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Simulation and manufacturing of modified circular monopole microstrip antenna for UWB applications

Bilal S. Taha[1], Hamzah M. Marhoon[2]
[1]Iraqi Ministry of Health, Baghdad, Iraq
[2]Department of Computer Techniques Engineering, Al-Esraa University College, Baghdad, Iraq

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ABSTRACT

Ultra-wideband (UWB) technology is one of the most promising wireless communication solutions to be developed quickly because of the high-speed data, wide bandwidth and excellent immunity to multipath interference. In this work, the compact design of a modified circular monopole microstrip antenna is simulated and manufactured for the UWB applications. The simulation process of the proposed antenna was done based on the finite integration of the computer simulation technology (CST) microwave studio (MWS). The proposed antenna comprises a copper radiating patch, Roger's Kappa-438 substrate, and a single stub act as a reflector. The simulation results showed a reasonable agreement with the results of the measurement and good performance was achieved in the range from 1.8 to 10 GHz with VSWR less than 2.0.

Corresponding Author:

Hamzah M. Marhoon
Department of Computer Techniques Engineering
Al-Esraa University College
Al-Karada, Baghdad, Iraq
Email: hamzaalazawy33@yahoo.com

1. INTRODUCTION

In general, the antenna is a transducer that converts the guided present in a transmission line or feeder cable into radiated electromagnetic energy travels in free space to the receiver or vice versa. Antennas can also be viewed as an impedance transformer, coupling between an input or line impedance and free space impedance [1]. Ultra-wideband (UWB) technology is one of the most successful communication systems solutions, because of its higher data rate and good immunity against multipath interference, the technology of UWB is used in various fields such as radar, remote sensing, and military communication [2]. Table 1 is showing standards of UWB technology.

In 2002, the Federal Communication Commission (FCC) allocated an unlicensed 7.5 GHz band (i.e., from 3.1 to 10.6 GHz) for the indoor UWB wireless system applications. Figure 1 shows the spectral mask of the indoor/outdoor handheld applications and the different frequency spectrum was specified by FCC in the United States. The Industrial standards such as IEEE 802.15.3a of the high rate of data and IEEE 802.15.4a of the very low rate of data was established on the basis of UWB technology. The FCC defines UWB technology as any wireless system with a fractional bandwidth of more than 500 MHz or 20% of the absolute bandwidth [3].

In addition, the passive radio frequency identification (RFID) tag is one of the UWB wireless system's most commonly used applications. It is called passive due to the absence of the active elements and the RFID tag doesn't require a battery for feeding, the tag can be attached to a package or pets for tracking and identification. The other applications of UWB are in the radar applications, medical applications or in the wireless personal area networks (WPANs) [4], [5].

The features of the UWB system include wide bandwidth, directional/omnidirectional radiation pattern, constant gain in specific directions, constantly desired polarization, moderate radiation efficiency, linear phase response, compact size, low profile, and low manufacturing cost [6]. UWB technology has multiple unique advantages over conventional wireless communication technology, such as low power consumption, big data rates and less multi-path spread, due to the mentioned benefits, the UWB technology always attracts researchers for different applications where UWB offers many levels of security and highly reliable communication systems [7].

In this paper, a modified circular monopole microstrip antenna (MMA) with compact-sized is simulated and fabricated for the UWB applications. The paper organised as follows: Section 2 presents a brief description of the MMA specifications, applications, and structure. Section 3 illustrates the steps for the antenna design process, where the first step is summarised by determining the antenna dimensions through the necessary equations and the second step is the simulation of the proposed antenna using the computer simulation technology (CST) microwave studio (MWS). Section 4 includes a presentation and discussion for the obtained results from the solver of the CST-MWS such as the antenna gain, voltage standing wave ratio (VSWR), and return loss (S_{11}). Section 5 presents the antenna fabrication process also presents the measured results for the S_{11}. Finally, section 5 provides the conclusion of this paper.

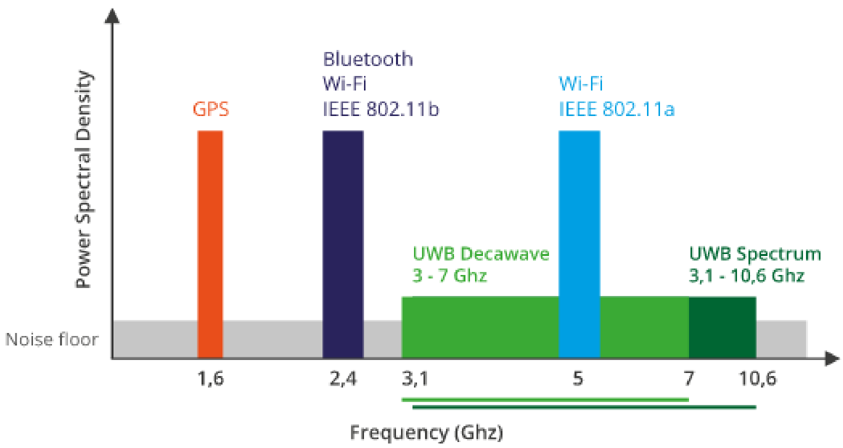


Figure 1. UWB frequency spectrum

Table 1. Standards of UWB technology

Country	Bands of frequency	Organized by
Europe	3.1–4.8 GHz with Detect And Avoid (DAA) restrictions; 6–8.5 GHz band with no restrictions	Electronic Communications Committee (ECC)
America, Canada	3.1–10.6 GHz unlicensed band without restrictions	Federal Communication Commission (FCC)
Japan	3.4–4.8 GHz with DAA restrictions; 7.25–10.25 GHz unlicensed band	Ministry of Internal Affairs & Communications (MICs)
Korea	3.1–4.8 GHz with DAA restrictions; 7.2–10.2 GHz band with no restrictions	Electronics and Telecommunications Research Institute (ETRI)
Singapore	6–9 GHz band with no restrictions; 3.4–4.2 GHz band with DAA restrictions	Infocomm Development Authority (IDA)

2. MONOPOLE MICROSTRIP ANTENNA

The MMA is a type of the radio antenna formed by replacing one half of a dipole antenna with a ground plane at right angles to the remaining half. If the ground plane is large enough, the monopole behaves exactly like a dipole, as if its reflection in the ground plane formed the missing half of the dipole [8].

In a variety of commercial applications like mobile satellite communications, direct broadcast systems (DBS), global positioning system (GPS), remote sensing, and biomedical applications, the MPA becomes attractive candidates. The basic form of the MPA is consists of a radiating patch sitting on a dielectric material called substrate and a partially ground plane can be printed on the bottom of the substrate or as a small plate printed on the face of the substrate, as illustrated in Figure 2 [9], [10].

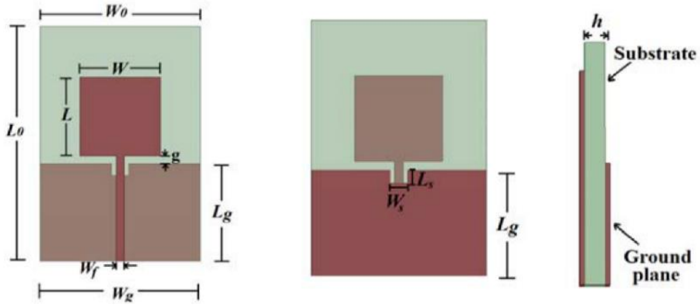


Figure 2. The MMA structure

3. ANTENNA DESIGN

The antenna design is done by using CST-MWS, the essential parameters for designing the UWB antenna includes the operating frequency range, substrate dielectric constant, substrate height, conductor thickness, loss tangent, substrate width, substrate length, and input impedance, Table 2 illustrates the fundamental parameters used to simulate the antenna.

Table 2. Fundamental parameters of the proposed UWB antenna

Parameter	Value
UWB Frequency	1.8-10 GHz
Dielectric constant (εr)	4.38
Height of substrate	1.524 mm
Substrate width	50 mm
Substrate length	50 mm
Height of conductor	0.035 mm
Substrate material	Roger'sKappa-438 substrate
Loss Tangent tan (δ)	0.005
Input impedance	50 Ω

The substrate dimensions of the simulated antenna can be obtained by using the simple equations of a rectangular microstrip patch antenna, as follows [11]:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{\frac{-1}{2}} \quad (1)$$

$$W = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (2)$$

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \quad (3)$$

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left[\frac{w}{h}+0.264\right]}{(\varepsilon_{reff}-0.258)\left[\frac{w}{h}+0.8\right]} \quad (4)$$

$$L = Leff - 2\Delta L \quad (5)$$

$$ws = 2 \times W \tag{6}$$

$$Ls = 2 \times L \tag{7}$$

where, ε_{reff} is the effective dielectric constant, εr is the dielectric constant of substrate, c is the light speed in free space, h is height of substrate. W is the patch width, L_{eff} is effective length, L is the actual patch length, ws is the substrate width, and Ls is the substrate length. The steps to design the patch with the circular shape was done using (8)-(10) [12].

$$a_e = a\left\{1 + \left(\frac{2h}{\pi a \varepsilon_r}\right)\left[\ln\left(\frac{\pi a}{2h}\right) + 1.7726\right]\right\}^{\frac{1}{2}} \tag{8}$$

$$a = \frac{F}{\{1+\frac{2h}{\pi \varepsilon_r F}[\ln\left(\frac{\pi F}{2h}\right)+1.7726]\}^{\frac{1}{2}}} \tag{9}$$

$$F = \frac{8.791\times10^{9}}{f_r\sqrt{\varepsilon_r}} \tag{10}$$

After calculating the essential parameters of the circular microstrip patch antenna through the previously mentioned equations, the first simulated circular shape and S_{11} are illustrated in Figure 3.

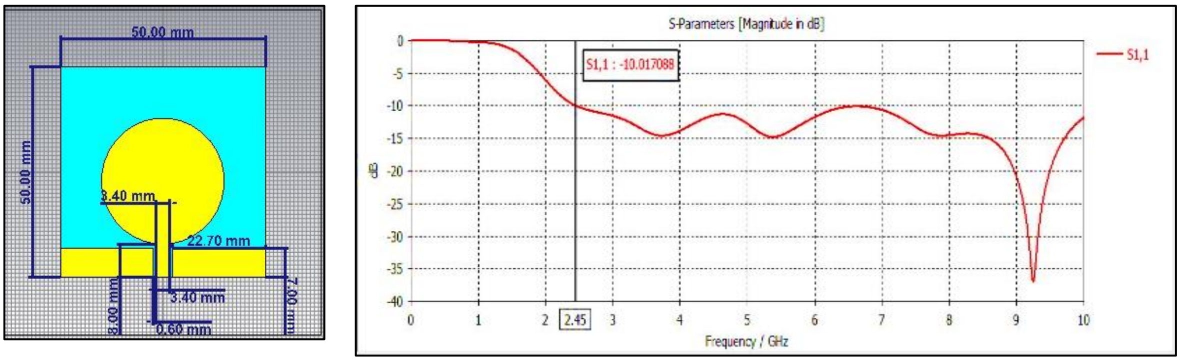


Figure 3. The simulated UWB antenna inside CST-MWS

As observed from the previous design the bandwidth impedance matching starting from 2.45 to 10 GHz with a notch at 6.5 GHz, the desired UWB operating frequency band and S_{11} are not achieved. So, should attempt to modify the previous design by adding a second circle patch to improve the overall performance of the antenna, such as enhance the radiation pattern and changing the current distribution over the radiating patch, Figure 4 illustrates the modified antenna design and return loss after adding the 2nd circle.

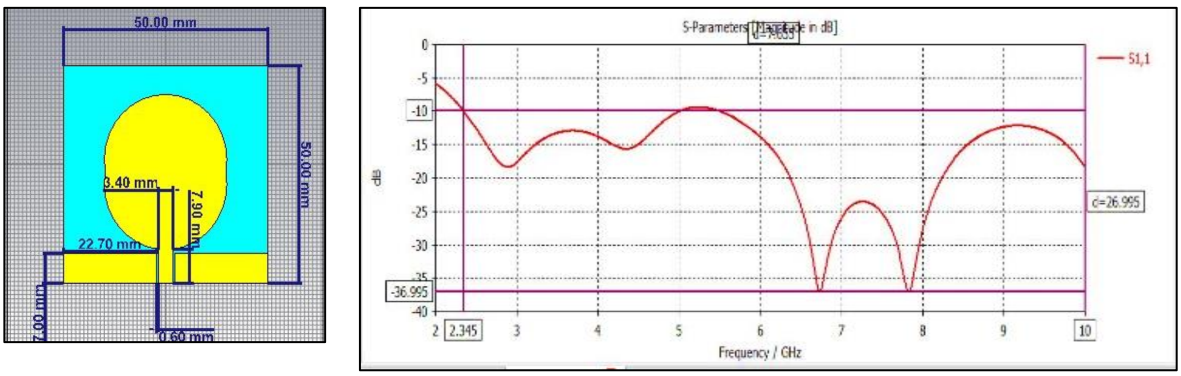


Figure 4. The simulated 2nd circular MPMA antenna

To increase the antenna radiation, an additional circle was created with a radius of 7 mm in the middle of the patch. Figure 5 illustrates the return loss and gain after adding the 3rd circle is getting better.

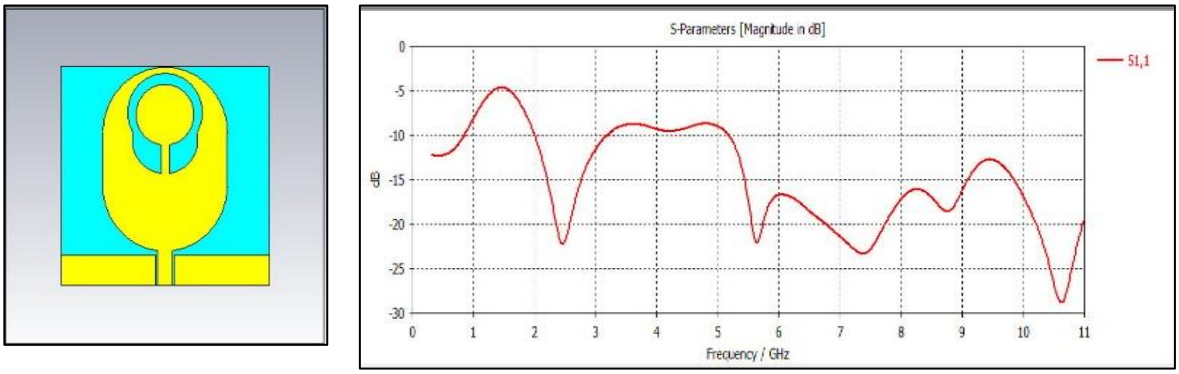


Figure 5. The 3rd simulated MPMA

In Figure 6, the feed length is increased to 10.31 mm and 6 arcs are added on both sides of the patch, to enhancing the overall antenna performance. Slits were used in the antenna to create additional frequencies and increase antenna gain, bandwidth, radiation pattern, and S_{11}.

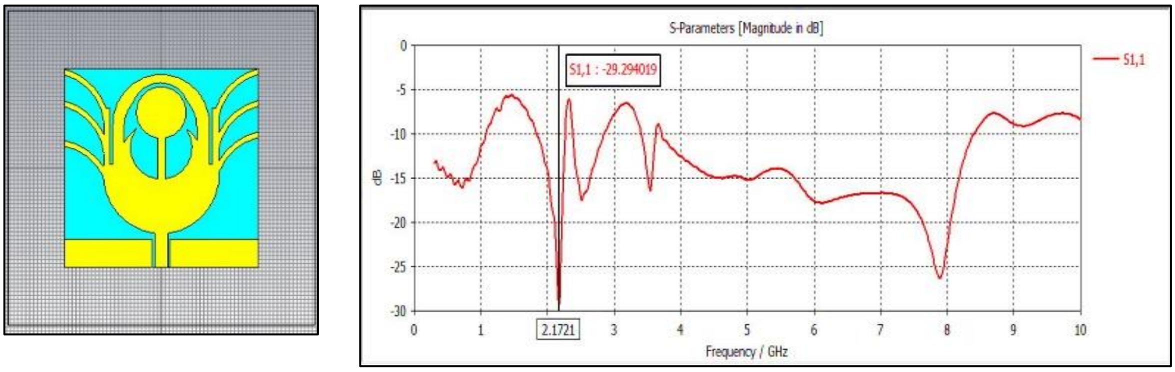


Figure 6. The 4th simulated MPMA

After many trials of the design modification for the simulated antenna, a single plate was present at the right edges as a reflector to achieve the best results as illustrated in Figure 7.

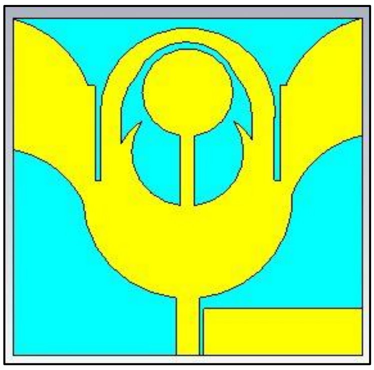


Figure 7. The final simulated MPMA

4. SIMULATION RESULT

This subsection comprises a presentation of the simulated antenna gain, $VSWR$, and S_{11} results which were obtained from the transient CST-MWS solver after the antenna simulation process has been completed. Figure 8 and Table 2 illustrate the simulated antenna results for the S_{11} and $VSWR$ of the final design of the proposed antenna

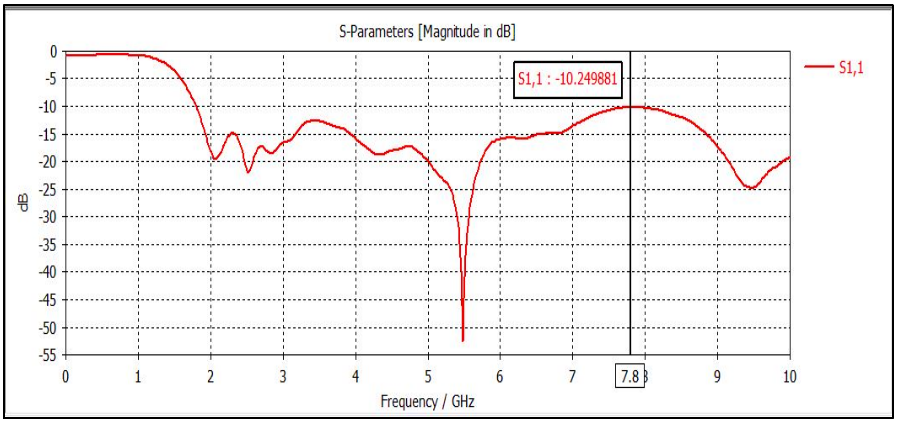


Figure 8. S_{11} of the final simulated antenna

Table 3. Return loss and $VSWR$ results of the simulated antenna

Frequency (GHz)	Return loss (dB)	VSWR
1. 9	-13.95	1.5
2.1	-19.24	1.24
2.45	-18.88	1.25
3.1	-16	1.37
5.8	-17.87	1.29
6.5	-15.16	1.42
10	-19.26	1.24

The microstrip antennas is well known for its poor gain; this due to the gain of the microstrip antennas are affected by the h and the ε_r where, the Gain is inversely proportional with ε_r and directly proportional with the h [13]-[15]. Figures 9 and 10 illustrate the simulated broadband antenna gain and the 3D far-field results of the simulated antenna respectively.

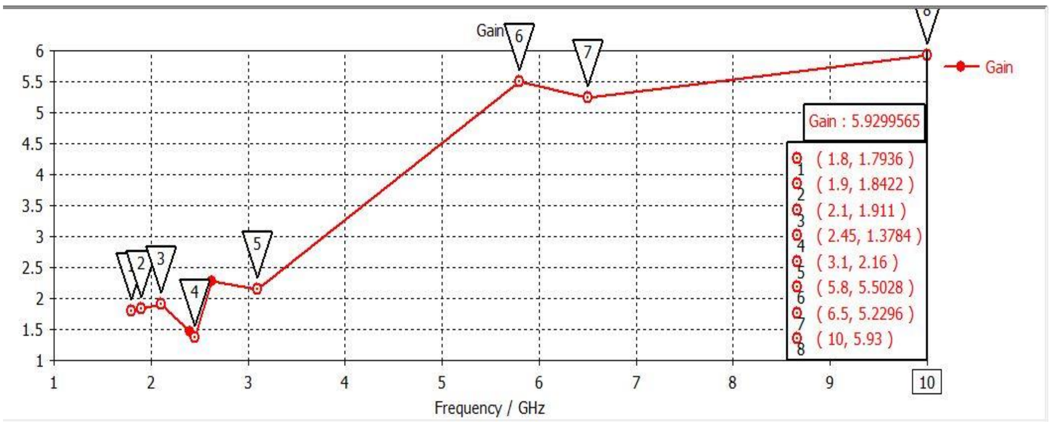
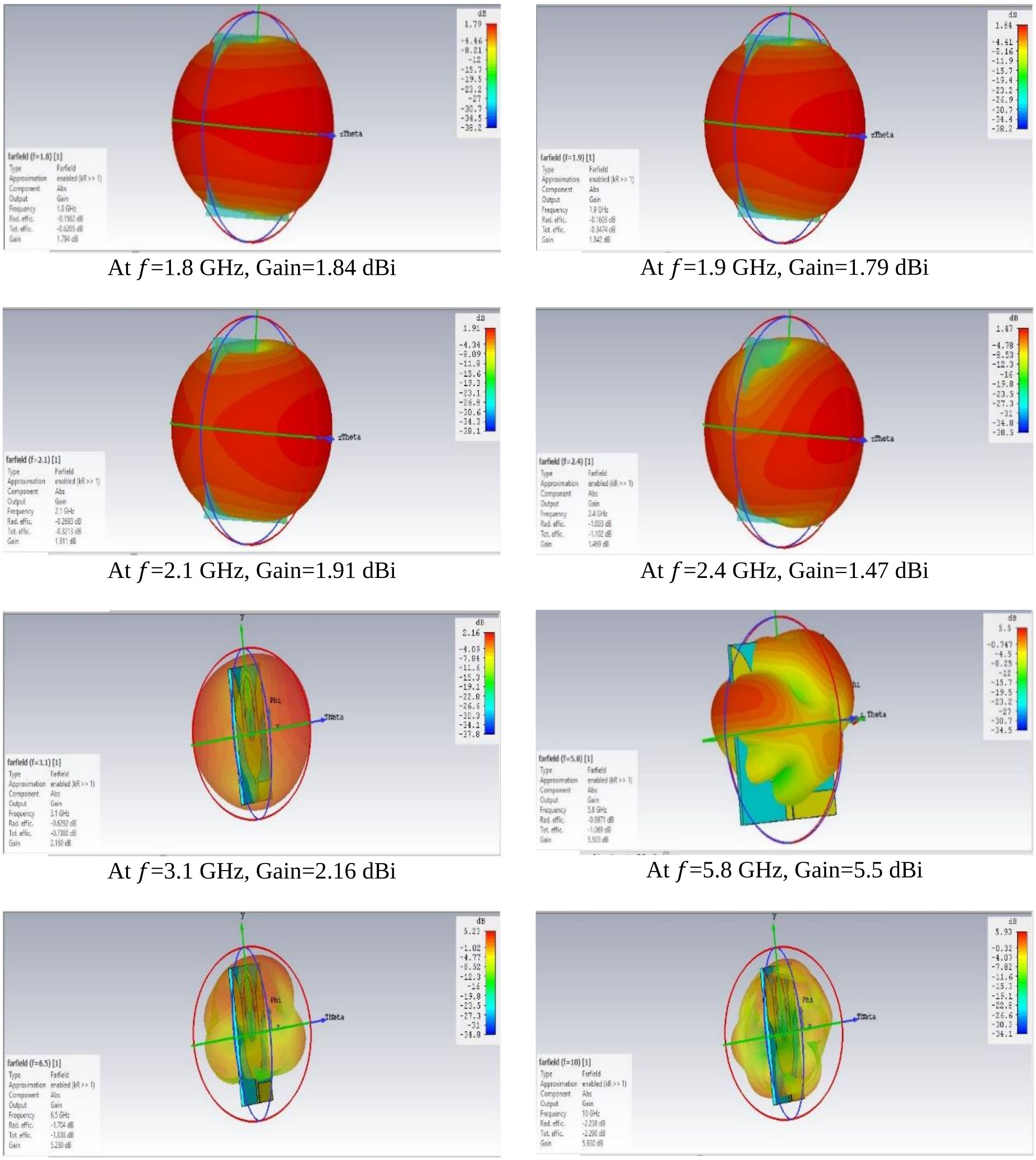


Figure 9. Broadband gain of the simulated antenna



At f=1.8 GHz, Gain=1.84 dBi

At f=1.9 GHz, Gain=1.79 dBi

At f=2.1 GHz, Gain=1.91 dBi

At f=2.4 GHz, Gain=1.47 dBi

At f=3.1 GHz, Gain=2.16 dBi

At f=5.8 GHz, Gain=5.5 dBi

At f=6.5 GHz, Gain=5.23 dBi

At f=10 GHz, Gain=5.93 dBi

Figure 10. Far field result of the simulated antenna

5. ANTENNA FABRICATION

After the antenna simulation has been completed in the CST-MWS, the simulated antenna Gerber file is exported and sent to the factory for the manufacturing process. The designer commonly used the FR-4 substrate, but in this work the Roger Kappa-438 substrate is used instead of the FR-4 substrate, since both types have similar dielectric characteristics constant and the same substrate height, h = 1.524 mm but the different in loss tangent, Roger Kappa-438' loss tangent is 0.005 while the FR-4 is 0.015, this effects on the performance of the antenna [16]. A simple, compact UWB antenna with a single slot, and a microstrip feed line is being implemented as illustrated in Figure 11. The manufactured antenna showed consistent gain characteristics as well as a 2:1 $VSWR$ was achieved in the UWB range. The physical surface area of the design is reduced by implementing the circular shape of the patch in this work. The manufactured antenna covers a frequency range of 1.8 to 10 GHz. Figure 12 and Figure 13 illustrate the measured S_{11} via spectrum analyzer Anritsu-site master S362E which is limited to 6 GHz, respectively.

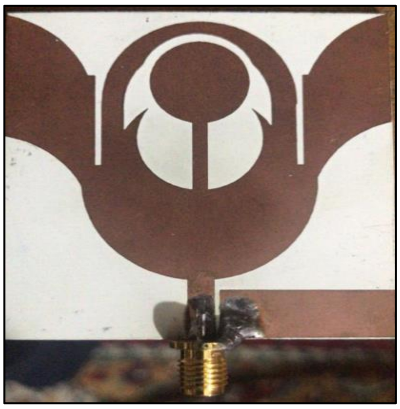


Figure 11. The fabricated antenna

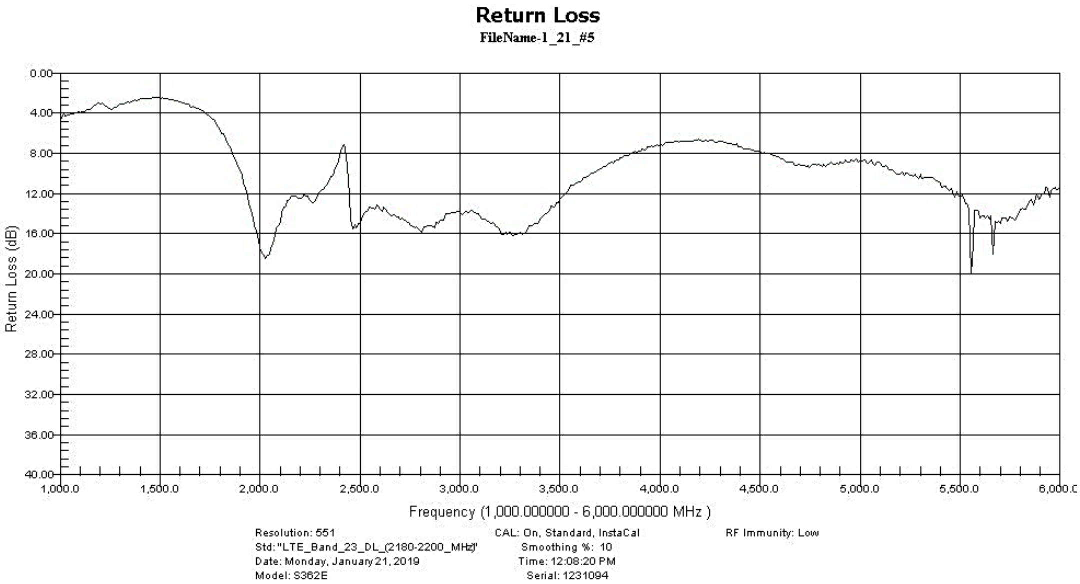


Figure 12. The measured S_{11} in Anritsu-site master S362E

6. CONCLUSION

Due to the rapid growth of mobile systems towards the 5th generation, that requires many frequency bands, the UWB is suitable for such applications. In this paper, a modified circular monopole microstrip antenna has been designed, simulated, fabricated and measured by using the photo resistive technique for the UWB applications. The simulated antenna covers the frequency range between 1.8 to 10 GHz with reasonable S_{11}, radiation pattern, and gain. The S_{11} of the manufactured antenna is measured practically by using Anritsu-site Master S362E.

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BIOGRAPHIES OF AUTHORS

Bilal S. Taha was born in April-1980 in Iraq, Baghdad. In 2014 he received his BSc. Degree in Communication Engineering from AlM'amon University College, and a BSc Degree in Physics from Al-Mustansiriya University College. Currently, he works in the ministry of health, in the republic of Iraq. He obtained MSc. degree in communication engineering from Al-Ahliyya Amman University, Amman, Jordan in 2019. E-mail: belalsal@yahoo.com

Hamzah M. Marhoon received his B.Sc. degree in Electrical Engineering (Rank 2) from College of Engineering Al-Mustansiriyah University, Baghdad, Iraq in 2016. He obtained his M.Sc. degree in Communications Engineering (Honours) in 2020 from Al-Ahliyya Amman University, Hashemite Kingdom of Jordan. He works as an Assistant Lecturer at Al-Esraa University College, Baghdad, Iraq. His research interests include Antennas, Tuneable Antennas, Energy Harvesting Antennas, SSR, IoT, and Embedded Systems. https://orcid.org/0000-0001-5613-6685.