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Design and Realization of Minkowski Fractal Antenna Dual Band at Frequency 2450MHz and 5800MHz Based On Microstrip

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Abstract: *Antennais atransformerortransmissionstructurebetweenguidedwave(transmission line) to thefree spacewaveorvice versa. Diverseforms ofthe antennaaccording to the design, deploymentpatterns, and the frequencyandgain. WhileIEEE802.11isa set ofstandards forimplementingwireless local area network(WLAN) computer communicationin the2.4GHz, 3.6 GHzand 5GHzfrequencybands. FortheWirelessLAN, usingthe center frequencyof 2.45 GHzand 5.8GHzas standardWi-Fi networks.Therefore, inthisfinaltask will bedesigned and realizeddualbandantennathat works onboth frequencies.*
Antennatypesto be madeis that using microstri pfrac talantenna with Minkows kimethod, and manufacturing of the antennawill be donethroughphotoetching. Before thephotoetching, antennadesignwill be done withthe counting processtoobtain theidealdimensionofthe antenna, and the antennais designedin the form ofhardware.Once that was done, including measurement of antenna impedance measurement, measurement ofVSWR, return lossmeasurement, bandwidth measurement, radiationpatternmeasurements, polarizationmeasurementsandmeasurements ofgain, the followinganalysis tocompare themeasurement resultswith the earlier specification.
Theresult of measurements of Minkowski fractalantenna characteristicsareobtainedtwoworking frequency: 2.35GHz-2.57GHzand5.67GHz-6.66GHz.With VSWR<1.3, obtaineda fairly widebandwidthofboth frequenciesrespectively240MHzand990MHz. Gainis achievedat2.21dBiand 2.18dBi, theradiation patternbidirectional.
Key words: *Antenna, Microstrip, Fractal, Minkowski, Dual Band*

I. Introduction

Fractal antenna is an antenna which has the Minkowski geometry of fractals that can generate a bigger return loss[2]. While printed antenna is a type of antenna that has the form of a thin, lightweight, and simple so that it has the qualifications to apply to wireless technology. In general the antenna using Epoxy FR4 substrate printing due to the cheap price and the manufacturing process is simple.

Based on the background, it will be designed and realized the antenna microstripMinkowski form of Fractals with 2 iteration, using Epoxy FR4. This antenna will work on a frequency of 2450 MHz and 5800 MHz, each with a width of 245MHz and 580MHz on SWR<1.3. Distributing on this antenna using microstrip line techniques.

II. Minkowski Fractal Antenna

Fractal antenna Minkowski is one type of antenna a basic square shape (square patch) where there are parts that are removed are symmetrical and make use of the properties and characteristics of fractal geometry, namely self similiarity, repetition and scaling. Determination of dimensions in geometry can be done in several ways, dimension Euclidean topology, self similiarity dimension, and Haussdorfdimension[3]. This Minkowski antenna offers a range of advantages, antennas can be made with a small size, resulting in multiple resonant frequencies (multiband), and can optimize the gain[4].

2.1 Minkowski Fractal Antenna Iteration

The initial geometry of fractals, called initiator, is a square: each of the four straight segment of the initial structure was replaced with a generator[2]. Patch antennas made by generating an initial model generator early on each side of a square patches, as shown in "Figure 1". Initial altitude generator called with indentation depth (Wp) as depicted in "Figure 1" is generally smaller than the Ws/3, and is the iteration factor[11]:

$$\eta = \frac{Wp}{Ws/3}; 0 < \eta < 1 \qquad (1)$$

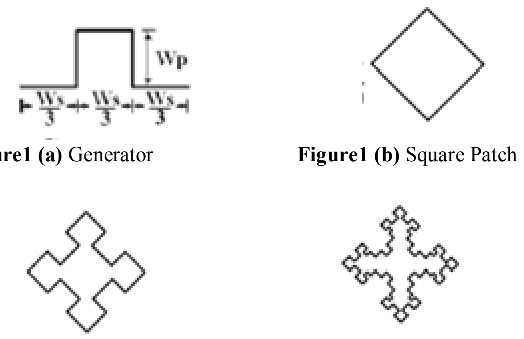


Figure1 (a) Generator **Figure1 (b)** Square Patch

Figure1 (c) 1st Iteration **Figure1 (d)** 2nd Iteration

Figure1.Initial generatormodel[4]

Antenna configurations to be created, such as in "Figure 2", is the monopole antenna square patch with fractal geometry of Minkowski on a modified at second iteration and on its groundplane.

The antenna consists of a square patch with the patch width (Ws), the feeder to match the impedance 50 Ω which has wide strip (Wf), and modified on the bottom layer groundplane to increase bandwidth, impedance and radiation patterns at high frequencies. Modified dimension groundplane include the width of Wg, Wgt, Wgf and the length Lg, Lgt, Lgf. Small gap between radiation patch and modified groundplanenotedas g[4].

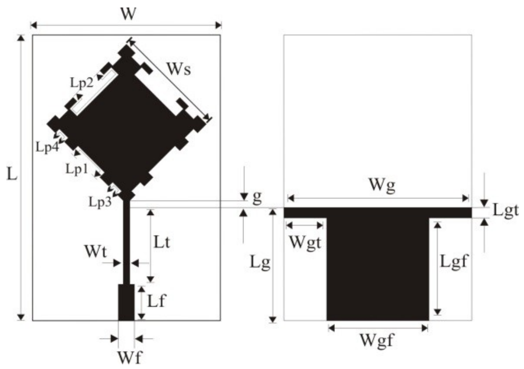


Figure2Antenna scheme with fractal geometry, modified Minkowski square patch and modified groundplane

III. Design and Realization

3.1 Antenna Spesification :

Frequency : 2450MHz & 5800 MHz
VSWR : ≤ 1.3
Return Loss : ≤ -17 dB
Gain : ≥ 1.5 dBi
Bandwidth :10%(245MHz & 580MHz)
Radiation Pattern : Bidirectional
Polarization : Linear

Dielectric material used as a substrate is Epoxy FR4. Basic characteristic of Epoxy FR4 is as follows:

Permitivitas relative : 4.4
Loss tangent : 0.012
Dielectric thickness : 1.6 mm

3.2 Antenna Dimension

To get the antenna dimensions total, first calculate the dimensions for a frequency of 2.45 GHz to the first iteration. The frequency of 2.45 GHz is placed as the first iteration because as the highest frequency of the frequency will be designed.

$$\lambda_0 = \frac{c}{f} = \frac{3 \times 10^8}{2.45 \times 10^9} = 0.122 \text{ m}$$

$$\text{Ws} = \frac{0.49\lambda_0}{\sqrt{\varepsilon_r}} = \frac{0.49 \times 0.122}{\sqrt{4.4}} = 0.0286 \text{ m} = 28.6 \text{ mm}$$

Later with iteration factor of 0.66, to obtain the dimensions of the indentation depth where Ws as generator length.

For 1st iteration:

$$0.66 = \frac{Wp}{28.6/3}$$

$$Wp_1 = 0.66 \text{ x } 9.53 = 6.292 \text{ mm}$$

For 2nd iteration:

$$0.66 = \frac{Wp_2}{Wp_1/3} = \frac{Wp_2}{6.292/3}$$

$$Wp_2 = 0.66 \text{ x } 2.097 = 1.384 \text{ mm}$$

This two indentation factor are used to determine the dimension of fractal antennas Minkowski as shown in "Figure 2 using perimeter Lp1, Lp2, Lp3. and Lp4:

Lp_1 = 22.11 mm
Lp_2 = 30.414 mm
Lp_3 = Lp_4 = 4.86 mm

To obtain the matching impedance can be done with the transformator technique. To determine thistransformator line, it need to know terminal impedance and port impedance. Port impedance is equal to the impedance connector SMA Femaleby 50 Ohm. To know the impedance of the terminal through a simulation by putting direct port on a corner feed, as shown in "Figure 3.

Figure 3(a) Square Patch **Figure 3(b)** 2nd Iteration Fractal
Figure 3Corner feed to determine terminal impedance

Terminal impedance simulation results can be seen in "Figure 4", retrieved the terminal impedance for square patch is 50.48 – j24.25Ohm at resonance frequency. While terminal impedance for the patch with two fractal iteration is49.08 – j0.409 Ohm. Since the impedance on both types of this patch is approaching the 50 Ohm impedance, which means that the load impedance is equal to the input impedance (Z_{in} = Z_L), it used tranformator λ/2 between the load with the input. Retrieved line length λg/2 (Lf) of 12.4 mm.

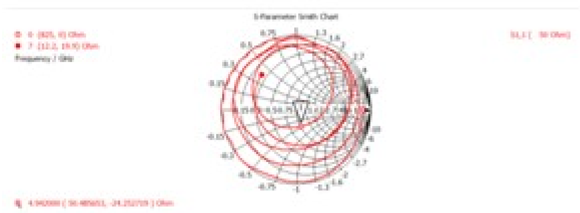


Figure 4 (a) Impedance of corner feed for square patch

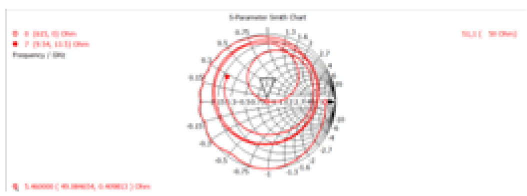


Figure4 (b) Impedance of corner feed for 2nd Iteration Fractal
Figure 4Terminal impedance of corner feed

It used Epoxy FR4 substrate with thickness of 1.6 mm. Dimensions of the substrate obtained by calculating the value of the minimum of the substrate are allowed. The dimensions of these substrates can be obtained from the following equation:

L = 6h + a + Pstrip (2) (3.2)

W = 6h + b (3)

By using thicker substrate h = 1.6 mm, patch height a = 40.44 and width b = 40.44 mm, as well as line strip length = 20.66 mm, it will be obtained at minimum dimensions of groundplane 70.7 mm x 50.44 mm rectangular shaped.

Then it used partial ground plane. The size of the ground plane used follows the shape of the antenna substrate, but there are modifications to the length of the ground plane. With the value g (gap between patch with modified ground plane) is 0.15 mm, then the length of the ground plane used was along the lines of the strip which is 20.51 mm, whereas for the width as width of the substrate, 50.44 mm. So the size of the ground plane used is 20.51 mm x 50.44 mm

3.3 Antenna Simulation in CST Studio Suite 2010 Software

3.3.1 Ground planedan Number of Iteration

In "Figure 5" comparison graph can be seen to return loss when the antenna was designed with full ground plane and modified ground plane. The chart shows the return loss improvement of modified ground plane, formerly with full ground plane can not be achieved return loss < -17dB. By getting return loss far below -17 dB, wider bandwidth can also be achieved.

Figure5 (a) Full GP **Figure5 (b)** Modified GP

Figure5 Bottom layer ofantenna prototype

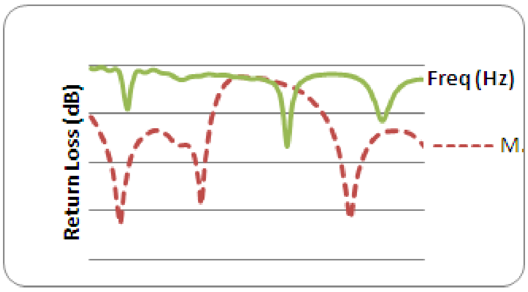


Figure6 Return loss of full ground plane and modified ground plane

"Figure 8" shows the comparison of return loss between antenna Minkowski geometry of Fractals with one iteration and two iteration. It can be seen that the antenna with two iterations can produce a second resonance frequency, 5.8 GHz, with better and more stable, in terms of return loss that can reach far below-17dB.

Figure7Minkowski Fractal Antennawith 0 to 2 Iteration

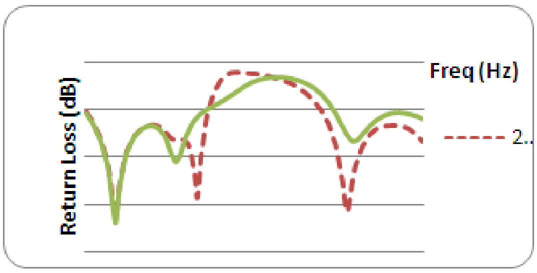


Figure8Return loss of 1st and 2nd Iteration

Moreover, its analyzed influences the number of iterations to gain and resulting radiation patterns too. "Figure 9 and 10"show the influence of the number of iterations on the full ground plane and modified ground plane conditions. It can be seen that in the circumstances of the full ground plane, the more the number of iterations, the gain for the first resonance frequency is getting smaller, while the gain for the third resonance frequency is precisely greater.

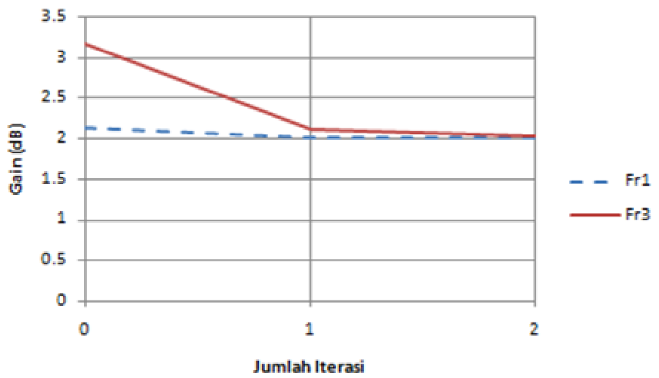
On modified ground plane condition, the more the number of iterations, the gain is generated for the first and third frequencies are getting smaller. However, there is an increase in the gain for a third frequency on the second iterations, this is because it is already done some optimization components of second iteration.

Figure 9 Gain the number of iterations for full ground plane

Figure 10 Gain the number of iterations for modified ground plane

Also can be seen by comparing the two graphs above, the gain with modified ground plane is greater compared to the full ground plane. Even on the full ground plane, gain of third resonant frequencyis negative.

Below is the radiation pattern from simulation to an antenna without iteration, oneiteration and two iterations.



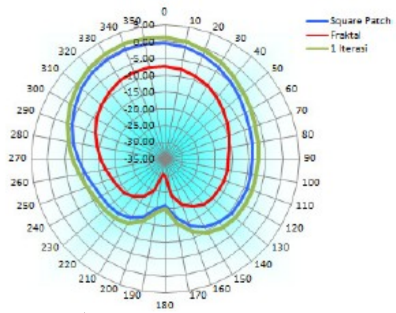


Figure 11(a)1st resonance frequency for full gp

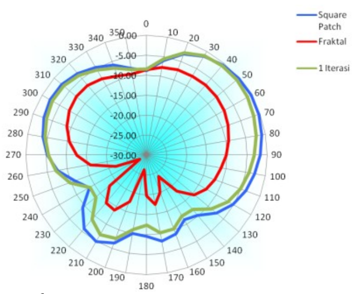


Figure 11(b) 2nd resonance frequency for full gp

Figure 11 Radiaton pattern of antenna with full ground plane

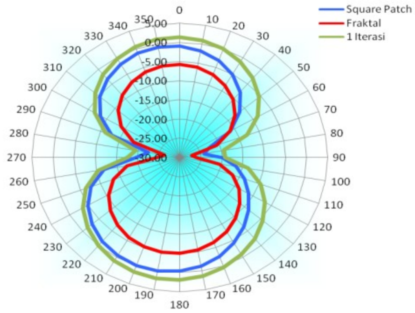


Figure 12(a)) 1st resonance frequency for modified gp

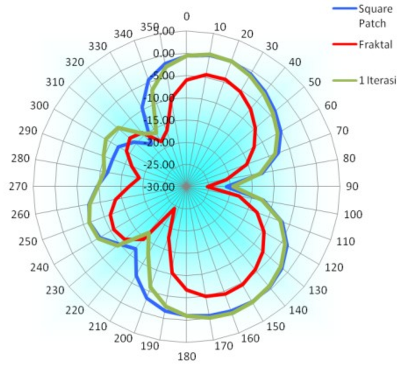


Figure12 (b) 2nd resonance frequency for modified gp

Figure 12Radiaton pattern of antenna with modified ground plane

On the antenna with full ground plane, radiation pattern generated is unidirectional, this is because the ground plane is intact, so that the entire field is reflected by the ground plane of focus to one direction. While the antenna with modified ground plane generated radiation pattern bidireksional, due to a crack on the surface of the ground plane.

The influence of the iteration itself is clearly visible only in the resonant frequency is higher. The more the number of iterations, the gain of the side lobe closer to main lobe, almost form a main lobe and back lobes only, without the side lobes.

The last parameter to be analyzed is polarization. The resulting polarization can be seen from the axial ratio. There are the axial ratio for antenna square patches, antenna with one iteration Fractals Minkowski, and two iterations:

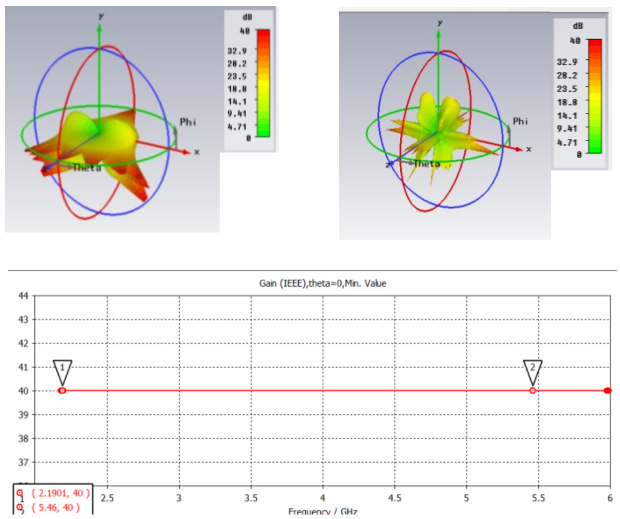


Figure13 Axial Ratio of polarizationfor square patch antenna

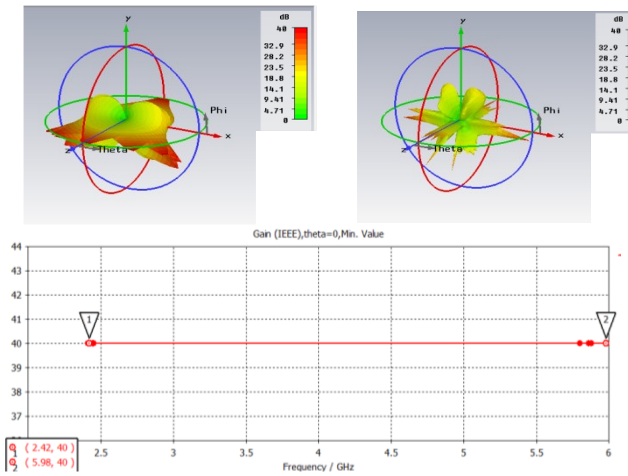


Figure 14 Axial Ratio of polarization for 1st iteration antenna

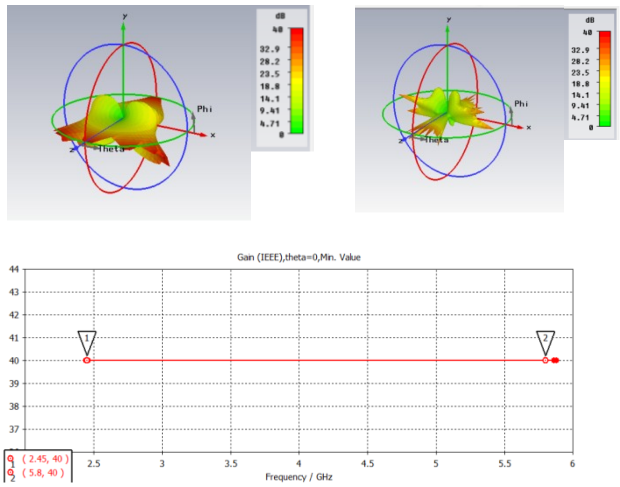


Figure 15 Axial Ratio of polarization for 2nd iteration antenna

It can be seen that the polarization of an antenna without iteration, with one iteration, iteration, and two equally produce linear polarization with attention to the axial ratio(40dB). Axial ratio of 40 dB is large enough to meet the criteria of linear polarization, which is supposed to have an axial ratio approaches ∞.

3.3.2 Perimeter Length

After the results of the simulation approaches the specification expected, do the optimization on the length of the perimeter of the iteration that is affected by a factor, Lp1, Lp2 Lp3, and Lp_4,and the width of the gap between patch with modified ground plane noted byg[11]. Each of these parameters is simulated on a different value to see its influence on simulation result of antenna. These values are taken from some of the most optimum to obtain great return loss of frequency 2.45 GHz and 5.8 GHz.

To design these antenna, the configuration parameters: Lp_2= 35.2 mm, Lp_3 = 6.08 mm, and Lp_4 = 6.08 mm, with various value of Lp_1. Return loss comparison for various value Lp_1 can be seen in Figure 3.14. Increasing the value of resonance frequency Lp_1 caused second and third shifts to the left, but not overly affect the frequency of the first resonance. For the length of Lp_1 = 18.3 mm, return loss for a third frequency is too small, does not even reach 17dB. So Lp_1 = 11.3 mm choosen in which generates return loss in the optimum frequency of first and third.

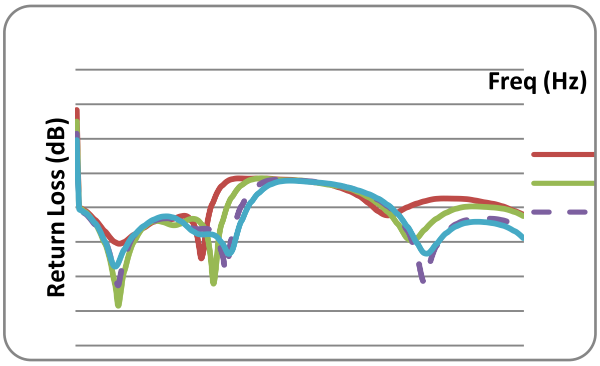
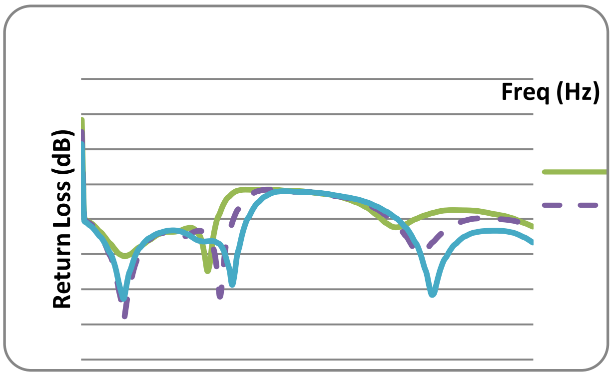


Figure 16 Return loss for various Lp_1 (mm)

Once set Lp_1, the next optimization is done by varying the value Lp_2. Comparison of return lossto value different Lp_2 can be seen in Figure 3.15. The Lp_2changing does not overly affect frequency shift of the first and third frequency, but few affect the return loss frequency of the third. In fact with Lp_2 = 21.7 mm can eliminate second frequency, but the first frequency shifted to the left and the third frequency shifts to the right too, even close to 6 GHz. So, the most optimum Lp_2 is 25.2 mm, where the return loss at least first and third frequency bias reaches more than 30 dB compared to the second frequency. With Lp_2 amounted to 15.7 mm, the first and third frequencies are not shifted too far away from the initial specification.

Figure 17 Return loss for various Lp_2 (mm)



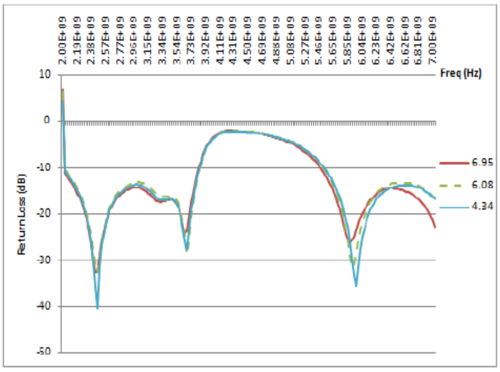


Figure 18 Return loss for various Lp_3 (mm)

Furthermore, the influence Lp_3 of simulation results antennas can be analysedby"Figure18". Increased Lp_3cause return loss for second and third frequencies were increased, but the effect on the contrary on the frequency first. Length of this Lp_3 does not affect the three resonant frequency shift significantly. Then choose Lp_3 = 3.43 mm because it produces the optimum return loss on the third resonance frequency.

To influence last perimeter, which can seen in Figure Lp_4 3.17, there is no significanteither to frequency shifting or return loss. Lp4 = 6.08 mm selected, which generates return loss is big enough for the first and third frequencies, but still close to the frequency of the initial specification.

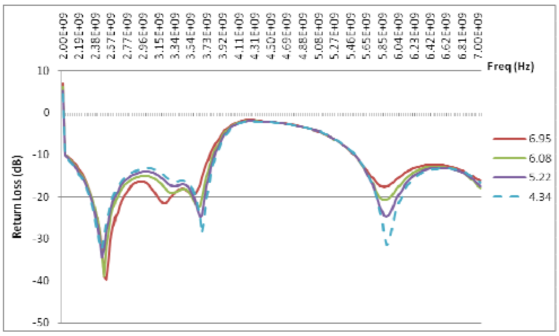


Figure 19 Return loss for various Lp_4 (mm)

In "Figure 20" can be seen changing of return loss to some varoiusvalue g. With value of gdecrease, then the value of return loss for frequency 5.8 GHz is getting smaller, but the cause of the first resonance frequency shifted to the left. Due to this trade off, it needs to choose the most optimum value for g, that is, the value of g that does not cause resonance frequency first shifted too far away from 2.45 GHz but also produces the second resonance frequency on 5.8 GHz which is quite stable. Whereas in order to avoid the existence of resonance frequencies at 3.64 GHz, the value of g is almost no influence, both on the return loss or shift in frequency. Then g = 0.875 was selected as the most optimal.

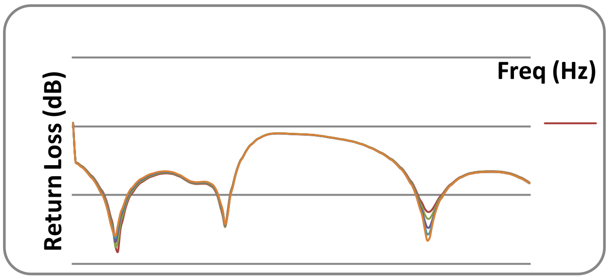


Figure 20 Return loss for various g (mm)

In "Figure 21"shows Monkowskifractal antenna display on CST.

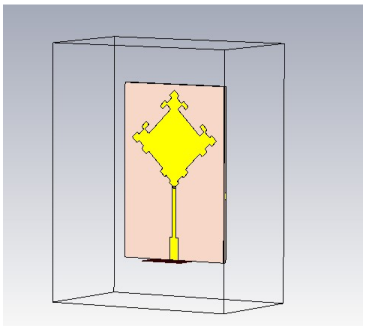


Figure21Minkowski fractal antenna display on CST

Below is size of a fractal antenna Minkowski table from the calculation result and antenna optimization through simulation using CST software:

Tabel1Antenna Dimension

Component	Design (mm)	Simulation (mm)
Ws	28.6	24.878
L	70.7	63
W	50.44	41.3
Lt	12.4	14.5
Wt	1.63	1.44
Lf	6.16	8.085
Wf	3.17	3.55
Lp_1	22.11	11.3
Lp_2	30.414	25.207

Lp_3	4.86	4.34
Lp_4	4.86	5.214
Lg	20.51	24.96
Wg	50.44	41.3
Lgt	10	2.312
Wgt	16.72	9.4
Lgf	10.51	22.65
Wgf	17	22.5

1.4 Simulation Results

The "Figure 22" was chart that shows the frequency to VSWR of VSWR value < 1.3 works on two different frequencies, on the frequency of 2.45 GHz with a bandwidth of 210 MHz with range 2.24 GHz - 2.62 GHz. Next frequency on 5.8 GHz with 410 MHz bandwidth with range 5.71 GHz – 6.12 GHz.

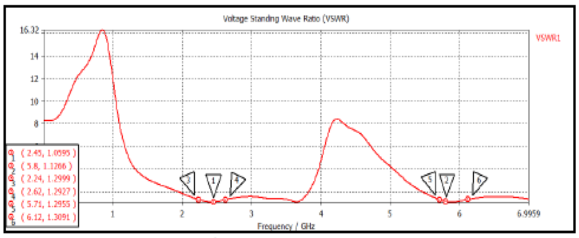
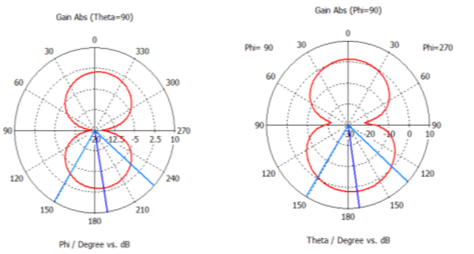


Figure 22 VSWR and Bandwidth

"Figure 23 and 24" explain radiation pattern for each frequency. The radiation pattern is divided into two, namely the azimuth and elevation. It seen that for each frequency, the resulting pattern will be different but the resulting pattern is equally a bidirectional or focus on two directions.



Figur 23 Radiation pattern freq 2.45 GHz

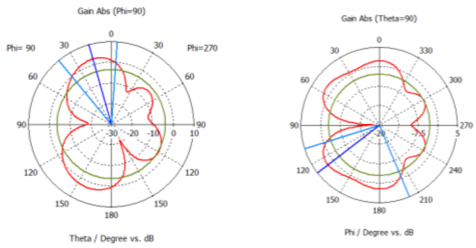
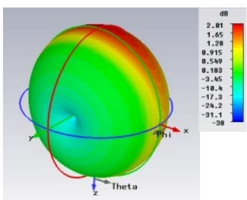


Figure 24 Radiation pattern freq5.8 GHz

"Figure 25 and 26" shows radiation pattern in the 3-dimensional form of antenna and antenna gain for each frequency.



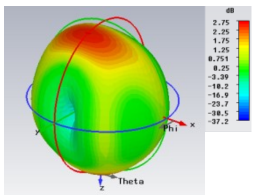


Figure25 Gain 2.45 GHz Figure26 Gain 5.8 GHz

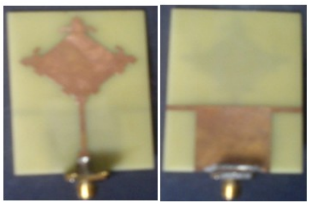


Figure 27 Minkowski fractal anttenna realization

After the making of the film negative, the next step is antenna layout realization to PCB Epoxy FR4 material.

IV. Measurement Results

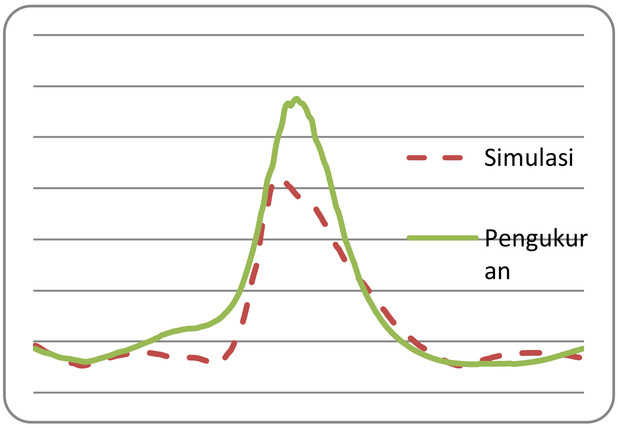


Figure 28VSWR comparison chart of simulation result with measurement (VSWR vsFrequnecy)

On the graph can be seen VSWR of measurement results approaching VSWR of simulated results. Even isolation between both the resonance frequency is greater than the simulation results. The frequency shifts that occur are also not too far away, it's just VSWR measurement results is higher than simulation results, VSWR for each resonance frequency, which can be seen in Table 2.

Table 2VSWR comparison simulation result with measurement

	SIMULASI		PENGUKURAN	
Frek (GHz)	2.45	5.85	2.45	5.96
VSWR	1.059	1.065	1.205	1.102

Frequency shiftingin measurementresults could be due less ofits input impedance match load (antenna) and transmission line as well as the distribution of the current inefficient for low frequency or it could be because the permittivity of materials that do not comply with the datasheet. In addition, for high frequency on dual band does tends to be unstable, if looking at the analysis of the results of the simulation in the previous section. Although many of the factors that make frequency measurement results shifted, however, it produced similar to resonant frequency characteristics of simulation results which generate two range of frequency.

The following is a table of bandwidth with VSWR <1.3 based on "Figure 28".

Tabel 3 Bandwidth comparison simulation result with measurement

VSWR	SIMULATION			MEASUREMENT		
	FrekBawah (GHz)	FrekAtas (GHz)	BW (Mhz)	FrekBawah (GHz)	FrekAtas (GHz)	BW (Mhz)
≤ 1.3	2.24	2.62	380	2.35	2.57	240
	5.71	6.12	410	5.67	6.66	990

From table 3can be seen that at the value of VSWR < 1.3 there are two resonant frequencies, where the resulting bandwidth is different with the simulated results. But the resulting bandwidth still covers the criteria. Narrowing of the bandwidth on the first resonant frequency due to lacking match the input load impedance of antenna and transmission line as well as the distribution of the current inefficient for low frequencies. As wider bandwidth for the second frequency, due to the widening effects of modified ground plane are indeed intended to widen the bandwidth at high frequencies.

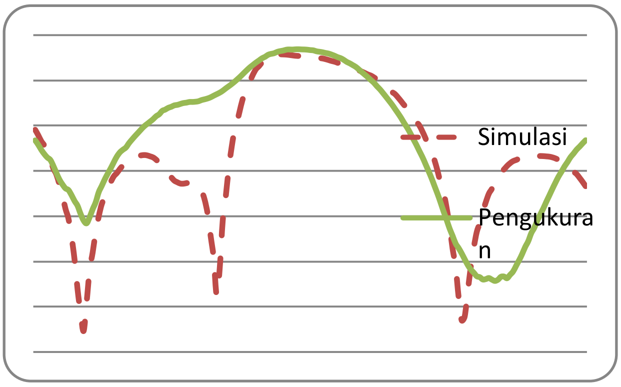


Figure 29Return loss comparison chart of simulation result with measurement (Return Loss vsFrequnecy)

The frequency shift on "Figure 29" more evident when compared with simulation results. The factor that cause frequency shifting is air gap is between the substrate that accumulates. Because the air has a different permittivity material with Epoxy FR4 resonant, resulting a shift of resonant frequency, especially in the second frequency.

It can be seen that the resonant frequency is also that were in between the first and second resonant frequency is not displayed at measurement. This is due to possibility of changing the size of the perimeter in photoetching process. As it has been analyzed in simulation results, that just a little changes on the length of the perimeter, Lp_1 and Lp_2 can cause return loss changes on each of resonant frequencies. In this case, change on perimeter length cause the return loss decreased significantly, so frequency 3.64 GHz no longer appear on the measurement results.

Table 4 Measurement result of impedance

Frequency (GHz)	Impedance (Ohm)
2.45	42.025 – j3.045
5.8	51.888 – j7.472

The obtained antenna gain for each frequency is :

Table 5 Measurement result of gain

Frequency(GHz)	Gain (dBi)
2.45	2.21
5.8	2.18

The value of the gain for each frequency is different from simulation results, it is becausemeasurement conditions are not ideal.

The results of measurements of the radiation pattern of antennas at an angle of azimuth and elevation, respectively, is shown in "Figure 30 and 31":

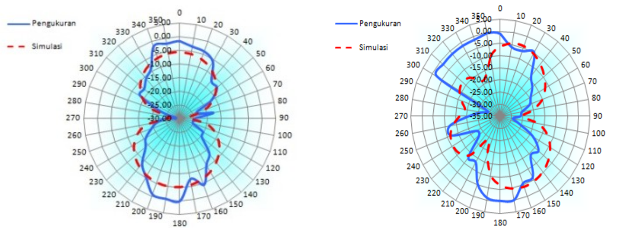


Figure 30(a) Freq2.45 GHz **Figure 30 (b)** Freq5.8 GHz

Figure 30Radiation pattern of azimuth direction

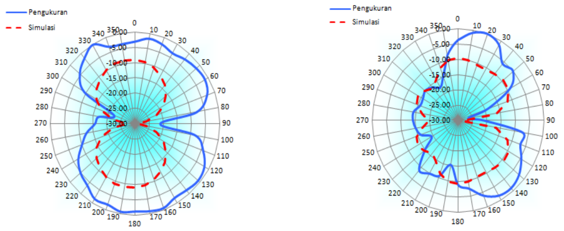


Figure31 (a) Freq2.45 GHz **Figure31 (b)**Freq5.8 GHz

Figure 31Radiation pattern of elevation direction

Following are the measurement results of polarization for each frequency:

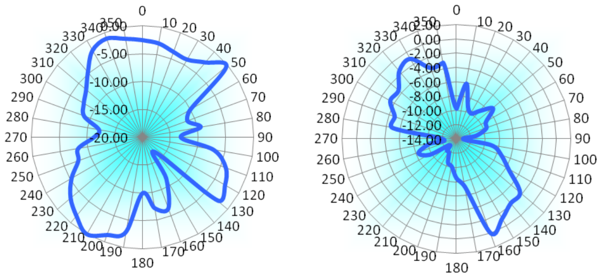


Figure32 Polarization

From measurements results of the polarization, obtained these following data:

- **Frequency 2.45GHz:**

Maximum power received (major axis)
= -33.9 dBm = 4.07x 10^{-7} Watt
Minimum power received (minor axis)
= -50.02 dBm = 0.099 x10^{-7} Watt

- **Frequency 5.8GHz:**

Maximum power received (major axis)
= -40.8 dBm = 8.32x 10^{-8} Watt
Minimum power received (minor axis)
= -53.85 dBm = 0.41 x10^{-8} Watt

With the analysis of electric field strength ratio, then it can be known its polarisation type:

$$E = \sqrt{\frac{P_{watt}x377}{A_e}} \qquad (4.6)$$

Ratio of electric field strength (numeric)

$$=\frac{\text{Mayor}}{\text{Minor}} = \frac{\sqrt{\frac{P_{watt\ \ mayor}\times 377}{A_e}}}{\sqrt{\frac{P_{watt\ \ minor}\times 377}{A_e}}} \qquad (4.7)$$

Ratio of electric field strength for frequency 2.45GHz

$$= \frac{\sqrt{P_{watt\ \ mayor}\ \text{x}\ 377}}{\sqrt{P_{watt\ \ minor}\ \text{x}\ 377}} = \frac{\sqrt{4.07\ \text{x}\ 10^{-7}\ \text{x}\ 377}}{\sqrt{0.099\ \text{x}\ 10^{-7}\ \text{x}\ 377}} = \frac{12.38\ \text{x}\ 10^{-3}}{1.932\ \text{x}\ 10^{-3}} = 6.4 = 8.067\ \text{dB}$$

Ratio of electric field strength for frequency 5.8GHz

$$= \frac{\sqrt{P_{watt\ \ mayor}\ \text{x}\ 377}}{\sqrt{P_{watt\ \ minor}\ \text{x}\ 377}} = \frac{\sqrt{8.32\ \text{x}\ 10^{-8}\ \text{x}\ 377}}{\sqrt{0.41\ \text{x}\ 10^{-8}\ \text{x}\ 377}} = \frac{5.6\ \text{x}\ 10^{-3}}{1.24\ \text{x}\ 10^{-3}} = 4.52 = 6.55\ \text{dB}$$

So calculation of electric field strength ratio of two frequencies is R > 1 (the ratio of the electric field is greater than 1 or R > 0 dB), as well as the ratio of the electric field strength < ∞, then AUT can still be said to be a linear polarization.

V. Conclusion

Minkowski fractal antenna that has been realized can work on a multiband frequency, 2.35 to 2.57 GHz and 5.67 -6.66 GHz at VSWR <1.3. Bandwidth for both the resonant frequency is quite wide, which is 240MHz and 990MHz, according to the modified gains ground plane can produce a wide bandwidth compared with full ground plane.

The number of iterations on Minkowski fractal antenna design affects the return loss for higher frequency(s) in this multiband antenna. The length of the perimeter of the iteration also affect the return loss and the resulting resonant frequency.

It generated bi-directional radiation pattern, linear polarization, and the resulting gain dBi and 2.18 dBi 2.21 for each frequency.

Last, the precision and accuracy in the process of building prototypes, as well as the antenna measurement process and greatly affect the characteristics of the antenna.

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