Compact low profile 5.8 GHz MPA for on-body applications

Siba Monther Yousif [1], Anwer Sabah Mekki[2], Ahmed Jumaa Lafta[1]
[1]Department of Electronic and Communications Engineering, College of Engineering, Al-Nahrain University, Baghdad, Iraq
[2]Department of Medical Devices Techniques Engineering, Al-Turath University College, Baghdad, Iraq

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ABSTRACT

A compact microstrip patch antenna (MPA) with a T shape monopole technique is designed, simulated, and measured. By using fire retardant material (FR-4) as a substrate with a low profile, the proposed antenna is designed and simulated to be used for on-body biomedical applications. A center frequency of 5.78 is achieved with a gain of 11.78 dB and a matching impedance of -47.47 dB. A 1.48 W/Kg (10 gm) as a specific absorption rate (SAR) is achieved and 29.69 dB front to back ratio with a bandwidth of 3.376 GHz. The antenna was examined in free space as well as on-body using CST-MW software. The proposed antenna is fabricated and examined. Finally, a comparison is done among simulated results, measured results, and the dual-band dual-mode antenna. The proposed antenna overcomes the latter work in terms of small size, high matching impedance, high front to back ratio, and operating bandwidth.

Corresponding Author:

Anwer Sabah Mekki
Department of Medical Devices Techniques Engineering, Al-Turath University College
Baghdad, Iraq
Email: anwer.sabah@turath.edu.iq

1. INTRODUCTION

Microstrip patch antenna (MPA) is considered a great revolution technique due to its specifications as well as flexible designs that can be achieved [1]–[3]. Conventional MPA has two disadvantages which are the narrow bandwidth and low gain. In wireless body area network (WBAN) the antenna should achieve many requirements, such as high gain, good directivity, high matching impedance, and low specific absorption rate (SAR). SAR represents the quantity of microwave frequency that can be absorbed by human tissues. Therefore, it is considered the most important parameter due to the influence of microwave frequency on body tissues [4]–[7]. Consequently, measuring of SAR should be done with high resolution [8], [9]. The human body tissues are affected by microwave in terms of tumors, cancers, and cell damages due to high vibration as well as thermal effects caused by microwave frequency sources [10]. SAR is the absorbed energy that has a thermal effect on the human body in terms of tumors and cancers. In wireless medical applications [7], SAR, as an important parameter, is measured in W/Kg according to the International Commission Non-Ionizing Radiation Protection (ICNIRP) guideline 1998 [11] with a maximum acceptable limit of 2.0 W/Kg for 10 g of tissue. In the American National Standards Institute (ANSI) and Federal Communications Commission (FCC) [12], the maximum acceptable SAR is 1.6 W/Kg for 1 g of tissue. Currently, the focus on SAR measurement is greater than before [13], [14].

The new technologies led to invent many medical gadgets to be used for on, in, and off-body antennas [15]–[17], which achieved real time investigation. According to Gao *et al.* [18], a flexible MPA with a circular ring is designed to resonate at 2.4 GHz as a center frequency. The design adopted electromagnetic band-gap (EBG) for on-body applications. According to Ashyap *et al.* [19], a textile antenna is presented with an inverted E-shape to resonate in the industrial, scientific, and medical (ISM) band. The antenna achieved a small size of 30×20×0.7 mm^3 with linear efficiency of 79%. According to Shah *et al.* [20], a wearable textile MPA resonates at 2.45-5.8 GHz is implemented.

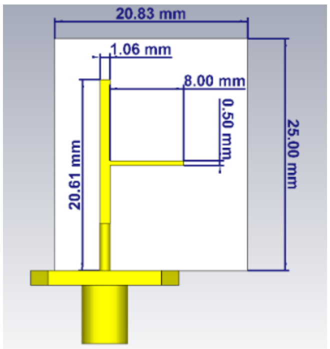
The design achieved low SAR and good matching impedance. Monopole antennas are used for medical applications as wearable antennas [21]–[23]. According to Radi *et al.* [24], an ultra-wide band antenna which resonates at 2.85 GHz and 7.38 GHz is presented. The design adopted FSS techniqueto achieve SAR of 1.06 W/Kg in 10 g. According to Hamid and Chisab [25], an analysing of the field near by the human head and its calculations.

In this paper, a compact microstrip antenna with a T shape monopole technique is designed, simulated, and measured. The proposed design is based on fire retardant material (FR-4) substrate with a thickness of 1.6 mm, a relative permittivity of 4.3, and a tangent loss of 0.025. The proposed antenna is designed to be used for biomedical applications on a body. Good results are achieved; a gain of 11.78 dB, matching impedance of -47.47 dB, SAR equals to 1.48 W/Kg (10 gm), voltage standing wave (VSWR) ratio of 1.0039, and 28.7 dB front-to-back ratio with a bandwidth of 3.3 GHz at -10 dB. The antenna is simulated in free space as well as on-body. The measured results show good agreements with the simulated results.

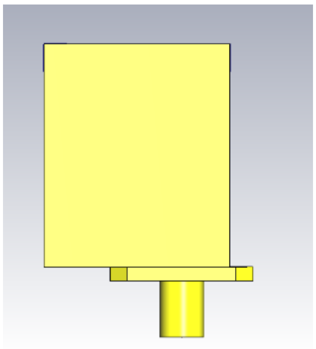
2. METHOD

The proposed antenna is designed to propagate at 5.8 GHz with a human body located in the near-field region of the proposed antenna. The theoretical equations can estimate an overview of the center frequency as well as simple parameters, such as the width and length of the antenna. Due to the limited variables used in theoretical equations, the results will not be accurate and demandable to be used during the fabrication process. CST-MW is an appropriate software that can be used to design, analyze, and optimize the antenna design due to the use of finite element technology and a high number of variables. These considerations make the simulation more efficient to be close enough to the fabricated one. Accordingly, the use of CST-MW is an essential step to design and optimize the design especially when the design is not a traditional shape.

The proposed antenna is based on FR-4 layer of 4.3+j0.025 relative permittivity and a 25 mm long with 20.8 mm width. The feeder is connected to the port using an SMA connector of 50 Ω. The long part of the T- shape is approximately equal to half of the average wavelength (λ) of the working frequency whereas the short part is equal to λ/4 of the working frequency. The proposed antenna, with its dimensions, shown in Figure 1 is designed to work at the ISM band with a center frequency of 5.8 GHz. FR-4 was chosen as a substrate of 1.53 mm thickness, relative permittivity of 4.3+j 0.025. Figure 1(a) shows the patch layer of the simulated antenna and Figure 1(b) illustrates the ground layer of this antenna. The proposed antenna has a minimum size of 832 mm^3 with a ground layer composed of a fully copper layer. From Figure 1, it can be seen that the feeder is not located at the center of the proposed antenna's width. This location is fixed through the optimization technique which is a very important procedure that makes the design more efficient and reliable before the implementation process [26].



(a)



(b)

Figure 1. Proposed antenna design (a) patch view and (b) GND

3. SIMULATION RESULT

The proposed antenna is calculated using the theoretical equations. Then, the antenna is designed, simulated, and optimized using CST-MW. The proposed antenna is designed to work with the ISM band at a center frequency of 5.8 GHz. The FR-4 layer is identified as the substrate with relative permittivity of 4.3+j

0.025 and a thickness of 1.53 mm. This thickness of the antenna makes the proposed design low profile and the proposed antenna has a minimum size of 832 mm^3.

The parameters of the proposed T-shaped MPA are examined in free space as well as on a human body with a distance of 5 mm from the abdomen. The simulation results are illustrated in Table 1. From Table 1, it can be seen that the proposed antenna has better performance with on-body case than the free space one. The reason behind that is the influence of parasitic elements of the human body tissues on the near-field propagation specifications of the proposed antenna. The matching impedance (S11) of the proposed antenna with on-body case is shown in Figure 2. The front to back ratio as well as the gain of the proposed antenna are shown in Figure 3.

Table 1. Comparison between free space and on-body parameters of the proposed antenna

Parameter	Free space	On-body	Unit
Center frequency	5.71	5.78	GHZ
Bandwidth	3.23	3.3	GHz
S11	-37.08	-47.47	dB
VSWR	1.028	1.0084	-----
Gain	8.299	11.78	dB
F/B ratio	15.009	29.69	dB
Directivity	8.52	12.2	dBi
SAR	-------	1.48	W/kg (10g)

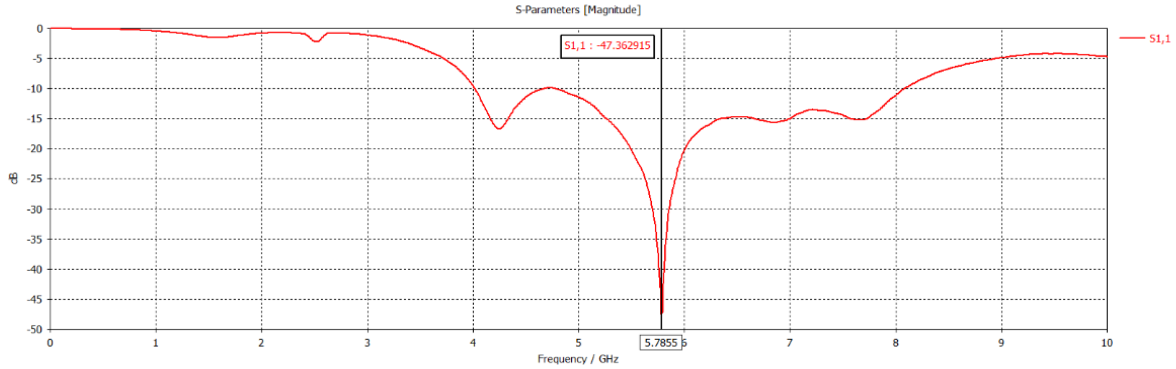


Figure 2. The S11 of the proposed antenna with on-body case

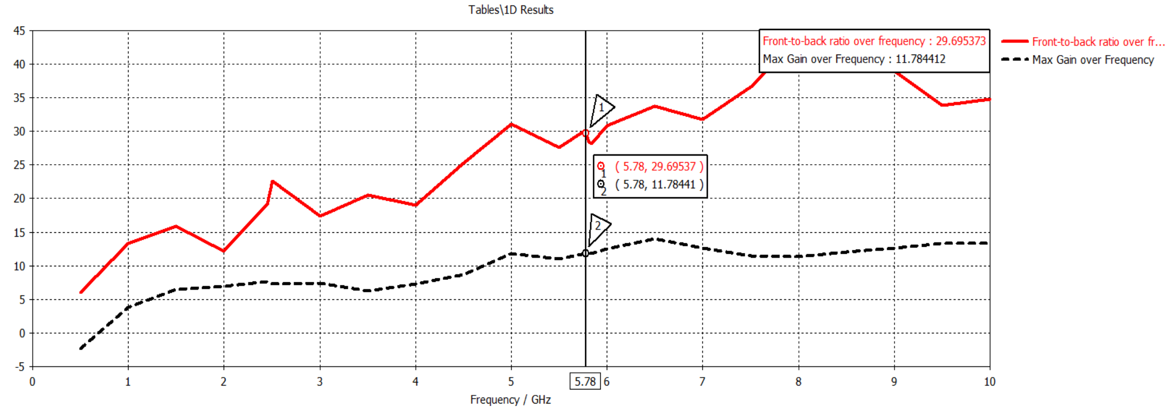
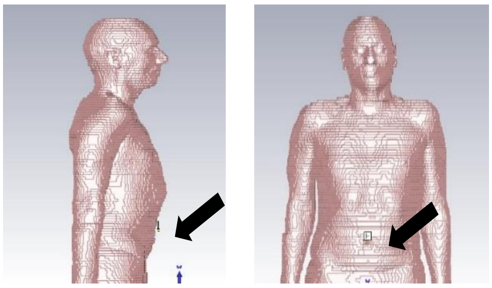


Figure 3. The F/B ratio and maximum gain at the center frequency with on-body case

The SAR is the main parameter used to characterize the power absorbed by the human body. Therefore, it is considered the most important parameter that specifies the workability of an antenna in WBAN. The proposed antenna is simulated on a voxel model with a distance of 5 mm between the proposed antenna and the human's abdomen as illustrated in Figure 4, where Figure 4(a) illustrates the side view of the antenna and human body and Figure 4(b) shows the front view of the antenna and human body. The value of SAR is very important due to its influence on human tissues. Accordingly, wireless propagation should be used within the standards of the SAR test. The simulated value of SAR is shown in Figure 5 and it can be seen that the current distribution is very safe regarding human tissues. The SAR value of the proposed design is 1.48 W/Kg (10 gm) which is less than the acceptable range. This means that the use of the proposed antenna for on-body application is safe and accepted. It is important to know that the SAR test should be done practically under high-level laboratories and high technical staff due to direct contact with human body health. Moreover, the frequency absorbed by human tissues is the main reason for tumors and cancer diseases. The E-field and H-field of the proposed antenna, which is located in front of the human's abdomen with a 5 mm distance, are shown in Figure 6(a) and Figure 6(b), respectively.



(a) (b)

Figure 4. Proposed on-body antenna's location (a) body side view and (b) body front view

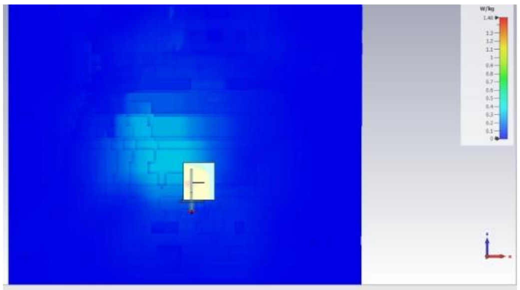
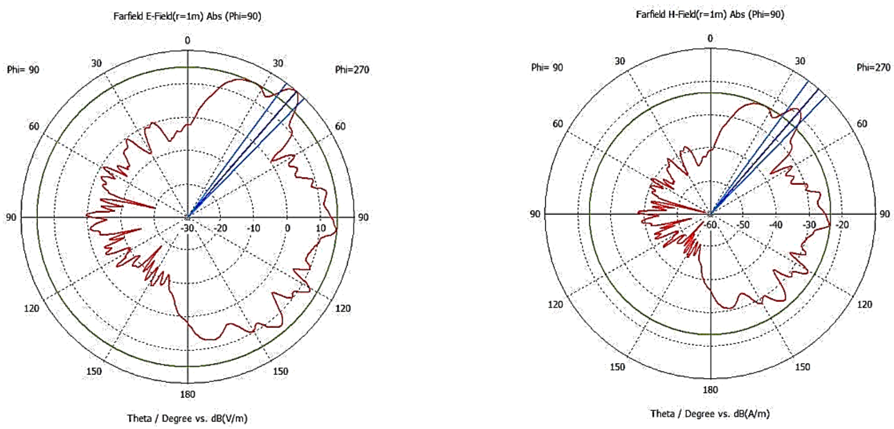


Figure 5. The simulated results of SAR for the proposed on-body antenna

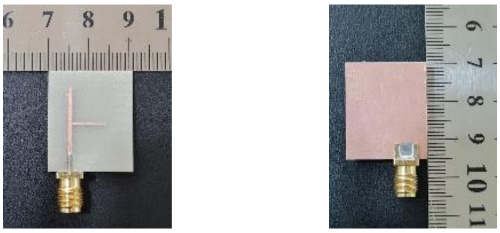


(a) (b)

Figure 6. Propagation field of the proposed antenna (a) E-field and (b) H-field

4. MEASUREMENT

The proposed antenna is fabricated on FR-4 layer of 1.6 mm thickness and relative permittivity of 4.3+j 0.25 and examined as on-body antenna at 5 mm distance from the abdomen. Figure 7(a) shows the patch layer of the fabricated antenna and Figure 7(b) illustrates the ground layer of this antenna. Figure 8 shows the proposed antenna under test. A layer of Styrofoam of 5 mm thickness is used as a spacer between the human body and the proposed antenna. The antenna is examined using agilent VNA model E5071C an two horn antennas.



(a) (b)

Figure 7. Fabricated proposed antenna (a) patch layer and (b) GND layer

Figure 8. The fabricated antenna under test

5. COMPARISON

A comparison is done between the simulation and fabricated results of this work in terms of center frequency, S11, and bandwidth. The comparison shows a good agreement as shown in Figure 9. Finally, a comparison is done between this work and the work presented in [27] as shown in Table 2. From Table 2, it can be demonstrated that the parameters achieved in this work overcome the parameters in [27] in terms of small size, matching impedance, high F/B ratio, and operating bandwidth except for the simulated value of SAR. However, the SAR value achieved in this work is acceptable according to the standard of IEEE C95. Moreover, the high F/B ratio is achieved using an optimization technique regardless the use of a reflector layer. This technique makes the antenna size small enough to be used for on-body WBAN applications even though the substrate is rigid and not flexible.

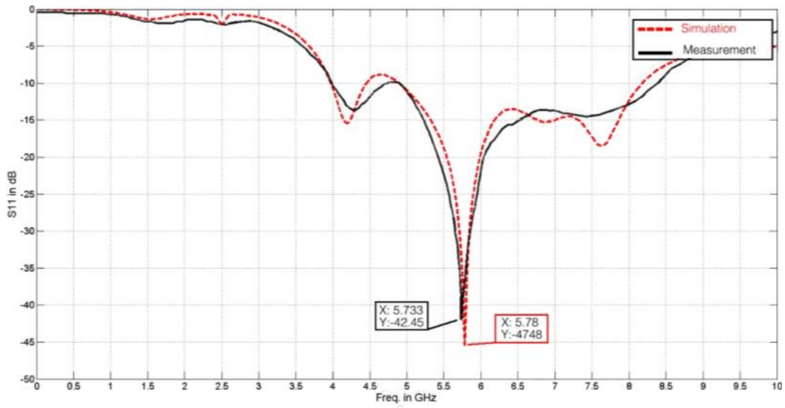


Figure 9. Comparison between simulated and measured results of the proposed antenna

Table 2. Comparison between this work and [27]

References	[27]	This work
Substrate	FR-4	FR-4
Center frequency (GHz)	5.8	5.78
Dimension (L×W×H) (mm)	44×44×7.2	25×20.83×1.6
Peak gain (dBi)	7.9	11.78
Front to back ratio	11.9	29.69
Return loss (dB)	-17	-47.47
Bandwidth (GHz)	0.243	3.03
Efficiency (linear)	----	0.94
SAR (10 g)	0.166	1.48
Reflector	Yes	No

6. CONCLUSION

In this paper, a compact MPA with a T shape monopole used in WBAN is designed and fabricated. The effect of electromagnetic (EM) radiations emitted from the antenna on the human body is investigated, analyzed, and examined. The resultant parameters indicate that the proposed antenna is suitable to be used for on-body applications. The center frequency is located at the ISM band with a very good matching impedance of -47.47 dB with high linear radiation efficiency. Moreover, the proposed antenna is designed on a lossy material, FR-4, which is considered very cheap and available. However, it is very hard to use this material to design a highly efficient antenna.

The high F/B makes the antenna very safe due to the good isolation between the propagated signal and the human tissues. SAR is another significant parameter that measures the microwave's absorption rate in the human body tissues. Through the comparison between the proposed antenna and a dual-band dual-mode antenna, it is proved that the proposed antenna overcomes the other antenna in terms of small size, matching impedance, and high F/B ratio without using a reflector layer. The SAR value of the proposed design is located within the standards but it is higher than the one presented in the other work. The measured results indicate that the proposed antenna has good parameters to be used for on-body biomedical applications.

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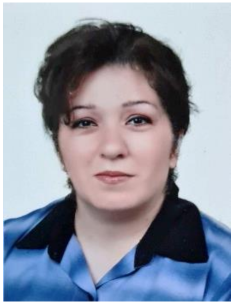
BIOGRAPHIES OF AUTHORS



Siba Monther Yousif was born in Baghdad, Iraq, in 1970. She received B.Sc. degree in Electronic and Communications Engineering and M.Sc. degree in Electronics Engineering from University of Technology, Baghdad, Iraq, in 1992 and 2007, respectively. She received Ph.D. degree in Electronics Engineering from Universiti Putra Malaysia, Malaysia, in 2016. She has 12 years of experience in designing and developing electronic circuits. She joined the staff of the Department of Electronic and Communications Engineering at Al-Nahrain University, Baghdad, Iraq, since 2007. She can be contacted at email: siba.monther.1@nahrainuniv.edu.iq.

Anwer Sabah Mekki was born in Iraq, in 1968. He received B.Sc. degree in Electronic and Communications Engineering from University of Technology (UOT), Baghdad, Iraq, in 1992. He received Ph.D. degree in Electronic and Communications Engineering-Sensor Technology from Universiti Putra Malaysia (UPM), Malaysia, in 2016. He has many published papers and a patent in the field of sensors. Currently, he is the head of Department Medical Devices Techniques Engineering at Al-Turath University College, Baghdad, Iraq. He can be contacted at email: anwer.sabah@turath.edu.iq

Ahmed Jumaa Lafta received his B.Sc. and M.Sc. degree in Electronic and Communications Engineering from the University of Baghdad, Iraq in 2002 and 2005, respectively. He received his Ph.D. degree in Data Telecommunications and Networks Engineering from the University of Salford-Manchester, United Kingdom in 2017. He is currently one of the academic staff in the Department of Electronic and Communications Engineering of Al-Nahrain University, Baghdad, Iraq since 2006 till now. His research interest includes telecommunications networks, communications systems, wireless and mobile communications, computer networks. He can be contacted at email: ahmed.jumaa.1@nahrainuniv.edu.iq.