

Calculate the optimum slot area of elliptical microstrip antenna for mobile application

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ABSTRACT

Designing and analysis the antenna parameter, for the calculation optimum the slot area for a new broadband elliptical antenna for mobile application, to enhancement impedance bandwidth. Two equations have been obtained, representing the first relationship between the area of the slot and the area of the patch, and the second represents the area of the slot to the wavelength of the band frequency. The antenna was implemented and gets simulation result using CST software and manufacturing on an FR-4 material with $\epsilon_r=4.3$, $\tan(\delta)=0.002$ and the feeding line has a characteristic impedance of 50Ω . The proposed antenna is operating in the bandwidth 24GHz and the gain (6.8) dBi.

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1. INTRODUCTION

The microstrip is often composed of a metal piece connected to a substrate from a face called a patch and the other side is printed from a conductive material called ground. The conductor material is made of copper or any material that has high conductivity. This type of antenna is characterized by lightweight and small Its size makes it easy to use in most wireless communication devices in mechanical and military applications. There are many types of polarization, which are used in wireless communication systems, especially 5G, to increase safety, which requires a narrow bandwidth where the radiation power increases with frequency. There are three methods used to analyze the antenna are the model transmission line, the cavity model, the full-wave model is very accurate but more complicated, the model transmission line is simpler and less precise. [1].The broadband elliptical microstrip patch antenna has been investigated in literature as follows. Mohamed B. El-Mashad, Ehab A. Hegazy [2] presents four elements 28GHz micro-strip patch array antenna for future 5G mobile phone applications. Mohammed H. Abu Saada designs for microstrip antennas single element and arrays at 28 GHz, where 28GHz is one of the standard frequencies of the 5G communications[3].

2. ANALYSIS OF PROPOSED ANTENNA

The antenna performance is mainly affected by the geometrical and electrical parameters, such as the size and position of the slots.

2.1. Summarize Procedure Design of Slot Antenna

Summarized for the selected slot in the designing antenna [4]:

- a) Calculate the slot length its depend on resonance frequency.
- b) Calculate the waveguide size of the operating bandwidth.
- c) Determine the number of slots required.
- d) Determine the wavelength at the operating frequency.
- e) Locating the slot position.

2.2. Size and Position of the Slots

The increase of the impedance matching, especially at high frequencies inserting slots with various shapes by cutting a part of the radiator resulting in this is due to changing the path of the current and the input impedance. When opening any slot, we look at the distribution of the current in the patch to widening the band or obtain the desired band. If we want to improve the gain, we open the slot in the ground.

The plane elliptical of the slot, the magnetic component of the radiated field is [5].

$$H_{\phi} = \frac{(a_s + b_s)V e^{-jKr}}{120\pi\lambda r} \left[\int_0^{2\pi} \cos(\phi - \phi') e^{jK a \sin\theta \cos(\phi - \phi')} d\phi' \right] \tag{1}$$

Where a_s is the major radius of the ellipse slot, b_s is the minor radius slot, V ; is the voltage across the slot, and $K = \frac{2\pi}{\lambda}$

For $(a_s + b_s) < \frac{\lambda}{2\pi}$
 Then

$$H_{\phi} = j \frac{V e^{-jKr}}{60r} \frac{A}{\lambda^2} \sin\theta \tag{2}$$

Where $A = \pi ab$ is the area of elliptic.

The integral in H_{ϕ} can be evaluated exactly as:

$$H_{\phi} = j \frac{(a+b)V e^{-jKr}}{60r} J_1(K a \sin\theta) \tag{3}$$

Where J_1 is the Bessel function of the first kind and the first order.

Determine the gain from the formula:

$$G = 10 \log \left[\frac{N \cdot \text{slot spacing}}{\lambda_o} \right] \text{ dB} \tag{4}$$

$$\text{And, Beamwidth} = 50.7 \frac{\lambda_o}{\frac{N}{2} \cdot \text{slot spacing}} \text{ degrees} \tag{5}$$

Where $N = \text{total number of slot}$.

And, $\lambda_g/2 = \text{slot spacing}$ slot.

To calculate the slot displacement using the formula for normalized slot conductance is:

$$\frac{G_{\text{slot}}}{G_{\text{waveguide}}} \left[2.09 \frac{\lambda_g}{\lambda_o} \frac{a_s}{b_s} \cos^2 \frac{\pi \lambda_o}{2 \lambda_g} \right] \sin^2 \frac{\pi x}{a_s} \tag{6}$$

Where

a_s & b_s major and minor dimensions of elliptical.

$x = \text{slot displacement}$.

Figure 1 shows the slot is configured as proposed an ellipse antenna with the FR-4 material substrate, which has $\epsilon_r = 4.3$ and $h = 1.6$ mm. The slot antenna is found by equating the space of the slot formation with the space of the cylindrical wire. The frequency of the lower edge can be found for approximately the bandwidth. In the proposed antenna, the frequency corresponding to the lower edge of the bandwidth can be roughly predicted by calculating the antenna configuration area equation with the area of the indicated cylindrical wire. Figure 2 shows the equivalent radius (r) and its height (l) as follows [6-9]:

$$2\pi r l = 108.244 - 25 a_s^2 \tag{7}$$

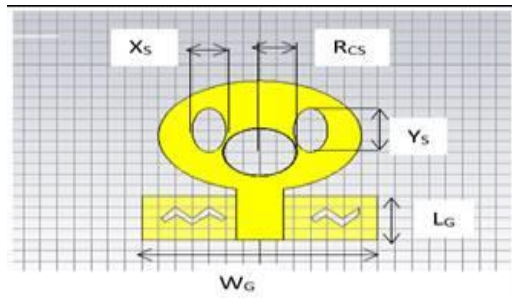


Figure 1. The Elliptic slot antenna

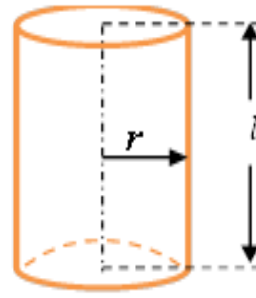


Figure 2. Cylindrical wire antenna

The input impedance of the above cylindrical wire antenna becomes a real value when its length (l), which is the same as the height of the planar configuration, is made slightly smaller than that of a thin wire monopole antenna and given by.

$$l = 0.24\lambda \frac{l}{l+r} \quad \text{or} \quad \lambda = \frac{l+r}{0.24} \quad (8)$$

Therefore, the planar configuration is given the lower resonant frequency by [10].

$$f_L = \frac{c}{\lambda} = \frac{3 \times 10^8 \times 0.24}{(l+r)} \quad (9)$$

By setting l , a_s in (7) and substituting the resulted value of r in (9), the lower resonant frequency f_L in GHz becomes:

$$f_L(\text{GHz}) = \frac{7.2}{(a_s + 0.4356a_s)} \quad (10)$$

where l , r and a_s Are all in centimeters.

The substrate includes the effect of relative permittivity constant, then the above equation should be modified as:

$$f_L(\text{GHz}) = \frac{7.2}{(a_s + 0.4356a_s) \sqrt{\epsilon_{\text{reff}}}} \quad (11)$$

Where ϵ_{reff} can be found and given by the equation below so represented of the dielectric substrate [11-15].

$$\epsilon_{\text{reff}} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + 12 \frac{h}{w}\right)^{-1/2} \quad (12)$$

The area of the elliptical patch effected.

$$A_{\text{patch}} = [ab\pi + (L_f \times W_f)] - [2(a_s b_s \pi) + (a_s^2 \pi)] \quad (13)$$

From the optimization dimension ellipse slot for the design used:

$$b_s = 2a_s \quad (14)$$

$$\text{Then } A_{\text{patch}} = [ab\pi + (L_f \times W_f)] - [8(a_s^2 \pi)] \quad (15)$$

Where, a_s the major radius of the ellipse and circular slot, b_s the minor radius slot.

$$A_{\text{patch}} = 108.244 - 25a_s^2 \quad (16)$$

From the optimum elliptical patch affected area. Then the slot area is:

$$A_{\text{patch}} = 3.9 A_{\text{slot}} \quad (17)$$

From (12) can be calculated ϵ_{reff} is equal to 3.9 area slot is:

$$A_{slot} = \frac{[ab\pi+(L_f \times W_f)]}{\epsilon_{reff}} \tag{18}$$

The slot area is calculated by (18) is 27.75mm²

The lower edge frequency (f_L) of the bandwidth is given by [15-20]:

$$f_L (GHz) = \frac{30 \times Q}{(l+r)} \tag{19}$$

Where, Q is an element factor, which can take values of 0.32 for an elliptical slot, and 0.35 for the circular slot. These two values of Q are tested, and the first one is found suitable for ellipse patch, therefore,

$$f_L (GHz) = \frac{9.6}{(a_s+0.4356a_s)\sqrt{\epsilon_{reff}}} \tag{20}$$

Where l, r, a_s Are all measured in centimeters?

The main radius (a_s) of the ellipse patch can be calculated according to (20) as 5mm. and the radius circular slot is:

$$f_L (GHz) = \frac{10.6}{(a_s+0.4356a_s)\sqrt{\epsilon_{reff}}} \tag{21}$$

From (20) can be calculated the lower frequency also impose the highest frequency and then found the bandwidth so that finding the wavelength is 12.5mm.

$$\lambda_o = \frac{C_o}{BW} \tag{22}$$

Where $BW = F_H - F_L, \lambda_o$ The wavelength in free space, C_o Light velocity in free space. The compare the value wavelength with the area slot the differentiating factor is 2.22 then the slot area is

$$A_{slot} = 2.220\lambda_o \text{ mm}^2 \tag{23}$$

Also, the slot area is calculated by (23) is 27.75mm²

The values circular radius patch (ac) is calculated according to (20) as 5.44mm. From the above, we conclude that the (18) and (23) make it easier to calculate the area of the slot relative to the area of the patch as well as to the value of the wavelength.

3. GEOMETRY PROPOSE ANTENNA

Through the results of the proposed antenna, it has been proposed to design and manufacture a single antenna working in wireless communication, especially 5G Mobile, which has higher specifications, where the bandwidth of 24 GHz from (6.94 to 30.95) GHz and high gain (6.8 dBi). FR-4 substrate with $\epsilon_r = 4.3$ has been used in designing and manufacturing an antenna for the availability of the material. Figure 3a, b is shown the proposed antenna, and Figure 4 is shown the manufacturing antenna. The parametric design of the proposed antenna is illustrated in Table 1 and fabricated using FR-4 material with size (17 × 14 × 1.6) mm³.The proposed geometry is simulated with CST and the bandwidth with reflection Coefficient (S_{11}) is observed shown in Figure 5 and the gain is around (6.8) dBi as shown in Figure 6. Figure 7 is shown the compares between simulation and practical results for input reflection coefficient (S_{11}).

Table 1. Parametric Design

Parameters	Values in m	Parameters	Values in mm	Parameters	Values in mm
L	17	W	14	H	1.6
R _x	6	R _y	5	W _f	2.8
L _f	5	X _s	1	Y _s	2
R _{CS}	2.2	L _G	4	W _G	14

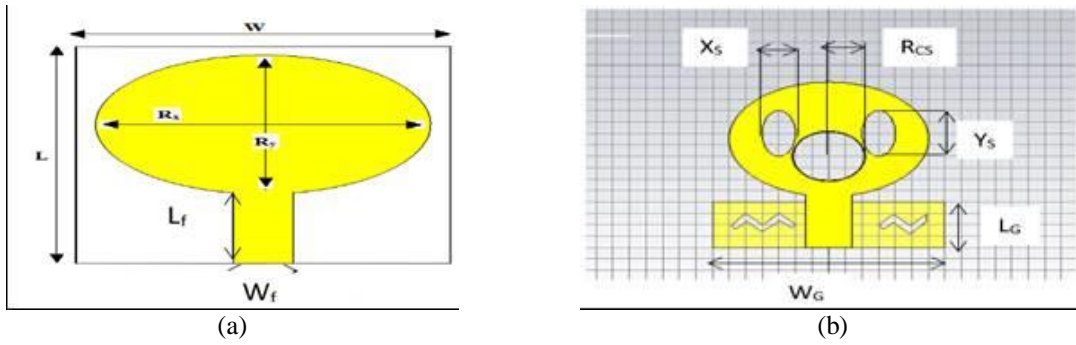


Figure 3. The Elliptic antenna (a) Prototype antenna, (b) improvement antenna Patch, microstrip and ground

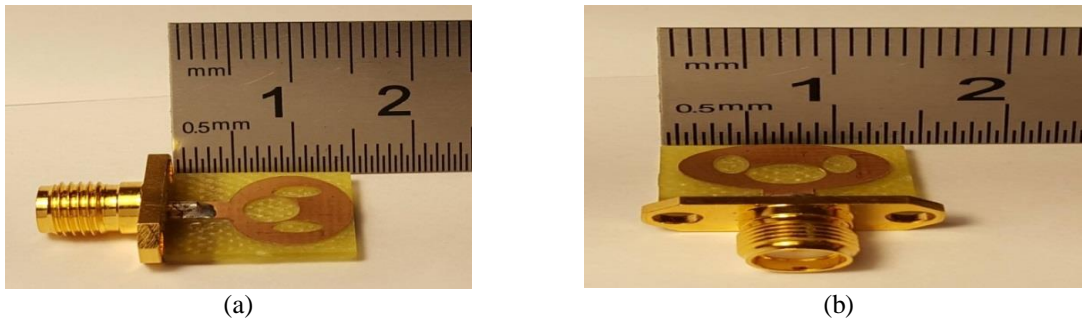


Figure 4. The practical proposed antenna

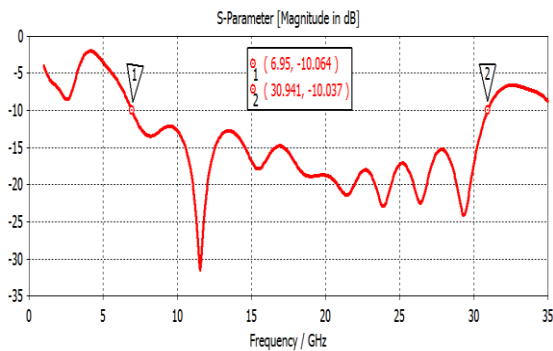


Figure 5. S_{11} versus frequency

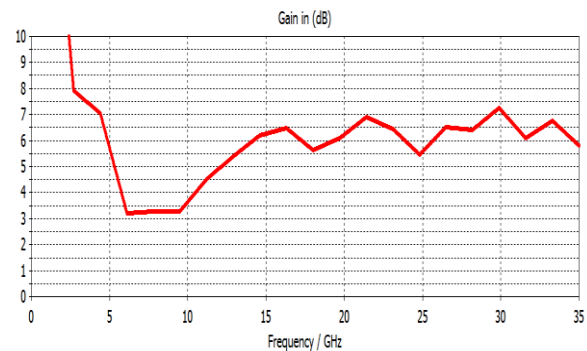


Figure 6 Gain versus frequency

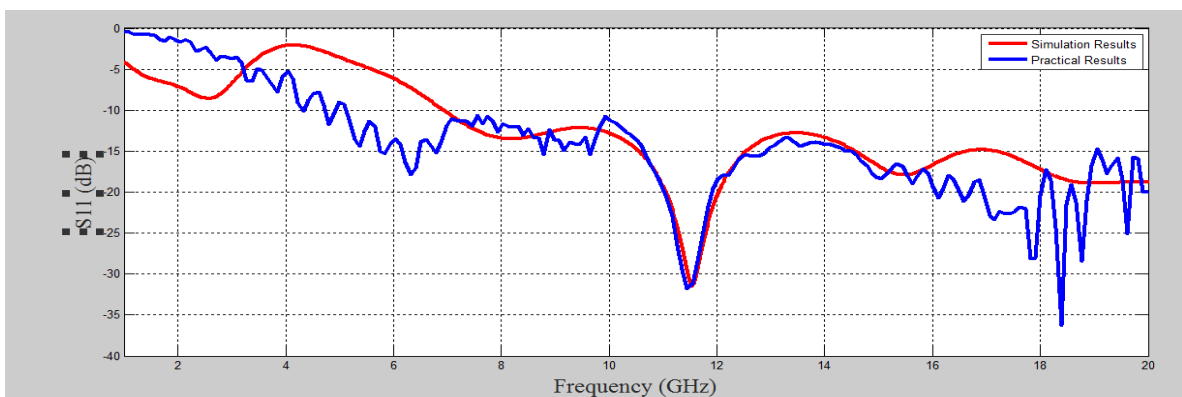


Figure 7. S_{11} results of simulation and practical

The group time delay of the antenna designed should be able to transmit the electrical pulse with minimum distortion is calculated of the proposed antenna is around to zero with variation is than 0. Insec due the frequency band from (6.95 - 30.94) GHz as shown in Figure 8 and the voltage standing wave ratio (VSWR) is also less than ≤ 2 as shown in Figure 9 so it considers as a measure for the mismatch between the line and the load. The real and imaginary parts of the input impedance are shown in Figures 10 and 11 respectively, are acceptable with the real is around 50Ω and the imaginary impedance is around zero.

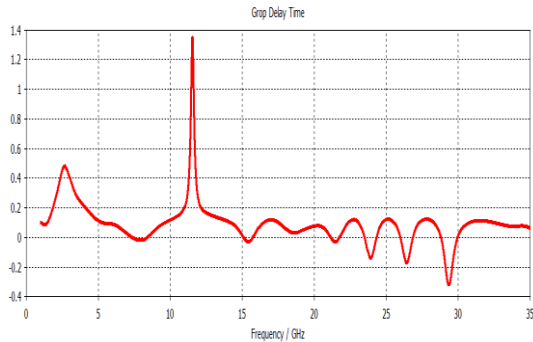


Figure 8. Group time-delay, antenna

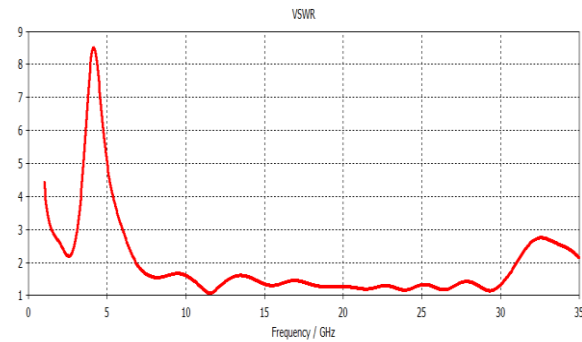


Figure 9. VSWR antenna

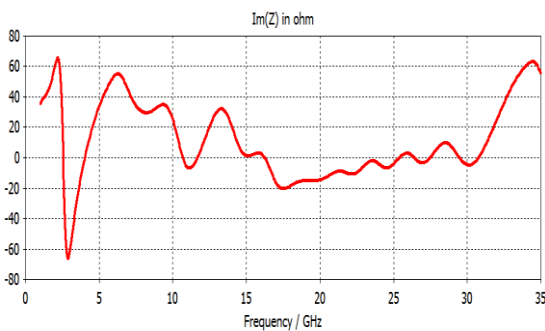


Figure 10. Imaginary impedance

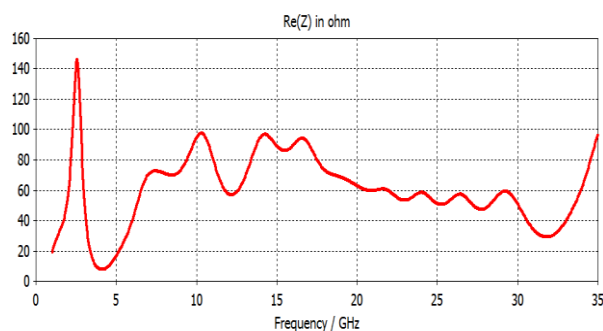


Figure 11. Real impedance

4. CONCLUSION

Slot antennas possess many great merits such as lightweight, very low profile, wide rate of bandwidth as well as ease of manufacturing. Then the calculated optimum the slot area for designing a proposed antenna with optimum parametric and fabricated manufactured to enhancement bandwidth. Two new equations have been obtained, representing the first relationship between the area of the slot and the area of the patch $A_{slot} = \frac{[ab\pi+(L_f \times W_f)]}{\epsilon_{reff}}$ mm² and the second represents the area of the slot to the wavelength of the band frequency $A_{slot} = 2.220\lambda_o$ mm². And the bandwidth is 24GHz, with maximum gain 6.8dBi.

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