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Implementation of a Circular Shape Patch Antenna at 2.4 GHz for Different Wireless Communications

Ali H. Khidhir
Department of Physics, College of Science, University of Baghdad, Baghdad, Iraq

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Abstract
In this work, the circular patch antenna was fabricated and analyzed. Microwave Studio (version 2019) computer simulation technology (CST) was used to design the circular patch antenna. The material FR-4 was used to build this antenna, using the computer numerical control (CNC) method to implement this work. For the purpose of accomplishing this design, the values of the resonant frequency, dielectric constant and dielectric thickness of the material used as in 4.424, 2.4 GHz and 0.159 cm respectively were used as inputs to the CST program to get the said program outputs for the required antenna radius with the logarithmic function (F) of the circular patch antenna 1.6909 cm and 1.7415 cm respectively. Practically, the best values for the antenna were obtained in terms of return loss, voltage standing wave ratio (VSWR), and input impedance, -25.72 dB, 1.1092, and 54.391 Ω respectively at the resonant frequency of 2.360 GHz. Where it were good values compared to the results of others.

Keywords: Microstrip circular patch antenna, resonant frequency, VSWR, Return loss, Bandwidth, input impedance.

تنفيذ هوائي الرقعة الدائري بتردد 2,4 جيجا هرتز للاتصالات اللاسلكية المختلفة

علي حسن خضر
قسم الفيزياء، كلية العلوم، جامعة بغداد، بغداد، العراق

الخلاصة
في هذا البحث تم تصنيع وتحليل هوائي الرقعة الدائري. تم استخدام تقنية محاكاة الكمبيوتر (CST) في Microwave Studio (الإصدار 2019) لتصميم هوائي الرقعة الدائري. لتنفيذ هذا العمل تم استخدام مادة FR-4 لبناء هذا الهوائي باستخدام طريقة التحكم العددي الحاسوبي (CNC). لإنجاز هذا التصميم ، تم استخدام قيم تردد الرنين وثابت العزل وسمك المادة العازلة المستخدمة 4.424 و 2.4 جيجا هرتز و 0.159 سم على التوالي كمدخلات لبرنامج CST للحصول على مخرجات البرنامج المذكورة لـ نصف قطر الهوائي المطلوب مع الوظيفة اللوغاريتمية (F) لهوائي التصحيح الدائري 1.6909 سم و 1.7415 سم على التوالي. عمليًا ، تم الحصول على أفضل القيم للهوائي من حيث خسارة العودة ، ونسبة الموجة الدائمة للجهد (VSWR) ، ومقاومة الادخال، −25.72 ديسيبل ، 1.1092 ، و 54.391 Ω على التوالي عند تردد الرنين 2.360 GHz. حيث كانت قيمًا جيدة مقارنة بنتائج الآخرين.

*Email: dr.alihassankhidhir@gmail.com

1. Introduction

An antenna is a metal structure designed to radiate and receive electromagnetic energy. The antenna acts as a transitional structure between a guiding device and free space. A vector device, which may be a waveguide or a transmission line, is used to transmit electromagnetic energy from the transmitting source to the antenna, which is said to be a transmitting antenna, or to transmit electromagnetic energy from the antenna to the receiver, in this case a receiving antenna. The same antenna can be used for both transmission and reception [1].

Circular patch antennas have particularly wide applications in the field of medical, military, mobile and satellite Communications. Therefore, the antenna can be defined in a simple way as a metal structure used to transmit and receive electromagnetic waves and radio waves, in addition to converting electrical energy into electromagnetic waves at the transmitting unit, while in the receiving unit the opposite occurs [1, 2]. This type of antenna has become widely spread, especially in wireless applications, due to its small size, ease manufacture and cheap cost. Circular (as shown in Figure 1) and rectangular shapes are the most common antennas used for ease of analysis and attractive radiation. Therefore, it is widely used in portable devices such as mobile phones [3].

This antenna is usually used at resonant frequencies that are $f>1GH$. Practically, there are many ways to feed this type of antenna, and it is basically divided into two main parts, the first is connected and the second is unconnected. In this research, the connected feeding method was used. For the connected method, the power of the radio signal is delivered directly to the radiated antenna patch using a connecting connector between them [4, 5].

As mentioned earlier, there are different shapes and sizes of antennas suitable for different wireless applications. The shape, size of the antenna and the type of material it is made of play a large role in determining the characteristics of the antenna. The main types of antennas are [6]: Wire antennas, aperture antennas, microstrip antennas, array antennas, and reflector antennas. In this work the microstrip antennas were used.

Contemporary applications in the field of mobile communications and the continuous quest to reduce the size and weight of equipment, especially portable ones, reduce transmission power and find antennas that operate on several frequencies, have forced antenna engineers to improve their performance by increasing their efficiency, increasing their profit and reducing their size, and developing new technologies and forms. Among these contemporary technologies are smart antennas and fractal elements antennas [7, 8].

The main aim and novelty of this work is to consider the mobile phone as one of the most widely used wireless services, as mobile phone services are not limited to making calls only, but also with the development of technology and the development of mobile phones, we are able to listen to the radio, connect to the Internet, Bluetooth service and geolocation service And other services through smart phones. Therefore, the desired antenna was designed and implemented to operate within these applications. The aim of this project is to implement a circular antenna operating in the 2.4 GHz band (S-Band over wireless communication frequency bands) for use in 4G cell phones, Bluetooth, Wi-Fi, smart home and Zigbee Application.

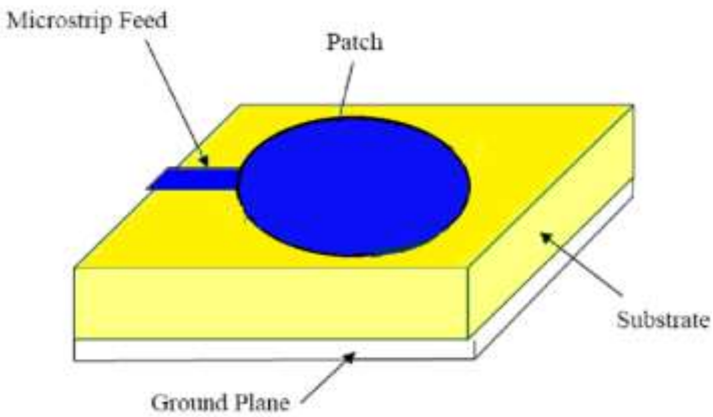

Figure 1: The circular patch antenna shape

2. Antenna Design

In this work, the circular patch antenna was made, so the radiation radius can be calculated from equation (1), as shown below [9]:

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

The parameters given in the above equation can be clarified
a = The circular radius of the used antenna measured in cm.
F = Logarithmic function (F) of the circular patch antenna
ε_r = dielectric constant
h = substrate thickness (cm)
While can be specified Logarithmic function (F) of the circular patch antenna by equation (2) [9]:

$$F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}} \qquad \text{.........(2)}$$

where
f_r = The resonant frequency of the antenna used (GHz)

The circular patch antenna is made of two layers of copper material, between them is an insulating material made of FR-4. To calculate the exact value of the width of the feed line for the proposed antenna, a special algorithm was used by the MATLAB programming language. Microwave Studio (version 2019) computer simulation technology (CST) was used to design the circular patch antenna, as shown in Figure 2. It shows the antenna size and all relevant parameters.

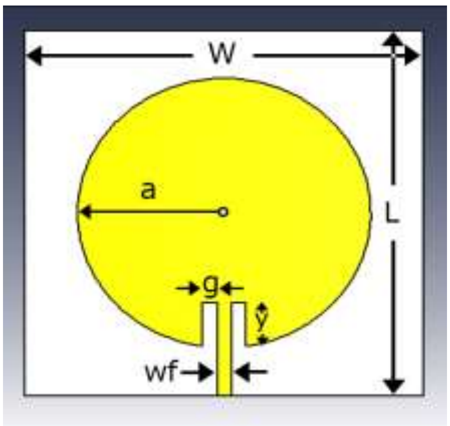

Figure 2: Structure of the proposed circular patch antenna with all values of measured dimensions

Figure 3 represents the graphical interface that was used in the MATLAB program to calculate the input parameters such as the dielectric constant, the resonant frequency, and the thickness of the dielectric layer to obtain the most important parameters for the output, such as the circular radius of the used antenna and the logarithmic function (F) of the circular patch antenna.

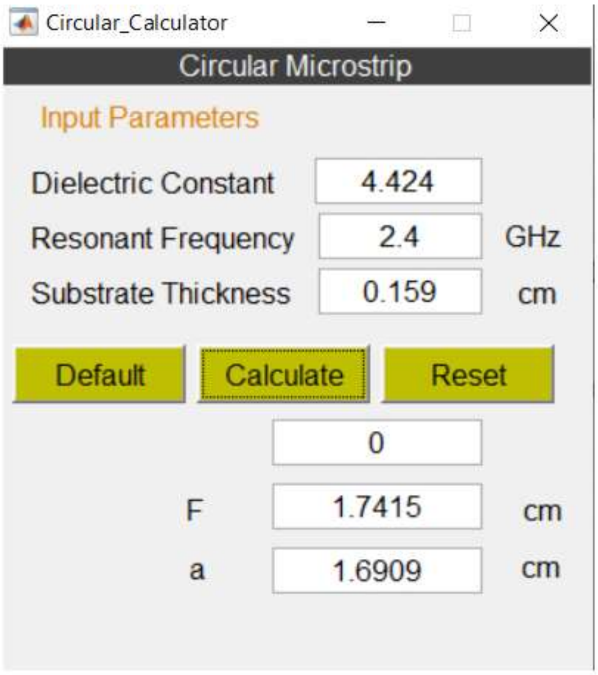

Figure 3: Calculation of radiation circular radius

Table 1 represents the inputs, outputs and some basic parameters of the proposed circular shape patch antenna sacrificed in Figure 1. These parameters have been calculated theoretically and on the basis of which purpose the required antenna is built.

Table 1: shows all the parameters that were used in this research to build the desired antenna

No.	parameters	Expression	Value
1	Width of substrate	W	80 mm
2	length of substrate	L	80 mm
3	Gap of patch antenna	G	3 mm
4	Depth of patch antenna	Y	10 mm
5	Transmission line width	W_f	2.75 mm
6	Copper thickness	h_c	0.035 mm

In this paper, the above values were used to construct the desired antenna

3. Experimental Results

Figure 4 shows the circular patch antenna that was implemented based on the measurements shown in Table 1 above. The material FR-4 was used to build this antenna, using the computer numerical control (CNC) method to implement and accomplish this antenna. It has a resonant frequency of 2.4 GHz with the dielectric constant of 4.424 and substrate thickness of 0.159 cm.

Figure 4: Front view of the implemented circular patch antenna.

The antenna was experimentally tested using SiteMaster (Anritsu S362E) as shown in Figure 5.

Figure 5: SiteMaster device

Figure 6 shows the practical result of the return loss(RL) for this antenna. Figure 7 shows the practical result of the return loss of the circular patch antenna using the SiteMaster device. The return loss (or S-Parameters) for the experimental result has to decreasing to -25.72 dB. This result is better than the results Abdulhussein et al. [10] and Obot et al.[11]. While the practical results of RL for the patch antennas in other researches amounted to -38.86 dB, so the practical result of this research is of good value compared to the research and results of Abdulhussein et al. [9].

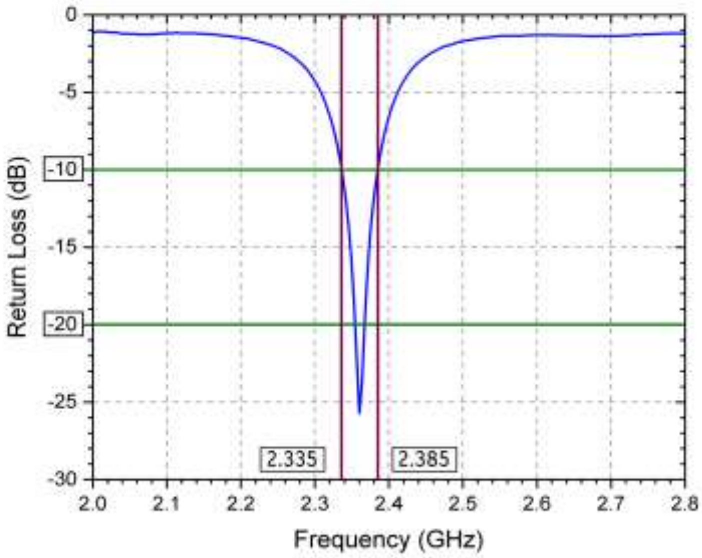

Figure 6: Practical result of return loss for circular patch antenna

Figure 6 above also shows the process of calculating the working area bandwidth through return loss practical graph. The solid horizontal line is set at -10 dB Determine the antenna's working area. The two parallel vertical lines define the frequency working space. The difference between high frequency (2.386 GHz) and low frequency (2.338 GHz) gives a bandwidth equal to 0.048 GHz or 48 MHz. This result is considered the best compared to the results of others, which was 84 MHz [12].

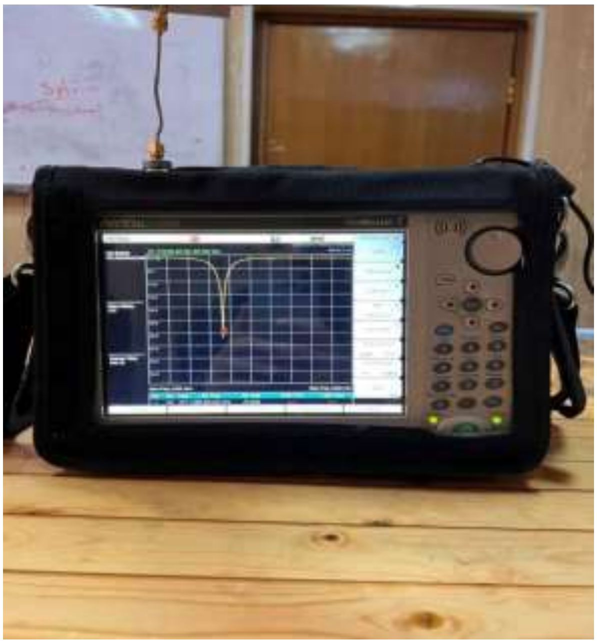

Figure 7: Practical result of the return loss of the circular patch antenna using the SiteMaster device

Figure 8 represents the simulated pattern directivity in 3-D model form of the circular patch antenna. The major lobe of this model shows that the intensity of radiation is mainly on the y-axis. This direction indicates the front side of the used antenna. Where it was obtained using Microwave Studio (version 2019) computer simulation technology (CST).

The radiation pattern of antenna (As shown in Figure 8) is the non-uniform distribution of the energy radiated by the antenna, and it is a graphical representation that shows how the actual field strength of the electromagnetic field changes at different points at equal distances from the antenna, and is therefore of a three-dimensional nature and therefore cannot be fully represented on a paper.

The practical analysis indicates that the strength of the energy radiated by the antenna is not the same in all directions, and this indicates that there is no uniformity in terms of the strength of the radiated energy, where the irregularity of the field strength is of the type that is more in one direction and relatively less or zero in other directions. The antenna diagram is considered the basic requirement for the antenna, because it is directly related to how the radiant energy is distributed in space, as illustrated in Figure 8.

Through Figure 8, the color ramp is demonstrating the distribution of intensity for the directivity from -43 to 2.97 Decibels Per Isotropic (dBi). Here, the radiation intensity values are illustrated with the associated color. Generally, the highest value of these regions is taken as the best value for the directivity of the antenna used, whose value is equal to2.97 dBi. This result is good compared to the results of Sener [13]. This result, in addition to the gain value, was practically not obtained due to the unavailability of a chamber room to take measurements for these results.

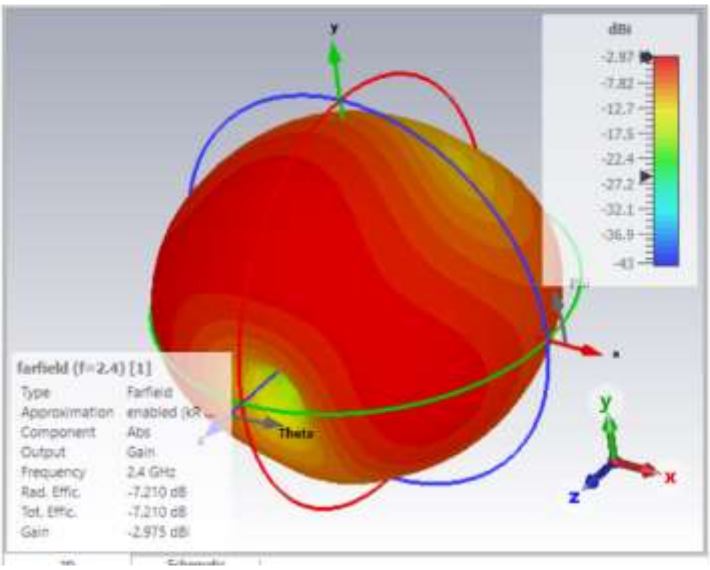

Figure 8: 3-D radiation pattern of the directivity

Ideally, the value of the voltage standing wave ratio (VSWR) is between 1 and 2, as it is practically obtained with a value of 1.1092 at 2.36 GHz which was achieved as shown in Figure 9. This result is better than the values obtained by Dad et. al. [14]. Therefore, it is an important factor to consider when conducting technical research on radio frequencies on antennas. Therefore, VSWR is a measurement of the level of the wave standing on the feed line. It is an important factor to consider when conducting technical research on radio frequencies on antennas. It is a measure of how efficiently RF energy is transmitted from the power source through the transmission line and ultimately goes into the load. Therefore, it is possible to observe the practical value of VSWR for other antennas by 1.02, which is the closest practical result to the practical value obtained in this research.

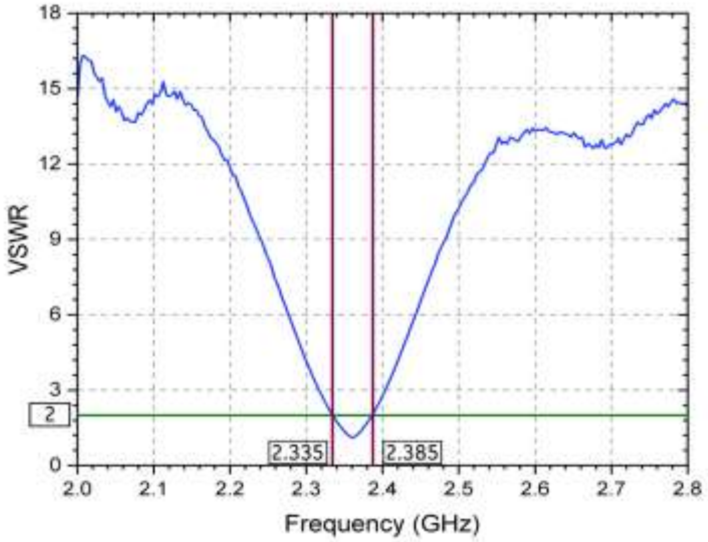

Figure 9: VSWR of the practically implemented circular microstrip patch antenna

In this work, a Smith scheme was used to calculate the input impedance of a desired antenna, a graphical calculator designed for radio frequency (RF) researchers to help solve problems with transmission lines and matching circuits. The Smith diagram can be used to display multiple parameters simultaneously, including impedances. Which is illustrated by the Figure 10.

The practical result of the input impedance (Zin) of the antenna used in this research is represented in Figure 10, this result was presented by Smith chart. The value of Zin is 54.391Ω at the 2.360 GHz for operating frequency. This value is so close to the reference impedance value (50 Ω). This is close to result reported by Ram and Singh which was 49.9 Ω [15].

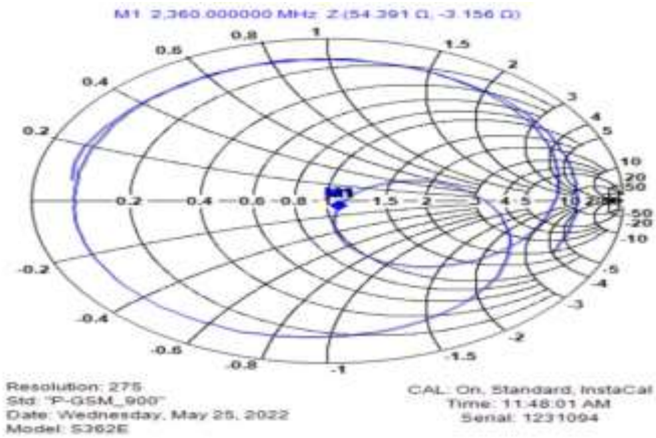

Figure 10: Smith chart to find the amount of input impedance

Figure 11 shows the measurement system for the antenna used to obtain Smith chart using SiteMaster device. In all wireless communications that depend on antennas as a main working tool, the value of the input impedance for these antennas is about 50 ohms. Through Smith's scheme, this impedance was obtained, which is practically equal to 54.391Ω at the resonant frequency of 2.360 GHz. As shown in Figure 11. This result is very close to the antenna's work area, and it is possible to work with good efficiency for this value of the breach impedance based on the values of Abdulhussein et al. [16], Hossain et al. [17], Hadi et al. [18], and Abbas et al. [19].

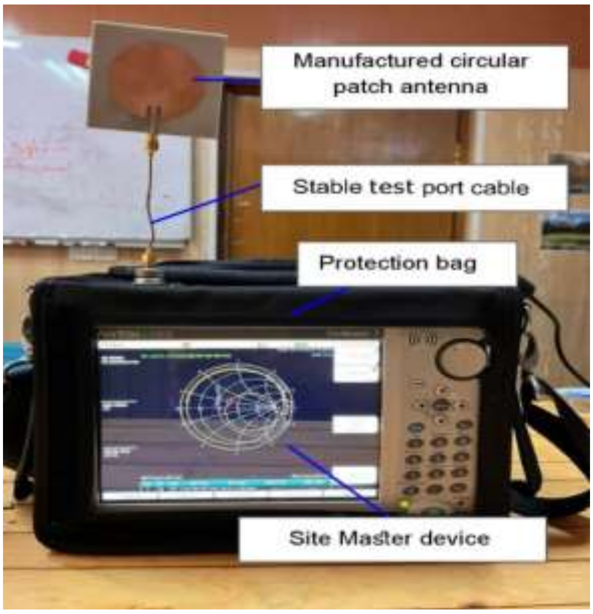

Figure 11: Smith chart to extract the input impedance using the SiteMaster device.

Finally, the theoretical results that were adopted to build this antenna using CST of the resonant frequency of 2.4 GHz. However, during the implementation process using the CNC method, a light layer was scraped from the upper layer of the of the FR-4 substrate that was used in the manufacture of this antenna. So the working area of the resonant frequency of the port antenna is 2.360 GHz due to the slight scraping condition of the substrate material, this is the reason for the slight difference in the working area of this antenna. But this result is a good practical result compared to the values of the other results.

The novelty in this research is the implementation of an antenna that operates within the permitted frequencies for the fifth generation of rapidly spreading cellular phone systems, where it is expected to become the dominant network in the world early next year 2023 AD, scientists are currently looking at and researching the next generation of networks, which is the sixth generation (6G) network, which is expected to start commercial operation at the beginning of 2030 AD. Thus, there has become an urgent need to develop the work of antennas of all kinds and for the various frequency bands of the wireless communication systems on which these antennas depend.

4. Conclusion

In this work, we have implemented a circular patch antenna operating at the S frequency region band, within the internationally approved wireless communication frequencies. The practical results showed that the amount of return loss, VSWR, and input impedance whose values are -25.72 dB, 1.1092, and 54.391Ω at the 2.360 GHz sequentially are good and acceptable to implement the circular patch antenna operating within the wireless communication frequency range applied in Wi-Fi, Bluetooth, and ZigBee applications, as well as Smart technology home applications that operate with antennas designed within frequency regions.

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