions of triangle	34.5mm
Width of microstripline feed	1.25mm
Length of microstripline feed	60.3 mm
Substrate length (Lg)	136mm
Substrate width (Wg)	136mm

4. Results and discussion

All the simulations related to Fractal Triangular microstrip patch antenna array design for MIMO applications are carried out using CST MWS version 10 and the simulated results are presented in the following subsections.

4.1. S_{11} (dB) results

Reflection coefficient (S_{11}) gives the ratio of the amplitude of a wave reflected from a surface to the amplitude of the incident wave. The graph of impedance bandwidth with respect to a S_{11} (dB) value on Y axis (of less than -10 dB) is shown in Figure 3 that represents bandwidth plot for the first iterations, the results were not satisfactory so the second iteration was carried out. The Figure 4 represents the S_{11} (dB) plot against frequency for the second iteration. An impedance bandwidth of 284.1MHz around 5.62 GHz with a peak S_{11} (dB) less than -20dB and is covered by the patch antenna and is considered to be an optimized one. Figure 4 also shows that the S_{21} and S_{12} have negligible value (of -9 dB) for the current band and therefore the performance of the antenna is suitable for the desired wireless applications.

4.2. Radiation pattern

Figure 5 shows the E-field plot of the proposed array in far field at a frequency of 5.62GHz. At excitation port 1, the E_{max} value is 10.85V/m and total efficiency of 0.93, Similarly at excitation port (2), the E_{max} value is 10.80V/m and total efficiency of 0.927.

4.3. Correlation coefficient

In a MIMO system, the envelope correlation coefficient “ ρ ” is defined as the effect of radiation from one antenna on the other in an array environment due to mutual coupling between the antennas. The approximation of values for this coefficient is based on a simple closed-form equation for which the value of ECC should be less than 0.5.

A low correlation between the two outputs obtained from the antenna shows that they do not induce currents on each other much. The correlation coefficient is calculated using scattering parameters which are given by equation (2):

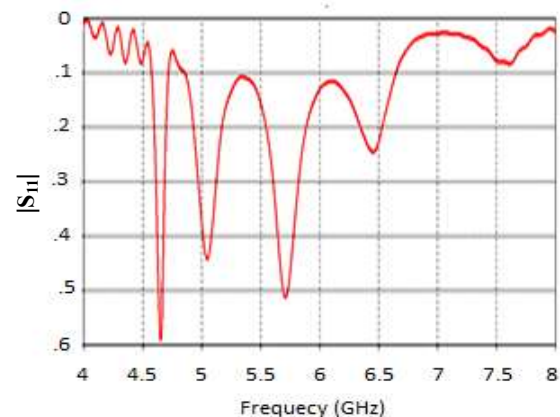


Fig.3. S-parameter Magnitude in (dB) of fractal triangular patch antenna of first order

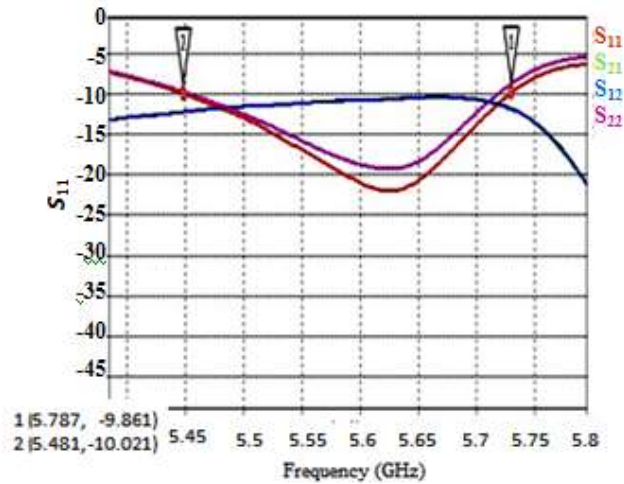


Fig.4. S-parameter Magnitude in (dB) of fractal triangular patch antenna of second order

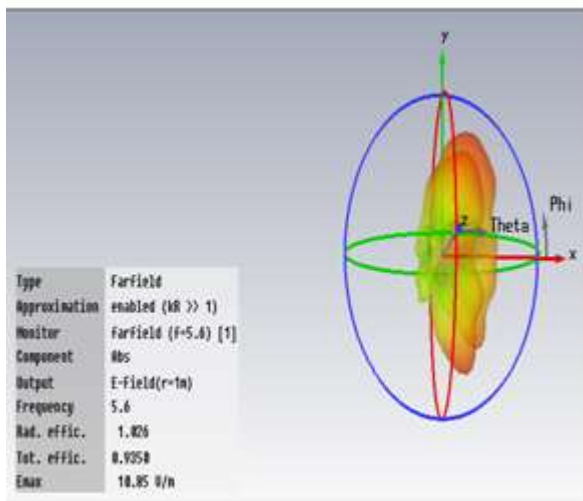
$$\rho = \frac{|S_{11}^* S_{12} + S_{21}^* S_{22}|^2}{(1 - |S_{11}|^2 - |S_{21}|^2)(1 - |S_{22}|^2 - |S_{12}|^2)} \quad (2)$$

where, S_{11} is the reflection coefficient at antenna port 1, S_{12} and S_{21} are the transmission coefficients between the two antennas.

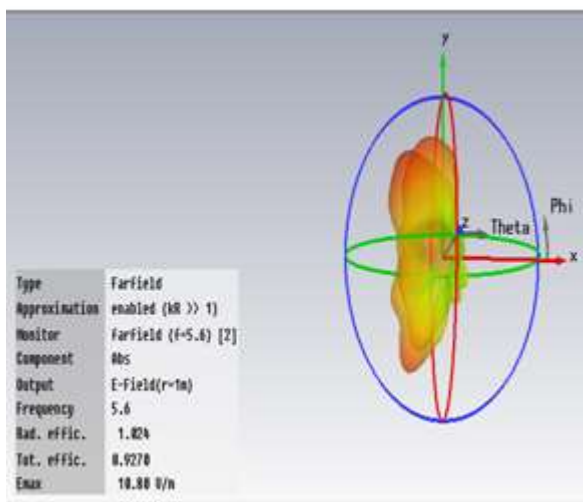
Figure 6 shows that the designed antenna array presents a correlation coefficient of 0.01 at the resonant frequency of 5.62 GHz, which is good for a satisfactory performance of the proposed system.

4.4. Diversity gain

As diversity in terms of multiple antenna systems is employed here, the diversity gain represents an increase in signal-to-interference ratio, or it gives the estimation for the reduction in transmission power when a diversity scheme is introduced, without any performance loss. Figure 7 shows that the proposed antenna array possesses diversity gain of 9.9 at the resonant frequency of 5.62GHz of antennas operation. This implies that even with a low transmission power, the system would provide a good Signal to interference ratio, and this makes the system practically feasible too.



(a)



(b)

Fig.5. Radiation pattern (a) due to excitation 1 at 5.62 GHz (b) due to excitation 2 at 5.62 GHz

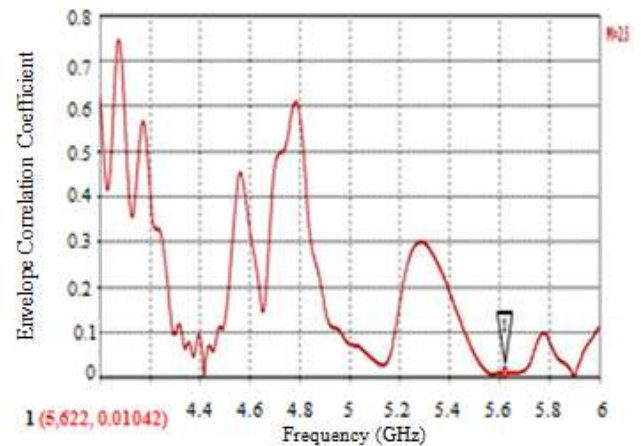


Fig 6. Envelope correlation coefficient of fractal triangular patch antenna

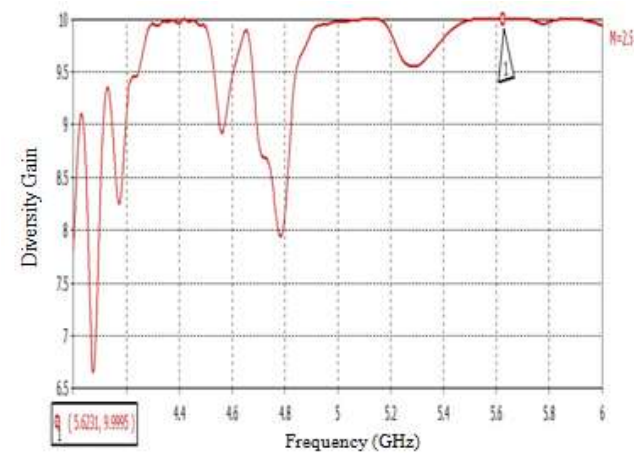


Fig 7. Diversity gain of fractal triangular patch antenna

5. Theoretical capacity analysis offered by the proposed antenna array

In order to analyze the applicability of the proposed antenna array, the capacity analysis for a given wireless communication scenario is important. The current analysis is done taking a Rayleigh fading environment into consideration as it represents an environment with the maximum amount of reflections present in the wireless channel.

5.1 Capacity versus signal power

An increase in signal power leads to more SNR and thus an increase in the capacity of the channels shown in Figure 8. It is plotted using the equation (3)

$$C = B \cdot \log_2 \left(1 + \frac{P}{N_0 \cdot B} \right) \quad (3)$$

It shows that increased signal power will mean that splitting the signal level into more number of levels ensuring low bit error probability. Hence, increased signal power will give more capacity. It can be observed from Figure 8 that increasing capacity is a logarithmic function of power. The Figure 8 is plotted using a bandwidth of 284.1MHz, noise power N_0 as 2 dBm ideally.

5.2 . Capacity versus bandwidth

A more bandwidth supported by this array gives more data rate supported by the system; this is plotted using equation (2). Figure 9 shows that increasing the bandwidth tends to higher the capacity as the no. of transmissions per second is also increased.

6. Conclusion

A Sierpinski gasket fractal based antenna array has been investigated in this paper, to design microstrip antennas for MIMO systems. Since the antenna covers a band from 5.42 to 5.72 GHz, it is well suitable for WLAN and UWB systems. Use of fractal geometry allows the antennas size to

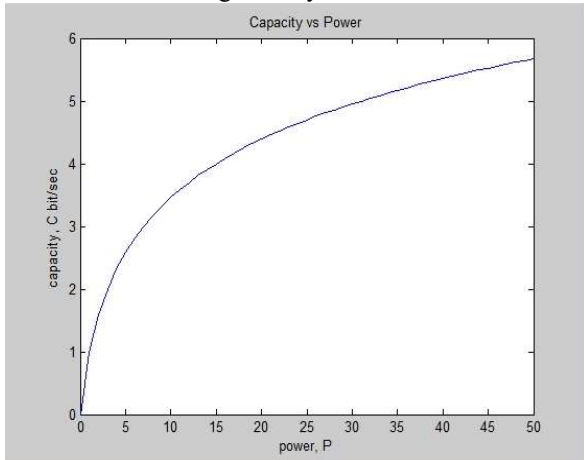


Fig. 8. Capacity vs Power

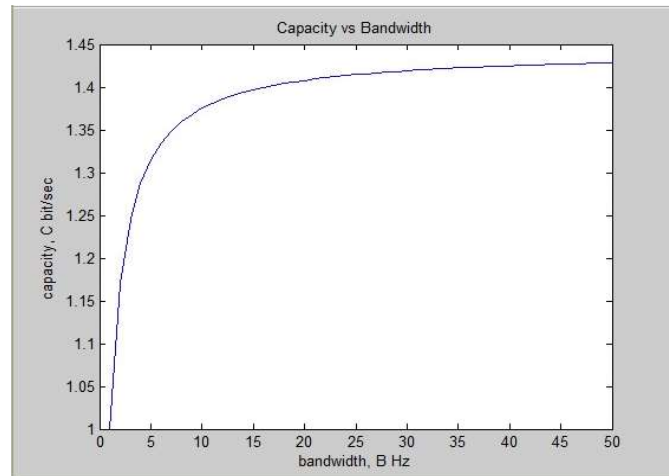


Fig. 9. Capacity vs Bandwidth

get reduced by 10% as compared to a conventional antenna for the same resonant band of operation. According to simulation results, the suggested system offers <10 dB impedance bandwidths of about 284.1 MHz with an isolation of less than -10dB. This antenna gives good radiation characteristics and can be used in wireless communication systems. The proposed antenna can be fabricated and tested for the mentioned wireless applications of interest.

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