Improvement Of Coplanar Vivaldi Antenna Radiation Patterns With Fractal Structure For Ultra-Wideband Applications

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Abstract

The need for telecommunications technology requires fast data transfer and increasing capacity. Therefore, telecommunications technology continues to be developed by creating transmitter and receiver devices that can work at Ultra-Wideband (UWB) frequencies. This study aims to design a coplanar Vivaldi antenna with a fractal structure so that the performance of the antenna radiation pattern can increase to apply UWB frequency. The conventional coplanar Vivaldi antenna, model-A, and Model-B fractal antennas are designed to see the performance of return loss values less than -10 dB, VSWR less than 2, and working frequency of 2-10 GHz. The fractal model is created with a circular repeating structure given at the edges of the antenna patch. From the simulation results, the main lobe value of the conventional Coplanar Vivaldi antenna was 5.21 dBi, the model-A fractal was 7.02 dBi, and the Model-B fractal was 7.84 dBi. The order of the best sidelobe performance at a frequency of 6 GHz is obtained for the model-A fractal of -9 dB. Beamwidth of 46 degrees and the best main lobe direction of 0 degrees is obtained for fractal model-B. By adding a fractal structure, the lobe magnitude/directivity, sidelobe level, beamwidth, and main lobe direction can be improved.

Keywords: Antenna, Vivaldi, Directivity, Fractal, Ultra-Wideband.

I. INTRODUCTION

Technology that can be used at wide frequencies strongly supports optimization in telecommunication devices. Ultra-Wideband (UWB) is a broadband technology that has been widely developed and is a communication system with a vast bandwidth. In 2002 the UWB was first issued by the Federation Communication Commission (FCC). Wide UWB requires a fractional bandwidth greater than 20% of the middle frequency [1].

Advances in wireless technology can be attributed to the development of antennas, which can access high data speeds, providing significant reinforcement and radiation characteristics [2]. UWB antennas are better suited to apply RADAR and PC peripheral due to their high precision and low power consumption [3]. In addition, UWB technology currently has operating frequency extensions ranging from 3.1-10.6 GHz with low cost, low complexity, high gain, high data resolution, low interference, lightweight, and easy to be made into an assortment of wireless communication applications [4].

However, the difficulty in designing the UWB must be electronically small and at a low cost without impeding its performance. In addition, high acquisition, stable radiation patterns, linear phase variations, and low profiles are also required to meet the prerequisites for UWB applications. The application of UWB has been conducted in various studies, such as microwave imaging, radar systems, astronomy, vehicle communication, and localization through walls.

This research refers to previous research conducted by Baso Maruddani et al. 2019 Perancangan dan Optimasi Antena Vivaldi pada Sistem Radar Penembus Permukaan (Ground Penetrating Radar) [6]. The optimization of the Vivaldi antenna can be done by changing the value of antenna parameters which includes antenna length, tapered length, antenna width, and tapered rate. Changes in the value of the antenna width and tapered slot parameters can significantly shift the working frequency of the antenna. In 2018, Mardaputri Rannu Pairunan et al. research was conducted on Validation of Characteristics on 27 GHz Coplanar Vivaldi Antenna with Scaling Down Method to 2.7 GHz. The scaling method is a technique that can be performed to carry out antenna measurements that are related to immense structures. The scaling down method can be a solution for measuring characteristic parameters (VSWR, return loss, and radiation patterns) at a frequency of 2.7 GHz [7]. The two studies above are antenna coplanar Vivaldi but without the use of fractal structure.

Despite all the advantages of UWB, there are some fundamental problems such as designing coplanar vivaldi antenna with fractal structure, determining the performance of antennas with return loss parameters and radiation patterns without fractal structure and with fractal structure. Therefore, coplanar vivaldi antenna for Ultra-Wideband (UWB) applications will be designed in this study to be able to work with many types of UWB antennas that have a working frequency at 2-10 GHz with a return loss of less than -10 dB.

The author wants to develop a coplanar Vivaldi antenna design for UWB applications with various structures to achieve the best performance by performing coplanar Vivaldi antennas with fractal structures.

II. LITERATURE REVIEW

Ultra-Wideband (UWB)

In the era of 1960, Ultra-Wideband technology (UWB) was used for communication in the military field. The wireless technology currently widely used is UWB submitted as a UWB communication system in 2002 by the Federal Communication Commission (FCC) [1].

UWB technology has some advantages such as faster transfer rate, has a wide range, can be used in streaming multimedia, and can perform multiconnection simultaneously. Another advantage of this UWB technology is that the interference is small because the spread of transmission through the spectrum radio and scattered signal makes this more difficult to inhibit, making this signal share space with the radio signal not to cause service to be disrupted. Various services, almost using all areas on this radio spectrum [8].

The main requirement of UWB is that bandwidth width exceeds 500 MHz or fractional bandwidth has a value greater than 20%. Fractional bandwidth is the ratio of bandwidth to its middle frequency. Fractional bandwidth values can be obtained by applying the equation [8]:

$$\text{Fractional bandwidth} = \left[\frac{2(fh-fl)}{fh+fl} x100\%\right] \quad (1)$$

Description : fh = highest frequency (Hz)
fl = lowest frequency (Hz)

Definitions and Parameters of Antenna

According to Webster's Dictionary, an antenna is a metal device (such as a wire or stick) that receives or transmits radio waves. Based on the IEEE standard, an antenna is a helpful tool for receiving or transmitting radio waves. In other words, an antenna is a transitional structure between guiding devices and free space [9].

Examples of the antenna with various shapes are seen in **figure 1.**

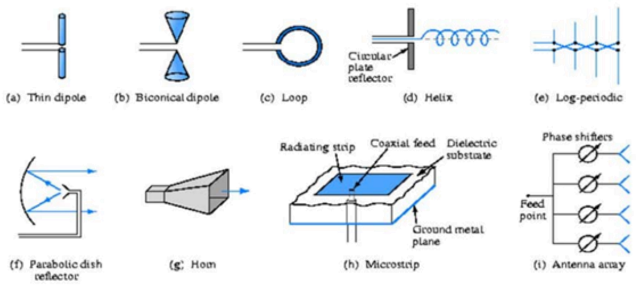


Figure 1. Examples of various antenna shapes [9]

S-Parameter

Scattering parameter (S-Parameter) is a quantity to express power ratio reflected against the power that enters into a transmission line [9].

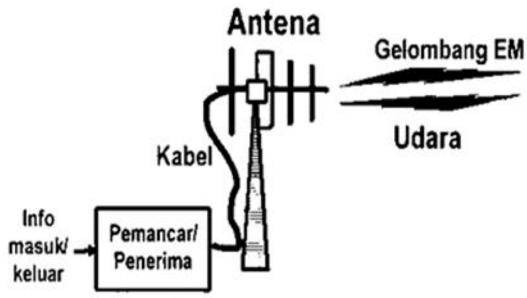


Figure 2. Antena System [9]

S-Parameter is used to analyze response between two terminals (Port) or more, the calculation and tool design on microwaves with linear shape. **Figure 3** below shows two-terminal systems and S-parameter.

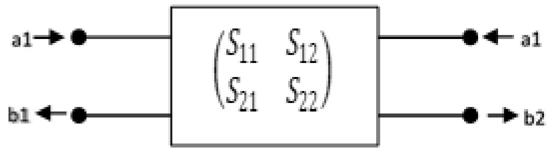


Figure 3. Concept of S-parameters on the two-terminal system [9]

Voltage Standing Wave Ratio (VSWR)

VSWR compares the minimum standing wave amplitude (| V| min) with a maximum (| V| max). There are two voltage wave components in the transmission line, the transmitted voltage (V0+) and the reflected voltage (V0-). The comparison of the reflected voltage with the transmitted voltage is called the coefficient of reflected voltage (Γ) formulated as in equation no. 2 [9]:

$$\Gamma = \frac{V_0^-}{V_0^+} = \frac{Z_L - Z_0}{Z_L - Z_0} \quad (2)$$

Where Z_L is load impedance and Z_0 is channel impedance. Therefore the formula for finding VSWR can use equation 3 as follows [9]:

$$s = \frac{|V|max}{|V|min} = \frac{1+|\Gamma|}{1-|\Gamma|} \quad (3)$$

Description :
S = VSWR
$|V|_{max}$ = maximum standing wave
$|V|_{min}$ = minimum standing wave
Γ = coefficient of reflection

Radiation Patterns

Antenna radiation pattern is a graphical picture of antenna radiation characteristics as a function and coordinates of space. This pattern describes the direction and magnitude of antenna radiation. Radiation patterns will be measured on distant terrain and depicted as directional coordinates [9]. There are two radiation patterns, horizontal pattern and vertical pattern.

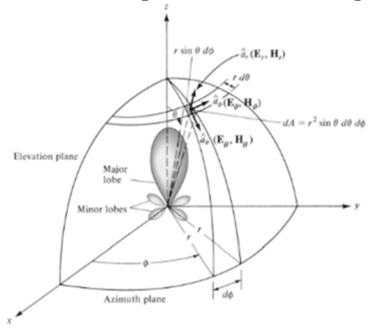


Figure 4. Coordinate System for Antenna Radiation Pattern [9]

Bandwidth

The bandwidth of an antenna is defined as the large frequency range in which an antenna works. The antenna's performance is related to various characteristics (such as polarisation, input impedance, beamwidth, radiation pattern, gain efficiency, return loss, VSWR, axial ratio*)* to meet the standard specifications. The value on the bandwidth will be known if the value of the lower frequency and the upper frequency on an antenna are known. The lower frequency is the initial frequency value of the antenna working frequency. On the contrary, the upper frequency is the final frequency value of the working frequency of the antenna [9].

Gain

Gain compares radiation intensity in a particular direction and the radiation intensity isotropically from antenna power. Gain also enlarge the signal amplitude from input to output. Here is the equation to formulate gain:

$$Gain = 4\pi \frac{\text{radiation intensity}}{total\ input\ (accepted) power} = 4\pi \frac{U(\theta,\phi)}{Pin} \quad (4)$$

Description :

U(Θ,) = radiation intensity
Pin = total power received

Return Loss

Return loss is a parameter used to determine the amplitude comparison of reflected waves (V0-) against the transmitted wave amplitude (V0+). Return loss is used to see the loss of the transmitted power. One of the things that affects return loss is the incompatible antenna connector with the media connector [9]. The amount of return loss will vary, depends on the frequency used, and can be calculated using the equation:

$$RL = 20\ logs|\Gamma|dB \quad (5)$$

Description :

RL = Return loss
Γ = coefficient of reflection

Directivity

Directivity compares the maximum power density on the primary file against the average power density that is radiated [9]. The directivity value of an antenna can be known from radiation patterns. Directivity can be calculated using the equation:

$$\boldsymbol{D} = \frac{\boldsymbol{Umax}}{\boldsymbol{Uo}} \quad (6)$$

Description :

D = Directivity
Umax = Maximum radiation intensity
U0 = Radiation intensity at isotropic source

Microstrip Antenna

A microstrip antenna is an antenna with a conductor/ very thin heat transmitter placed on the ground plane. Between the strip with the conductor is separated by a dielectric substrate with a specific value of dielectric constants (εr) [10].

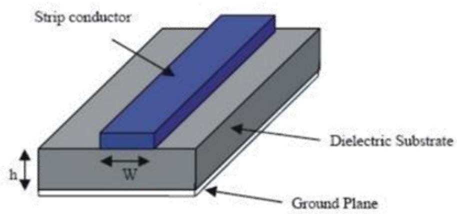


Figure 5. Microstrip Antenna Structure [10]

Some types of microstrip antennas are shown in figure 6**.**

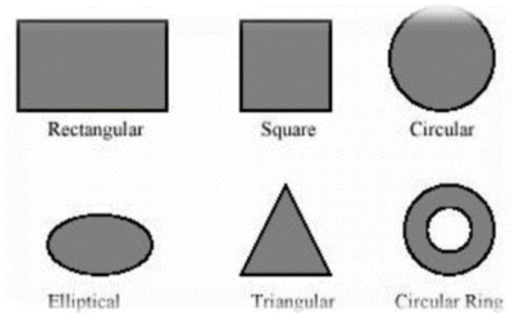


Figure 6. Types of Microstrip Antenna [10]

Vivaldi Antenna

Gibson was the creator of Vivaldi Antenna in 1979 and was first publicized in *"*The Vivaldi Aerial*"*. Various applications using Vivaldi antennas include microwave imaging, wireless communications, and Ground Penetrating Radar (GPR). Vivaldi Coplanar Antenna, Antipodal Vivaldi Antenna (AVA) and Balanced Antipodal Vivaldi Antenna (BAVA) are categories of vivaldi antennas. Vivaldi antenna has a wide bandwidth so that the frequency of its work is also vast. Vivaldi antenna is a unique antenna of Tapered Slot Antenna (TSA) which has an exponential form or commonly known as Exponentially Tapered Slot Antenna (ETSA) [11]. Here is the structure of the vivaldi antenna:

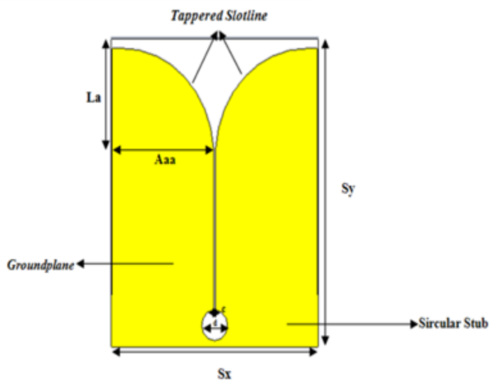


Figure 7. Front View of Vivaldi Antenna Structure [11]

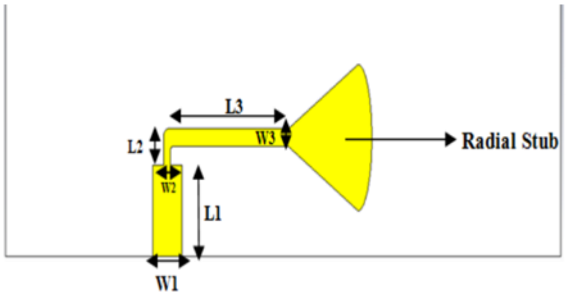
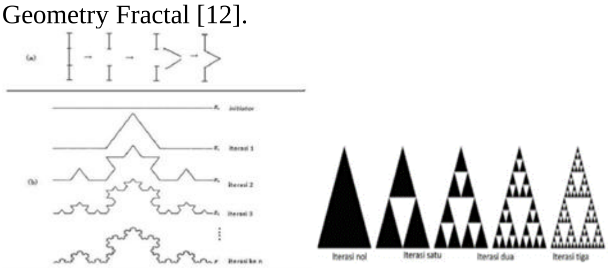


Figure 8. Rear View of Vivaldi Antenna Structure [11]

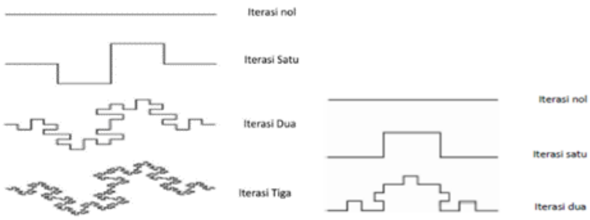
Fractal Antenna

The fractal structure is a recurrent structure. Some geometry can not use Euclidian geometry, such as trees, coastline, mountain clouds, etc. Benoit B. Mandelbrot obtained the term fractal after researching natural geometry. Fractals have been combined with electromagnetic theories in which fractal radiation patterns work better than traditional antennas [11]. There are two types of fractals, deterministic fractal type, and random fractal type.

Random fractal combines freely selected rules on different scales—examples: mountains, clouds, a coastline, trees. The deterministic fractal is a constantly repeated deterministic rule that tends to form symmetrical shapes, e.g. Koch Curve Fractal, Sierpinski Gasket Fractal, Minkowski Curve Fractal, and Cohen-Minkowski Geometry Fractal [12].



(a) (b)



(c) (d)

Figure 9. Forms of fractal:
(a) Koch Curve, (b) Sierpinksi Gasket, (c) Minkowski Curve,and (d) Cohen-Minkowski Geometry [12]

III. METHOD

Research Approach

The approach used in this study is quantitative. Quantitative research is a process of finding the knowledge by using numerical data as a tool to analyze information about what you want to know.

In addition, this study determines the initial design of the antenna. Comparing simulation results of antennas needs the required specifications of a computer to run the simulation quickly and accurately by using CST Studio Suite 2018. The antenna parameters that will be used for this study is shown in Table 1.

Table I. Antenna Design Criteria

Parameters	value
Frequency	2 – 10 GHz
Constant dielectric	4,3
Dielectric loss tangent (tan)	0,002
Substrate Thickness (h)	1.6 mm
Return loss	<-10 dB
Gain	≥ 2.5 dB
VSWR	≤ 2

IV. RESULTS AND DISCUSSION

Determine Design Specifications

The desired antenna performance close to the UWB application can be determined by the criteria and specifications of the antenna design. Design criteria are required in the antenna coplanar Vivaldi design before simulated. **Table 2**. indicates the dimensions of the antenna connected to Figure 10.

Table 2. Antenna Dimensions mm

Symbol	Dimension	Symbol	Dimension
A	60	F	42.35
B	60	G	12.28
C	30	H	1.5
D	3	I	0.35
E	0.5	J	15^0

The design of the coplanar Vivaldi antenna is shown in Figure 10. used FR4 substrates, with dielectric constants of 4.3, substrate thickness of 1.6 mm, and copper thickness of 0.035 mm. Adding fractal structure to the conventional coplanar Vivaldi antenna pattern in Figure 10 (a) at both edges of the copper radiator can improve the performance of antenna radiation patterns, i.e. the performance of the main lobe direction magnitude or antenna directivity, sidelobe level, beamwidth, and main lobe direction angle. The fractal structure is a complex and repetitive structure that mimicking the self-likeness of its structure. There are two patterns of fractal structure created in this study: Model-A and Model-B fractal as seen in Figure 10.

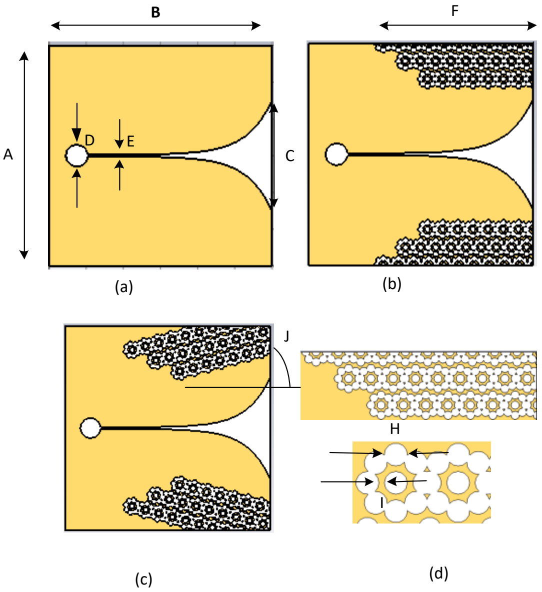


Figure 10. Coplanar vivaldi Antenna Elements: (a) Conventional, (b) Model-A, (c) Model-B

Simulation with CST Microwave Studio

Three different designs will result in return loss performance and performance of different radiation patterns. The simulation obtained three return loss performances with different result in figure 11.

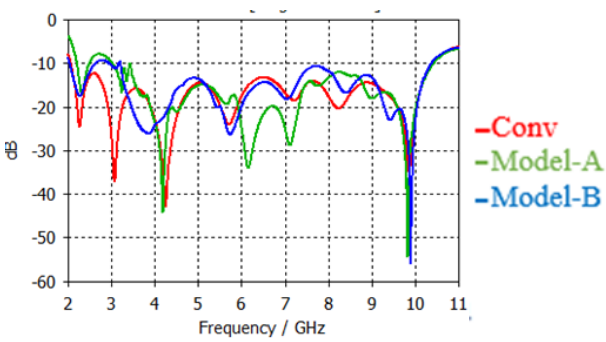


Figure 11. Return loss from conventional coplanar vivaldi, Model-A and Model-B

Return loss value of 10 dB for conventional coplanar vivaldi antenna at lowest frequency was 2.0655 GHz, Model-A fractal antenna was 2.2027 GHz, and Model-B fractal antenna was 2.-396 frequency. In comparison, the return loss performance of 10 dB at the highest frequency was at the frequency of 10.4 GHz.

From the simulation results obtained the performance of radiation patterns taken at a frequency of 6 GHz dan7 GHz. Performance of radiation patterns for the three antennas at the frequency of 6 GHz and 7 GHz can be seen in figure 12 and Table 3.

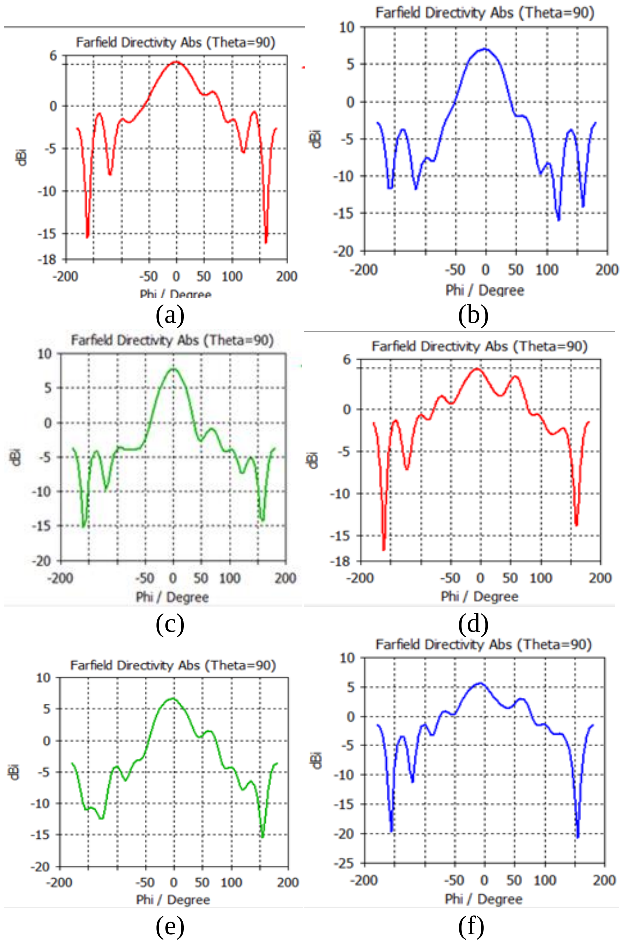


Figure 12. Farfield Directitivity : (a) Conventional 6 GHz Frequency, (b) Model-A 6 GHz Frequency, (c) Model-B 6 GHz Frequency, (d) Conventional 7 GHz Frequency, (e) Model-A 7 GHz Frequency, (f) Model-B 7 GHz Frequency

Table 3. Farfield Directivity Comparison

	Parameters	Konv	Mod A	Mod B
6 GHz	Main lobe magnitude	5.21 dBi	7.02 dBi	7.84 dBi
	Main lobe direction	-1.0 deg	-5.0 deg	0.0 deg
	Angular width (3 dB)	79.0 deg	61.7 deg	46.2 deg
	Side lobe level	-3.5 dB	-9.0 dB	-8.8 dB
7 GHz	Main lobe magnitude	4.82 dBi	6.63 dBi	5.57 dBi
	Main lobe direction	-6.0 deg	-5.0 deg	-10.0 deg
	Angular width (3 dB)	64.4 deg	56.3 deg	59.4 deg
	Side lobe level	-0.9 dB	-5.1 dB	-2.6 dB

Graph (a) conventional, (b) Model-A, and (c) Model-B are Fairfield charts with a frequency of 6 GHz, while graph (d) conventional, (e) Model-A, and (f) Model-B are far-field graphs with a frequency of 7 GHz. At a frequency of 6 GHz, 7.84 dBi was the highest main lobe magnitude value on the Model-B, and the best sidelobe level on the Model-A was -9.0 dB. While at a frequency of 7 GHz, 6.63 dBi was the highest main lobe magnitude value and the lowest sidelobe level on the Model-A was -5.1 dB.

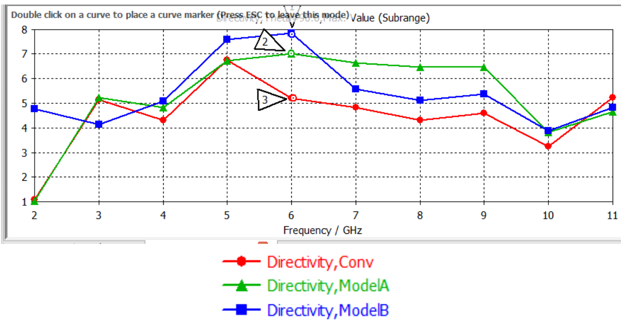


Figure 13. Conventional Directivity Performance, Model-A, and Model-B

Figure 13 shows *a* directivity performance comparison for conventional coplanar Vivaldi antennas, Model-A fractals, and Model-B fractals. The highest directivity performance was obtained for the Model-B at 6.0152 GHz at 7.802 dBi. The model-A fractal's best side lobe level performance was -9 dBi at a frequency of 6 GHz. The best beamwidth/angular width performance (3 dB) was 46.2, and the best main lobe direction of 0 degrees was obtained for coplanar Vivaldi antenna Model-B fractal at 6 GHz frequency. However, at high frequencies, the directivity performance of the Model-A is better than that of the B-model fractals.

The design of conventional coplanar Vivaldi antennas, Model-A fractals, and Model-B fractals result in return loss performance and different radiation patterns. The radiation pattern of the Vivaldi antenna is relatively stable in the operating frequency band, which makes it suitable to apply UWB. When compared to conventional antennas, by adding fractal structure, antenna radiation patterns, namely main lobe magnitude, sidelobe level, beamwidth, and main lobe direction, can be increased to improve antenna performance applied in UWB frequencies.

V. CONCLUSION

The simulation of 3 coplanar Vivaldi antennas, namely conventional coplanar Vivaldi antennas, Model-A fractal, and Model-B fractals antennas, produces different return loss performance and radiation patterns. At a frequency of 6 GHz, the highest main lobe magnitude value is 7.84 dBi or model-B fractal antennas. The best sidelobe level on the Model-A is -9.0 dB. The beamwidth and main lobe direction values are best obtained for coplanar Vivaldi antenna Model-B fractal. By adding fractal structure, the performance of antenna radiation pattern, i.e. main lobe magnitude, sidelobe level, beamwidth, and main lobe direction, can be increased to improve the antenna performance that can be applied in UWB frequency.

Suggestion

Based on the conclusions, some suggestions can be made to develop and improve the radiation pattern of coplanar Vivaldi antenna with the fractal structure to apply Ultra-Wideband (UWB) with other structures for maximum results for more comparison of return loss and radiation patterns. Therefore, it is necessary to tighten the antenna bandwidth to work at more than 10 GHz.

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