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Analysis of Bandwidth and Working Frequency of Bi-circular Antenna

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ABSTRACT

This paper discusses the analysis results of determining the bandwidth and working frequency of a bi-circular antenna design. The analysis was carried out using three approaches, namely the FDTD simulation method, the measurement method using a network analyzer on the fabrication results of the antenna design, and the method of applying the bi-polygonal antenna model to the bi-circular antenna design. The novelty in this research is the application of the bi-polygonal antenna model and the comparison of the results of determining the bandwidth and working frequency of a bi-circular antenna with these three methods. Based on the results of the analysis using these three methods, it was found that different bandwidth values and the same antenna working frequency value were 2.45 GHz. The modeling results give a narrow and symmetrical form of return loss vs. frequency curve, the simulation results give a wide and slightly symmetrical form of return loss vs. frequency curve, and the measurement results give a wide and asymmetrical shape of return loss vs. frequency curve.

Key words: Bi-circular antenna, Bi-polygonal antenna model, FDTD simulation, Network analyzer

1. INTRODUCTION

Nowadays, communication and information are the main needs of modern society. The technology that is constantly being developed and is closely related to communication and information is wireless technology. One of the main components of wireless technology is an antenna. The antenna acts as a component that sends and receives electronic signals or data. Antenna performance must be made more reliable so that communication and data transmission can run smoothly and quickly [1].

The increasing need of modern society for communication and information has made antenna an important component in information and communication technology (ICT). Antennas can also be used as part of a wireless remote control system [2], [3]. A practical antenna design, small, large capacity, and mobile is a demand that must be met. For example, mini antennas for IoT Applications [4], mobile antennas for mapping systems with drones, and wireless devices [5].

A microstrip antenna is an option to meet these needs. Many studies have been conducted to obtain a more reliable microstrip antenna design such as having a wide bandwidth [6]–[9]. In connection with the research of microstrip antennas, the Physics department of the Sepuluh Nopember Institute of Technology (ITS) has researched the microstrip slot antenna 3 array double bowtie [10], V-shaped CPS microstrip antennas [11], and a new analysis method for designing CPW microstrip antennas [12].

The bi-circular antenna is a circular antenna design. Research on the antenna with circular geometry has been carried out by several researchers. Research on the loop antenna analysis method has been conducted by Sen et al., about the general method of current excitation reconstruction in cylindrical antenna arrays [13], Joshi and Behera about the method of moment analysis in circular loop linear arrays and loop arrays [14]. Research on the characteristics of circular loop antennas has been carried out by Hamed and Bashir on the characteristics of circular loop antennas [15], Salem, and Caloz about the emission of electromagnetic fields by arbitrary currents in circular loops [16]. Research on loop antenna applications has been conducted by Vembarasi et al. regarding the design of bi-circular antennas as wideband antennas [17], Zheng et al. about the use of loop wire antenna as an orbital angular momentum generator [18].

This paper will discuss the results of the analysis on a bi-circular antenna design. There are two characteristics of the antenna being analyzed, namely the bandwidth and working frequency of the bi-circular antenna. Analysis of the bi-circular antenna design is carried out using three approaches. The first method uses the FDTD simulation method based on the propagation of electromagnetic waves on the antenna material medium [19], [20]. The second method is based on the measurement results using a network analyzer on the fabrication results of the antenna design [21]. The third method uses the application of the bi-polygonal antenna model to the bi-circular antenna design [22], [23].

The novelty in this research is twofold. The first novelty is the application of the bi-polygonal antenna model to the bi-circular antenna design to determine the antenna bandwidth and working frequency. The second novelty is the comparison of the results of determining the bandwidth and working frequency of bi-circular antennas from the three methods used in the study.

2. ANTENNA DESIGN

The shape and geometric parameters of the bi-circular microstrip antenna design used in this study are shown in Figure 1.

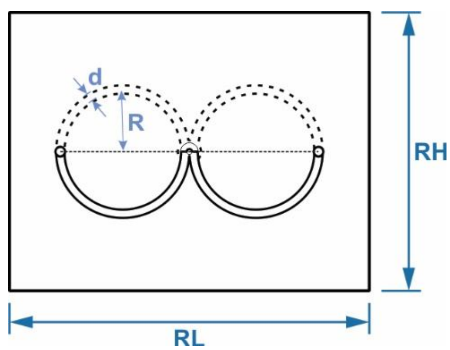

Figure 1: Bi-circular antenna design parameters

In Figure 1, the value of each antenna geometry parameter is as follows:
- The substrate material is Teflon (PTFE) whose dielectric constant is 2.1.
- The substrate thickness is 1.54 mm
- Circumference antenna is 93.93 mm
- The copper thickness (T) is 0.03 mm
- The diameter of copper (d) is 2 mm.
- The radius of the circular antenna (R) is 14.95 mm.
- The length of the antenna board (RL) is 86.11 mm.

To measure the bi-circular antenna design, it is necessary to fabricate the bi-circular antenna design. Figure 2 shows the fabricated form of a bi-circular antenna.

Figure 2: Bi-circular antenna fabrication results

3. METHODS

3.1 FDTD Simulation

The simulation method is based on the phenomenon of observing short wavelength electromagnetic waves (microwaves) propagating in an antenna design as the propagation medium. The analysis is carried out by applying Maxwell's equation to the antenna medium. The characteristics of the antenna are obtained by solving Maxwell's equations for microwaves propagating in the antenna medium using the Finite Difference Time Domain (FDTD) method [19], [20].

In the FDTD method, time or space is divided into separate segments. Space is segmented into box-shaped cells that are smaller than the wavelength. The electric field is located on the edge of the box and field magnets are placed p no surface box. Time is quantized into small steps where each step represents the time it takes for the plane to move from one cell to the next. Given the offset in the magnetic field space to the electric field. The electric and magnetic fields are renewed using an alternating frog jumping scheme. At each time step, the waveform values over that period are added to the field values. The surrounding plane will scatter the input waveform across the FDTD grid precisely depending on the characteristics of each cell. The calculation must be continued until the conditions of convergence are reached. This condition means that all field values have decayed to zero or are at least 60 dB down from their peak.

In this study, the FDTD method was used to obtain the return loss value of the bi-circular antenna design in Figure 1 in the frequency range from 2 GHz to 3 GHz.

3.2 Measurement Using Network Analyzer

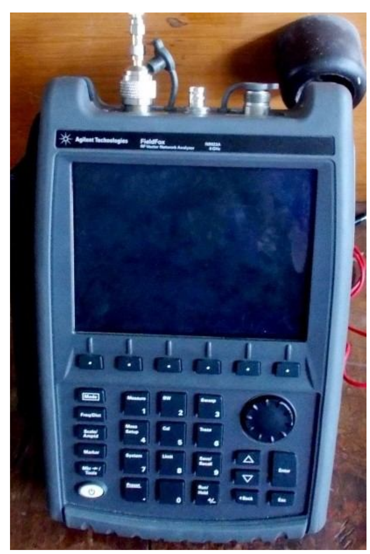

Figure 3: Agilent N9923 Network Analyzer

Network analyzers are used to measure VSWR, scattering parameters, and bi-circular antenna reflection coefficient. The antenna is connected to the transmitter port on the Network Analyzer. This Network Analyzer measures the frequency range of 2 to 3 GHz. The measurement data obtained from the Network Analyzer are frequency data, scattering parameters, and VSWR [21]. Figure 3 shows the Agilent N9923, the Network Analyzer used in the study.

Data obtained from measurement there are three types, namely the scattering parameters, VSWR, and radiation patterns. Based on the scattering parameters and VSWR, the measurement results are calculated using certain equations to get the characteristic impedance of the antenna and the return loss on the antenna.

From the VSWR can be determined the characteristic impedance of the antenna:

$$Z_0 = VSWR \cdot Z_r \qquad (1)$$

with
Z_0 = Characteristic impedance of the antenna
Z_r = Reference impedance

From scattering parameters can be determined the value of Return Loss:

$$RL = -20 \log \left| S_{1,1} \right| \qquad (2)$$

3.3 Bi-Polygonal Antenna Model

The bi-polygonal antenna model is a proposed model for analyzing several antenna characteristics based on its multiple polygonal design parameters. In the bi-polygonal antenna model, calculations for the determination of the inductance of a bi-polygonal antenna in the form of a regular polygonal wire are carried out with some restrictions for simplifying calculations [22], [23].

Based on these approaches, the total magnetic field at the polygonal center is the sum (resultant) of all magnetic fields generated by each side of the polygonal:

$$\begin{aligned} B_{tot} &= nB \\ &= \frac{\mu_0 In}{2\pi a}\cos\alpha \\ &= \frac{\mu_0 In^2}{\pi s}\frac{\cos\alpha}{\tan\alpha} \end{aligned} \qquad (3)$$

The next calculation is the calculation of the polygonal cross-sectional area:

$$\begin{aligned} A_{tot} &= nA = n\frac{1}{2}la \\ &= \frac{s^2}{4n}\tan\alpha \end{aligned} \qquad (4)$$

with:

$$\alpha = 90^0 - \frac{1}{2}\theta$$

$$\theta = \frac{360^0}{n}$$

$s =$ polygonal circumference length
$n =$ number of polygonal sides

Based on these approaches, the bi-polygonal wire inductance is calculated as follows:

$$\begin{aligned} L &= \frac{B_{tot}A_{tot}}{I} \\ &= \frac{\mu_0 ns}{4\pi}\sin\left(\frac{180^0}{n}\right) \end{aligned} \qquad (5)$$

with:
n = number of sides of the bi-polygonal antenna
s = perimeter of the bi-polygonal antenna
μ_0 = permeability of the vacuum or air medium
L = inductance of a bi-polygonal antenna

Based on the results of calculations using a bi-polygonal wire antenna inductance formulation and RLC circuit modeling, the antenna bandwidth formula can be derived:

$$RL = -10$$

$$20\log\left(1 - \frac{R}{Z}\right) = -10$$

$$\frac{\sqrt{10}}{\sqrt{10}-1}R = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2} \qquad (6)$$

Suppose $x = \frac{\sqrt{10}}{\sqrt{10}-1}$

$$xR = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

$$L\omega^2 - R\left(\sqrt{x^2-1}\right)\omega - \frac{1}{C} = 0 \qquad (7)$$

By using the ABC formula, we get:

$$\omega_{1,2} = \frac{R\sqrt{x^2-1} \pm \sqrt{R^2(x^2-1) + \frac{4L}{C}}}{2L}$$

So that the bandwidth is in angular frequency:

$$\Delta\omega = \omega_2 - \omega_1$$

$$= \sqrt{\frac{R^2}{L^2}(x^2 - 1) + \frac{4}{LC}} \quad (8)$$

And bandwidth in frequency:

$$\Delta f = \frac{1}{2\pi}\sqrt{\frac{R^2}{L^2}(x^2 - 1) + \frac{4}{LC}} \quad (9)$$

and the working frequency of antenna [24] :

$$f = \frac{1}{2\pi\sqrt{LC}} \quad (10)$$

with:
C = antenna capacitance
R = antenna resistance

4. RESULT AND DISCUSSION

4.1 Simulation Results Data

Table 1: Return loss vs. frequency from 2 GHz to 3 GHz of the simulation results

f	Return Loss	f	Return Loss	f	Return Loss
2.00	-0.815	2.34	-11.019	2.68	-10.051
2.01	-0.875	2.35	-11.932	2.69	-9.762
2.02	-0.939	2.36	-12.939	2.70	-9.487
2.03	-1.007	2.37	-14.061	2.71	-9.226
2.04	-1.077	2.38	-15.329	2.72	-8.980
2.05	-1.150	2.39	-16.784	2.73	-8.746
2.06	-1.227	2.40	-18.492	2.74	-8.525
2.07	-1.307	2.41	-20.563	2.75	-8.314
2.08	-1.393	2.42	-23.202	2.76	-8.112
2.09	-1.486	2.43	-26.863	2.77	-7.917
2.10	-1.586	2.44	-32.989	2.78	-7.727
2.11	-1.698	2.45	-67.893	2.79	-7.541
2.12	-1.821	2.46	-33.643	2.80	-7.357
2.13	-1.960	2.47	-27.758	2.81	-7.173
2.14	-2.114	2.48	-24.428	2.82	-6.990
2.15	-2.288	2.49	-22.139	2.83	-6.806
2.16	-2.481	2.50	-20.421	2.84	-6.621
2.17	-2.697	2.51	-19.063	2.85	-6.436
2.18	-2.937	2.52	-17.952	2.86	-6.252
2.19	-3.201	2.53	-17.020	2.87	-6.068
2.20	-3.491	2.54	-16.221	2.88	-5.888
2.21	-3.808	2.55	-15.524	2.89	-5.711
2.22	-4.152	2.56	-14.905	2.90	-5.539
2.23	-4.526	2.57	-14.346	2.91	-5.374
2.24	-4.929	2.58	-13.836	2.92	-5.217
2.25	-5.363	2.59	-13.364	2.93	-5.068
2.26	-5.829	2.60	-12.921	2.94	-4.927
2.27	-6.328	2.61	-12.502	2.95	-4.795
2.28	-6.863	2.62	-12.104	2.96	-4.671
2.29	-7.435	2.63	-11.724	2.97	-4.555
2.30	-8.048	2.64	-11.359	2.98	-4.446
2.31	-8.707	2.65	-11.010	2.99	-4.342
2.32	-9.417	2.66	-10.676	3.00	-4.243
2.33	-10.184	2.67	-10.356		

Table 1 presents the Return Loss data in dB of the bi - circular antenna design in the frequency range from 2 GHz to 3 GHz obtained from the simulation results. The numbers in the blue box in Table 1 represent the upper or lower frequency limits of the bandwidth range and the antenna Return Loss value for each of these frequencies which is about -10 dB. The numbers in the green box in Table 1 indicate the working frequency and the return loss antenna value at the working frequency based on the simulation results.

4.2 Measurement Result Data

Table 2: Return loss vs. frequency from 2 GHz to 3 GHz of the measurement results

f	Return Loss	f	Return Loss	f	Return Loss
2.00	-1,796	2.34	-10,990	2.68	-3,887
2.01	-2,279	2.35	-12,247	2.69	-4,111
2.02	-2,701	2.36	-13,690	2.70	-4,397
2.03	-3,042	2.37	-15,401	2.71	-4,691
2.04	-3,286	2.38	-17,338	2.72	-4,986
2.05	-3,386	2.39	-19,697	2.73	-5,284
2.06	-3,376	2.40	-22,039	2.74	-5,620
2.07	-3,267	2.41	-24,437	2.75	-6,017
2.08	-3,102	2.42	-27,560	2.76	-6,442
2.09	-2,870	2.43	-30,653	2.77	-6,884
2.10	-2,645	2.44	-34,621	2.78	-7,348
2.11	-2,479	2.45	-38,304	2.79	-7,853
2.12	-2,346	2.46	-35,363	2.80	-8,339
2.13	-2,275	2.47	-29,148	2.81	-8,817
2.14	-2,226	2.48	-24,041	2.82	-9,223
2.15	-2,238	2.49	-20,234	2.83	-9,608
2.16	-2,280	2.50	-17,631	2.84	-9,920
2.17	-2,363	2.51	-15,509	2.85	-10,106
2.18	-2,520	2.52	-13,437	2.86	-10,092
2.19	-2,706	2.53	-11,520	2.87	-9,825
2.20	-2,937	2.54	-9,894	2.88	-9,318
2.21	-3,202	2.55	-8,571	2.89	-8,591
2.22	-3,457	2.56	-7,399	2.90	-7,825
2.23	-3,790	2.57	-6,504	2.91	-6,972
2.24	-4,138	2.58	-5,728	2.92	-6,101
2.25	-4,529	2.59	-5,050	2.93	-5,266
2.26	-4,964	2.60	-4,515	2.94	-4,487
2.27	-5,456	2.61	-4,183	2.95	-3,805
2.28	-5,955	2.62	-3,905	2.96	-3,223
2.29	-6,534	2.63	-3,724	2.97	-2,718
2.30	-7,188	2.64	-3,624	2.98	-2,235
2.31	-7,940	2.65	-3,603	2.99	-1,822
2.32	-8,826	2.66	-3,642	3.00	-1,452
2.33	-9,842	2.67	-3,740		

Table 2 presents the Return Loss data in dB from the bi-circular antenna design in the frequency range from 2 GHz to 3 GHz obtained from the simulation results. The numbers in the blue box in Table 2 represent the upper or lower frequency limits of the bandwidth range and the antenna Return Loss value for each of these frequencies which is about -10 dB. The numbers in the green box in Table 2 indicate the working frequency and the Return Loss antenna value at the working frequency based on the measurement results.

4.3 Modeling Result Data

Table 3: Return loss vs. frequency from 2 GHz to 3 GHz of the modeling results

f	Return Loss	f	Return Loss	f	Return Loss
2.00	-0.82344	2.34	-4.07488	2.68	-1.96293
2.01	-0.84534	2.35	-4.53466	2.69	-1.87872
2.02	-0.86829	2.36	-5.10088	2.70	-1.80160
2.03	-0.89237	2.37	-5.81243	2.71	-1.73072
2.04	-0.91766	2.38	-6.72823	2.72	-1.66536
2.05	-0.94427	2.39	-7.94082	2.73	-1.60490
2.06	-0.97229	2.40	-9.60206	2.74	-1.54880
2.07	-1.00184	2.41	-11.9749	2.75	-1.49663
2.08	-1.03305	2.42	-15.5512	2.76	-1.44798
2.09	-1.06608	2.43	-21.3854	2.77	-1.40251
2.10	-1.10106	2.44	-32.6023	2.78	-1.35991
2.11	-1.13820	2.45	-72.3279	2.79	-1.31993
2.12	-1.17770	2.46	-32.6708	2.80	-1.28234
2.13	-1.21977	2.47	-21.5097	2.81	-1.24691
2.14	-1.26470	2.48	-15.7141	2.82	-1.21348
2.15	-1.31277	2.49	-12.1614	2.83	-1.18188
2.16	-1.36432	2.50	-9.80158	2.84	-1.15197
2.17	-1.41975	2.51	-8.14692	2.85	-1.12360
2.18	-1.47951	2.52	-6.93708	2.86	-1.09667
2.19	-1.54413	2.53	-6.02187	2.87	-1.07107
2.20	-1.61421	2.54	-5.30969	2.88	-1.04670
2.21	-1.69047	2.55	-4.74221	2.89	-1.02347
2.22	-1.77377	2.56	-4.28084	2.90	-1.00132
2.23	-1.86510	2.57	-3.89926	2.91	-0.98015
2.24	-1.96569	2.58	-3.57897	2.92	-0.95992
2.25	-2.07697	2.59	-3.30665	2.93	-0.94055
2.26	-2.20074	2.60	-3.07251	2.94	-0.92200
2.27	-2.33917	2.61	-2.86921	2.95	-0.90421
2.28	-2.49498	2.62	-2.69114	2.96	-0.88714
2.29	-2.67159	2.63	-2.53395	2.97	-0.87075
2.30	-2.87334	2.64	-2.39424	2.98	-0.85499
2.31	-3.10584	2.65	-2.26927	2.99	-0.83983
2.32	-3.37646	2.66	-2.15687	3.00	-0.82523
2.33	-3.69502	2.67	-2.05524		

Table 3 presents the Return Loss data in the dB design of a bi-circular antenna in the 2 GHz to 3 GHz frequency range obtained from calculations using bi-polygonal antenna modeling. The numbers in the blue box in Table 3 represent the upper or lower frequency limits of the bandwidth range and the value of the antenna's Return Loss on each of these frequencies which value is around -10 dB. The numbers in the green box in Table 3 indicate the working frequency and the Return Loss antenna value at the working frequency based on the modeling results.

4.4 Discussion

To be able to see the difference between the return loss vs. frequency simulation results, the return loss vs. the measured frequency, and the return loss vs. the frequency of the bi-polygonal antenna modeling results on a bi-circular antenna, the three graphs are presented in one frame in Figure 4.

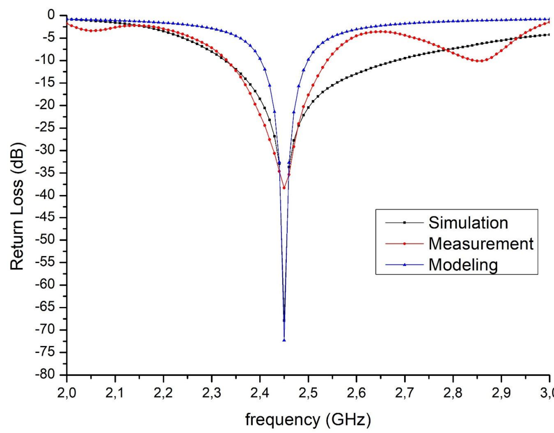

Figure 4: Graph of return loss vs. frequency of bi-circular antennas

The black curve shape of the simulation result shows a wide and deep valley. The shape of the red curve in the measurement results shows a wide and shallow valley with oscillating curved wings. The shape of the blue curve as a result of the bi-polygonal antenna modeling can be seen in the form of a narrow and deep valley with both symmetrical wings.

The curve form of the return loss vs. the frequency of the modeling results appears more symmetrical than the black curve, the return loss vs. the frequency of the simulation graph, and the red curve of the return loss vs. the frequency of the measurement results. The curve shape of the return loss vs. frequency graph of the bi-polygonal antenna modeling in the form of a narrow, deep, and symmetrical valley is an ideal condition for modeling an RLC antenna circuit. This ideal condition is formed from the theoretical characteristics of the RLC circuit. The shape of the graph curve of return loss vs. frequency of the result of mulching in the form of a wide, deep, and less symmetrical valley is a less ideal condition according to the RLC antenna circuit modeling. This less than ideal condition is formed from the presence of various external factors that influence the ideal characteristics of the RLC circuit. The shape of the graph curve of return loss vs. frequency measurement results in the form of a wide, shallow, asymmetric valley is a condition caused by several factors. The two main factors that cause it are accuracy in the antenna fabrication process and accuracy in the antenna sizing process.

Based on the data presented in Table 1 simulation results, Table 2 measurement results, and Table 3 modeling results, it can be determined that the bandwidth and working frequency of the bi-circular antenna for each of these methods can be determined. In Table 1, the simulation results show that the bi-circular antenna has a lower frequency of 2.33 GHz bandwidth and an upper frequency of 2.68 GHz bandwidth (a frequency with a return loss value of around -10 dB, blue box), so the bandwidth is 2.68 - 2.33 = 0.35 GHz. In Table 1, it can be seen that the frequency with the lowest return loss value is 2.45 GHz (green box). This frequency is the working frequency of the bi-circular antenna according to the simulation results. In Table 2, the measurement results show that the bi-circular antenna has a lower frequency of 2.33 GHz and an upper frequency of 2.54 GHz, so the bandwidth is 0.21 GHz. The frequency with the lowest return loss value is 2.45 GHz. This frequency is the working frequency of the bi-circular antenna based on the measurement results. In Table 3, the modeling results show that the bi-circular antenna has a lower frequency of 2.40 GHz and an upper frequency of 2.50 GHz, so the bandwidth is 0.10 GHz. The working frequency of the bi-circular antenna based on the modeling results is 2.45 GHz. The results of determining the bandwidth and working frequency of a bi-circular antenna based on the results of simulation, measurement, and modeling are presented in Table 4.

Table 4: The results of determining the bandwidth and working frequency of bi-circular antennas

Analysis Method	**Antena Bi-circular**	
	Bandwidth (GHz)	**Working Frequency**
Simulation	2.68 - 2.33 = 0.35	2.45 GHz
Measurement	2.54 - 2.33 = 0.21	2.45 GHz
Modeling	2.50 - 2.40 = 0.10	2.45 GHz

The comparative results of the simulation method and the measurement of the bandwidth and working frequency of the bi-circular antenna design in this study have the same return loss vs. frequency graph curve pattern similar to previous research on bi-circular loop antenna with plane reflector and coaxial fixed [21]. The pattern of similarity is that the measured curve is a wide, shallow, and asymmetrical valley when compared to the simulation result curve in the study. The same results were obtained in this study, namely the two curve wings that oscillate on the return curve vs. the frequency of the measurement results.

The application of the bi-polygonal antenna model to the bi-circular antenna design in this study gave slightly different results from the results of previous studies. In previous studies, the bi-polygonal antenna model gave the results of the return loss value at the working frequency of the bi-hexagonal antenna which was different from the return loss value simulated on the bi-hexagonal antenna design [23]. In this study, the bi-polygonal antenna model gives the return loss value at the working frequency of the bi-circular antenna which is almost the same as the return loss value of the simulation results.

Based on the results of this study and previous studies, the bi-polygonal antenna model still needs to be improved and developed further. Improvements to the bi-polygonal antenna model were carried out so that the results of the modeling did not differ greatly from the results of antenna simulations and measurements. The bi-polygonal antenna model has the potential as a simple method for predicting the bandwidth characteristics and working frequency of antennas that have a bi-polygonal geometric shape. Further development of the bi-polygonal antenna model needs to be done so that the process of designing antennas with bi-polygonal geometries can be carried out simpler. One of the potential applications of the bi-polygonal antenna model is as a method of rapid analysis in the application of antennas with bi-polygonal geometry as a bandpass filter antenna [25].

5. CONCLUSION

Analysis of the characteristics of the bi-circular antenna design based on FDTD simulations, measurements on the antenna design fabrication, and the application of the bi-polygonal antenna model have been carried out to obtain the bandwidth and working frequency of the antenna. Based on the results of the analysis using these three methods, it is obtained that different bandwidth values and the same antenna working frequency value are 2.45 GHz. The modeling results give a narrow and symmetrical form of return loss vs. frequency curve, the simulation results give a wide and slightly symmetrical form of return loss vs. frequency curve, and the measurement results give a wide and asymmetrical shape of return loss vs. frequency curve.

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