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Design and Optimization of Circular Microstrip Patch Antenna at 2.4 GHz for Different Wireless Applications

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Abstract

In this paper, the required antenna was designed and simulated using mathematical equations and algorithms for the maximum accuracy of the required frequency. As well as using the MATLAB programming language to program and design a graphical interface that calculates the basic measurements required by the graphical user interface development environment (GUIDE) for the required antenna design. Also, the use of computer simulation technology software for the simulation process to design the required model and test it virtually before implementation. As a result, the most important parameters that describe the quality and efficiency of the antenna used were calculated and studied. These parameters are return loss, standing wave voltage ratio, input impedance which are very important for antenna work, frequency bandwidth of the signal used. These values are -47.008702 dB, VSWR of 1.0089659, input impedance of 50.233036 Ω, and bandwidth of 51.4 MHz (ranging from 2.3747 to 2.4261 GHz) respectively, which operating at 2.4 GHz for the resonant frequency used.

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1. Introduction

The antenna is a metal structure designed to transmit and receive electromagnetic waves and radio waves, converting electrical energy into electromagnetic waves when transmitting, and the opposite occurs when receiving. Antennas come in many shapes and sizes, from rooftop shapes that receive television broadcasts to those that pick-up signals from satellites millions of miles away, in addition to wireless communication applications [1].

The thin antenna, or it is called the patch antenna, has become one of the widely spread antennas for ease of analysis. This antenna is usually used at frequencies that are in gigahertz $f > 1$ GHz and is used in many applications such as mobile devices and satellites, as well as in aircraft. This antenna consists of two good layers conduction is like copper or gold, the first is as a patch, while the second is as a ground surface between them is an electrical insulator. As mentioned in Figure 1 [1].

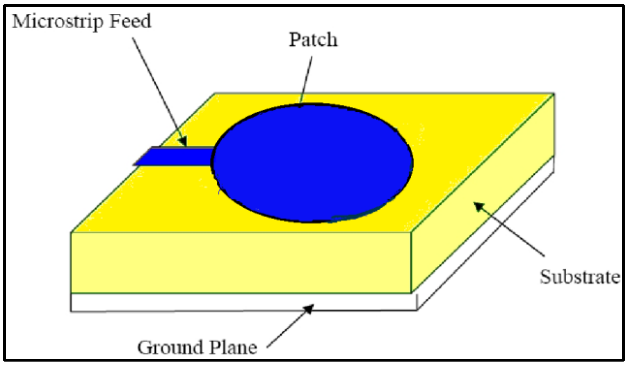

Figure 1. Microstrip circular shape patch antenna.

This type of antenna has become widely spread, especially in wireless applications, due to its small size and ease manufacture and relatively cheap. Therefore, this antenna is usually used in portable devices such as mobile phones [2]. The patch on the electrical insulator has several different shapes, but the most famous are circular, square, and rectangular [3].

There are many ways to feed this antenna and it is basically divided into two main parts, the first is connected and unconnected. For the connected method, the power of the radio signal is delivered directly to the radiated antenna patch using a link connector between them, as for the non-contact method, the power of the radio signal is connected by linking the electromagnetic field for antenna patch [4].

In this paper, we have designed a circular microstrip patch antenna operating at a frequency of 2.4 GHz. It is designed on a FR4 (Flame Retardant 4) substrate having a dielectric constant, ε_r = 4.424 and height of the substrate h = 0.159 mm. The required antenna has also been designed and simulated with mathematical equations and algorithms especially with an extreme precision of the desired frequency. MATLAB programming language was used for programming and designing a graphical interface calculates the basic measurements required by the graphical user interface development environment (GUIDE) for antenna design required. A computer simulation technology program was used for the simulation process to design the model required and tested by default before execution. One of the advantages of this program is the ability to change measurements input to give the desired results during the process of implementing and testing the antenna designed to operate in an environment relevance.

Finally, the unidirectional patch antenna has been shown to have the ability to work well for applications wireless communication required.

2. Antenna Design

To perform a typical design of a circular patch antenna, the required resonant frequency, insulator thickness and the dielectric constant of the substrate are initially determined, these parameters must be known or selected initially. In this design of circular microstrip antenna, FR4 dielectric material (ε_r = 4.424) with substrate thickness, h = 159 cm. Then, a circular patch antenna that operates at the specified operating frequency f_r = 2.4 GHz can be designed by using transmission line model equations [5], Inset feeding used as a feeding method.

The formulas used to calculate the radius (a) by calculating the resonance frequency by equation (1) are shown below [6].

$$(f_r)_{110} = \frac{1.8412\, c}{2\pi a\sqrt{\varepsilon_r}} \quad \ldots(1)$$

where c is the speed of light in vacuum, ε_r is the dielectric constant, $(f_r)_{110}$ is the resonant frequency of the effective pattern circular correction antenna cavity TM^z_{110} in the direction of z, and a is the actual radius of the required antenna.

The resonance frequency mentioned in equation (1) is not taken until after the correction factor is entered. For a circular patch antenna, we take the effective radius (a_e) to replace the actual radius (a), which will be given by equation (2).

$$a_e = a\left\{1 + \frac{2h}{\pi a \varepsilon_r}\left[\ln\left(\frac{\pi a}{2\pi}\right) + 1.7726\right]\right\}^{1/2} \quad \ldots(2)$$

Therefore, the resonant frequency according to equation (1) for the dominant mode (TM^z_{110}) must be adjusted using equation (2) to be:

$$a_e = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}}$$

Substituting equation (3) with equation (2) we will get the actual radius (a) for the antenna mentioned in this research, which will be indicated by equation (4) [6]:

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[ln\left(\frac{\pi F}{2\pi}\right)+1.7726\right]\right\}^{1/2}} \quad \ldots(4)$$

$$F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}} = a_e \quad \ldots(5)$$

here we must mention that equations (4) and (5) are measured in centimeters.

To design the proposed circular microstrip patch antenna, the need for a programming language to calculate measurements became necessary. MATLAB R2015a software (version 8.5) from MathWorks company employed to programming and design graphical user interface calculator. Computer simulation technology (CST) studio suite (version 2019) microwave studio from dassault systems company utilized to modeling and simulate the measured structure in 3-dimention.

The above equations were programmed using the MATLAB programming language and a graphical interface design by the graphical user interface development environment to calculate the basic measurements required for the required antenna design, as shown in Figure 2. It shows two fields of study, the first field includes the input parameters such as dielectric constant, resonant frequency, and substrate thickness. The second field includes the effective radius and the practical radius for the antenna to be studied in units of centimeters.

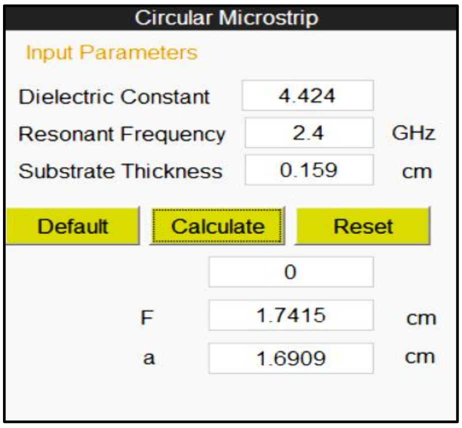

Figure 2. Circular microstrip patch antenna calculator of input-output parameters for the required antenna design using GUIDE.

Table 1 shows a set of parameters related to the circular patch antenna using the CST program mentioned above, which include the width of the insulator, length of the insulator, thickness of the antenna copper layer, width of the feed line, the feeding gap, and depth of the feed line. All parameters of this table are measured in millimeters.

Table 1. The dimensions of circular microstrip patch antenna.

No.	Parameter	Value (mm)	Description
1	*W*	80	Width of substrate
2	*L*	80	Length of substrate
3	h_c	0.035	Thickness of patch
4	W_f	2.75	Feed line width
5	*g*	3.0	Inset feed gap
6	*Y*	10	Feed line depth inside the antenna

Figure 3 shows the design of the circular patch antenna using the CST program based on the above data

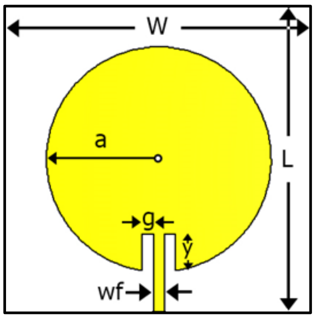

Figure 3. Dimensions of the circular microstrip patch antenna.

3. Simulation Results

In this section, the simulation results will be discussed for the circular microstrip patch antenna which have been calculated through CST microwave studio. Return loss (RL)، voltage standing wave ratio (VSWR), input impedance, directivity, and gain have been simulated at the range of 2 to 2.8 GHz of frequency. The bandwidth has been measured from RL curve manually.

Figures 4 - 7 show the return loss of –47.008702 dB, VSWR of 1.0089659, input impedance of 50.233036 Ω, and bandwidth of 51.4 MHz (ranging from 2.3747 to 2.4261 GHz) respectively, which operating at 2.4 GHz of resonant frequency. These values are in agreement with the findings of other researchers [7].

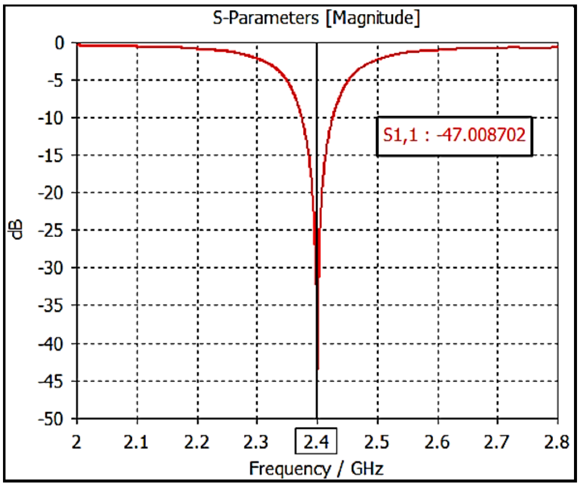

Figure 4. Return loss of the antenna.

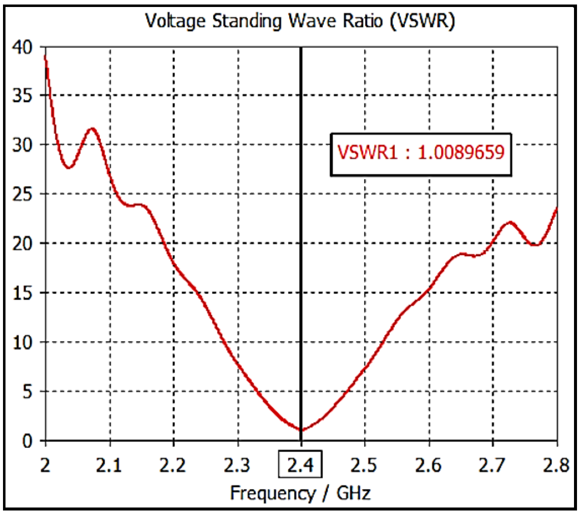

Figure 5. VSWR of the antenna.

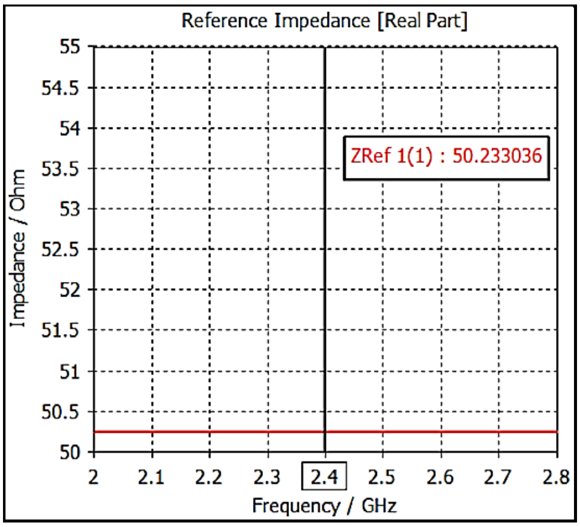

Figure 6. Input impedance of the antenna.

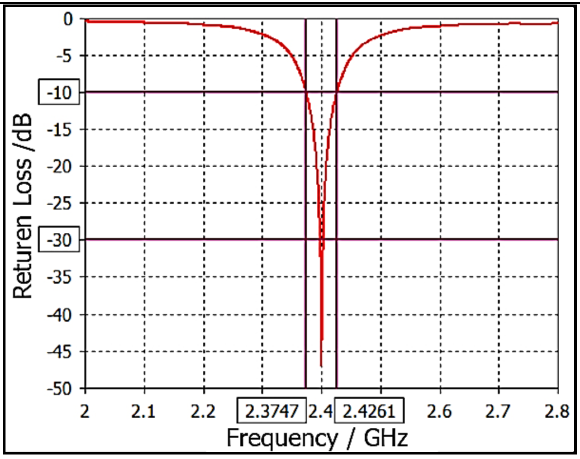

Figure 7. Bandwidth of the antenna.

The directivity and gain can be illustrated through the three-dimensional simulation pattern of the used antenna, as shown in Figure 8. It is noticed from the figure that the main lobe of the simulation model shows that the radiation intensity is located on the z-axis. The color gamut shown in the figure below represents the directionality distribution of color intensity from –43 to 2.97 decibels per isotropic (dBi), where the radiation intensity values are indicated by the associated color. Orange and red colors areas have values of –7.82 dBi and –2.97 dBi, respectively. These areas can be worked in. Generally, the highest value for these areas is considered as the best value. The directivity of the antenna used is –2.97 dBi. The results are close to the values reached by others during their research [8].

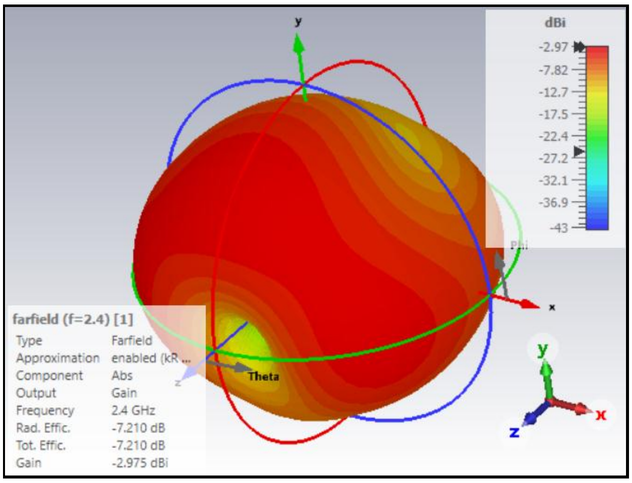

Figure 8. Three-dimension radiation pattern of the directivity for the desired antenna.

Figure 9 shows the gain values for the polar form. The red ring shown in the figure below is a cross-section of the gain of the main lobe from the top view. In this figure, the blue line shows the highest value gain level for the polar shape whose angular displacement is about 47.0 deg from radiation center. The effective gain area is defined by two separate orange lines where its value is –2.975 dBi, with an angular displacement of 64.7 degree. Accordingly, when $\Phi = 90°$ as shown in Figure 8, the main lobe of radiation was found to be 4.24 dBi. This result is considered good in relation to the values of others [9].

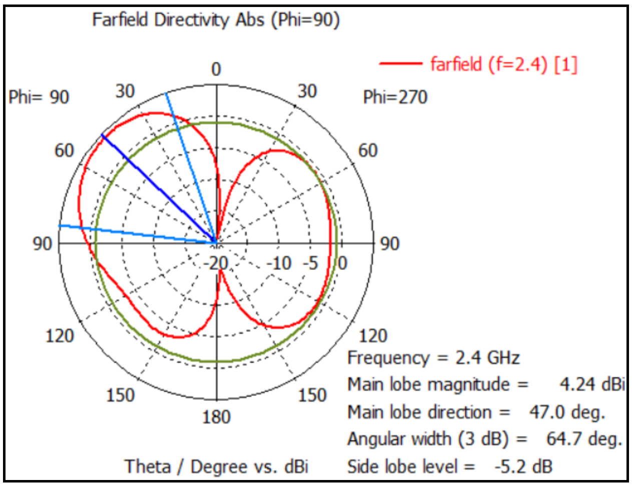

Figure 9. Polar plots of the gain ($\Phi = 90°$) for the desired antenna.

The values obtained in this research have been improved and modified to the extent that it is possible to obtain the best results for the circular patch antenna, so it can be approved before implementation [10].

4. Conclusions

In this work, the most important values of return loss and VSWR were obtained, as their values were equal to –47.008702 dB and 1.0089659, respectively. It is one of the most important conclusions reached by the work. Therefore, it can be considered that this antenna works well at the resonant frequency of 2.5 GHz. So, that it is possible to use this design as a receiving and transmitting element for many wireless communication applications, such as Wi-Fi, Bluetooth and ZigBee applications.

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