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Design and Optimization High-Performance Bi-Circular Loop Antenna with Plane Reflector and Coaxial Feed Line at 2.45 GHz Frequency

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***Abstract*— The aim of this study is to find the best design for high-performance medium range antenna by simulating bi-circular loop antenna with plane reflector. The coaxial feed line at 2.45 GHz frequency Finite Different Time-Domain (FD-TD) method was employed in simulation. The simulation results showed that the best parameters value are 14.95 mm of loops radius, 1.15 mm of links radius, and 15.57 mm of reflector gap. In these parameters, the antenna had a characteristic value of return loss -36.65 dB, bandwidth 354 MHz, gain 9.04 dB, VSWR 1.001, and the characteristic impedance of 49.97 Ω. Moreover, it was also used as IoT or other medium range communication applications.**

Keywords*— *Antenna, circular loop, plane reflector, coaxial feed line, high-performance

I. Introduction

Internet of Things (IoT), at medium range, uses Wi-Fi as data transmitter [1-2]. As IoT develops, it requires wireless devices which have high performance, compact and small dimension. The antenna is an important device for transmitting and receiving modulated waves as well as sending and receiving data.

The loop antenna is a simple antenna, inexpensive, versatile, and easy in analysis and manufacture [3]. Some of the loop antenna types are the square loop, quad loop, and circular loop. An antenna which has small elements of V-shapes coplanar stripline (CPS) combination [4] with multiple angles and separation gap is considered as circular loop antenna. Characteristics combination of different CPS angles leads to characteristic, namely wideband characteristics. These characteristics have been demonstrated in the fabrication of circular patch antennas with small circular slots [5]. Some formulations were applied as well as investigation in

There are formulations and studies have evaluated the design of circular loops [6-25]. However, none of these formulations and studies has investigated antenna device applications, specifically in microwaves at 2.45 GHz which work perfectly.

In this regard, we focus on the bi-circular loop antenna which combines with the plane reflector [3] and coaxial feed line at 2.45 GHz. The parameters investigated are scattering-parameters ($S_{1,1}$) as the effect of changes in the loops radius, links radius, and the reflector gap. To test simulated design, Finite Different Time-Domain (FD-TD) method was employed.

II. Antenna Design

The geometry of the proposed antenna is shown in Fig. 1. This antenna design uses two layers of substrate (Fig.1. (a)) with length W (86.11 mm) and width H (66.98 mm) and there is a gap d between two substrates. The substrate material is FR-4 of 1.54 mm thickness and dielectric constant ε_r 4.3. At the first layer, consisting of the front side and back side, there is double half-loop copper strip-line with radius R (Fig.1. (b)). The two double half-loops are connected with a link, with radius r, becomes the double full loop. The front side double half-loop and the back side double half-loop have different polarization. The copper patch width w is 2.00 mm and 0.03 mm thickness. On the other hand, the second layer consists of copper patches on the entire surface.

Coaxial feed line structure contains a copper core with a radius value a_1 is 0.63 mm (Fig. 1. (c)). The dielectric material is used to separate the two copper is Teflon (PTFE) with a dielectric constant ε_r is 2.1. With these dielectric constants, if the coaxial characteristic impedance Z_0 *coax* equal to reference impedance Z_i=50 Ω, the Teflon radius a_2 can be calculated by equation (1)[26].

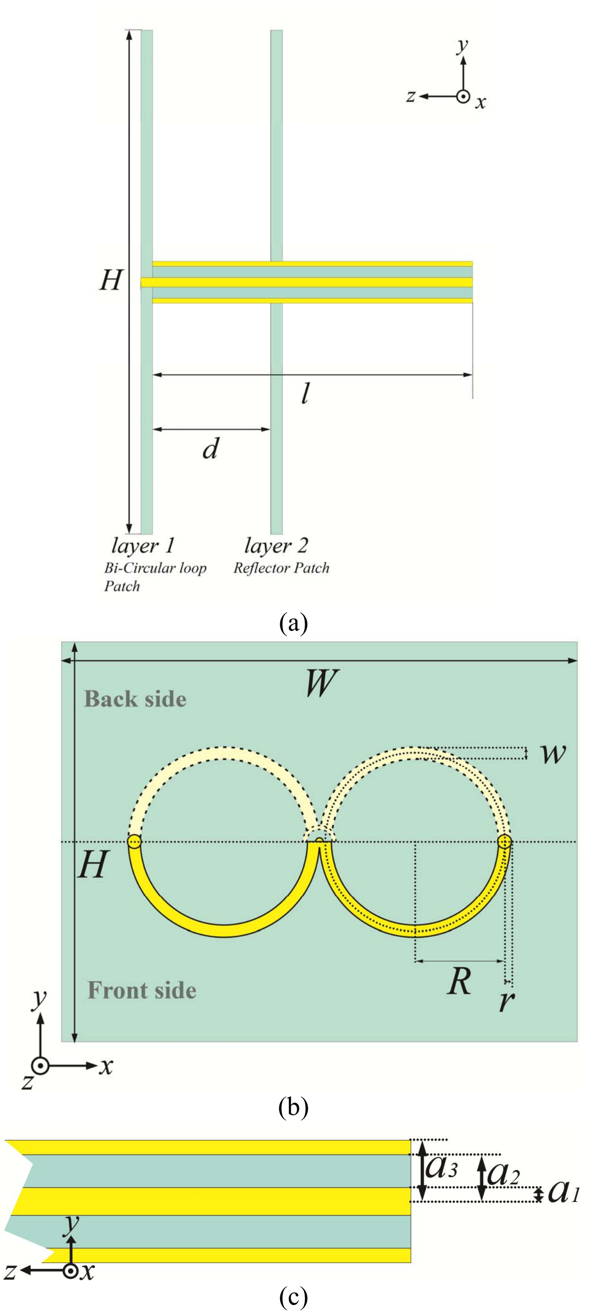

Fig. 1. Design of bi-circular loop antenna with plane reflector and coaxial feed line, (a) side view, (b) front view of layer 1 substrate, and (c) side view of coaxial feed line

$$a_2 = 10^{\left(\frac{Z_i\sqrt{\varepsilon_r}}{138}\right)} \cdot a_1 \qquad (1)$$

From (1), the value of a_2 is 2.11 mm and the outer copper thickness is 0.66 mm, thus the value of a_3 is 2.77 mm.

At the 2.45 GHz frequency (λ_0 = 122.36 mm) and dielectric constant of Teflon, for phase matching, the length l of the coaxial feed line can be determined by following equation [27].

$$l = \frac{1}{2}\lambda_g = \frac{\lambda_0}{2\sqrt{\varepsilon_r}} \qquad (2)$$

From (2), the value of l is 42.21 mm.

TABLE 1. FIX PARAMETERS OF ANTENNA

Parameter	**Size (mm)**
W	86.11
H	66.98
substrate thickness	1.54
w	2.00
copper thickness	0.03
a_1	0.63
a_2	2.11
a_3	2.77
l	42.21

III. SIMULATION RESULT AND DISCUSSION

The parameters that are manipulated are the loops radius, links radius, and the reflector gap. Changes in each parameter affects the value of $S_{1,1}$ at 2.45 GHz. The result of this change is described in the ensuing sections.

A. Effect of the Loops Radius

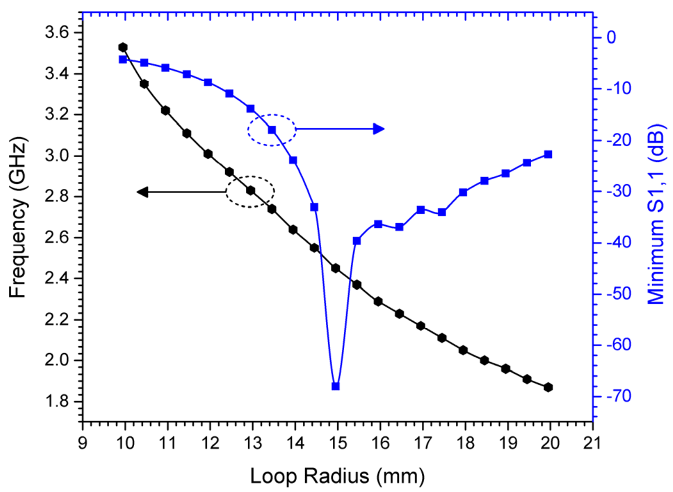

Fig. 2. The effect of the loops radius change on the frequency shift with minimum s-parameter value

The loops radius change not only affects the value of $S_{1,1}$ but also the frequency shift. In this shift, there is a minimum $S_{1,1}$ value. Fig 2indicates that on a 14.95 mm loop radius, at

2.45 GHz frequency there is a minimum $S_{1,1}$ value of -68.009 dB. This occurs since the length of the coaxial feed line, for phase matching, has been set for 2.45 GHz frequency.

This frequency shift data is essential in determining minimum $S_{1,1}$ value for expected frequencies. For example, at frequency of 3.01 GHz, the antenna will be optimal if the loop radius is 11.95 mm. In optimizing the value of $S_{1,1}$, it can be pointed out by adjusting the length of the coaxial feed line.

B. Effect of the Links Radius

There is no frequency shift with minimum $S_{1,1}$, when the link radius is changed. Changing the links radius affects the value of $S_{1,1}$ at a specific frequency which has been set tothe loop radius change (Fig. 2). Additionally, it is also resulting on antenna impedance change (Fig. 3).

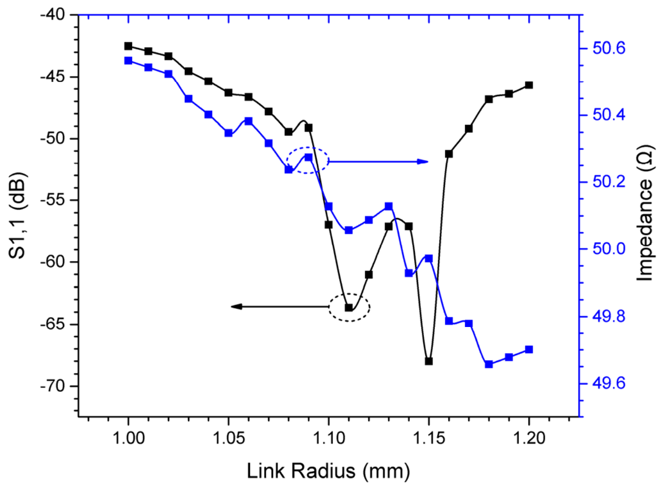

Fig. 3. The effect of the radius link changes to the s-parameter value and antenna impedance at 2.45 GHz frequency

Fig. 3shows that the impedance of the antenna can be controlled by changing the links radius. This method is easier because does not need to calculate the input impedance to allow impedance matching [17]. At a links radius of 1.11 mm, $S_{1,1}$ determines the value of -63.656 dB with impedance value 50.057 Ω or 0.057 Ω difference from reference impedance. At radius links of 1.15 mm, S1,1 shows the value of -68.009 dB with an impedance value 49.972 Ω or 0.028 Ω difference from reference impedance. The best $S_{1,1}$ value occurs when the antenna impedance reaches the reference impedance at 50 Ω.

C. Effect of the Reflector Gap

The current is flowing on the copper loops at the 0° phase as illustrated in Fig. 4. Reflections of waves occur at the ends of the loops, by the links wire, form the current nulls. In one loop there are two current nulls, where at the bottom and at the top. The current is starting from current null at the bottom and end at current nulls at the top. The current null at the bottom is considered as positive voltage-current null and the current null at the top namely negative voltage-current null. Current flow will reverse in the event of a polarization change in the loops, at a phase of more than 90°, and reversed again at phase more than 270°.

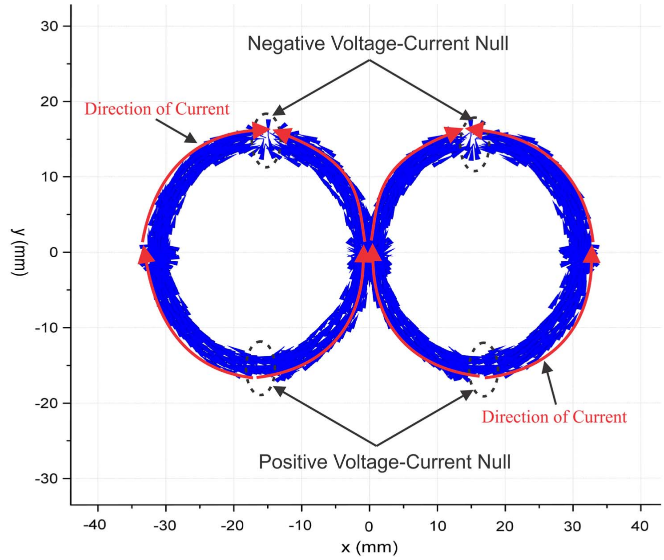

Fig. 4. Surface current on copper loops with 2.45 GHz frequency and 0° phase

The antenna is regarded as four horizontal electric dipoles, as shown in Fig.4. In addition, reflector distance influence is analyzed by image theory. The reflector gap manipulated ranges from 15.35 mm (0.125λ) to 15.70 mm (0.128λ). Fig. 5 describes the greater the reflector gap, the more it affects the smaller antenna gain. This result is compatible with the area of the reflector gap which less than 0.25λ in [3].

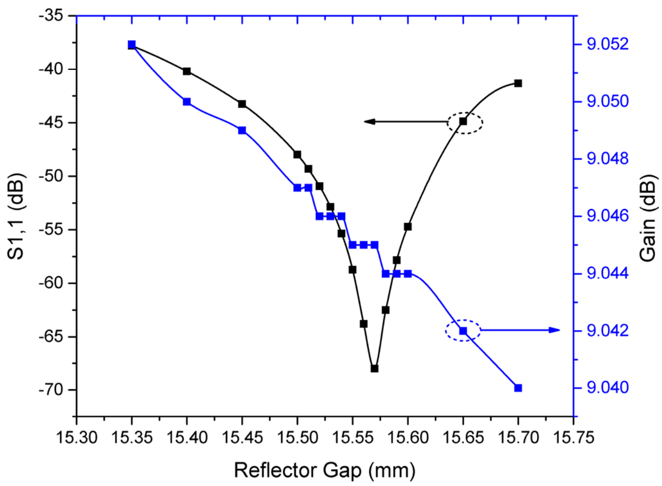

Fig. 5. The effect of the reflector gap changes on the s-parameter value at 2.45 GHz frequency

The reflector is a copper layer with an electric conductivity σ of 5.8x107 S/m. Reflector gap on the horizontal electric dipole has a significant effect on the input impedance, conversely to the vertical electric dipole [3]. Impedance matching condition of the 15.57 mm reflector gap allows the antenna has a minimum $S_{1,1}$ value.

D. Antenna Characteristics of the Best Parameters Result

At the best parameters result, the $S_{1,1}$ value of -68.009 dB at 2.45 GHz frequency. This suggests that the antenna has Return Loss value of -36.651 dB. Fig. 6describes $S_{1,1}$ is less than -10 dB is at the frequency of 2.328 GHz and 2.682 GHz. Hence, the antenna bandwidth improves to 354 MHz. The Fig. 7 shows VSWR antenna at 2.45 GHz is 1.001. This antenna is less than 2.000 which has the same range as $S_{1,1}$ bandwidth.

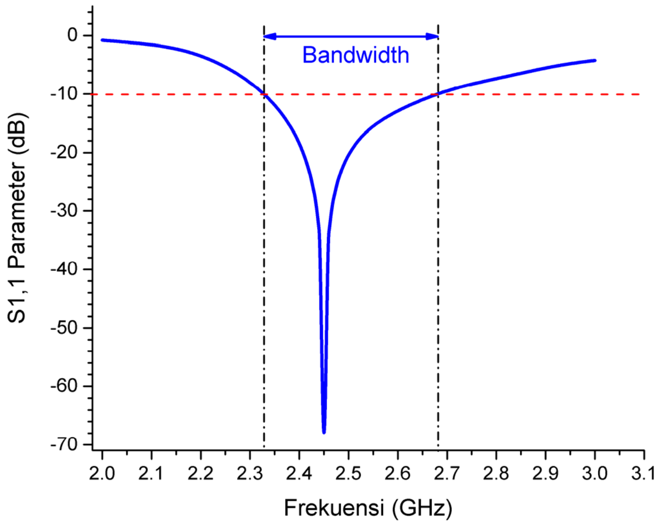

Fig. 6. The relation between frequency and $S_{1,1}$-parameters on the best parameters result

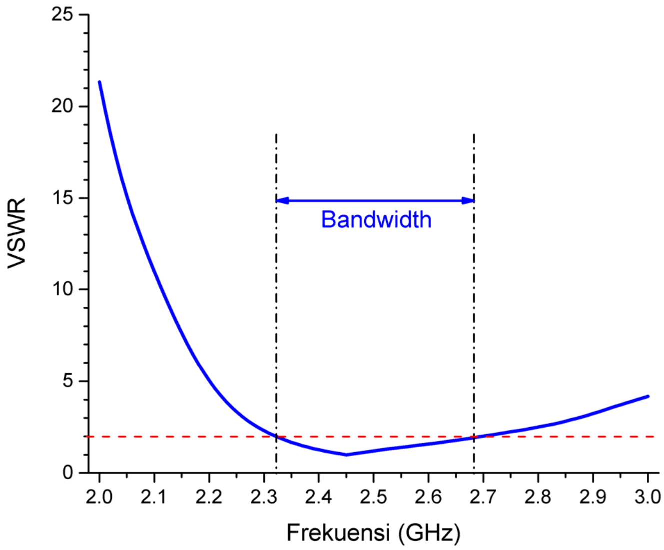

Fig. 7. Relation between frequency and VSWR on the best parameters result

Bandwidth in the Fig. 6 and Fig. 7 can be explained by current null analysis. Bandwidth is the ability of the antenna geometry to maintain the current null position in a specific frequency range. In Figure 4, the antenna has a wide bandwidth when the current null remains at the top and bottom peak positions, having the strongest electromagnetic field, over wide frequency range. The bi-circular loop antenna has good bandwidth characteristics, instead, needs to be improved.

Fig. 8 indicates the antenna's directional radiation pattern with the main lobe being on theta 0°,gaining on the main lobe of 9.045 dB. The increased gain with the addition of arrays is a good step. The gain can be normalized by subtracting the gain value at a specific angle with maximum gain value. The normalized gain value of -3 dB is a half of the antenna power. An angle value which is more than half power is called half power beam width (HPBW). The bi-circular loop antenna has HPBW of 66.3°, while the HPBW is used to find out how optimal angle of antenna work.

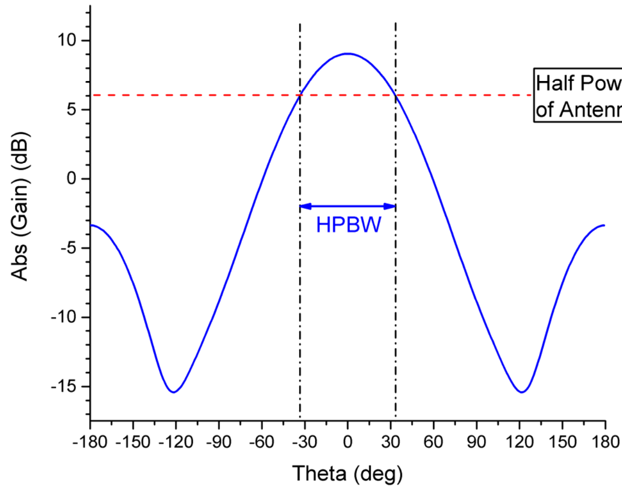

Fig. 8. Relation between theta and gain pattern on the best parameters result

IV. Conclusion

The design and optimization of the bi-circular loop antenna have been presented in this study. The results reveal that the high-performance of the designed antenna is developed for different frequencies by manipulating some parameters. It is also observed that the parameters described in order to achieve optimal results. Antenna design can be arranged as an array antenna to provide better performance.

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