IJEIT
The International Journal of Engineering and Information Technology
journal homepage:www.ijeit.misuratau.edu.ly
IECMU 2021 International Engineering conference Misurata University

Design of a Dual-Band Printed Antenna for Modern Wireless Communications and Internet of Things Applications

Hamza A.saoud
Libyan Center for Engineering Research and Information Technology
Bani -Walid, Libya
hamza.fughi@gmail.com

Yahya E. Mansour
College of Technical Sciences
Bani -Walid, Libya

Abstract— **Wireless technology is increasingly influenced by the advanced technological development of antennas. With the rapid expansion of Internet of Things (IoT) application in the contemporary communication networks, the demand for small printed antennas is increasing, due to their small size and ease of design and manufacture to suit their various application. In this paper, the antenna is designed which is operating at two different frequency bands 2.40GHz and 5.78GHz. The design parameters of the antenna have been calculated using the transmission line model, and an antenna design program has been used for the simulation process is HFSS (High frequency simulator structure) tool, which is based on Finite Element Method (FEM). In this work, the proposed slot dual band patch antenna is implemented using FR4 substrate material with a thickness 1.6mm and relative permittivity 4.4. The size of the proposed antenna is just (28 × 27.7mm). The proposed antenna has Omni-directional radiation patterns on most of the operating band. The dual band antenna is designed by addinga slot to the top of the radiated patch. Therefore, the proposed dual- band antenna shows good performance, which is suitable for modern wireless communications and Internet of Things (IoT) applications. The measurements are found to be in good accordance with the simulated results.**

Index Terms: **Dual band Antenna, Wireless, Slotantenna, Microstrip antenna, Patch antenna.**

I. INTRODUCTION

Internet of things (IoT) is a concept that applies wireless network technology to improve different industries and the environment for a higher quality of life in society. It consists of smart devices that communicate with each other.

It enables these devices to collect and exchange data. Besides, Internet of Things (IoT) now has a wide range of life applications such as industry, transportation, logistics, healthcare, smart environment to conduct information exchange and communication and big data transfers, networking, and artificial intelligence technologies to provide complete systems for a service or device over wireless networks with high data rates [1].

Microstrip patch antennas consider being communicative device to support modern (IoT) wireless communication applications. These devices consist of very profitable qualities such as small size, low cost, easy to fabricate [2]. However, this antenna inherently has narrow bandwidth and low efficiency [2]. Thus, to improve the performance of this antenna, we can achieve this by adding slots at the top of the layer. Dual-band antenna may be achieved by several techniques. It is observed that dual-band patch can be achieved by inserting the T-slot into the microstrip patch [3]. Therefore, this printed antenna with its small size is suitable for working in wireless applications with high efficiency. These applications include wireless LAN, wireless devices connected to Internet of Things (IoT) and mobile satellite communication, and global system for mobile communication, missile, and so on.

In this study, the goal is to design dual band microstrip patch antennas to operate in two different frequency bands, where some countries cover 2.4GHz Bluetooth / Wi-Fi / GPS / band [3] and most of the bands of 3G, 4G, at the frequency of the other band operating being 5.78GHz a very low-profile antenna makes it very suitable for modern Wireless Communications in Internet of Things applications [1].

Microstrip antennas has many advantages such as compatibility with integrated circuits, low cost and easy to fabricate, but it suffers from low gain and narrow bandwidth [4]. There are several ways to feed the antenna directly and indirectly. Also, there are many types and shapes of microstrip antennas, rectangular, square or circular shape [4].

In our work, the antenna is designed on a simple square shape by a 50Ω line fed for good results which were designed to work in wireless communication band such as C-slot, E-shape, T-shape and etc [2]. The proposed antenna has been designed as a Single Slot Dual- Band Microstrip antenna with 50 omh fed line .The antenna simulation is done by ANSYS High Frequency Structural Simulator (HFSS) software.

Received 24 Aug , 2021; revised 26 Sep, 2021; accepted 27 Sep, 2021.

Available online 13 Sep, 2021.

In its most basic form, a microstrip patch antenna is a single-layer design which consists of a metal patch on top of a grounded dielectric substrate [4], as shown in "Figure. 1,"

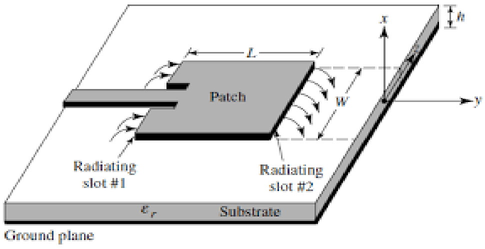

Figure 1. Geometry of microstrip patch antenna.

II. TRANSMISSION LINE MODEL

This method was used because it is easy and gives accurate results. The dimensions of the designed antenna were calculated from the following equations;

To calculate the operating frequency of the antenna from the equation [5]

$$f_r = \left(\frac{c}{2\,L\,\sqrt{\varepsilon_{eff}}}\right) \tag{1}$$

The width W of the patch it was calculated from the following equation

$$W = \frac{c}{2f_c\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{2}$$

Where,

W= Width of the patch, f_r= Frequency of operation,

c= Speed of light, ε_r= Dielectric constant of substrate.

The value of the effective dielectric constant (ε_{eff}) is calculated from the following equation

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\ \frac{1}{\sqrt{1+\ 12\frac{h}{W}}} \tag{3}$$

Due to filed fringing , the size of the antenna is changed and increased in value by an amount of (ΔL). So the extended length is calculated from the equation [5]

$$\Delta L = h\ (0.412)\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \tag{4}$$

h= height of substrate

The length L of the microstrip antenna is determined as follows [5]

$$L = (L_{eff} - 2\Delta L) \tag{5}$$

Then we can find the width of ground plane W_g and length L_g which are calculated from equation

$$W_g = 6h + W \tag{6}$$

$$L_g = 6h\ + L \tag{7}$$

III. PROPOSED ANTENNA DESCRIPTION

The wide range of applications of the antennas gives the interested people the ability to do a lot of designs and modifications. Antenna solutions are still needed for (IoT) wireless networks area to enhance services and applications [1]. The idea of this work is to design single slot microstrip patch antenna dual band for Internet of Things (IoT) wireless applications.

The proposed single slot dual band microstrip patch antenna is shown in "Figure. 2,". The antenna is designed to operate in 2.40GHz and 5.78GHz, and its shape was chosen to be a square patch antenna with the dimensions (W × L) (27.5 × 28mm) and FR4 substrate with the dielectric constant of 4.4 and loss tangent δ = 0.025 with 0.035 mm in metal thickness. The substrate's height is equal to 1.6mm. The slot is modified randomly until specific return loss values, S_{11} < -10dB, are achieved. The feeding technique is a microstrip transmission line, which is an easy technique to be calibrated and fabricated and easy to obtain a input match [6].

In dual band designation, it is hard to get the bands in just one-step and calculation. Some techniques are used in order to get the needed band. For example, dual feed antenna is a good technique to design dual band antennas, but it has some disadvantages such as difficulty in matching since it has to be done for two ports, not just one. Here in this work, the proposedantenna was designed in two steps. Firstly, the concentration was to get the antenna to work at the first band (2.4GHz). To achieve this, the antenna dimensions were based on 2.4GHz asresonance frequency where the finalized dimensions were obtained by optimizing the design to specific goals. Secondly, the other band (5.78GHz) was obtained by adding a small slot on the patch, as it is already known that adding a slot to a microstrip antenna design will a lead to additional a resonant frequencies. This gives results when using a resonant frequency at 5.78GHz in (IoT)` applications for the designed antenna.

Table 1. Proposed antenna design parametres

Parameters	Values
Height of substrate h	1.6 mm
Dielectric constant ε_r	4.4
Length of the patch L	27.5 mm
Width of the patch W	28 mm
Ground plane length Lg	50 mm
Ground plane width W	80 mm
Loss tangent δ	0.025
Impedance Z0	50 Ω
Feeding method	Microstrip Line Feed
Copper Thickness	0.035 mm

All of these parameters are designed using these dimensions of a micorstrip antenna with a line fed using HFSS simulator.

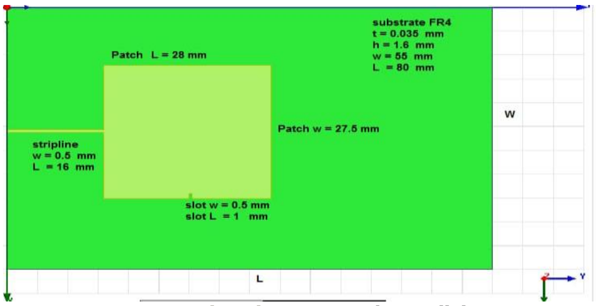

Figure 2. Proposed single antenna with overall dimensions.

The dimension of the slot also changed gradually in order toinvestigate the effect of this action on antenna results, especially on S_{11}. This slot is placed at the patch and its dimensions W × L (0.5× 1mm), and feeding the antenna with 50 Ω and dimensions of the feed line for this antenna 0.5 ×0.16mm.

Table 2. Microstrip line impedance dimension

Impedance	Width (mm)	Length (mm)
50 Ω	0.5	1

It was observed that there was a small shift in frequency when the slot size changed. Because of this frequency change, return loss value can change drastically at 2.4 and 5.78 GHz.

Table 3. Antenna performance with slot

Slot Length (mm)	Slot Width (mm)	S11 (dB) at 2.4GHz	S11 (dB) at 5.78GHz
`1	0.5	-11.7	-18.7
3	0.5	-7.7	-13.4
5	0.5	-3.8	-14.2
5	1	-2.8	-14.6
3	1	-2.4	-6.7
0.5	1	-12.1	-21.2

IV. MEASUREMENT SIMULATION AND RESULTS

The antenna was fabricated using the substrate with the final dimensions (27.5 x 28mm) described in the previous section. The patch antenna was etched on epoxy FR-4, which has a dielectric constant of 4.4, substrate thickness of 1.6 mm and metal thickness of 0.035 mm. Epoxy FR-4 was used because it has a low dielectric constant, and it had also a reasonably thin substrate [7] . however, the substrates that are most desirable for good antenna performance are thick ones, whose dielectric constant is in the lower end of the range because they provide better efficiency [8].

"Figure. 3," shows a single slotted microstrip antenna on FR-4 substrate. "Figure. 4," shows the same single slot microstrip antenna connected to a network analyzer, during measurement in antenna laboratory.

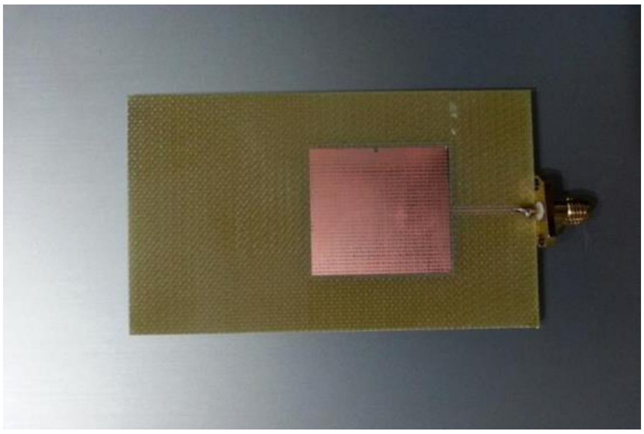

Figure 3. Photograph of fabricated single slot microstrip antenna on FR-4 substrate.

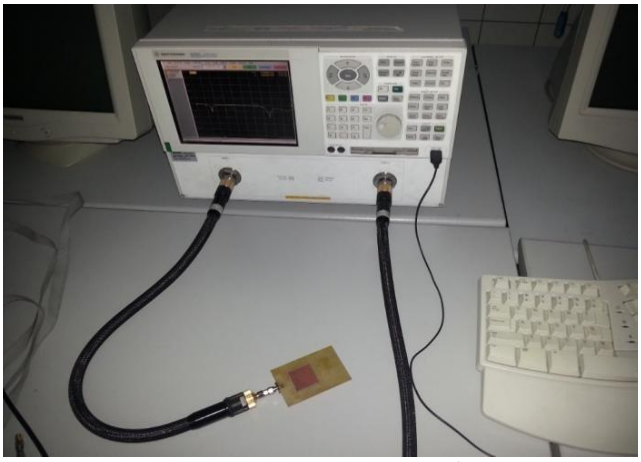

Figure 4. Antenna connected to network analyzer for measurement in laboratory.

Due to the good performance of the antenna design on FR-4 glass-reinforced epoxy laminate [9], the measurement simulation results for the dual-band antenna at 5.78GHz indicate that the simulation and measurements of the best returen loss (S_{11}) at 5.78 GHz is -21.2 dB. (should be ($|S11| < -10dB$) [10]. The maximum gain at 2.40 GHz is about 1.47 dB while at 5.78 GHz it is 3.84dB, also at 5.78GHz the antenna has a three-dimensional beamwidth (HPBW) of 38.22° and a directivity of 3.94dBi, the efficiency of the designed antenna has increased 94%, which is promising gain for IoT applications. Therfore, the proposed antenna improved results at higher frequency bands. From these results, it can be seen that excellent agreemen between the measurement and simulation results are obtained. Thus, the designed antenna works in wireless communication applications and Internet of Things devices.

The radiation or antenna pattern describes the relative strength of the radiated field in various directions from the antenn [11]. "Figure. 5" depicts the simulated radiation pattern with peak gain of 3.84dB for proposed antenna configuration at 5.78GHz using HFSS software. Thus, the antenna design has Omni-directional shaped radiation patterns in all planes as expected since the antennas are patch type.

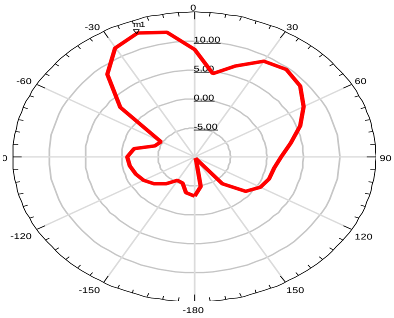

Figure 5. Far-field pattern for single antenna at 5.78GHz.

The gain is quantity describing antenna performance or the ability to focus energy through a direction to give a better picture of radiation performance [13]. Usually the gain of a single antenna is limited (4-5dB).

3D gain plot of the far field pattern of the designed antenna was obtained using HFSS . This plot is shown in "Figure.6 ". The peak gain of single antenna is 3.84dB at frequency 5.78GHz using a FR-4 substrate material. Red color is the maximum antenna gain at this frequency.

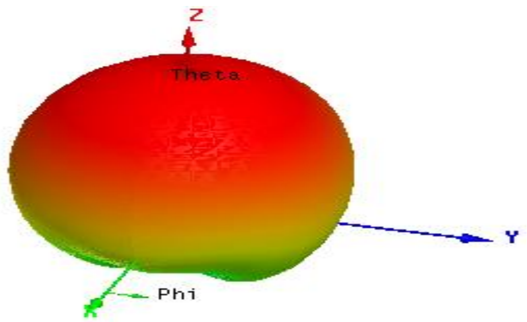

Figure 6. 3D Gain polar plot at 5.78GHz.

The efficiency of the dual- band antenna up to 94 %, we notice an improvement in the efficiency value that reaches at 5.78 GHz frequency band. It can be said that this improvement is due to the less loss of copper losses or electrical insulators of the material in the antenna, also using microstrip line feed.

Table 4. Performance of dual-band patch antenna on substrte material

Substrate material	Band width (MHz)	S_{11} (dB)	Radiation pattern	Gain (dB)
FR-4 $\epsilon r = 4.4$	436.6	-21.2	Omni-directional	3.84

V. CONCLUSIONS

In this paper, a dual-band microstrip patch antenna that feed by microstrip line has been designed and implemented to support Internet of Things IoT wireless applications with their frequency bands .

The goal of this study is to design a dual band microstrip patch antenna on a glass epoxy FR- is capable of operating at resonating frequency bands of 2.40GHz and 5.78GHz for modern (IoT) wireless communications application. The ground plane dimensions for the patch is 50mm by 80mm and it could be smaller than these dimensions. In addition, the patch dimension is 28 mm by 27.7mm. After that, the other resonance frequency at 5.78GHz is obtained by etching a slot on the patch. So the designed antenna is suitable for (IoT) wireless technologies. The proposed antenna shows directional radiation pattern, good return loss, and better gain with acceptable radiation efficiency.

The dual band microstrip antenna was simulated and fabricated in this work, and the most important issue is about how to control or get a dual band antenna. The method of etchingslots on such antenna is useful to get the other frequency band. Also by changing the slot position and dimension W or L , reasonable return loss S_{11} values will be obtained. In conclusion, this antenna is best applicable to modern (IoT) communication devices and wireless communication frequencies operating at 5.78GHz.

For future work, one may modify any antenna shape to a specific application. Future work will concentrate on how to tackle the size and performance this type of antennas. Triple band with high gain will be a good idea to continue the studies in this field.

REFERENCES

[1] Serpanos, Dimitrios, and Marilyn Wolf. Internet-of-things (IoT) systems: architectures, algorithms, methodologies. Springer, 2017.

[2] Garg , Ramesh, et al. Microstrip antenna design handbook. Artech house, 2001.pp. 2-3.

[3] Awais, Qasim, Hassan Tariq Chattha, Mohsin Jamil, Yang Jin, Farooq Ahmad Tahir, and Masood Ur Rehman. "A novel dual ultrawideband CPW-fed printed antenna for Internet of Things (IoT) applications." Wireless Communications and Mobile Computing 2018 (2018).

[4] Constantine A. Balanis, Antenna Theory; Analysis and Design, Third edition, Wiley and Sons, New York, 2005. pp.811–813.

[5] Stutzman, Warren L., and Gary A. Thiele. Antenna theory and design. John Wiley & Sons, 2012, pp.468–469.

[6] Varshney, Hemant Kumar, et al. "*A survey on different feeding techniques of rectangular microstrip patch antenna*." International Journal of Current Engineering and Technology 4.3 (2014): 1418-1423.

[7] Khan, Anzar, and Rajesh Nema. "*Analysis of five different dielectric substrates on microstrip patch antenna*." International journal of computer applications 55.14 (2012).

[8] Najeeb, Rozh, Diyari Hassan, Dana Najeeb, and Huseyin Ademgil. "*Design and simulation of microstrip patch antenna array for X-Band applications*." In 2016 HONET-ICT, pp. 79-83. IEEE, 2016.

[9] Sanapala, Ravikumar, Bhanu Sood, Diganta Das, and Michael Pecht. "*Effect of lead-free soldering on key material properties of FR-4 printed circuit board laminates*." IEEE Transactions on Electronics Packaging Manufacturing 32, no. 4 (2009): 272-280.

[10] Ping, Lee Chia, Chandan Kumar Chakrabarty, and Rozanah Amir Khan. "*Design of Ultra Wideband slotted microstrip patch antenna*." In 2009 IEEE 9th Malaysia International Conference on Communications (MICC), IEEE, 2009.

[11] Sanapala, Ravikumar, Bhanu Sood, Diganta Das, and Michael Pecht. "*Effect of lead-free soldering on key material properties of FR-4 printed circuit board laminates."* IEEE Transactions on Electronics Packaging Manufacturing 32, no. 4 (2009): 272-280.

[12] Kaushal, V., Singh, T., Kumar, V., Kumar, A., & Kumar, D. D. (2014). A Comprehensive Study of Antenna Terminology Using HFSS.

[13] Hill, J.E., 1976. Gain of directional antennas. Watkins-Johnson Company, Tech-notes.