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Open-loop Dipole Microstrip Antenna with U-shape Insertion for 2.45 GHz Wireless Applications

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***Abstract*- In this article, two structures of open-loop dipole microstrip antenna for 2.45 GHz wireless applications were investigated through numerical simulation and experiment. The characteristic impedance of the open-loop was 430 Ω. Both microstrip antennas substrate use FR-4 with1.6 mm thickness and 4.3 of relative permittivity. The whole dimensions were 85 mm x 95 mm x 1.6 mm. The differences between the two microstrip antenna structures were indicated by using U-shape inside the loop and without using U-shape. The U-shape inserted into the open-loop microstrip could improve the gain. Both results of the simulation and the measurement showed that the gain was increased from (3.6-3.7) dB to (4.3-5.5) dB at frequency 2.45 GHz with the return loss around -20 dB.**

***Index Terms*- open-loop dipole, U-shape, 2.45 GHz**

I. INTRODUCTION

The wireless communication system has grown rapidly so far. This growth is in line with the increasing number of users and the rapid development of communication support devices such as antennas and transmission systems. A device which its development covers the dynamic research is an antenna, particularly microstrip antenna. Microstrip antenna with opened folded dipole has several advantages, e.g. simple structure, easy fabrication, relatively inexpensive, good performance [1]. It has been widely used for many types of wireless communications because of its inexpensive and lightweight benefits. The dipole antennas have many application reviews such as wireless local networks and radio frequency identification systems. The wireless local area network (WLAN) systems are applied to communication devices [2].

The antenna can be designed in various forms and specifications as required, for example, E-shape [3] and Psi(Ψ)-shape structure for a wideband antenna [4], a microstrip bowtie for Wi-Fi [5-6] and microstrip reconfigurable for switching [7]. In general, the antenna has a low gain value. The gain is one of the important factors in designing an antenna. High gain value can affect the extent of area compliance which can be covered by an antenna. The structure of the antenna is CPS (coplanar strip line) in the form of a dipole rectangular open-loop by adding element between the resonators to maximise the gain and improve the resonant frequency of the proposed antenna [8].

Previous studies, according to dipole with U-shape, produced the asymmetric dipole with U-shaped structure for wireless cable modem application [9], the open-sleeve antenna with its arm folded inside a U-shape [10], a dual band SIR coupled dipole with U-shape for 2.4/5.2/5.8 GHz application [11], and a loop antenna with C-shaped resonator for USB applications [12]. These aforementioned papers presented the gain of antennas were around 3-4 dB [9], 1.77dB [10], 2.2-3.6 dBi [11], and 1.4 dBi [12]. The gains should be improved by modifying the structure.

In this paper, the novelty is the structure of the open-loop dipole antenna with an addition of U-shape inserted into the loop which can improve the gain for 2.45 GHz frequency operation. The

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proposed structure design has a simple configuration but good matching impedance. We also calculated the input impedance of the folded dipole using an approach that has been successfully carried out for the similar configuration [13].

The organisation of this paper is as follows. At first, the open-loop dipole is the platform of the proposed antenna design and its characteristic impedance is compared to Thiele's formulation. Secondly, the simulation is studied to improve the antenna gain with the addition of U-shape. The final presentation is the result of measurement of the antenna inserted with U-shape in open-loop dipole and it shows an improvement in antenna gain. In future the proposed antenna is favorable to apply in any array design with directional of arrival (DOA) system [14].

II BASIC THEORY

A. Impedance of a folded dipole

The microstrip open-loop dipole (folded dipole) is one of the most used structures for improving gain with its compact size. The structure of the antenna is a CPS (coplanar strip line) that consists of two strip lines patch which is separated by a gap as in Figure 1.

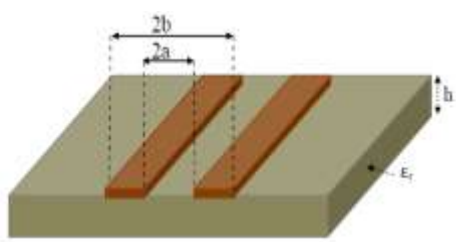

Fig 1.Coplanar strip line microstrip antenna

The impedance characteristics Z_0 can be determined using equation 1 [15], which also calculated successfully for a folded dipole [16].

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{eff}}} \frac{K(k_1)}{K'(k_1)} \quad (1)$$

Where

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2}$$

$$k_1' = \sqrt{1 - k_1^2}$$

$$k_1 = \frac{a}{b}$$

$$\frac{K(k)}{K'(k)} = \frac{\pi}{\ln\left[\frac{2\left(1+\sqrt{k'}\right)}{\left(1-\sqrt{k'}\right)}\right]} \; for 0 \le k \le 0,707$$

$$\frac{K(k)}{K'(k)} = \frac{1}{\pi}\ln\left[\frac{2\left(1+\sqrt{k}\right)}{\left(1-\sqrt{k}\right)}\right] \; for 0,707 \le k \le 1$$

To determine the characteristic impedance of the transmission line for the folded dipole, the formulation describing geometry as in Figure 2 can be used [13]. The formulation is given in equation 2.

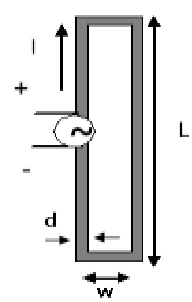

Fig 2.Folded Dipole [13]

$$Z_0 = 120\cosh^{-1}\frac{w}{d} \quad (2)$$

The *w* and *d* quantities are the width of folded and the diameter of the line. The input impedance is obtained from impedance transfer equation [13].

$$Z_t = jz_0 k \frac{L}{2} \quad (3)$$

The input impedance of a folded dipole

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$$Z_{in} = \frac{4z_t z_w}{z_t + 2z_w} \quad (4)$$

B. Gain

Meanwhile, in the proposed antenna, the improved gain was calculated with the basic formula of directivity *D* as follows.

$$D = \frac{4\pi U}{(\theta_{HP})(\varphi_{HP})} \text{ in radian, or}$$

$$D = \frac{41.258}{(\theta_{HP})(\varphi_{HP})} \text{ in degree} \quad (5)$$

where (Θ_{HP}) is half-power beam width (*HPBW*) in *E*-plane, (φ_{HP}) is *HPBW* in *H*-plane.

HPBW in *H*-plane is equal 2π, so the directivity is only determined by the value of *HPBW* in *E*-plane from the radiation pattern.

$$D = \frac{2}{(\theta_{HP})} \text{ in radian} \quad (6)$$

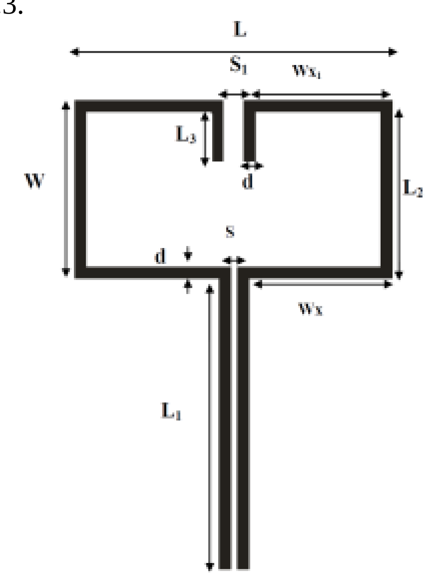
For example, in anisotropic case, $(\theta_{HP}) = 2(\pi$ radian), so the directivity $D=1$. The Gain of antenna is expressed as

$$G = \eta D \quad (7)$$

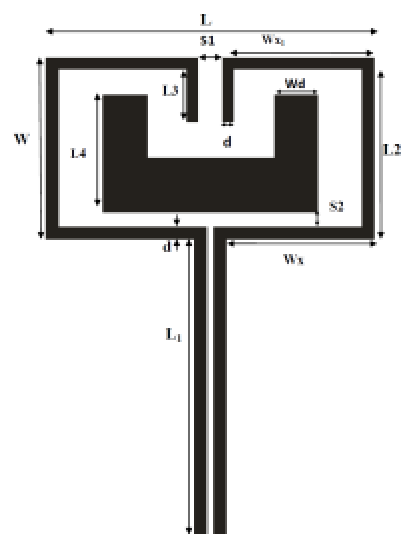
η is the antenna radiation efficiency (dimensionless) [17].

III. ANTENNA DESIGN AND ANALYSIS

The design of the open-loop dipole antenna and fix parameters are shown in Figure 3 (a) and Figure 3 (b) The antenna was designed on an FR4 dielectric substrate with the size of 85 mm × 95 mm × 1.6 mm. The open-loop dipole antenna was each sized *L= 60 mm, W= 31 mm*, *d* = 2 mm, *Wx* = 27 mm, Wx_1=25.75 mm, *Wd*= 8 mm, *L1* = 55 mm, *L2* = 29 mm, *L3* = 8 mm, *L4*= 12 mm, *S* = 2 mm, *S1* = 4.5 mm and *S2*=3 mm. The open-loop dipole is connected to the connector with 50 Ω resistance. To obtain the matching impedance of 50 Ω between the antenna and connector, the antennas are optimised to get a compact size and good agreement. The thick substrate has a thickness of 1.6 mm and relative permittivity of εr= 4.3.



(a)



(b)

Fig.3.Geometry of the proposed antenna: (a) The geometry of the antenna 1 (without U-Shape) and (b) The geometry of the antenna 2 (with U-shape)

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The characteristics impedance of the open-loop of every element in Figure 4 by using equation (1) are $Z_{01}=116.1\Omega$, $Z_{02} = 68.6\ \Omega$, $Z_{03}=247.3\ \Omega$, $Z_{04} =61.1\Omega$, *and* $Z_{05} =77.3\ \Omega$.. The characteristic impedance of this open-loop antenna is 454.3 Ω for an antenna with the length of 0.45λ. However, the determination of characteristic impedance of the open-loop design using equation (2) obtains 430Ω. It means that the value has a good agreement with the Thile's research which is 440Ω. The characteristic impedance in [13] has the discrepancy with the result of this proposed antenna, especially for large *w*/*d* comparison. The input impedance of the open-loop is 502 Ω by using equation 4 calculation.

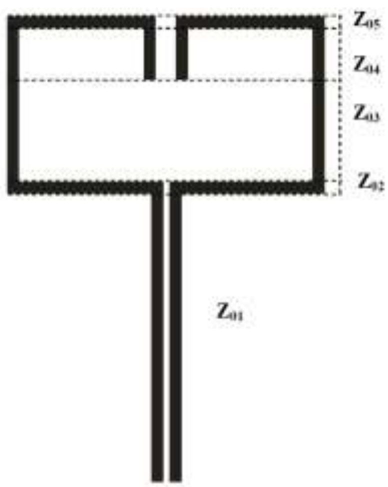

Fig.4. Characteristic impedance of the open-loop for every element

The frequencies correspond with the open-loop dipole design at each change of length (*L*) and width (*W*), it follows the formula [18]

$$f_r = \frac{V_o}{2L}\sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (8)$$

$$f_r = \frac{V_o}{2W\sqrt{\varepsilon_r}} \qquad (9)$$

Where f_r is frequency resonance, V_o is the free space velocity of light, L is the length of microstrip, W is the width of microstrip and ε_r is the relative permittivity constant.

The proposed antenna consisted of two antenna designs; a few modifications were added in the antenna with a U-shape element. The geometry of the U-shape is shown in Figure 3b. The length of the U-shape element was a quarter of wave $\lambda_g/4$ which was parallel to the resonators. The antenna was given in the element between the resonators and the gain of the proposed antenna increases. The proposed open-loop dipole without U-shape and with a U-shape antenna are fabricated as the photos shown in Figure 5.

(a)

(b)

Fig.5. Fabricated open-loop dipole microstrip of the proposed (a) antenna 1 (b) antenna 2.

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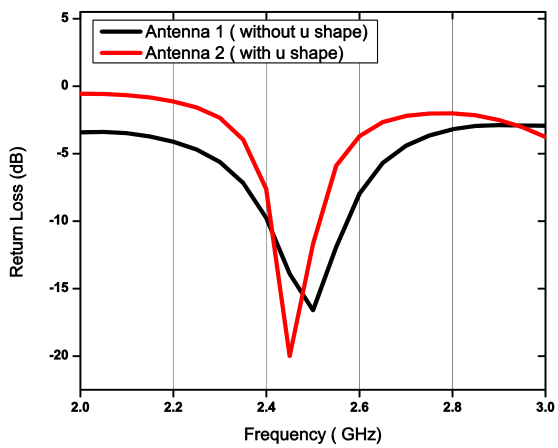
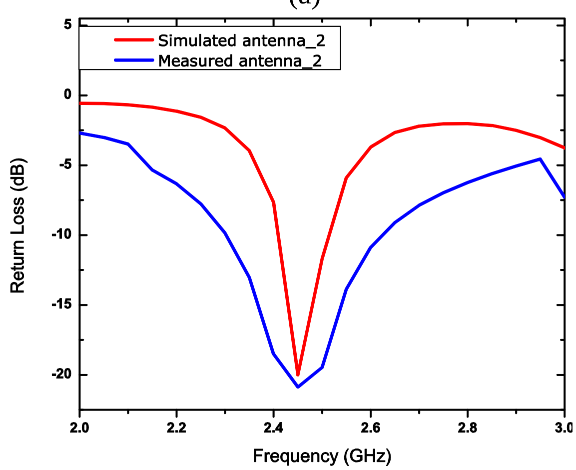
IV. RESULTS AND DISCUSSION

Figure 6(a) shows the return loss of numerical simulation resulting from the two models of antenna 1 and antenna 2. Both antennas give a good agreement in return loss between -16 dB to -20 dB. Figure 6(b) shows the return loss of both numerical simulation and measurement resulting from antenna 2 which has similar value.



(a)



(b)

Fig.6. (a) Return loss of antenna 1 and 2 by numerical simulation; (b) Return loss of antenna 2 by simulation and measurement

The proposed antenna has improved the gain with an addition of U-shape microstrip element. The gains from the simulated and measured antennas are illustrated in Figure 7 and Figure 8. The addition of U-shape of microstrip element could improve the gain because it could increase the capacitance and decrease the beam solid angle. The increased capacitance improves the amount of energy stored and radiated while the decreased beam solid angle enlarges the directivity of the antenna radiation. Consequently, the gain of the antenna using U-shape would be higher than those without U-shape. The gain value shows an improvement from 3.7 dB to 5.5 dB at 2.45 GHz frequency due to the addition of the U-shape.

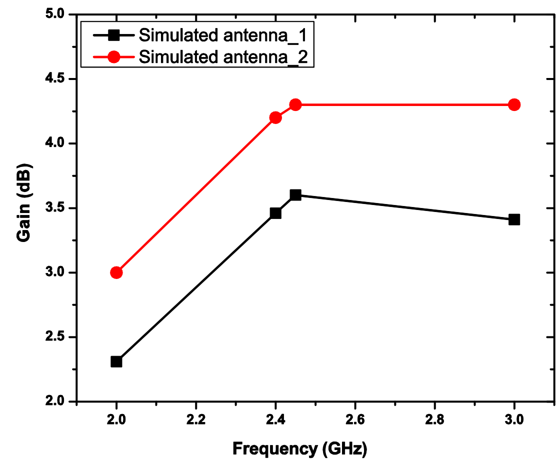


Fig.7. Simulated gain variations of the antenna 1 and antenna 2

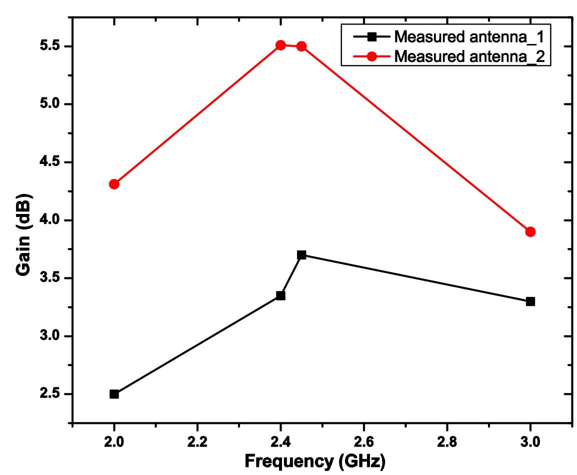


Fig.8. Measured gain variations of the antenna 1 and antenna 2

Meanwhile, the gain result of the folded arm with U-shape [9] and the gain of a dual band SIR

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coupled dipole with U-shape for 2.4/5.2/5.8 GHz application [11] are examined to have more complex designs. Nevertheless, the resulted gain is 3-3.38 dB for the frequency in range 2.4-2.5 [9], and the gain is 2.6 dBi at the frequency 2.48 GHz [11], while, our proposed antenna, with a simpler design, can reach larger gain at the same frequency range by the addition of the U-shape.

The radiation patterns of numerical simulation and the experiment at the frequency of 2.45 GHz are shown in Figure 9 and Figure 10 respectively.

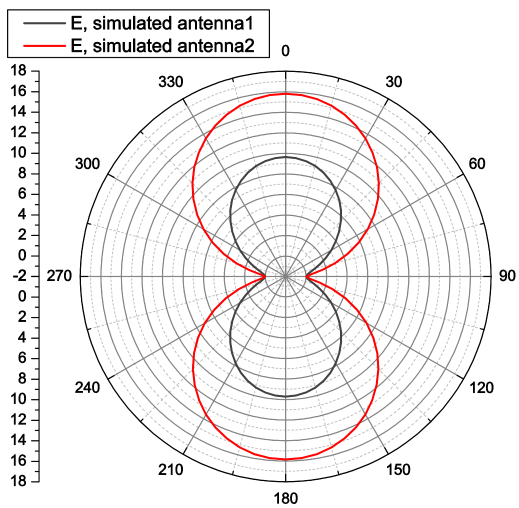

Fig.9. Simulated results of radiation pattern antenna 1 and antenna 2 at frequency 2.45 GHz

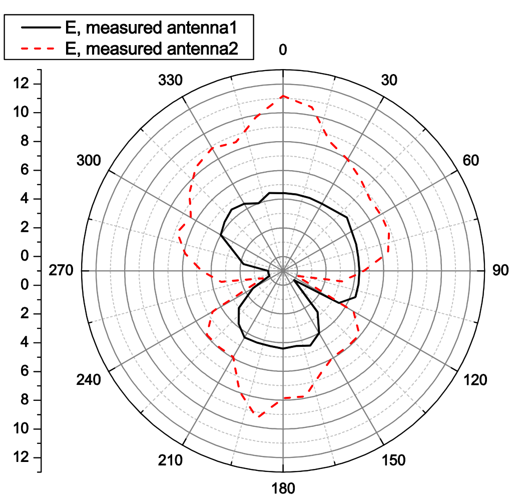

Fig.10 Measured results of radiation pattern antenna 1 and antenna 2 at frequency 2.45 GHz

Figure 9 and 10 show the power radiation efficiency of *E*-plane of antenna2 are higher than antenna1. Although the Half Power Beam Width (*HPBW*) of antenna2 seems to be larger than antenna1, the Gain of antenna2 is higher than antenna1 as mentioned in equation (6) and (7), namely antenna1 is equal 3.7 dB and antenna2 is 5.5dB.

The discrepancies between measurement and simulation radiation pattern can occur because the physical reality of the experiment has been often not exactly the same as the model as an approach. This was due to interference with the surrounding environment measurement. In addition, the intensity of radiation can be from the signal or wave around during measurements. So, this discrepancy between the amplitude of the radiation pattern simulation results and measurements at the same angle occurs.

V.CONCLUSION

The novelty of open-loop dipole antenna with the insertion of a U-shaped element can increase the performance of the antenna; the addition of U-shaped element is able to improve the gain of the antenna. The proposed antenna can be favourably applied to wide Wi-Fi communication.

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