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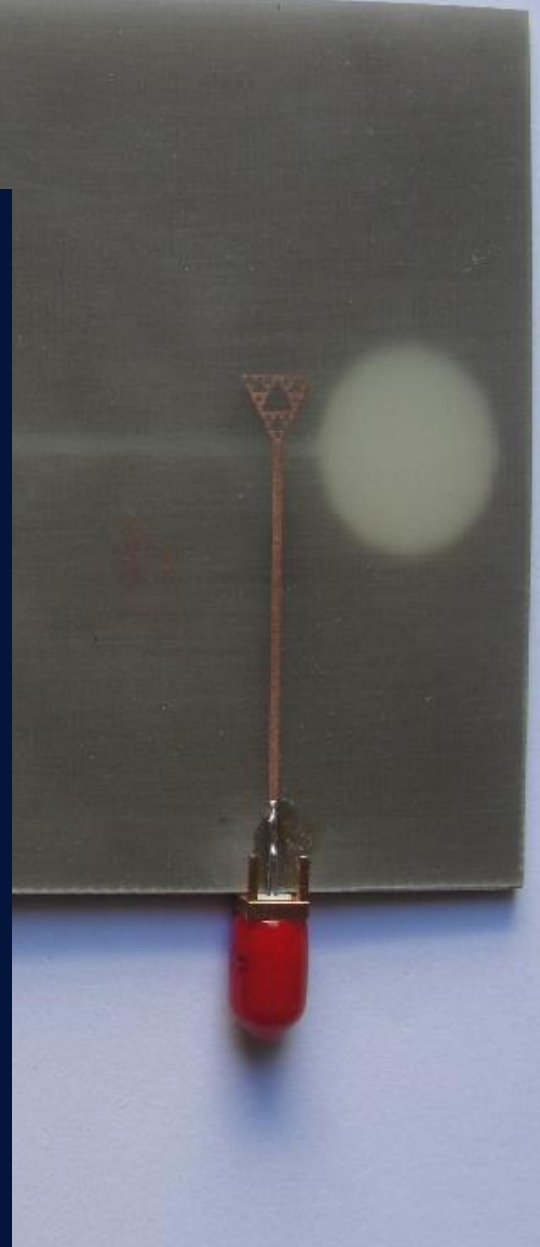
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Towards Fractal Antennas: A multiband Sierpinski Triangle (Gasket) fractal Vivaldi antenna



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Towards Fractal Antennas: A multiband Sierpinski Triangle (Gasket) Fractal Vivaldi Antenna

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Abstract

Using Sierpinski Triangle Fractals (STFs), a revised Vivaldi antenna with multiband coverage is presented. This report explains how fractal iterations can be increased to increase the impedance bandwidth and create new bands for multiband applications. A study has also shown that radiation patterns that resemble Euclidean shapes remain the same as their fractal iteration increases. The purpose of this study is to address a series of issues, including improvements in the impedance bandwidth, radiation properties, and a comparison between the simulated and measured results throughout the entire document, as well as the summary of findings within the report. Using fractal-structured Sierpinski gaskets in the feed line of the Vivaldi antenna, this project introduced a new method of feeding the antenna by using fractal structures Sierpinski gaskets. This project introduces a unique feeding method that was never discussed previously and is being tested for the first time. Using this method, a significant amount of work was accomplished in designing and optimizing the radial stubs of the antenna feeding lines for the Vivaldi antenna. It is designed so that when a feed line's central frequency corresponds with an antenna's bandwidth, its radial stub works

as a short circuit termination. It transfers energy to its slotted line when its center frequency corresponds with the antenna's bandwidth. The radial stub in the feed line of the Vivaldi antenna is usually designed this way and is typical of how it is usually constructed. Using the fractal patch method, as antenna bandwidth is moved away from the central frequency of the antenna, the dimensions of the radial stub will change in relation to the wavelength as the antenna bandwidth is moved away from its central frequency. As a result, the radial stub will no longer function as a short circuit termination, and as a result, the antenna will no longer function as an antenna. Consequently, the antenna's slotted line cannot transfer a sufficient amount of energy into the slotted line, which results in a reduction in efficiency. Based on this study's results, the main problem with this method is that the radial stab of the feed line has only one resonance frequency. The following report sums up my research from the NAMRL research laboratory as part of my master's studies [1].

1. Introduction

The concept of fractal antennas was first introduced in the 1980s by Nathan Cohen [1], [2]. Since then, the study and development of fractal antennas has grown rapidly, and they have been widely adopted in a variety of applications [1]. One of the main advantages of fractal antennas is their ability to achieve multi-frequency and multi-band operation [2-23]. This has made them particularly useful for wireless communication systems, where a single antenna must be capable of operating in multiple frequency bands. In addition to their multi-frequency capabilities, fractal antennas have also been shown to have improved electrical performance compared to traditional antennas [23],[24]. This includes higher gain, wider bandwidth, and improved impedance matching. These benefits, combined with their compact size, have made fractal antennas a popular choice for designers and engineers in the wireless communication industry [25-38].

In recent years, there has also been a growing interest in using fractal antennas for satellite communication, RADAR, and microwave imaging [1-12]. These applications benefit from the multi-frequency [1], [16] and multi-band operation of fractal antennas [1],[16] as well as their improved electrical performance [2]. Despite their many benefits, there are still some limitations to the use of fractal antennas [3]. For example, they can be difficult to fabricate and may have lower efficiency compared to traditional antennas

[16]. However, these limitations are being addressed through ongoing research and development in the field [1], [9]. A fractal antenna is a type of antenna that uses fractal shapes to enhance its electrical performance, such as bandwidth and gain [1-19]. The fractal form can be self-similar [19] at different scales, providing multi-frequency [16] and multi-band capabilities [19]. Fractal structures show multiband behavior in antenna design due to their unique geometrical properties [1], [9], [16], [19]. Fractal structures are characterized by a repeating pattern at different scales [16], [19], and this self-similarity provides multiple resonant frequencies in a single antenna [1].

When a fractal structure is used as an antenna, the repeating pattern creates multiple resonant frequencies, each with a different wavelength [9]. The resonant frequencies are a result of the constructive interference of the electromagnetic (EM) waves at the fractal structure [1-13]. The constructive interference occurs [19] when the phase of the EM waves is the same at a specific location, and the waves reinforce each other, producing a maximum electric or magnetic field [1-32]. The multiple resonant frequencies in a fractal antenna provide the multiband behavior [1], [19], allowing it to operate in multiple frequency bands. This is in contrast to traditional antennas [1-65], which are typically designed for a single frequency band [12-65] and may require multiple antennas to support different frequency bands [65-95].

There are several factors that determine the number of resonant frequencies in a fractal antenna and the bandwidth of each frequency band [1-2],[16],[19]. One important factor is the size and shape of the fractal structure [1], [9]. For example, a fractal antenna with a larger size will have a larger resonant frequency [19] and a wider bandwidth compared to a smaller fractal antenna [16]. Another important factor is the type of fractal structure used [1]. Different fractal structures have different geometrical properties [16], and some are more suitable for multiband operation than others [19]. For example, the Sierpinski fractal [1], [71, 72] and the Koch fractal [1], [71] have been widely used in antenna design due to their favorable properties for multiband operation [1], [16], [19], [77]. The multiband behavior of fractal structures in antenna design is a result of their unique geometrical properties [1], [71], including their self-similarity [71] at different scales and the resulting multiple resonant frequencies [19], [77]. The size, shape, and type of fractal structure all play a role in determining the number of resonant frequencies and the bandwidth of each frequency band [19]. The multiband [19] behavior of fractal antennas makes them attractive for use in wireless communication systems, where a single antenna must be capable of operating in multiple frequency bands [1-16].

Applications of fractal antennas include mobile phones [1], [71], Wi-Fi [1], [19], Bluetooth [19], GPS [21], and other wireless communication systems [1-95]. They also

have potential use in satellite communication, RADAR [95], and microwave imaging [67-95].

Benefits of fractal antennas include:

1. Compact size [1]: Fractal antennas are smaller in size compared to traditional antennas, making them suitable for portable devices and systems with limited space.
2. Multi-frequency and multi-band operation [16], [19]: The fractal geometry provides multiple resonant frequencies, making it possible to use a single antenna for multiple communication bands.
3. Enhanced performance [67-95]: The fractal shape can improve the electrical performance of an antenna, providing higher gain, wider bandwidth, and improved impedance matching.
4. Cost-effectiveness : Fractal antennas are cost-effective because they can replace multiple traditional antennas and reduce the size and weight of wireless communication systems.

An important aspect of fractal antenna design is antenna efficiency [16,19], which is so crucial in multiband antenna design [1,16,19]. The efficiency of fractal antennas can be improved in several ways, particularly for multiband antennas [16,19]. Among these methods are [1]:

1. Optimizing the geometry of the fractal structure [1, 16]: The geometry of the fractal structure is one of the main factors that determines its efficiency. By optimizing the geometry, such as the size, shape, and number of iterations, the efficiency of the fractal antenna can be improved. This optimization can be done through simulation and experimentation to determine the optimal design for a specific application.
2. Designing for optimal impedance matching [1,16]: Impedance matching is the process of ensuring that the input impedance of the antenna matches the impedance of the transmission line. If the impedance match is not optimal, the efficiency of the antenna will be reduced. To improve the efficiency of fractal antennas, designers must take into account the impedance match of the antenna and make adjustments to the geometry or other design parameters to achieve optimal impedance matching.
3. Using fractal structures with improved performance [1, 19]: There is ongoing research and development in the field of fractal antennas to improve their

performance. This includes the development of new fractal structures with improved performance, such as those with higher gain, wider bandwidth, and improved impedance matching. The use of these new fractal structures can improve the efficiency of fractal antennas, especially for multiband applications.

4. Employing proper feeding techniques [1]: The feeding technique used for the fractal antenna also plays a role in its efficiency. Proper feeding techniques [2-12], such as coaxial feeding [58] or microstrip feeding [1-20], can help to improve the impedance match and increase the efficiency of the antenna.
5. Utilizing advanced materials [65, 66, 67]: Advanced materials, such as metamaterials and composite materials, can be used to improve the efficiency of fractal antennas. These materials have unique electromagnetic properties, such as negative refractive index, which can be used to enhance the performance of the antenna.

Because fractals possess properties such as self-similarity [1-2], [16,19] and space-filling [1,3,16,19], they are gaining increasing attention in the electromagnetic engineering fields, particularly filter and antenna development. There are numerous wideband antennas available today, but the tapered slot antenna (TSA) is one of the most popular of them all. There has been a lot of use of the Vivaldi TSA in many different fields [95], such as microwave imaging [95] and ultra-wideband systems [3-47], as it was first proposed by Gibson in 1979 [3-10]. Since Vivaldi TSA antennas have an exponentially tapered shape, they have the advantage of being able to have an extremely wide bandwidth [5-10]. There are a number of advantages that Vivaldi antenna elements provide, including their wide-scan, wideband performance, their ease of fabrication with PCB techniques, as well as their ability to support microstrip or strip-line structures [5], [10-18]. A novel multi-resonance directive antenna for ultrawideband (UWB) applications is presented in this report by combining the best attributes of fractal concepts and Vivaldi antennas. Due to its self-similarity properties [1,16,19], this redesigned Sierpinski Fractal Vivaldi antenna (SFVA) demonstrated excellent multiband capabilities with a very small loss of bandwidth or directivity as a result of its self-similarity properties [1]. The number of fractal iterations does not significantly affect radiation patterns, as it does with Euclidean shape patches as well [2, 4], [11], and [12]. In order for the antenna to be suitable for multiband applications [19], [95], it must have a similar radiation pattern at different resonances [1-47]. This is a key parameter when it comes to multiband antennas [1,19]. We will be creating a new wideband impedance bandwidth using a Sierpinski triangle fractal patch [1-2] that will be embedded in the mesh. Considering the Sierpinski gasket fractal (SGF) triangle's height, it should have resonances that fall within a common range of frequencies, such as 2400–2484 MHz

(specified in IEEE 802.11b/g), 2500–2569 MHz (specified in IEEE 802.16e), and 5150–5350/5720–5825 MHz (specified in IEEE 802.11a) [1,16].

2. The Fractal Categorization of Multiband concepts

Fractal antennas can be classified into different categories based on both mathematical and antenna design perspectives [1-10], [16], [19], and [68-95]. The following is an overview of the fractal categorization of multiband antenna concepts [1].

Mathematical Perspective [1],[16],[19]:

1. Iterated Function Systems (IFS) [19], [67-95]: This type of fractal antenna is based on the iterated function system (IFS) mathematical concept [1-12]. IFS fractals are generated by iteratively applying a set of transformation functions to an initial shape, resulting in a self-similar fractal structure [1]. IFS fractals have been widely used in antenna design due to their ability to generate a large number of self-similar structures with different shapes and sizes.
2. Fractal Geometry [1]: This type of fractal antenna is based on the fractal geometry mathematical concept [16,19]. Fractal geometry is a branch of mathematics that deals with the study of shapes and structures that have a repeating pattern at different scales [19]. Fractal geometry is used to design fractal antennas [1-13] that have a repeating pattern at different scales, providing multiple resonant frequencies in a single antenna [1-10].
3. Chaos Theory: This type of fractal antenna is based on the chaos theory mathematical concept. Chaos theory is a branch of mathematics that deals with the study of systems that exhibit seemingly random behavior. Chaos theory has been applied to antenna design to generate fractal structures that exhibit a chaotic behavior, resulting in a multiband behavior [16,19].
- 4.

Antenna Design Perspective [1,16]:

1. Multifractal Antennas: This type of fractal antenna is designed to have multiple fractal structures in a single antenna, each with a different geometry and size [16]. Multifractal antennas provide a multiband behavior by combining the resonant frequencies of each fractal structure [1,16,19].

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2. Self-Similar Fractal Antennas [1,16,19]: This type of fractal antenna is designed to have a self-similar fractal structure at different scales [16], providing multiple resonant frequencies in a single antenna. Self-similar fractal antennas provide a multiband behavior by exploiting the self-similarity of the fractal structure.
 3. Chaotic Fractal Antennas: This type of fractal antenna is designed to exhibit a chaotic behavior, resulting in a multiband behavior. Chaotic fractal antennas are generated using chaos theory and are designed to have a fractal structure with a chaotic behavior [Not yet reported due to fabrication issues]. Indeed, the fractal categorization of multiband antenna concepts can be viewed from both a mathematical and antenna design perspective. From a mathematical perspective, fractal antennas can be classified based on iterated function systems, fractal geometry, and chaos theory [1-13].

3. Multiband Concepts Crucial Factors

Multiband antennas [1, 19] are a critical component in modern communication systems [1,16], as they allow for the simultaneous operation of multiple frequency bands within a single antenna [1-26]. The design of multiband antennas is a complex task that requires careful consideration of several technical factors. The following are some of the most significant technical aspects that need to be considered in designing multiband antennas [1-16].

1. Resonant Frequency [1,16,19]: The resonant frequency of an antenna is a critical factor in its performance, as it determines the frequency band that the antenna can operate in. The design of multiband antennas requires the optimization of multiple resonant frequencies [16] to allow for the simultaneous operation of multiple frequency bands [19]. This can be achieved by using different resonant structures within the antenna [1,16], such as fractal structures, slots, and patches [1-12].
2. Bandwidth [1]: Bandwidth is a measure of the range of frequencies that an antenna can operate in. In multiband antennas [1,16,19], the bandwidth of each frequency band is an important factor to consider, as it determines the performance of the antenna in each frequency band [1]. The design of multiband antennas [19] requires the optimization of the bandwidth for each frequency band to ensure that the antenna can operate efficiently in all frequency bands [1].

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3. Radiation Pattern [1]: The radiation pattern of an antenna determines the direction and shape of the electromagnetic waves that the antenna can emit. The design of multiband antennas [16,19] requires the optimization of the radiation pattern for each frequency band to ensure that the antenna can provide sufficient coverage in all frequency bands. This can be achieved by using different resonant structures within the antenna or by using different feed arrangements [1].
 4. Impedance Matching [1-12]: Impedance matching is the process of adjusting the input impedance of an antenna to match the impedance of the transmission line that it is connected to [19]. The design of multiband antennas requires the optimization of the impedance matching for each frequency band to ensure that the antenna can operate efficiently in all frequency bands [16]. This can be achieved by using impedance matching networks or by adjusting the geometry of the antenna [1].
 5. Size and Weight [1,16,19]: The size and weight of an antenna are important factors to consider, as they determine the practicality of the antenna for a specific application. The design of multiband antennas [16] requires the optimization of the size and weight to ensure that the antenna is practical for the intended application [19]. This can be achieved by using compact resonant structures within the antenna, such as fractal structures, or by using lightweight materials in the construction of the antenna [19].

So, the design of multiband antennas [1] ,[19] requires the optimization of several technical factors to ensure that the antenna can provide efficient operation in all frequency bands. The most significant technical factors that need to be considered in the design of multiband antennas [1] include resonant frequency [1], bandwidth [16], radiation pattern [19], impedance matching, and size and weight [20]. A thorough understanding of these technical factors is important for the successful design and optimization of multiband antennas [1, 19]. The Vivaldi antenna [95] is a popular type of broadband antenna that has been widely used in a variety of communication systems [1-12]. In this project [1], I hope to achieve several benefits in antenna design by combining the Vivaldi antenna with multiband fractal concepts. Some of the most significant benefits

include improved bandwidth, improved efficiency, reduced size, and improved performance in challenging environments.

1. **Improved Bandwidth:** One of the key benefits of combining multiband fractal concepts with Vivaldi antenna design [68-95] is the improvement of the bandwidth. Fractal structures have a self-similar geometry [19] that can provide multiple resonant frequencies [16] within a single antenna [1]. The combination of fractal structures [1],[16],[19] with the Vivaldi antenna [95] design can improve the bandwidth of the antenna by providing multiple resonant frequencies [95] that can operate in different frequency bands. This allows for the simultaneous operation of multiple frequency bands within a single antenna [16], [19], which can improve the overall performance of the communication system.
2. **Improved Efficiency:** The efficiency of an antenna is a critical factor in its performance, as it determines the amount of power that can be transmitted or received. The combination of multiband fractal concepts with Vivaldi antenna design can improve the efficiency of the antenna by providing multiple resonant frequencies that can operate in different frequency bands. This allows for the efficient use of the available power in each frequency band, which can improve the overall performance of the communication system [69-95].
3. **Reduced Size [1]:** The size of an antenna is an important factor to consider, as it determines the practicality of the antenna for a specific application. The combination of multiband fractal concepts with Vivaldi antenna design [95] can reduce the size of the antenna by providing multiple resonant frequencies [19] within a compact geometry. This allows for the design of compact multiband antennas that can be used in applications where size is a limiting factor.
4. **Improved Performance in Challenging Environments:** The performance of an antenna can be affected by the environment in which it is used. The combination of multiband fractal concepts with Vivaldi antenna design [95] can improve the performance of the antenna in challenging environments by providing multiple resonant frequencies that can operate in different frequency bands [19]. This allows for the simultaneous operation of multiple frequency bands, which can provide improved performance in environments where the performance of a single frequency band would be affected.

In technical results, the combination of multiband fractal concepts [19] with Vivaldi antenna design [95] has the potential to offer several benefits in antenna design [1]. These benefits include improved bandwidth, improved efficiency, reduced size, and

improved performance in challenging environments. The combination of these concepts can provide a new approach to the design of multiband antennas that can improve the performance of communication systems and meet the demands of modern communication applications. The main approach to this project's design is this concept [1].

4. Sierpinski Triangle Fractal

The Sierpinski triangle was named after Waclaw Sierpinski in 1919, who invented the Sierpinski gasket, which is also known as the Sierpinski sieve when he invented the Sierpinski triangle in 1915. Sierpinski gaskets are often used in chemical engineering to seal cracks in pipes or procedures. The Sierpinski triangle is regarded by many as a fractal that is self-similar and resembles itself. The construction of the Sierpinski triangle begins with any triangle in a plane [12]. Traditionally, in order to build a Sierpinski triangle, an equilateral triangle is used with the bases distributed equally along each edge [12]. Here is an example of a hierarchical Sierpinski triangle fractal [12] depicting its first five iterations displayed in Figure 1.



Figure. 1. Hierarchical Sierpinski triangle fractal [11,12] showing the first five iterations

These fractals are made by recursively multiplying a few values. Here is how they're made [12-14]:

5. The recursion will be based on a single triangle, which is the base case for recursion.
6. Using the midpoints of each side of the triangle, divide the triangle into four smaller triangles.

-
7. In order to leave three smaller triangles, you will need to remove the middle triangle you just created.
 8. In the same way, repeat this process for each smaller triangle by recursively doing it for each one.

It can be done by using any graphics software or language that can generate shapes and perform recursive functions [1-16]. In this case we will call this pattern a Sierpinski triangle, the result of this self-similar pattern. Sierpinski triangles can be created using any graphics software or programming language that can draw shapes and perform recursive functions. This type of triangle falls into the category of self-similar fractals, which means that they are self-similar in appearance, which means that they exhibit the property of self-similarity. In other words, there are various smaller copies of the fractal shape that make up the overall shape of the fractal. In terms of fractal dimensions, it is possible to measure a fractal's self-similarity [12-14]. Based on the box-counting or information dimension method, Sierpinski triangles have a fractal dimension of approximately 1.585. Additionally, the Sierpinski triangle has the feature of being able to be observed at different scales of the same pattern, which is another characteristic that defines self-similarity [12].

The Sierpinski triangle can produce a pattern that looks like the overall shape of the fractal when you zoom in on any part of it. This is due to the recursive algorithm that is used to create the Sierpinski triangle. It is essential to shrink the triangle to the height of $1/2$ and to the width of $1/2$, make three copies of the triangle and place the three copies in such a way that each triangle touches each other on each corner [1], [12]. In Figure 1, you can see the first five iterations of the Sierpinski triangle fractal with the same method of application recursively to smaller triangles [1], [12]. In [13], the turtle graphics module is used to create a Sierpinski triangle in Python using the Turtle graphics module in order to demonstrate how to do so [1], [12]. The program will allow us to create a Sierpinski triangle that has a depth of 3 (that is, it will be composed of 27 smaller triangles, each composed of three triangles) using the Sierpinski algorithm. The `drawSierpinski` function is used in the initial phase of the analysis as a source function for generating the triangle. In contrast, the `drawTriangle` function is used in the later stages of the analysis as a source function for generating each individual triangle. When using the `getMid` function, which is required in order for triangles to be divided by their midpoints, it is possible to find the midpoint of two points with the function [1], [12]. There is a `Triangle` class in this code with a `length` attribute and a `shrinking` method that returns a new, smaller triangle. This is half the length of its original length [1], [12], [13].

In this example, the triangle and the depth argument are taken, then Sierpinski is used to drawing the triangle with the specified depth through recursion. This triangle looks like it was made with turtle graphics because it's made using the turtle module [1], [12], [13].

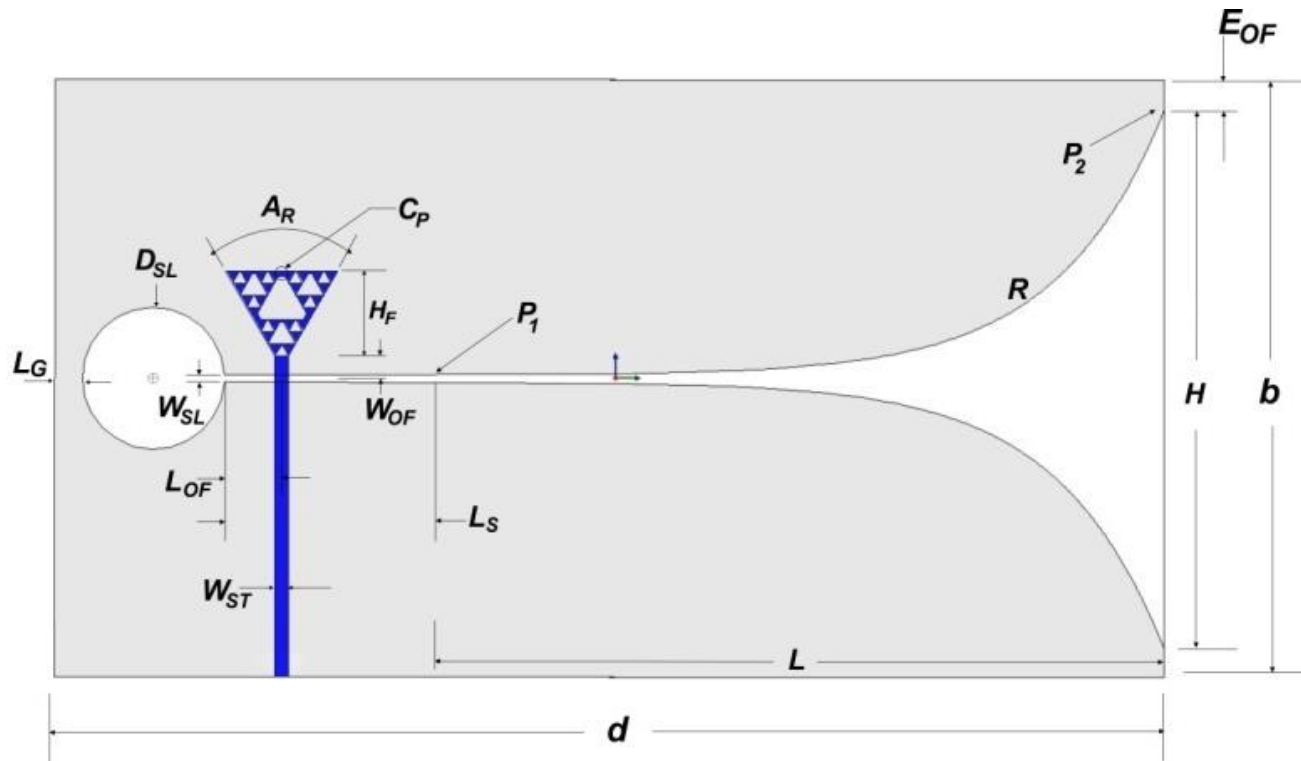


Figure 2 illustrates the proposed improved SFV antenna for multiband, multi resonance applications with its geometry [1].

9. Antenna Configuration and Results

The proposed architecture for improved SFV antennas for multiband applications can be seen in Fig. 2. We have been able to model the proposed SFV antenna structure using the commercial software Ansoft High Frequency Structure Simulator (HFSS, version .11) based on the results of this study. A proposed SFV antenna can be constructed using an exponential ground plane and a Sierpinski triangle fractal patch. As shown in the photo, the proposed SFV antenna was printed on Roger 4003 substrates with dimensions of 150 x 80 mm and a thickness of 0.5mm. For a 50-impedance characteristic similar to that of an SMA antenna, a microstrip line with a width of 3 mm is fixed in order to achieve that impedance characteristic. An Agilent 8722ES vector network analyzer was used to measure the proposed antenna's return loss. By adjusting the fractal dimensions, it is possible to estimate the desirable operating bands (2400-2484 MHz, 2500-2569 MHz, and 5150-5350/5725-5825 MHz) and their bandwidths that can be allocated [1], [11], [12]. SVF antennas were designed with this purpose in mind. Figure 1 illustrates five different fractal iterations for antenna designs:

Antenna 1: A first generation SVF antenna, using a 3 GHz resonance within both broadband and wideband capacities, showed a useful result that would suggest that Antenna 1 resonates at 3 GHz. Results of the first prototype of the SVF antenna indicated that it resonated at 3 GHz;

Antenna 2: Using the measurements of the SVF antenna (taking an equilateral triangle and joining the midpoints of each side of it, removing an inverted triangle from the parent triangle), we were able to improve match performance in the first band as well as wideband performance above approximately 6.1GHz as a result of the 2nd iteration of the antenna. According to the measured results in Table I, antenna two resonates at frequencies of 3.2 and 5.5GHz;

Antenna 3: A measurement revealed that the 3rd antenna displayed resonances at 2.5, 5.5, and 9-GHz after the 13 equilateral triangles were removed from the parent triangle in iteration 0 of the SVF antenna. With the 3rd iteration, the antenna is better suited to wideband operation and is better matched in the second band.

TABLE I

MEASURED CHARACTERISTICS OF SOME SVF ANTENNAS IN THE TABLE. IMPEDANCE BANDWIDTH IS FREQUENCY RANGE WHERE VSWR IS EQUAL TO OR LESS THAN 2; f_c IS THE BAND'S CENTER FREQUENCY

	f_n GHz	S_{11} dB	f_c GHz	f_c Gain dBi	BW ($VSWR = 2$) $f_l - f_u$, GHz
Ant 1	3	-21	3.83	2.9	3.010-4.65
Ant 2	3.2, 5.5	-38, -22	3.445 5.15	3.3 4.2	2.99-3.9 4.2-6.1
Ant 3	3.96, 4.8, 7, 9.5	-15, -17, -16, -26	6.2 4.5 2.21	4.3 7.5 9.8	2.8-5.8 6.5-8.3 8.4-11.2

$$\delta = \frac{h_n}{h_{n+1}} = 2 \quad \text{Equation.1}$$

$$A = \frac{y_2 - y_1}{e^{Rx_2} - e^{Rx_1}} \quad \text{Equation.2}$$

$$B = \frac{y_1 e^{Rx_2} - y_2 e^{Rx_1}}{e^{Rx_2} - e^{Rx_1}} \quad \text{Equation.3}$$

In the Sierpinski fractal model of the antennae, the height is 88.8, 44.4, 22.2, and 11.1 millimeters, respectively. The Sierpinski fractal model has a reduction factor of two [4]. During the course of conducting a study on the third iteration of SVF antennas, it was discovered that periodic resonances could be observed at the center frequencies of 2.25 GHz (f_1), 5.50 GHz (f_2), and 9.50 GHz (f_3). In the equation below, we can see that the frequency separation is calculated between three bands by calculating the frequency separation between each band's resonance frequency, f , and n is the number of bands in each band, which represent the frequency between the three bands, as shown in the equation 1. To achieve maximum impedance matching between frequencies, the parameters (H , R , and L) of the third iteration of the proposed SVF antenna were optimized to values of 0.44, 0.45, and 0.50, respectively. Figure 2 shows the slot-line patch,

the tapered length of the antenna, and the gradual exponential ratio of the antenna, represented by H, L, and R, respectively.

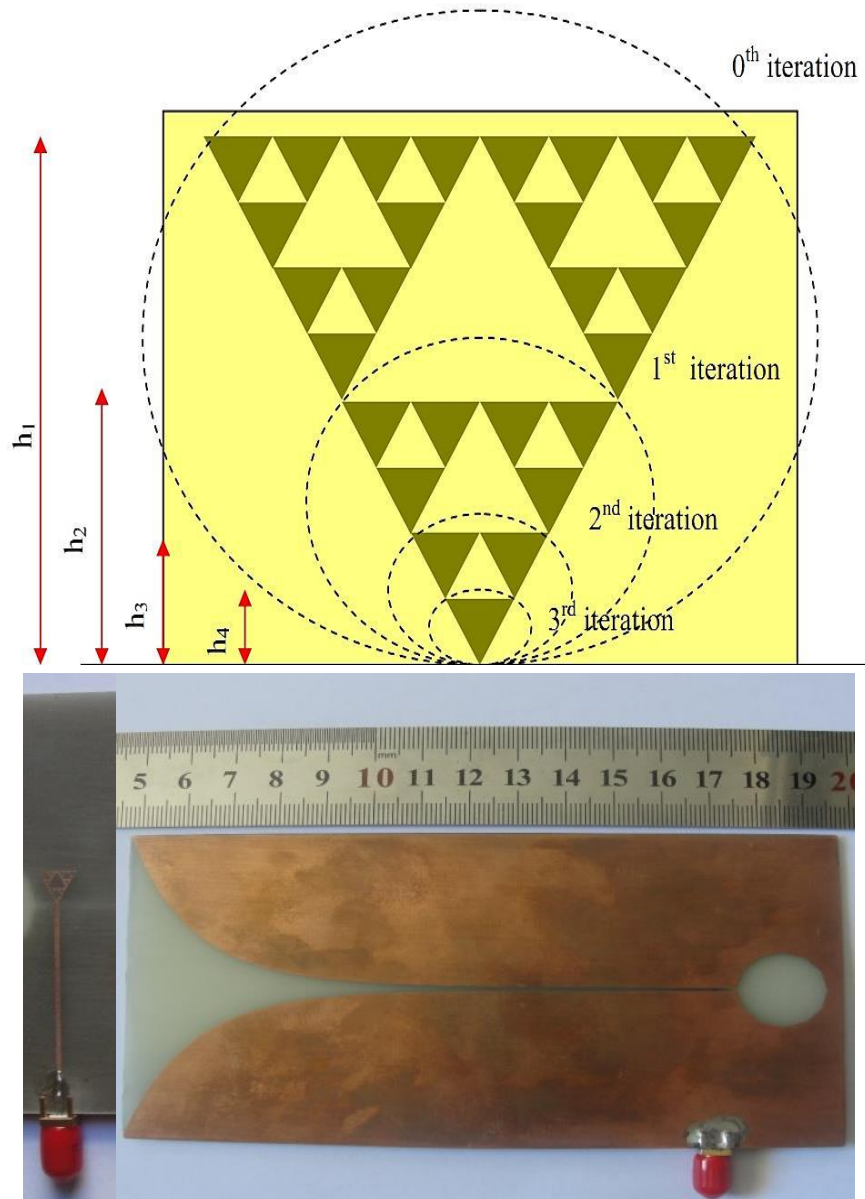
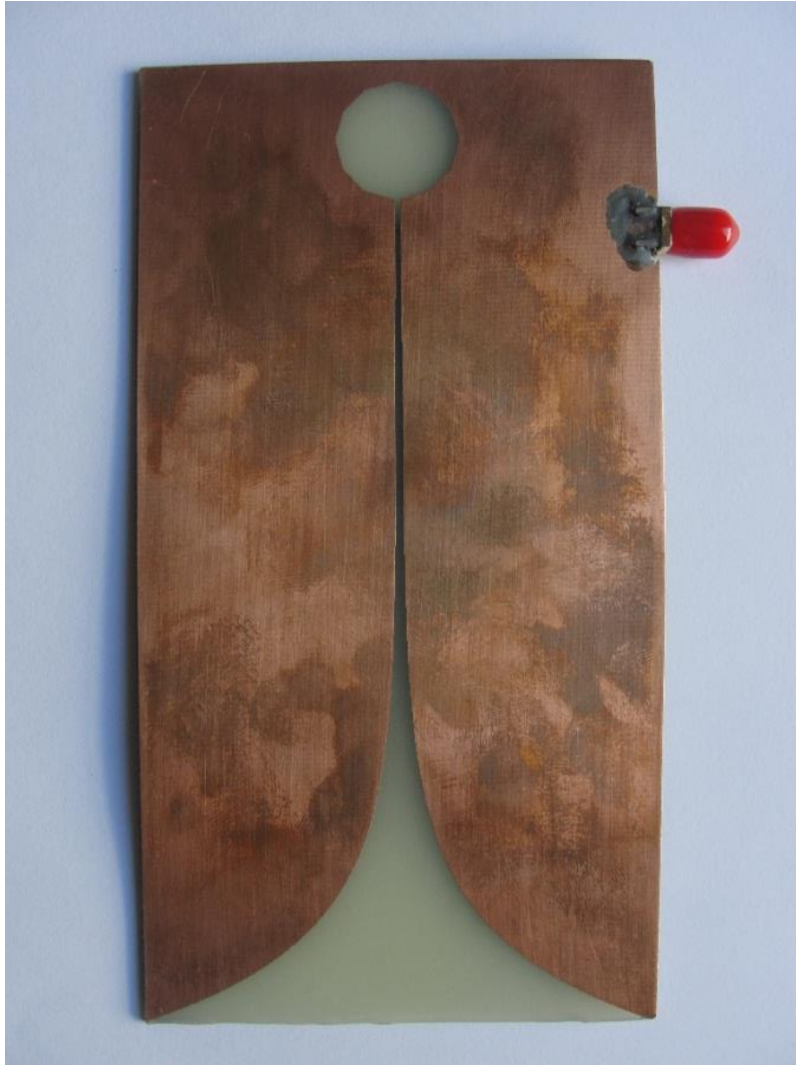


Fig. 3. Photograph of the new Fractal Vivaldi antenna that was manufactured with Sierpinski Gasket.



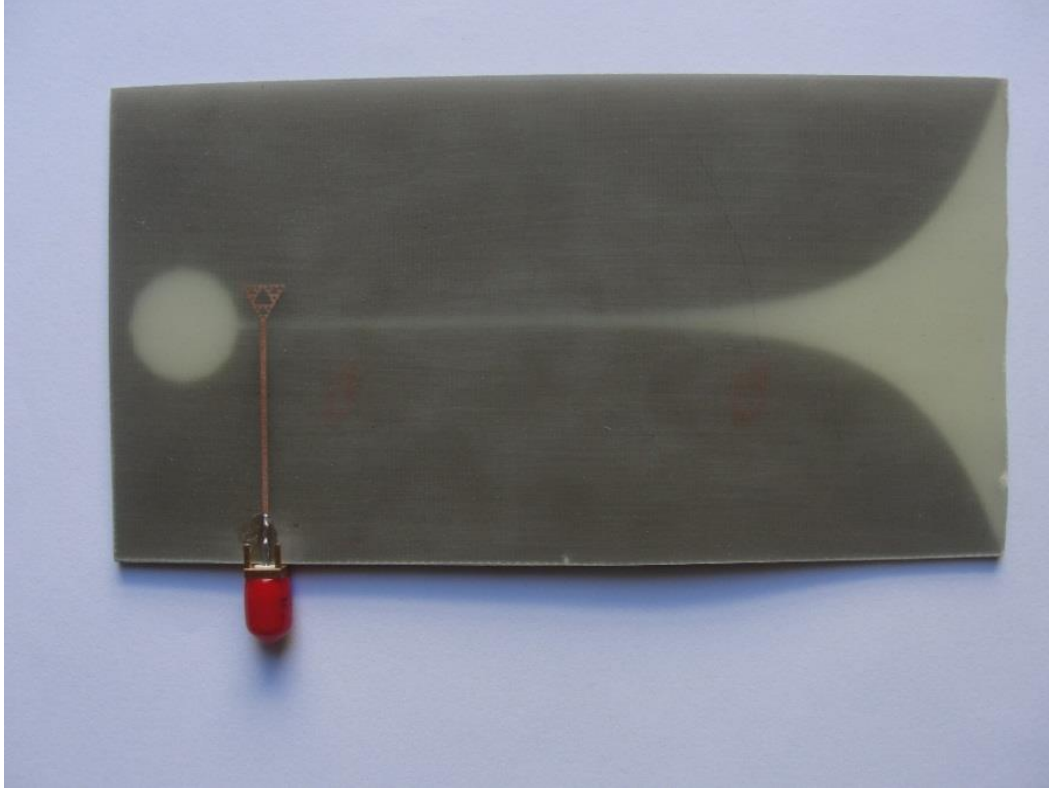


Fig. 4. A photograph of the Fractal Vivaldi antenna manufactured on both sides

As part of the design process of the Vivaldi antenna, these parameters are essential to keep in mind because they directly impact its capability. Parametric studies have shown that even with a slight change in slot line width (H), the impedance matching of all three iterations of the fractal antenna is greatly affected by variations in slot line width. As a result of the work, the slot-line width would be determined by the higher cutoff frequency (f_H) and the lower cutoff frequency (f_L). In this case, the widest and narrowest H s are $1.3 \lambda_{sl}$ and $20\% \lambda_{SH}$, respectively (Note: λ_{SH} is the wavelength of the lower cutoff frequency, whereas λ_{SH} is the wavelength of the higher cutoff frequency).

Considering the requirements of the project, namely designing an antenna with a bandwidth (3-11GHz) and $VSWR \leq 2$, we were able to obtain appropriate initial values for each of these parameters based on the project requirements. Three models were designed such that they covered only the parameters involved in them. It was not necessary to use the full antenna model to select the initial values of these parameters because they directly affect the return loss response and antenna characteristics. The third model simulated the return loss and radiation pattern of the antenna using the entire antenna design. The parameters of the system were examined in order to see how they affected the radiation pattern and return loss. It is imperative to keep in mind that in order to fully understand the effect that each of these parameters has on

antenna characteristics, it is critical to remember that the initial values of each of these parameters are equally significant. In other words, if the material or the thickness of the substrate is changed when checking the microstrip line width parameter, it will result in new and different values for the microstrip line width parameter as a result. Our objective is to achieve the optimal value for all the parameters involved in the antenna design process simultaneously. This will enable us to obtain the most effective results by optimizing all these parameters simultaneously at the same time.

It is the purpose of the HFSS software to use the optimization algorithms it offers to optimize the parameters of the SVF antenna in accordance with the project specifications. Within the software, there is a wide variety of optimization algorithms available to optimize the parameters of any structure that has been designed within the software. These algorithms are outlined below. These algorithms are used by the software in order in order to optimize the parameters of any structures that have been built within it [1-45], [95].

- Sequential Mixed-Integer Nonlinear Programming
- Sequential nonlinear programming
- Quasi-Newton
- Pattern Search
- Genetic algorithm

The genetic algorithm is used as a method of optimizing parameters in this project. Using this algorithm, the minimum and maximum values of each parameter are determined, as well as the starting point of the optimization process. To optimize each parameter, this must be done for each. In general, the shorter the interval between parameter changes and the closer the starting point is to the optimal value, the less time it will take to achieve optimization. Depending on the parameters that are being optimized, a goal must also be defined for the optimization algorithm. This means that the optimal output of each parameter and the error that can be allowed must be defined.

$$d = L_G + 2D_{SL} + L_S + L \quad \text{Equation 4}$$

$$b = H + 2E_{OF} \quad \text{Equation 5}$$

Despite this, it is important to note that the thickness and material of the substrate are not continuous values. In addition, the specifications of the substrate are limited to the specifications provided by the manufacturer of the substrate. As a result, the antenna design did not take these parameters into consideration when optimizing it. Therefore, it was decided to optimize the antenna design using the substrate selected in the first stage. There is no doubt that when we have similar material and thickness of the substrate, it will have a different outcome for every experiment we conduct over the coming season, depending on the changes we make to these two factors.

Here we intend to use the constant A_R as the parameter of our example, and the value of this constant is going to be equal to $A_R=60^\circ$. The fractal structure of the stable radial is completely altered when this parameter is changed, and therefore, different results can be obtained depending on how the parameter is changed. In order to avoid producing this parameter as a constant value, we use the A_R value of 60° as the parameter. This is because we designed the radial stable fractal structure in the previous chapter based on $A_R=60^\circ$, as shown in Fig.2.

Table 2

Based on the fact that the antenna has the following length:

parameter	Value
W_{ST}	0.9 mm
H_F	6.2 mm
L_{OF}	3.9 mm
W_{OF}	0 mm
CP	0.45 mm
D_{SL}	9.45 mm
W_{SL}	0.9 mm
L_G	3.7 mm
L_S	15 mm
L	112.4 mm
R	.6
H	75 mm
E_{OF}	2.5 mm

Figure 5 shows the VSWR diagram for the final designed antenna, which covers the frequency range of 2-12 GHz, and displays VSWR diagram for the final designed

antenna, respectively. The final designed antenna shows a VSWR of 2.5-11.4 GHz, resulting in 8.5 GHz bandwidth. This antenna is very suitable for UWB systems because of its bandwidth and high and low cutoff frequencies, which fall within UWB systems' bandwidth. In this design, the gradual exponential ratio (R) can be determined by the exponential curve $y = Ae^{Rx} + B$, A, and B can be calculated using Eqs. 2 and 3. (Note: (x_1, y_1) and (x_2, y_2) are the start and end points of the exponential curve, respectively). To achieve maximum impedance matching, tapered antenna lengths need to be between 3 and 5 times of center wavelengths. This will enable maximum impedance matching, thus completing the transition from feeding to radiation parts. Parametric studies show that tapered antenna length (L) should be between 3 and 5 center wavelengths corresponding to the center work frequency in order to provide maximum impedance matching, thus completing the transition from feeding to radiation parts. For $H=45\text{mm}$, $L = 138\text{mm}$, and $R=0.05\text{mm}^{-1}$, we will have maximum matching and directivity. According to the above points, if $H=45\text{mm}$, $L = 138\text{mm}$, and $R = 0.05\text{mm}^{-1}$, we will obtain maximum matching and directivity. In Table 2, you can find a statistical summary of the proposed antenna parameters according to the criteria.

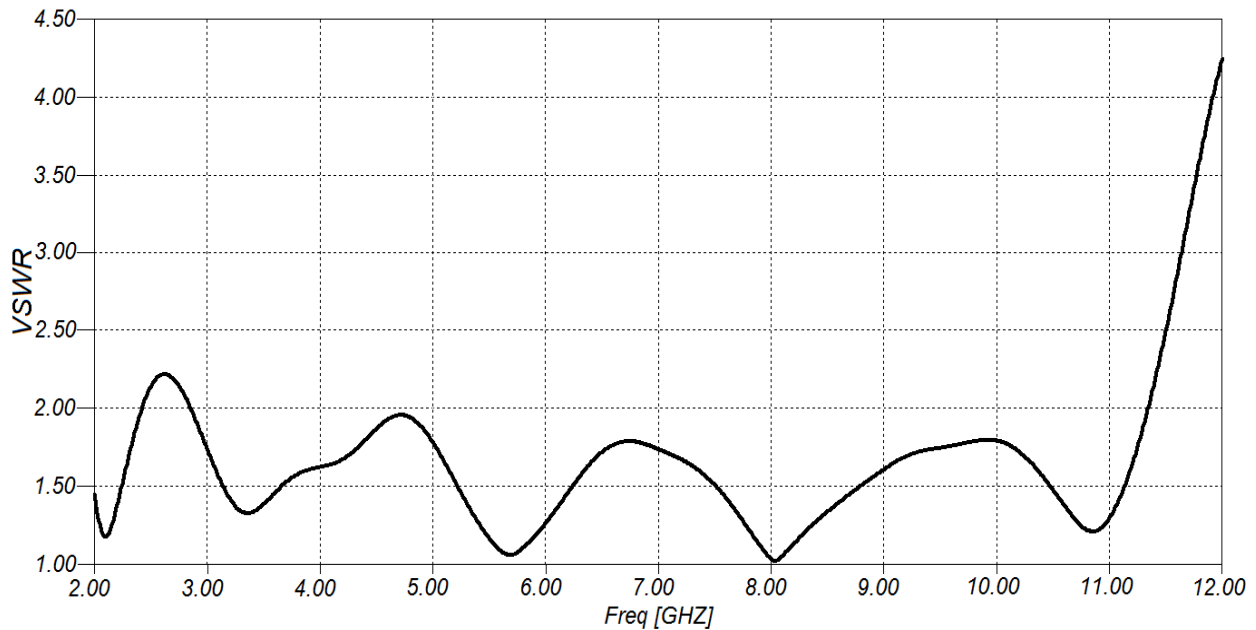


Fig. 5 shows the VSWR response of the final designed antenna.

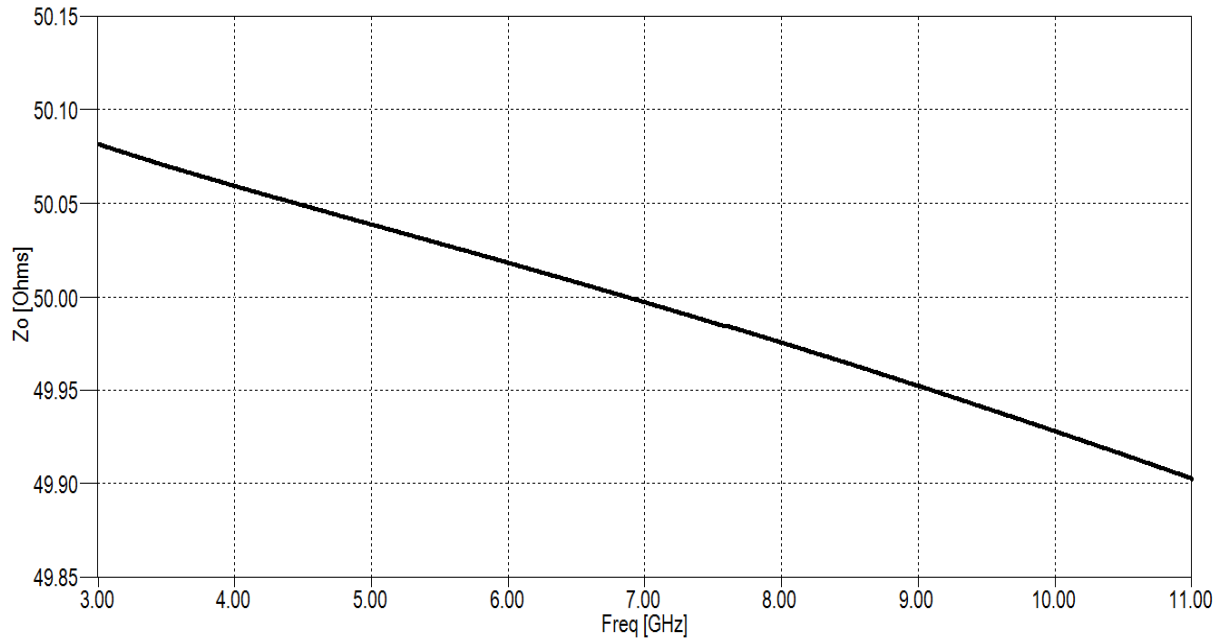


Fig. 6 Antenna input impedance over its entire bandwidth

Figure 6 shows a diagram of a typical antenna input impedance at frequencies around 3-11 GHz. Based on the results, it can be seen that the input impedance of the antenna has undergone little change ($\pm 1\Omega$) in its entire bandwidth. A very close match is observed between the antenna bandwidth's input impedance and the value $Z_0=50\Omega$. Accordingly, this means that an antenna's input impedance in its entire bandwidth can be calculated as $Z_0=50\Omega$ in our expectations. The radiation pattern of the proposed antenna is end-fire. This is one of the key features of Vivaldi antennas, and it is also evident in this project's antenna. The radiation pattern of the antenna also has its highest value in the positive direction of the X-axis. This is because the opening of the antenna designed in HFSS is in the positive direction of the X-axis. A diagram of E and H plane radiations and polarization components (Co, Cross) are shown for each plan over the operating band frequencies.

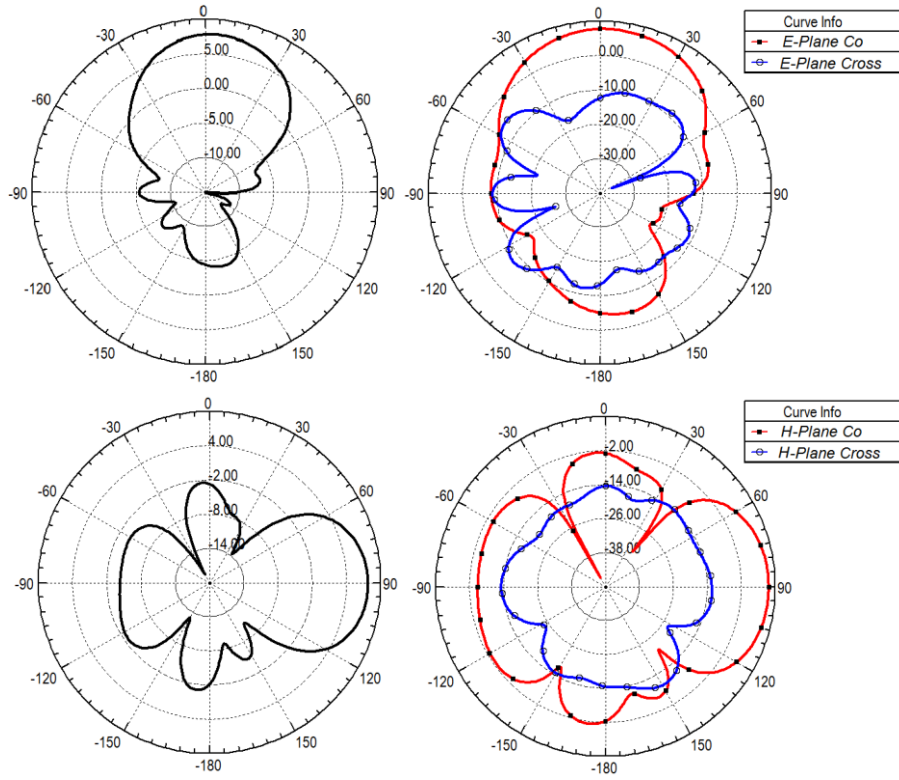
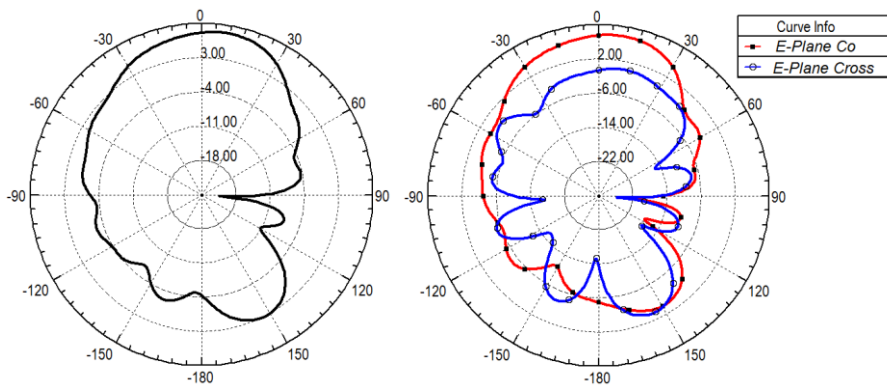


Figure 7. A diagram that illustrates the radiation beam of the antenna's E and H planes at the 3GHz frequency



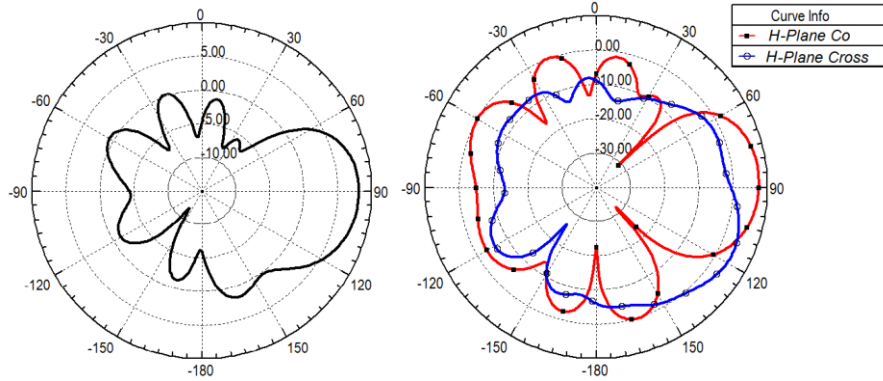


Figure 8. A diagram that illustrates the radiation beam of the antenna's E and H planes at the 4GHz frequency

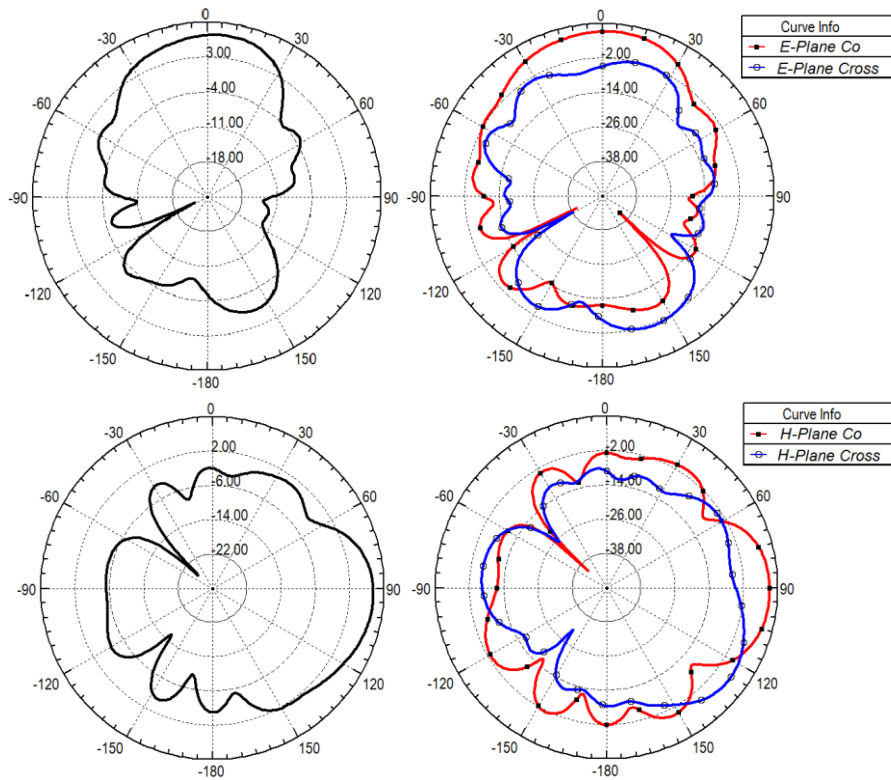


Figure 9. A diagram that illustrates the radiation beam of the antenna's E and H planes at the 5GHz frequency

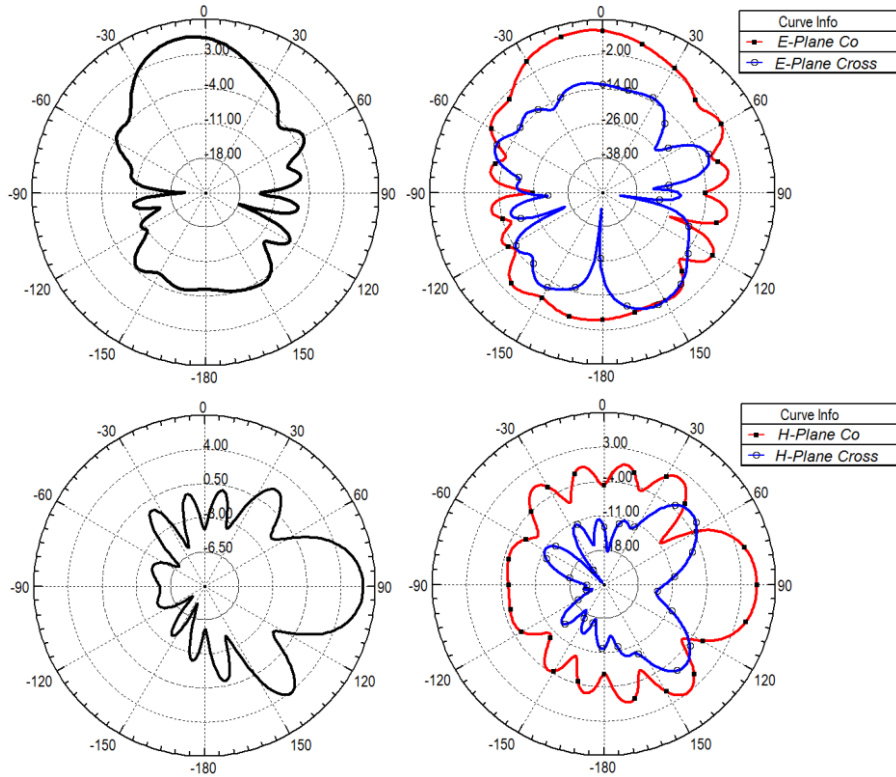


Figure 10. A diagram that illustrates the radiation beam of the antenna's E and H planes at the 6GHz frequency

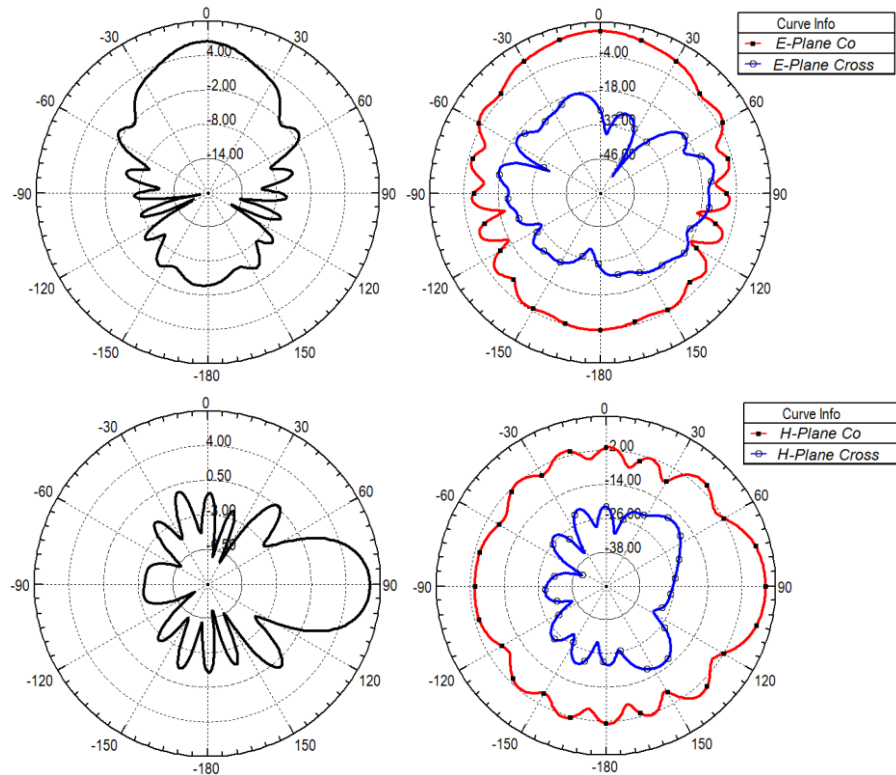


Figure 11. A diagram that illustrates the radiation beam of the antenna's E and H planes at the 7GHz frequency

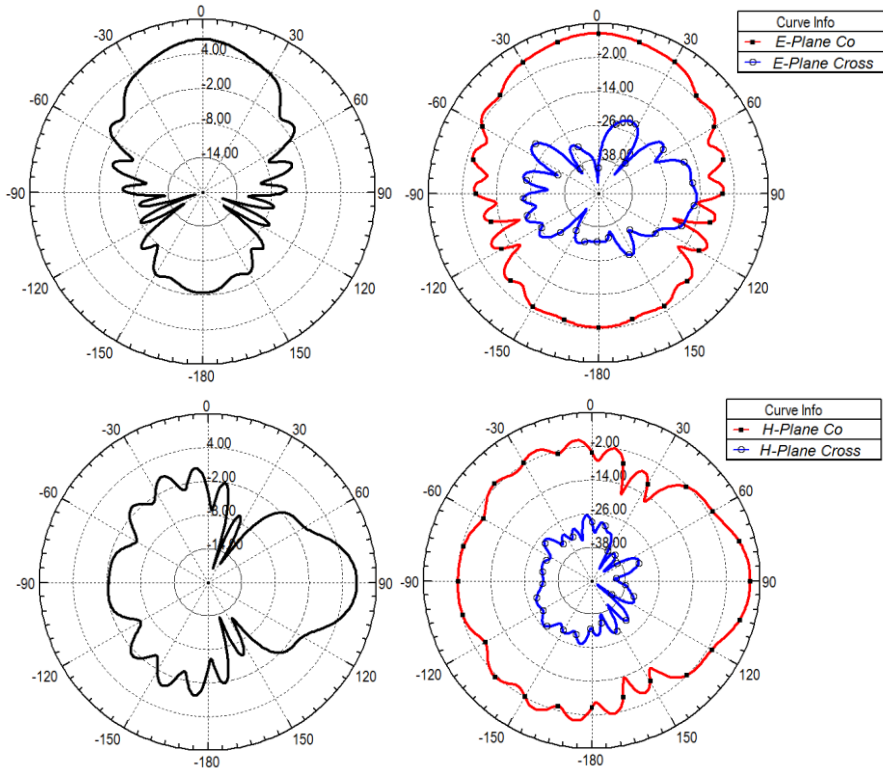


Figure 12. A diagram that illustrates the radiation beam of the antenna's E and H planes at the 8GHz frequency

With the Sierpinski triangle fractal structure, the radial stubs of the Vivaldi antenna that are part of the feed line of the antenna represent a network of resonance frequencies in this project. A larger number of resonance frequencies will be achieved in the antenna by increasing the number of fractal iterations in the radial stubs. This would result in the stub's effective performance being able to cover a wider bandwidth due to this work. By enhancing the effective bandwidth of the radial stubs of feed lines, they can transfer more energy to the slotted lines of the antenna. This allows more energy to be transferred to the antenna.

By first determining the bandwidth and center frequency of the Vivaldi antenna, this project proposes a method for developing an antenna based on the Vivaldi approach. It is therefore expected that the fractal structure of the radial stub will have resonance frequencies over the antenna's bandwidth, resulting in a larger fractal iteration. It is critical to optimize the parameters of the radial stub, as well as other parameters of the Vivaldi antenna, before creating the end product antenna. Therefore, it is possible to develop Vivaldi antennas with a wide bandwidth using this approach. It does not have to develop several radial stubs and experiment

with various methods to achieve the desired results. As a result, you need to make sure that the resonance frequencies of the radial stub are chosen in such a way that they effectively cover the entire antenna bandwidth. To design the antenna, it is necessary to optimize its parameters at the end of the project. With the method used in this project, other types of short circuit terminations can also be designed in the same way. Through the use of fractal structures in this project, it is possible to design short circuit terminations that operate at multiple frequencies instead of a single frequency (fractal resonance frequencies) in contrast to the single frequency terminations that were used employed. There is no doubt that an effective plan can be demonstrated by observing its optimal performance, as in some examples from previous reports. In figure 13, we can see how the antenna performs in an experiment and simulation. Based on the results in this figure, the simulation presented results and the experimental tests performed on the antenna are similar. Fig. 13 shows that the antenna has a usable bandwidth of 8 GHz. Its lower and upper cutoff frequencies are 2.8 GHz and 11.4 GHz, respectively. Simulations and measurements have been performed to simulate and measure the antenna's radiation pattern at different frequencies, as shown in Figures 14-21. Based on measurements and simulations conducted at various frequencies, we have confirmed that the proposed radiation pattern is stable as an endfire antenna.

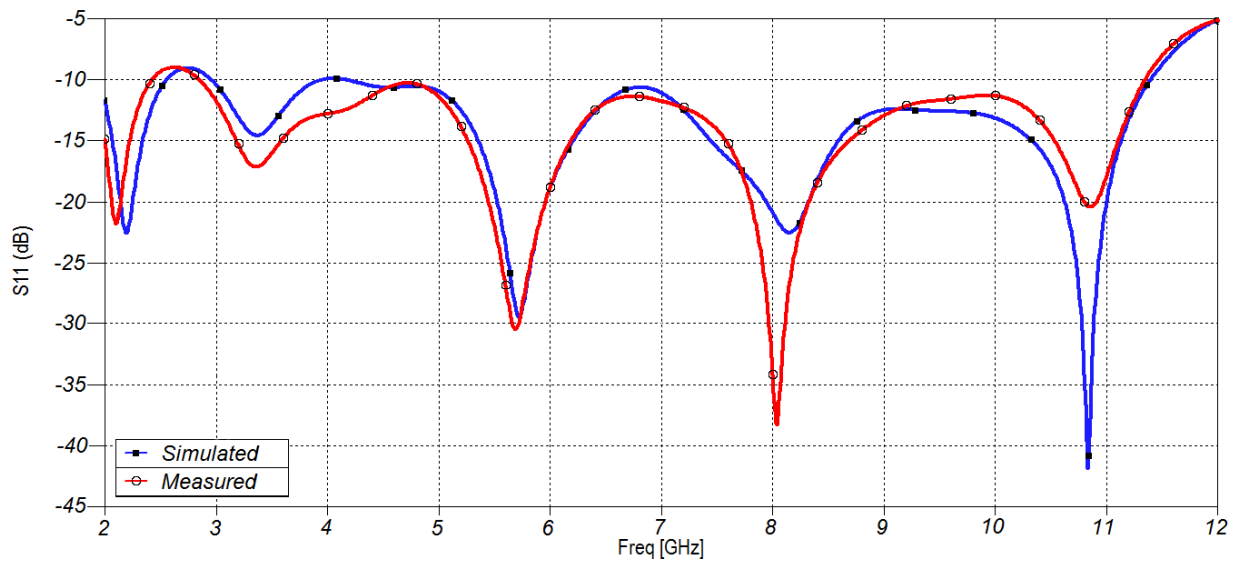


Figure 13: The diagram S_{11} depicts the results of the practical test and simulation of the designed antenna for the project that was performed during testing

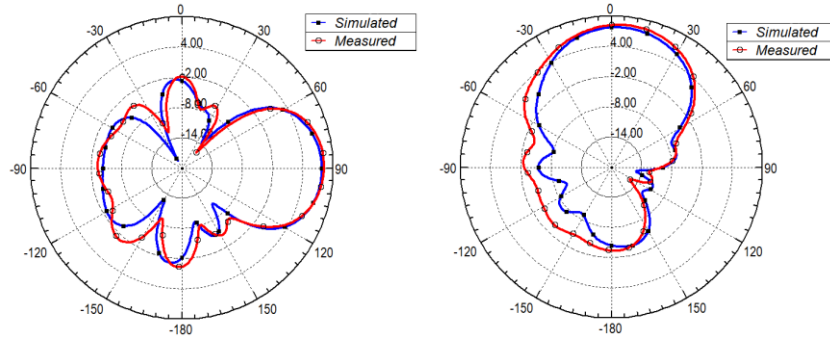


Figure 14. Measured and simulated radiation patterns for the E and H plates of the antenna at a frequency of 3 GHz.

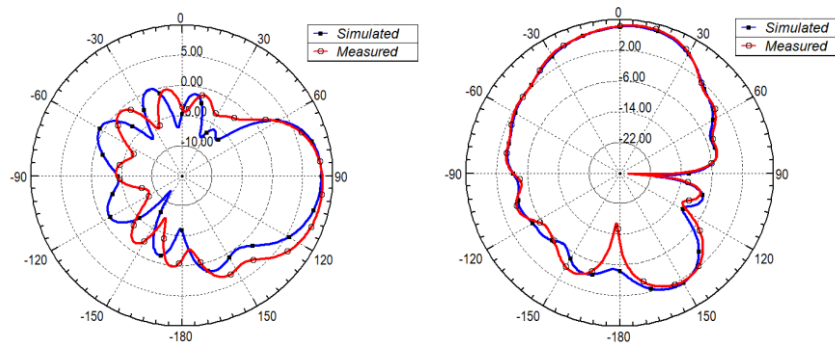


Figure 15. Measured and simulated radiation patterns for the E and H plates of the antenna at a frequency of 4 GHz.

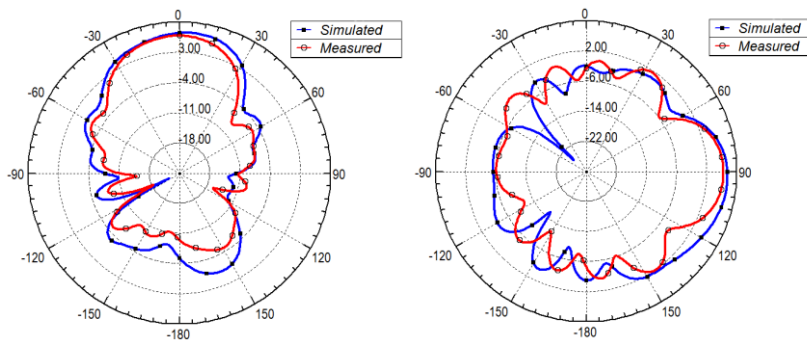


Figure 16. Measured and simulated radiation patterns for the E and H plates of the antenna at a frequency of 5 GHz.

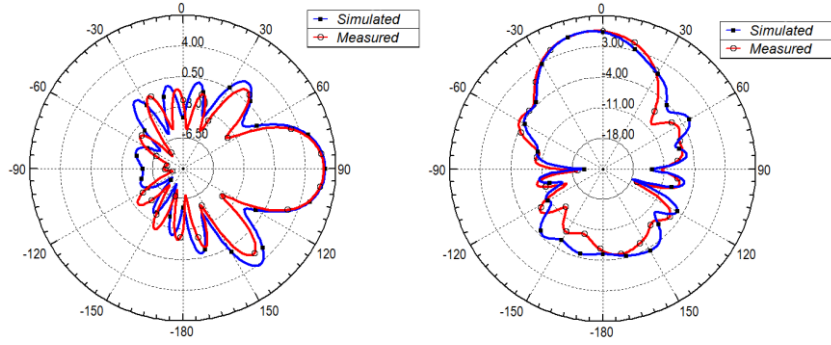


Figure 17. Measured and simulated radiation patterns for the E and H plates of the antenna at a frequency of 6 GHz.

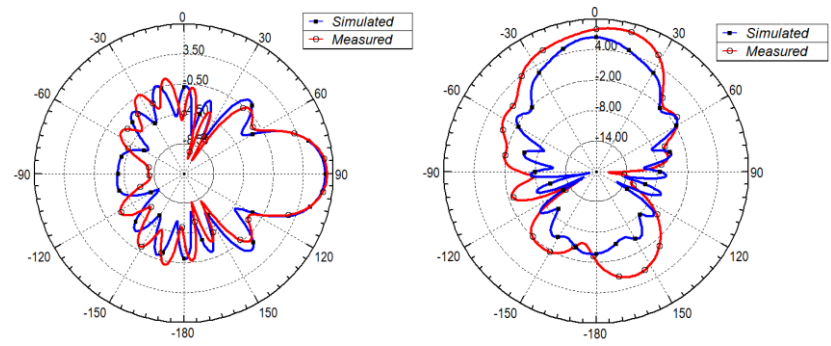


Figure 18. Measured and simulated radiation patterns for the E and H plates of the antenna at a frequency of 7 GHz.

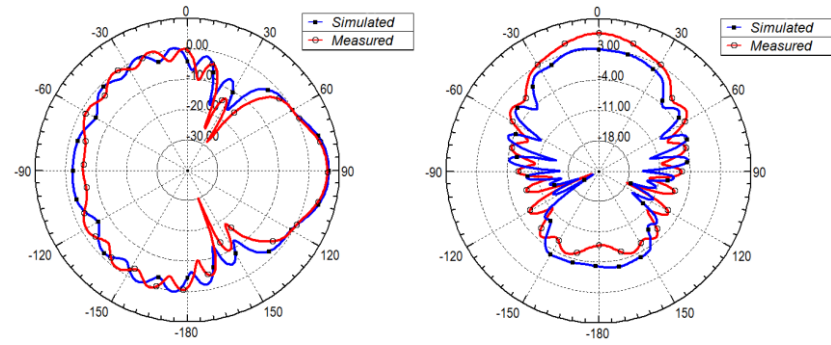


Figure 19. Measured and simulated radiation patterns for the E and H plates of the antenna at a frequency of 8 GHz.

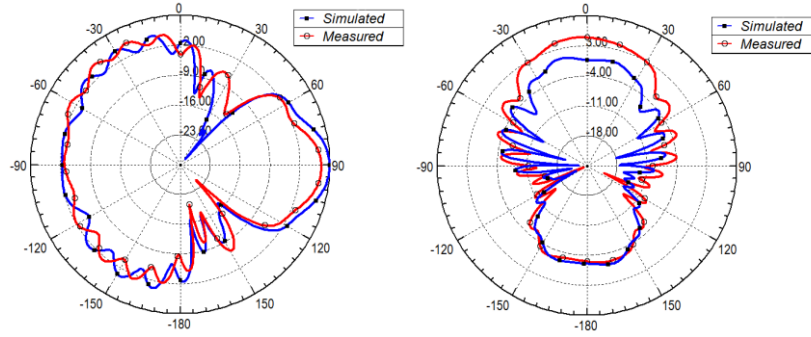


Figure 20. Measured and simulated radiation patterns for the E and H plates of the antenna at a frequency of 10 GHz.

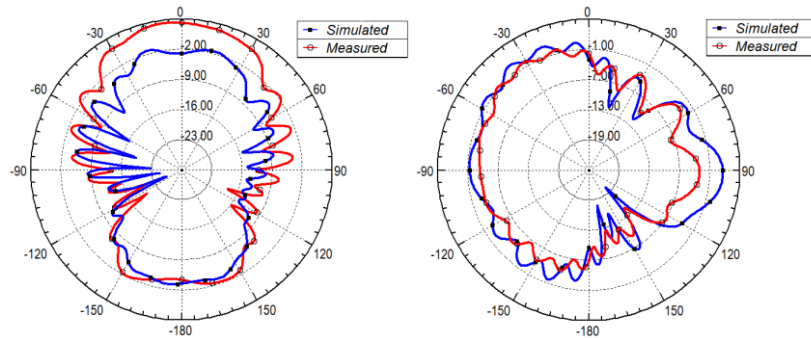


Figure 21. Measured and simulated radiation patterns for the E and H plates of the antenna at a frequency of 11 GHz.

10. Conclusion

A redesigned Vivaldi antenna with multiband characteristics is presented and investigated using Sierpinski triangle fractals. As a result of increasing the fractal iteration and tuning the Vivaldi antenna parameters correctly, a very good impedance match has been achieved. Due to the fact that Sierpinski gasket fractals are self-similar, this results in the formation of multiband characteristics. Using the proposed antenna, a very efficient bandwidth pattern, as well as a very directed radiation pattern, can be achieved. This is in accordance with IEEE 802.11b/g, IEEE 802.16e, and IEEE 802.11a standards. In multiband applications where a focused directional antenna is required the Sierpinski fractal property of the Vivaldi antenna makes it an excellent choice in multiband applications where a focused directional antenna is necessary. It is inevitable that an antenna will always be constructed incorrectly based on the measurements

obtained. However, it is not a guarantee that the antenna will be constructed exactly correctly. Even though measuring instruments may also produce errors, a certain amount of error will always be present. The antenna can be designed to match measurements exactly, despite these limitations. As seen on the previous pages, the measured and simulated characteristics of the antenna developed by the project have a lot in common. All parameters affecting the performance of an antenna have been selected and optimized in a systematic manner. This indicates that the antenna has been designed in such a way that all parameters have been considered. Based on the results of the third chapter's investigations, a significant factor in determining the antenna's bandwidth and performance is the fractal structure of the radial stub. From a theoretical perspective, the Sierpinski triangle fractal structure's resonance frequencies can be doubled by halving its dimensions. The upper and lower cutoff frequencies of the antenna can be doubled by optimizing the parameters of a fractal structure half the size of the one used in this project.

It is possible to design customized antennas with different specifications by employing different fractal structures for the radial stub of the Vivaldi antenna feed line, such as the Sierpinski carpet. You might also be able to use fractal structures to check the characteristics of slotted lines with cavities. It is also possible to test the characteristics of a slotted line and a radial shaft simultaneously by using fractal structures. The use of Sierpinski fractals in Vivaldi antennas has been shown to enhance the performance of the antennas in terms of bandwidth, gain, and directionality. They have potential applications in ultra-wideband (UWB) communication systems where high bandwidth signals are transmitted over short distances, such as in wireless personal area networks (WPANs) and radar systems. The best results will depend on the specific design parameters and operating conditions of the system, so further research and optimization is needed to fully realize the potential benefits of using Sierpinski fractals in Vivaldi antennas for UWB applications.

It is important to note that the specific design parameters and operating conditions will play a significant role in determining the performance of the fractal Vivaldi antennas. Further research and optimization are needed to fully realize the potential benefits of using Sierpinski fractals in Vivaldi antennas for UWB applications.

References

1. Javad Pourahmadazar. Design and Fabrication of a Novel UWB Antenna with New Geometrical Structures (Fractal and Euclidean). Engineering Sciences [physics]. Urmia University, 2011. English.
2. P. J. Gibson, "The Vivaldi aerial," in Proc. 9th Eur. Microw. Conf., Brighton, U.K., Jun. 1979, pp. 101–105.
3. Vinci, G. Weigel, R., "Multiband Planar Vivaldi Antenna for Mobile Communication and Industrial Applications", ICEAA, IEEE. Conf , 2010.
4. J. H. Shafieha, J. Noorinia, and Ch. Ghobadi, "PROBING THE FEED LINE PARAMETERS IN VIVALDI NOTCH ANTENNAS", Progress In Electromagnetics Research B, Vol. 1, 237–252, 2008.
5. B. Stockbroeckx and A. Vorst, "Copolar and Cross-Polar Radiation of Vivaldi Antenna on Dielectric Substrate," IEEE Trans. on Antennas and Propagation, vol. 48, pp. 19-25, Jan. 2000.
6. M. Greenberg et al., "Performance Characteristics of the Dual Exponentially Tapered Slot Antenna (DETTSA) for Wireless Communications Applications," IEEE Trans. on Vehicular Technology, col. 52, pp. 305 - 312, Mar. 2003.
7. E. Gazit, "Improved design of the Vivaldi antenna," IEE Proceedings, vol.135, pt. H, no. 2, Apr 1988.
8. S. Kim and K. Chang, "Ultra Wideband Exponentially-Tapered Antipodal Vivaldi Antennas," IEEE AP-S Int. Symp. Digest, Monterey, USA, pp. 2273-2276, Jun. 2004.
9. Jun-qian Niu, et al., "Application of Vivaldi Antenna on Wideband Measure System," Aerospace Measure Technology, 24(3): pp.21-24, 2004.
10. http://en.wikipedia.org/wiki/Sierpinski_triangle
11. <https://stackoverflow.com/questions/53106846/sierpinski-recursion-issue-with-order-triangles-are-drawn>
12. J. Pourahmadazar, C. Ghobadi, J. Nourinia, N. Felegari and H. Shirzad, "Broadband CPW-Fed Circularly Polarized Square Slot Antenna With Inverted-L Strips for UWB Applications," in *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 369-372, 2011, doi: 10.1109/LAWP.2011.2147271.
13. J. Pourahmadazar, C. Ghobadi, J. Nourinia, N. Felegari and H. Shirzad, "Broadband CPW-Fed Circularly Polarized Square Slot Antenna With Inverted-L Strips for UWB Applications," in *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 369-372, 2011, doi: 10.1109/LAWP.2011.2147271.
14. M. Farahani, J. Pourahmadazar, M. Akbari, M. Nedil, A. R. Sebak and T. A. Denidni, "Mutual Coupling Reduction in Millimeter-Wave MIMO Antenna Array Using a Metamaterial Polarization-Rotator Wall," in *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 2324-2327, 2017, doi: 10.1109/LAWP.2017.2717404.
15. S. R. Emadian, C. Ghobadi, J. Nourinia, M. H. Mirmozafari and J. Pourahmadazar, "Bandwidth Enhancement of CPW-Fed Circle-Like Slot Antenna With Dual Band-Notched Characteristic," in *IEEE Antennas and Wireless Propagation Letters*, vol. 11, pp. 543-546, 2012, doi: 10.1109/LAWP.2012.2199274.

16. J. Pourahmadazar, C. Ghobadi and J. Nourinia, "Novel Modified Pythagorean Tree Fractal Monopole Antennas for UWB Applications," in *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 484-487, 2011, doi: 10.1109/LAWP.2011.2154354.
17. N. Felegari, J. Nourinia, C. Ghobadi and J. Pourahmadazar, "Broadband CPW-Fed Circularly Polarized Square Slot Antenna With Three Inverted-L-Shape Grounded Strips," in *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 274-277, 2011, doi: 10.1109/LAWP.2011.2135832.
18. V. Rafii, J. Nourinia, C. Ghobadi, J. Pourahmadazar and B. S. Virdee, "Broadband Circularly Polarized Slot Antenna Array Using Sequentially Rotated Technique for CC-Band Applications," in *IEEE Antennas and Wireless Propagation Letters*, vol. 12, pp. 128-131, 2013, doi: 10.1109/LAWP.2013.2237744.
19. J. Pourahmadazar, C. Ghobadi, J. Nourinia and H. Shirzad, "Multiband Ring Fractal Monopole Antenna for Mobile Devices," in *IEEE Antennas and Wireless Propagation Letters*, vol. 9, pp. 863-866, 2010, doi: 10.1109/LAWP.2010.2071372.
20. Pourahmadazar, J.; Mohammadi, S.: 'Compact circularly-polarised slot antenna for UWB applications', *Electronics Letters*, 2011, 47, (15), p. 837-838, DOI: 10.1049/el.2011.1430
21. Pourahmadazar, J.; Rafii, V.: 'Broadband circularly polarised slot antenna array for L- and S-band applications', *Electronics Letters*, 2012, 48, (10), p. 542-543, DOI: 10.1049/el.2012.0294
22. S. Mohammadi, J. Nourinia, C. Ghobadi, J. Pourahmadazar and M. Shokri, "Compact Broadband Circularly Polarized Slot Antenna Using Two Linked Elliptical Slots for C-Band Applications," in *IEEE Antennas and Wireless Propagation Letters*, vol. 12, pp. 1094-1097, 2013, doi: 10.1109/LAWP.2013.2280457.
23. Pourahmadazar, J., Denidni, T.A. Towards Millimeter-wavelength: Transmission-Mode Fresnel-Zone Plate Lens Antennas using Plastic Material Porosity Control in Homogeneous Medium. *Sci Rep* 8, 5300 (2018). doi: 10.1038/s41598-018-23179-8
24. H. Boudaghi, J. Pourahmadazar and S. A. Aghdam, "Compact UWB monopole antenna with reconfigurable band notches using PIN diode switches," *WAMICON 2013*, Orlando, FL, USA, 2013, pp. 1-4, doi: 10.1109/WAMICON.2013.6572744.
25. J. Pourahmadazar and T. A. Denidni, "Multi-beam tapered slot antenna array using substrate integrated waveguide Rotman lens," 2015 European Microwave Conference (EuMC), Paris, France, 2015, pp. 1447-1450, doi: 10.1109/EuMC.2015.7346046.
26. Rezaeieh, S.A., Şimşek, S. and Pourahmadazar, J. (2013), Design of a compact broadband circularly-polarized slot antenna for wireless applications. *Microw. Opt. Technol. Lett.*, 55: 413-418. <https://doi.org/10.1002/mop.27303>
27. J. Pourahmadazar, S. Sahebghalam, S. Abazari Aghdam and M. Nouri, "A Millimeter-Wave Fresnel Zone Plate Lens Design Using Perforated 3D Printing Material," 2018 IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz Applications (IMWS-AMP), Ann Arbor, MI, USA, 2018, pp. 1-3, doi: 10.1109/IMWS-AMP.2018.8457170.
28. J. Pourahmadazar and T. Denidni, "X-band substrate integrated Rotman Lens with $\pm 24^\circ$ scanning capability," 2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, Vancouver, BC, Canada, 2015, pp. 232-233, doi: 10.1109/APS.2015.7304502.

29. B. Zarghooni, A. Dadgarpour, J. Pourahmadazar and T. A. Denidni, "Supershaped metamaterial unit-cells using the gielis formula," 2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, Vancouver, BC, Canada, 2015, pp. 458-459, doi: 10.1109/APS.2015.7304615.
30. Pourahmadazar, J, Denidni, TA. Millimeter-wave planar antenna on flexible polyethylene terephthalate substrate with water base silver nanoparticles conductive ink. *Microw Opt Technol Lett.* 2018; 60: 887– 891. <https://doi.org/10.1002/mop.31079>
31. J. Pourahmadazar and T. A. Denidni, "High Gain Substrate Integrated Waveguide Resonant Slot Antenna Array for mm-Wave Band Radio," 2015 IEEE International Conference on Ubiquitous Wireless Broadband (ICUWB), Montreal, QC, Canada, 2015, pp. 1-4, doi: 10.1109/ICUWB.2015.7324455.
32. J. Pourahmadazar, H. Shirzad, C. Ghobadi and J. Nourinia, "Using a MAM and genetic algorithm to optimize UWB microstrip monopole antenna with FEM and HFSS," 2010 5th International Symposium on Telecommunications, Tehran, Iran, 2010, pp. 115-119, doi: 10.1109/ISTEL.2010.5734009.
33. Rafii Vahid, Nourinia Javad, Javad Pourahmadazar, Jalili Faramarz. Circularly Polarized Circular Slot Antenna Array Using Sequentially Rotated Feed Network. *Journal of Communication Engineering*, 2012, 1 (1), pp.38-46. fahal-03914171f
34. Pourahmadazar, J, Denidni, TA. 60 GHz antenna array for millimeter-wave wireless sensor devices using silver nanoparticles ink mounted on a flexible polymer substrate. *Microw Opt Technol Lett.* 2017; 59: 2830– 2835. <https://doi.org/10.1002/mop.30834>
35. M. Dashti Ardakani, J. Pourahmadazar and S. O. Tatu, "A monopole antenna with notch-frequency function for UWB application," 2017 XXXIInd General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS), Montreal, QC, Canada, 2017, pp. 1-4, doi: 10.23919/URSIGASS.2017.8105323.
36. J. Pourahmadazar, M. Dashti Ardakani, S. O. Tatu and T. A. Denidni, "V-band dipole phased array antennas on extended hemispherical dielectric lenses," 2017 XXXIInd General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS), Montreal, QC, Canada, 2017, pp. 1-4, doi: 10.23919/URSIGASS.2017.8105327.
37. Shirzad, H. ., Virdee, B. ., Ghobadi, C. ., Shokri, M. ., Sedghi, T. ., Asiaban, S. ., & Pourahmadazar, . J. . (2021). Bandwidth Enhancement of Compact Planar Microstrip Antenna. *The Applied Computational Electromagnetics Society Journal (ACES)*, 28(05), 441–445.
38. J. Pourahmadazar, R. Karimian and T. Denidni, "8–12-GHz beam-shaping/steering phased antenna array system using SIW fed nonplanar director Yagi-Uda antenna," 2016 IEEE International Symposium on Antennas and Propagation (APSURSI), Fajardo, PR, USA, 2016, pp. 1145-1146, doi: 10.1109/APS.2016.7696280.
39. J. Pourahmadazar and T. A. Denidni, "X-band substrate integrated waveguide Rotman Lens," 2015 USNC-URSI Radio Science Meeting (Joint with AP-S Symposium), Vancouver, BC, Canada, 2015, pp. 188-188, doi: 10.1109/USNC-URSI.2015.7303472.
40. J. Pourahmadazar, M. Farahani and T. Denidni, "Printed Ridge Gap Waveguide Rotman Lens for Millimetre-wave Applications," 2018 18th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM), Waterloo, ON, Canada, 2018, pp. 1-2, doi: 10.1109/ANTEM.2018.8572972.

-
41. J. Pourahmadazar, R. Karimian, M. Farahani and T. Denidni, "Planar microwave lens based beam-forming phased antenna array system using non-coplanar SIW fed bowtie antenna," 2016 17th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM), Montreal, QC, Canada, 2016, pp. 1-4, doi: 10.1109/ANTEM.2016.7550154.
 42. J. Pourahmadazar, R. Karimian and T. Denidni, "A steerable Yagi-Uda array antenna using a substrate integrated waveguide Rotman lens," 2016 USNC-URSI Radio Science Meeting, Fajardo, PR, USA, 2016, pp. 15-16, doi: 10.1109/USNC-URSI.2016.7588489.
 43. R. Karimian, J. Pourahmadazar, M. Nedil and T. A. Denidni, "On the design of low SAR CPW antenna with magneto dielectric AMC based ground plane," 2016 10th European Conference on Antennas and Propagation (EuCAP), Davos, Switzerland, 2016, pp. 1-5, doi: 10.1109/EuCAP.2016.7481411.
 44. Y. Yousefzadeh, J. Pourahmadazar and S. A. Aghdam, "Compact UWB microstrip BPF using meander line resonator," 2013 IEEE Antennas and Propagation Society International Symposium (APSURSI), Orlando, FL, USA, 2013, pp. 802-803, doi: 10.1109/APS.2013.6711060.
 45. R. Amiri, B. Zarghooni, A. Dadgarpour, J. Pourahmadazar and T. A. Denidni, "Reconfigurable metamaterial unit-cell with controllable refractive index," 2016 17th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM), Montreal, QC, Canada, 2016, pp. 1-2, doi: 10.1109/ANTEM.2016.7550155.
 46. M. Farahani, J. Zaid, J. Pourahmadazar, T. A. Denidni and M. Nedil, "Millimeter-wave corrugated surface for mutual coupling reduction between dipole antennas," 2016 17th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM), Montreal, QC, Canada, 2016, pp. 1-2, doi: 10.1109/ANTEM.2016.7550158.
 47. R. Amiri, B. Zarghooni, A. Dadgarpour, J. Pourahmadazar and T. A. Denidni, "Anisotropic metamaterial unit-cell for millimeter-wave applications," 2016 17th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM), Montreal, QC, Canada, 2016, pp. 1-2, doi: 10.1109/ANTEM.2016.7550179.
 48. J. Pourahmadazar, R. Karimian and T. A. Denidni, "A High Data-Rate Kiosk Application circularly polarized fractal antenna for mm-wave band radio with 0.18 μ m CMOS technology," 2016 10th European Conference on Antennas and Propagation (EuCAP), Davos, Switzerland, 2016, pp. 1-4, doi: 10.1109/EuCAP.2016.7481317.
 49. Jalili Faramarz, Javad Pourahmadazar, Rafii Vahid, Nourinia Javad, "Circularly Polarized Circular Slot Antenna Array Using Sequentially Rotated Feed Network". Journal of Communication Engineering, 2012, 1 (1), pp.38-46.
 50. J. Pourahmadazar and T. Denidni, "V-band Printed Ridge Gap Waveguide Phased Array Antenna with $\pm 40^\circ$ Scanning Angular Sector and ETSI Class II Radiation Pattern," 2018 18th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM), Waterloo, ON, Canada, 2018, pp. 1-2, doi: 10.1109/ANTEM.2018.8572992.
 51. M. Farahani, J. Pourahmadazar, T. Denidni and M. Nedil, "Millimeter-Wave High-Gain Ridge Gap Beam Steerable Antenna for 5G wireless Networks," 2018 18th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM), Waterloo, ON, Canada, 2018, pp. 1-2, doi: 10.1109/ANTEM.2018.8572923.
 52. R. Karimian, J. Pourahmadazar, T. A. Denidni and M. Nedil, "Free space mutual coupling reduction between two SIW antennas at millimeter-wave frequency," 2016

-
- IEEE International Symposium on Antennas and Propagation (APSURSI), Fajardo, PR, USA, 2016, pp. 2183-2184, doi: 10.1109/APS.2016.7696798.
53. J. Pourahmadazar, R. Karimian, M. Farahani and T.A. Denidni, "10GHz Microwave Lens based Beam-forming Phased Antenna Array System Using SIW Fed Bow-tie antenna", *ANTEM*, 2016.
54. R. Karimian, M. Dashti, J. Pourahmadazar, S. Ahmadi and M. Zaghoul, "Non-Reciprocal Phased Array antenna," 2021 XXXIVth General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS), Rome, Italy, 2021, pp. 1-3, doi: 10.23919/URSIGASS51995.2021.9560450.
55. M. D. Ardakani, R. Karimian, J. Pourahmadazar, S. Tatu, S. Ahmadi and M. Zaghoul, "Characterization of a Highly Efficient Waveguide Front-End Direct-Conversion Receiver for 60-GHz Wireless Systems," 2021 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (APS/URSI), Singapore, Singapore, 2021, pp. 529-530, doi: 10.1109/APS/URSI47566.2021.9703708.
56. J. Pourahmadazar, R. Karimian, M. D. Ardakani, S. Ahmadi and M. Zaghoul, "Alumide as a Nonmagnetic Fresnel Zone Lens at 30 GHz," 2021 XXXIVth General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS), Rome, Italy, 2021, pp. 1-3, doi: 10.23919/URSIGASS51995.2021.9560347.
57. M. D. Ardakani, R. Karimian, J. Pourahmadazar, S. Tatu, S. Ahmadi and M. Zaghoul, "Compact Parallel Coupled-Line Bandpass Filter Dedicated to $\text{\$}\text{\$}$ -band Homodyne Front-End Radars," 2021 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (APS/URSI), Singapore, Singapore, 2021, pp. 1391-1392, doi: 10.1109/APS/URSI47566.2021.9704419.
58. Nader Felegari, Javad Pourahmadazar. A Novel Coaxial-fed Wide Band Circularly Polarised Patch Antenna for WLAN/ WiMax Applications. *International Journal of Natural and Engineering Sciences*, 2019, 5 (2), pp.11. fahal-03914172f
59. Pourahmadazar, J., Denidni, T.A. Author Correction: Towards Millimeter-wavelength: Transmission-Mode Fresnel-Zone Plate Lens Antennas using Plastic Material Porosity Control in Homogeneous Medium. *Sci Rep* 8, 10293 (2018). <https://doi.org/10.1038/s41598-018-28407-9>
60. J. Pourahmadazar and T. A. Denidni, "Extended hemispherical integrated lens antenna for F-band application," 2017 XXXIInd General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS), Montreal, QC, Canada, 2017, pp. 1-2, doi: 10.23919/URSIGASS.2017.8105165.
61. R. Amiri, B. Zarghooni, J. Pourahmadazar and T. A. Denidni, "The fabrication and test of paraffin-based dielectric lenses for metamaterial characterization using the free-space method for 10–18 GHz," 2017 11th European Conference on Antennas and Propagation (EUCAP), Paris, France, 2017, pp. 3235-3238, doi: 10.23919/EUCAP.2017.7928499.
62. J. Pourahmadazar, R. Karimian and M. D. Ardakani, "Towards E-band Wavelength: 3D Printed Gaussian Corrugated Horn for Cassegrain Antenna Application," 2022 United States National Committee of URSI National Radio Science Meeting (USNC-URSI NRSM), Boulder, CO, USA, 2022, pp. 86-87, doi: 10.23919/USNC-URSINRSM57467.2022.9881470.
63. Yousefzadeh, Y., Pourahmadazar, J. and Aghdam, S., 2013, January. 312.10: COMPACT UWB MICROSTRIP BPF USING MEANDER LINE RESONATOR.

In *INTERNATIONAL SYMPOSIUM DIGEST ANTENNAS AND PROPAGATION* (Vol. 1, No. 2, pp. 802-802). IEEE.

64. Yasin Yousefzadeh, Javad Pourahmadazar. Compact Low Pass Filter using Inter-Digital Loaded Defected Rectangular Stub Resonators. *International journal of Microwave and Optical Technology*, 2012, 7 (1), pp.35-38. fhal-03914108f
65. Pourahmadazar, Javad (2018). *Nouvelles antennes millimétriques à lentille utilisant des structures périodiques poreuses en plastique*. Thèse. Québec, Université du Québec, Institut national de la recherche scientifique, Doctorat en télécommunications, 196 p.
66. Javad Pourahmadazar. NEW MILLIMETRIC LENS ANTENNAS USING PERIODIC POROUS PLASTIC STRUCTURES. *Engineering Sciences [physics]*. Université du Québec, Institut national de la recherche scientifique,, 2018. English. (NNT :). (tel-03911562)
67. Javad Pourahmadazar. Towards BLUETOOTH: TECHNOLOGY, APPLICATIONS, and ANTENNAS. *Engineering Sciences [physics]*. Urmia University, 2011. English.
68. Ali Fahoul. Design and Fabrication of a Novel UWB fractal Vivaldi Antenna, Urmia University, 2012. Farsi.
69. Fractal antennas: Design, Characterizations, and Applications, J.Gianvittorio, UCLA, 2000.
70. A.J. Crilly, R.A. Earnshaw, H. Jones, editors. *Applications of Fractals and Chaos: the Shape of Things*, Berlin: Springer-Verlag, 1993.
71. C. Puente, J. Romeu, R. Bartoleme, and R. Pous, "Fractal multiband antenna based on Sierpinski gasket," *Electron. Lett.*, vol. 32, pp. 1-2, 1996.
72. C. Puente-Baliarda, J. Romeu, R. Pous, and A. Cardama, "On the behavior of the Sierpinski multiband fractal antenna," *IEEE Trans. Ant. Propagat.*, vol. 46, pp. 517-524, 1998.
73. N. Cohen, "Fractal antenna applications in wireless telecommunications," in *Professional Program Proc. of Electronics Industries Forum of New England*, 1997, IEEE, pp. 43-49, 1997.
74. C. Puente-Baliarda, J. Romeu, R. Pous, J. Ramis, and A. Hijazo, "Small but long Koch fractal monopole," *Electron. Lett.*, vol. 34, pp. 9-10, 1998.
75. B.B. Mandelbrot, *The Fractal Geometry of Nature*, New York: W.H. Freeman, 1983.
76. H.O. Peitgen, H. Jurgens, and D. Saupe, *Chaos and Fractals: New Frontiers of Science*, New York: Springer-Verlag, 1992.
77. K.J. Falconer, *Fractal Geometry: Mathematical Foundations and Applications*, New York: Wiley, 1990.
78. G.P. Cherepanov, A.S. Balankin, and V.S. Ivanova, "Fractal fracture mechanics, *Engineering Fracture Mechanics*, vol. 51, pp. 997-1033, 1995.
79. J.H. Jeng, V.V. Varadan, and V.K. varadan, "Fractal finite element mesh generation for vibration problems," *J. Acous. Soc. Amer.*, vol. 82, pp. 1829-1833, 1987.
80. A.E. Jacquin, "Fractal image coding: A review," *Proc. IEEE*, vol. 81, pp. 1451-1465, 1993.
81. B. Wohlberg and G. DeJager, "Review of the fractal image coding literature," *IEEE Trans. Image Processing*, vol. 8, pp. 1716-1729, 1999.
82. Gazit, "Improved design of Vivaldi antenna" *IEEE Proc. H*, 1988, pp.89-92
83. L. R. Lewis, M. Fassett, and J. Hunt, "A broadband strip-line array element" in *Dig. 1974 IEEE Antennas propagate. Symp, Atlanta, GA*, pp. 335-337
84. Yangvesson Et Al, "The tapered slot antenna-A new integrated element for millimeter wave application" *IEEE Transaction on Microwave Theory and Techniques*, Vol. 37, No. 2, February 1989, pp. 365-374

-
85. R.Q.Lee and R.N. Simons, "Effect of Curvature on Tapered Slot Antennas" Antennas and Propagation Society International Symposim. 1996, AP-S. Digest, Vol.1,pp. 188-191
 86. Daniel H.Schabert, Thomas L. Korzenovski. Joakim F.Johnsn, "Endfire Tapered Slot Antenna on Dielectric Substrates" IEEE Transaction on Antenna and Propagation, Vol. AP-33, No. 12, December 1985
 87. B. Schiek, J. Kohler, "An Improved Microstrip-to-Microslot Transition," IEEE Trans. on Microwave Theory and Techniques, Vol. 24, No. 4, April 1976, pp. 231-233.
 88. Weedon et al, "A step-frequency radar imaging system for microwave nondestructive evaluation progress in electromagnetic research, 2000. pp. 121-146
 89. Chien-Hsun Ho, Lu Fan and Kai Chang, "Experimental Investigation of CPW-Slotline Transition for Unipolar Microwave Integrated Circuit" 1993 IEEE MTT-S Digest
 90. K. S. Yngvesson., T. L. Korzienowski, Y. S. Kim, E. L. Kollberg, J. F. Johansson, "Endfire Tapered Slot Antenna on Dielectric Substrates," IEEE Trans. Antennas & Prop., Vol. AP-33, No. 12, December 1985, pp. 1392- 1400.
 91. Philip Felber, "FRACTAL ANTENNAS" Illinois Institute of Technology, December 12, 2000
 92. Schaubert & Shin, "A parameter study of stripline-fed Vivaldi notch-antenna arrays" IEEE Transaction on Antennas and Propagation, Vol. 47, No. 5, May 1999, pp. 879-886
 93. K.G Gupta, Ramesh Carg, Inder Bahl, Prakash Bhartia, "Microstrip lines and slotline" Artech House, boston, London, 1996.
 94. Tuan Anh Vu, Malihe Zarre Dooghabadi, Shanthi Sudalaiyandi, H° akon A. Hjortland, Øivind Næss, Tor Sverre Lande and Svein Erik Hamran, "UWB Vivaldi Antenna for Impulse Radio Beam forming" Dept. of Informatics, University of Oslo, Norway, 2009.