Radiation Profile of 2.45 GHz Bi-Circular Loop Antenna using Parabolic Reflector Made of Frying Pan (Wajanbolic)

J Annovasho¹ ² *, V Rahayu², A Ardimas² ³ and R A Firdaus⁴

¹ Tadris Fisika, IAIN Palangka Raya, Indonesia
² Fisika, Universitas Billfath, Kompleks YPP Al-Fattah, Indonesia
³ Department of Nanoscience and Technology, Chulalongkorn University, Thailand
⁴ Fisika, Universitas Negeri Surabaya, Indonesia

*Email: jhelang.annovasho@iai-palangkaraya.ac.id

Abstract. This study aims to determine the dimensions of the antenna and reflector which can optimally work at a frequency of 2.45 GHz. A good antenna is an antenna that has high directive capability, high performance, and inexpensive. In this work, the proposed antenna model was a Bi-Circular Loop (BCL) with a reflector using a frying pan (Wajanbolic). The methods were used in this research for instance computational simulation, fabrication, and characterization. Simulations were carried out using the Finite Different Time Domain (FDTD) technique. The simulation results were compared with the measurement process. In the first simulation, four reflector sizes could qualify as antennas, namely diameters of 309.00 mm, 335.00 mm, 364.00 mm, and 381.00 mm. The four reflectors sizes were optimized by changing the radius parameter of the BCL antenna. The best results were obtained on the reflector with a diameter of 364.00 mm and a BCL radius of 17.38 mm. The simulation results showed a radiation profile consisting of an RL value of -35.69 dB and a gain value of 16.40 dBi. Based on the fabrication and measurement of the antenna, the RL value was -54.75 dB and the directional antenna gain was 16.00 dBi. An antenna with such performance can be used as a point-to-point Wi-Fi transmitter.

1. Introduction
Utilization of the internet in rural areas will have many positive impacts on community development [1,2]. Internet access is limited in many villages due to the unfavourable geographical location. The difficulty is compounded by the high cost of instruments and required hardware maintenance in order to transmit internet data. The current obstacle is that there are unavailable antenna and working at a frequency of 2.45 GHz with optimal performance requirement.

Many previous studies had been carried out, such as using a step impedance resonator and using a dielectric taper [3,4]. The latest result presented that the gain value of antenna was about 4 dBi and required more costs and long process in terms of characterization and fabrication. A proposed solution for the antenna device to overcome the problematic above was to use a bi-circular loop (BCL) antenna. BCL is a dual-layer Printed Circuit Boards (PCB) based antenna. By using a flat reflector, the BCL simulation obtained a good performance with a return loss (RL) value of -68.009 dB and gain value of 9.04 dBi [5,6]. However, this antenna design did not have a good directivity value yet for long-distance point-to-point communication.
Changing the reflector type on the BCL is remarkably important in order to overcome the directivity problem. An alternative material that can be used is an aluminium frying pan. These materials have a low price, are available in the market, and allow people to carry out self-assembly and maintenance. In addition, an aluminium has constructive corrosion characteristics in consequence the long-term use does not significantly reduce the ability of the material. Several studies on Wajanbolic reflectors had been carried out, but its performance was not optimal. Yurandi et al. found that the gain generated by the Wajanbolic reflector was 17.065 dBi [7]. Moreover, Nafik et al. presented a gain value of 16 dBi on the 3G signal [8]. Karunnisa and Umben et al. obtained the gain results in the form of signal amplification [9,10]. A gain value of 14 dB and 8 dB were presented by Endri et al. and Handoko et al., respectively [11,12]. However, all of their studies have not discussed the basic radiation profile of the antenna, namely the Return Loss (RL) parameter.

Therefore, the purpose of this study is to design antenna and reflector devices that work at a frequency of 2.45 GHz. This study also discusses the characteristics of the RL in order to ensure the antenna having optimal performance. Antenna parameters were optimized using the Finite Different Time Domain (FDTD) technique. Then, the antenna was fabricated and measured to get the value of RL, gain, and radiation pattern. This research is quite important to produce antennas that allows rural communities getting easier internet access.

2. Method
2.1. Circular loop antenna
In the far-field region ($kr>>1$), the magnetic and electric fields in the circular loop are expressed by [13].

\[
H_{\theta} = -\frac{k^2 a^2 I_0 e^{-jkr}}{4r} \sin \theta = -\frac{\pi S I_0 e^{-jkr}}{\lambda^2 r} \sin \theta \tag{1}
\]

\[
E_{\phi} = \eta \frac{k^2 a^2 I_0 e^{-jkr}}{4r} \sin \theta = \eta \frac{\pi S I_0 e^{-jkr}}{\lambda^2 r} \sin \theta \tag{2}
\]

\[
H_{\phi} = H_{\theta} = E_{r} = E_{\theta} \tag{3}
\]

The ratio between $-E_{\phi}/H_{\theta}$ is the wave impedance which can be written in Equation (4).

\[
Z_w = -\frac{E_{\phi}}{H_{\theta}} = \eta \tag{4}
\]

where,

$Z_w$ = wave impedance

$\eta$ = characteristic impedance

The radiation intensity $U$ is expressed in Equation (5).

\[
U = r^2 W_r = \frac{\eta}{2} \left(\frac{k^2 a^2}{4}\right)^2 |I_0|^2 \sin^2 \theta \tag{5}
\]

$U_{\text{max}}$ occurs when phase $\theta=\pi/2$, then $U_{\text{max}}$ is presented in Equation (6).

\[
U_{\text{max}} = U \left|\frac{\eta}{e^{\frac{-\pi}{2}}} \right|^2 = \frac{\eta}{2} \left(\frac{k^2 a^2}{4}\right)^2 |I_0|^2 \tag{6}
\]

Loop directivity is calculated in Equation (7).

\[
D_\alpha = 4\pi \frac{U_{\text{max}}}{P_{\text{rad}}} \tag{7}
\]

The input impedance and characteristic-impedance in a circular loop are expressed by Equation (8) [14].

\[
Z_i = Z_0 \cdot \frac{e^{2\alpha y} - 1}{e^{2\alpha y} + 1} \tag{8}
\]
\( Z_0 \) and \( \gamma \) are expressed in Equations (9) and (10).

\[
Z_0 \approx \frac{R + j\omega L}{j\omega C}
\]

\[
\gamma \approx \sqrt{-\omega^2 LC + j\omega CR}
\]

where \( R \) is the resistance, \( L \) is the inductance, and \( C \) is the capacitance of the circular loop.

The Return Loss (RL) is the basic radiation profile of the antenna. The RL is expressed by Equation (11).

\[
RL = -10\log \frac{P_r}{P_i}
\]

where \( P_i = \frac{V_i^2}{R} \) and \( P_r = \frac{V_r^2}{R} \), then the RL can be obtained in Equation (12).

\[
RL = -10\log \left| \frac{V_r}{V_i} \right| = -20\log \left| \frac{V_r}{V_i} \right|
\]

where,

- \( P_i \) = input power
- \( V_i \) = reflected voltage
- \( P_r \) = reflected power
- \( \Gamma \) = reflection coefficient
- \( V_i \) = input voltage

2.2. Parabolic Reflector

By using the method of images as depicted in Figure 1, where the directrix axis is the symmetry axis on the parabola from the focal point. Thus, the distance from the focal point \( F(0, f) \) to \( M(x, y) \) is the same as the distance from \( M(x, y) \) to the directrix axis or point \( D(x, -f) \) \([8]\). So, it can be written in Equation (13).

\[
\sqrt{(x-0)^2 + (y-f)^2} = \sqrt{(x-x)^2 + (y-(y-f))^2}
\]

therefore,

\[
x^2 = 4yf
\]

\[
y = \frac{x^2}{4f}
\]

\[\text{Figure 1. Illustration of parabolic reflector}\]
Thus, the focal distance $f$ as the reflector distance to the antenna can be expressed in Equation (17).

$$f = \frac{D^2}{16h}$$

(17)

If the parabolic antenna is a circular aperture, the equation to determine the approximate gain value can be written as [8].

$$G \approx \frac{(\pi^2 D^2)}{\lambda}$$

(18)

where,

$G$ = isotropic gain  
$D$ = diameter of the reflector  
$\lambda$ = wavelength

2.3. Antenna design

Figures 2 and 3 show the schematic of the installation of the antenna and reflector in the simulation program. Parameters $D$ and $h$ were obtained from the measurement results of the reflector dimensions. The reflector was mounted on the back of the antenna. Thus, the reflector will face the direction of the wave propagation emitted by the antenna. The distance between the axis of the reflector (vertex) and the antenna are referred as well as the focal distance.

![Figure 2](image)

*Figure 2. Bi-Circular loop antenna design with a wajanbolic reflector, two-dimensional schematic seen from the side*

![Figure 3](image)

*Figure 3. Bi-Circular loop antenna design with a wajanbolic reflector, 3-dimensional image on the simulation program*

The focal distance $f$ is calculated based on Equation (17) [8,9]. The calculation results of the focal distance are presented in the Table 1.

| Frying Pan No. | $D$ (mm) | $h$ (mm) | $f$ (mm) |
|---------------|----------|----------|----------|
| 1             | 309      | 96.20    | 62.03    |
| 2             | 335      | 101.50   | 69.10    |
| 3             | 364      | 105.00   | 78.87    |
| 4             | 381      | 111.80   | 81.15    |

Table 1. Parameters of frying pan dimension
The prior simulation, the used of Bi-Circular Loop antenna with parameters from the simulations have been carried out by Annovasho et al. [5] and Bustomi et al. [6]. These parameters are the loop radius of 14.95 mm and the link radius of 1.15 mm. Other parameters are presented in Table 2.

| Parameter             | Size (mm) |
|-----------------------|-----------|
| $W$                   | 86.11     |
| $H$                   | 66.98     |
| substrate thickness   | 1.54      |
| $w$                   | 2.00      |
| copper thickness      | 0.03      |

2.4. Simulation method

Simulation was used to predict the antenna properties that was properly designed, so it is unnecessary to fabricate at first. It is believed that the simulation can save research material and can easily to understand various characteristics of the antenna. In this study, the Finite Integration Technique (FIT) analysis was used for characterizing the antenna which is relevant to FDTD for the transient solver [15].

2.5. Fabrication and measurement method

Installation of the antenna was applied on the reflector of the frying pan. PVC pipe can be used as testing purpose. PVC pipe is an insulating material which is lightweight and malleable. The PVC pipe was firstly measured, then in some parts it was shaped like a flattened T. To combine with other parts, shock/pipe connections were used on either straight or turn connections. The position of the antenna mount to the reflector and the reflector to the mast can be seen in Figures 4 and 5.

![Figure 4. Mounting of the antenna on the reflector (front side)](image1)

![Figure 5. Mounting the reflector on the support post (back side)](image2)
The measurement process was carried out with the NanoVNA V2 device [16]. For the measurement of radiation pattern, it can be applied on one receiving signal unit, one signal generation unit, and as well a directional transmitting antenna.

3. Results and Discussion

By using the BCL parameter in the previous explanation, the results were obtained in the following table.

| Frying Pan No. | Minimum Peak | |
|---------------|--------------|-----|
|               | RL (dB)      | Frequency (GHz) |
| 1             | -14.80       | 2.99 |
| 2             | -11.14       | 2.87 |
| 3             | -8.27        | 2.69 |
| 4             | -7.88        | 2.66 |

The next simulation step has been carried out to make the RL minimum peak shiftable at a frequency of 2.45 GHz by changing the loop radius. In the loop radius, if the value is increased, RL minimum peak will shift to the left. In contrast, if it is reduced, it will make the RL minimum peak shifts to the right [5]. From the simulation results of this parameter optimization, the following results are obtained.

| Frying Pan No. | Loop Radius (mm) | RL (dB) | Gain (dBi) |
|---------------|------------------|---------|------------|
| 1             | 21.09            | -21.28  | 11.90      |
| 2             | 18.91            | -18.14  | 13.90      |
| 3             | 17.38            | -35.69  | 16.40      |
| 4             | 17.05            | -19.00  | 16.80      |
Table 4 shows that the larger the reflector pan diameter gives the greater gain value. The antennas and reflectors as the researchers fabricated are those based on optimization simulations that have a minimum RL value, namely the combination of antenna and reflector or frying pan number 3. The focal distance affects the antenna impedance because the antenna polarization is parallel to the reflector plane [13]. In frying pan number 3, the focal distance provides optimal impedance to the antenna so that the antenna has a radiation profile in the form of a minimum RL value. In this condition, there is an impedance matching due to the characteristic-impedance as in Equation (9). The antenna and reflector system were equal to the input impedance of 50 Ω. The amount of radiation profile in the form of gain was influenced by the reflector diameter, as shown in Equation (18). The bigger diameter of the pan, the better the gain will be. In this condition, impedance matching has not achieved yet since the input impedance used is 50 Ω. However, it is important to pay attention to the RL value so that the antenna can radiate electromagnetic waves maximally to avoid power losses.

After the fabricated antenna has been measured, the results were obtained in frying pan no.3, loop radius BCL 17.38 mm, RL -54.75 dB, and Gain 16.00 dBi. From the radiation pattern graph (Figure 8), the antenna has the highest gain at an angle of 0°. It can be said that the antenna has a directional radiation pattern. This shows that the simulation results are valid. However, the antenna can be used as a medium-distance point-to-point network link (1-10 km). The results of RL and radiation pattern can be seen in the Figures 7 and 8.

![Figure 7. RL vs frequency graph](image1)

![Figure 8. Radiation pattern at 2.45 GHz](image2)

Compared to previous studies, the obtained result in this study provides a complete explanation of the radiation profile of the Wajanbolic reflector. The RL value indicates that the antenna works optimally with small power losses. Gain value indicates that the measured value is in accordance with the theory. This study can be used as reference in research especially on Wajanbolic reflectors. This research also opens the opportunity to investigate other characteristics of Wajanbolic antennas and reflectors in the future. The investigations that can be carried out later on in terms of the combinations of other types of antennas, optimization of reflectors with smaller sizes, and trials of their use in real conditions.

4. Conclusion

From the description above, it can be concluded that the best results were obtained on the reflector with a diameter of 364.00 mm and a BCL radius of 17.38 mm. Based on the simulation, these parameters produced a radiation profile in the form of RL value is -35.69 dB and a gain of 16.40 dBi. Based on the fabrication and measurement, the antenna had a radiation profile of the RL value of
-54.75 dB and the gain of 16.00 dBi on directional antenna. An antenna with such performance can be used as a point-to-point Wi-Fi transmitter.

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