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A Low SAR In-Body Antenna for Wireless Monitoring Purpose of Pacemaker System

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***Abstract*—This research paper deals with a low SAR patch antenna that resonates at 2.415 GHz. This antenna can be employed to monitor the pacemaker system wirelessly, considering its performances. The main aim was to operate the antenna at ISM (Industrial, Scientific and Medical) band (2.4–2.48 GHz) in the pacemaker system, where body granted materials were used to construct both the pacemaker and the antenna to ensure the biocompatibility. To investigate the antenna parameters' changes between free space and in-side body condition, the designed antenna was examined and compared for both conditions. The key speciality of this design is that the SAR (Specific Absorption Rate), which is the most crucial parameter for any in-body antenna, was found in a considerable-safe region. Moreover, Computer Simulation Technology (CST)-based desired findings of this antenna for return loss, VSWR, and far-field radiation characteristics were found with compared to other recent body-implantable antenna related published works.**

Keywords— ISM Band, Pacemaker Casing, Body Phantom, Wireless Monitoring System, Patch Antenna, VSWR, Low SAR, Far-field Radiation.

I. INTRODUCTION

Cardiac pacemaker is a small implantable medical device, which one can pace the heart artificially when required. Monitoring pacemaker through a traditional way is a time consuming as well as a stressful (for patients) process whereas, monitoring pacemaker system wirelessly can reduce the time consumption for a diagnosis in patients as well as it can reduce the physical or psychological stress of patients. As, this is a wireless system so, no need of wire to intersect the skin and that will reduce the cause of infection to the percentage of zero. In recent year wireless biotelemetry systems are getting so much attention. By using this system, patients will be able to send the data (condition of heart) to their corresponding doctors so, doctor could inform his/her stage of improvement or how much need to care [1]. This system also can be used to detect the pacemaker failure. Being this is a wireless system this system must need a body granted antenna.

Miniaturisation is the notable consideration to implant an antenna inside the human body. Another considerable issue to design an implantable antenna is radiated energy because variation of the electromagnetic energy absorbed by adjacent human tissue is needed to be considered. This electromagnetic energy can change the antenna behaviors such as tuning frequency and system impedance matching [2-3]. Warp up the antenna with bio-material is also a crucial issue to protect the human tissue from the antenna radiation [4].

To design a bio-favorable antenna, small number of bands are recommended by Federal communications commission (FCC) i.e., medical implant communication service (MICS), Wireless medical telemetry service (WMTS), Industrial Scientific and Medical (ISM). These bands assure diverse frequency range for biomedical devices. MICS band has lower frequency range due to its large wave length, therefore MICS band is not appropriate for implantable devices [5-6]. Whereas, ISM band is more appropriate for biomedical devices because of its higher frequency band-width and that is the reason behind of its small wave-length as well as additional rate of high bit after placement inside body [7-8].

Few researches have been leaded on the theme of traditional pacemaker antenna, so far. Where, most of them were not tested in a perfect bio-environment condition. Even, some of the antennas were just examined in free space condition, which is not enough to fulfill the requirements for a pacemaker antenna.

[9] is a very recent published work on traditional pacemaker antenna, which is an ISM band (2.464 GHz) patch antenna. Copper, Roger R3010 and Perfect Electric Conductor (PEC) were used as patch, substrate and ground, respectively for this design. Although, a pacemaker antenna should place in-side the pacemaker but in this paper authors placed the antenna out-side of the pacemaker box by embedding the antenna with superstrate material Rogger

R3010. Moreover, missing of SAR calculation makes this antenna imperfect to implant in-side body. In [10] Authors introduced 402.5 MHz operating meander line telemetry antenna for pacemaker application. Where, FR-4 was considered as substrate material for this design. Although, it is clearly stated in several reliable pacemaker related sources i.e., [11], [12] that a pacemaker antenna should be placed beneath of the skin and subcutaneous fat, this paper examined the antenna inside skin, which is not a perfect bio-environment condition to investigate a pacemaker antenna. On the other hand, human skin is not enough thick to implant a traditional pacemaker inside it. Furthermore, in this paper, antenna's SAR was not measured for human body, which leaves an "unsafe" mark on this antenna for body implantation. Like as, [10] in [13] also a skin model was taken as reference to implant the antenna. This antenna's operating frequency was 2.4 GHz and its pacemaker case was used as this design's ground, which was titanium or titanium alloy. Rogers R06010 was (thickness = 0.635 mm) used as its substrate. This paper also did not provide any SAR calculation for the design. Results were evaluated in air or vacuum in [14]. However, the prior works related to pacemaker antenna can be considered as body implantable antenna and their results were also satisfying except the missing of SAR results but their arrangement to bio-environment, does not define those works as a pacemaker antenna. Because parameters' value of those antennas can change after implanting those antenna at right position (between subcutaneous fat and muscle).

For which, in this study a miniaturised patch antenna that is able to resonate at 2.415 GHz, is proposed for monitoring pacemaker system wirelessly with right position implantation. Due to flexible property of Rogger R03010, it has been used as substrate material and to excite the antenna, 1 mwatt transmitting power is chosen [15]. As this antenna is small in size it is suitable for any kind of pacemakers. All significant characteristics of this antenna those are needed to investigate for considering this an efficient body implantable antenna such as VSWR, far-field radiation pattern, directivity and radiation efficiency have been observed via simulation of CST microwave studio after implantation in a body phantom model. Particularly, this work aims to design an antenna that fulfills all of the requirements of an implantable pacemaker antenna including SAR calculation. For this antenna, SAR is provided for 10 gram human body tissue that agrees with the requirement of an international authority (International electro-technical commission) regarding SAR calculation. Lastly, in the comparison section of this paper several body implantable antennas' findings are provided and compared to this work to evaluate this antenna's performance as a body implantable antenna, as pacemaker antennas are included in this category.

II. Modelling Methodology

Several numbers of steps had to complete to accomplish the goal of this research work, those are detailed as follows:

A. Antenna Modelling

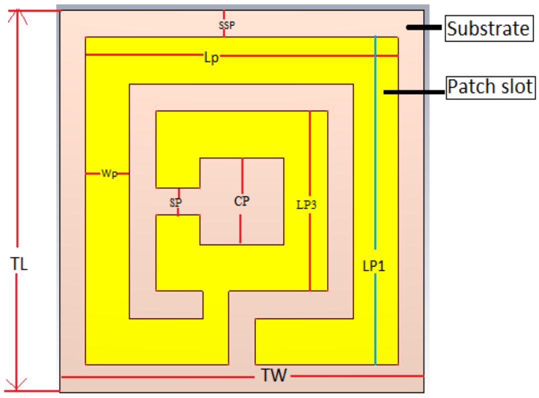
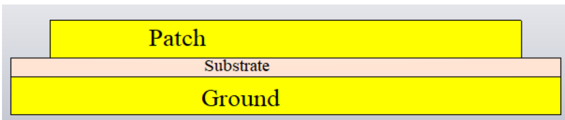
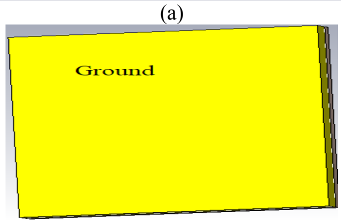


Fig. 1. Frontal view of the designed antenna with parameters labelling

A compact sized patch antenna with dimension of 14 mm x 14 mm x 2.5 mm (Total length, TL = 14 mm, Total width, TW = 14 mm and Total thickness = 2.5 mm), which is compatible to use in the monitoring system of wireless pacemaker is shown in Fig. 1. Flexible material is employed as substrate plate during the modelling of the mentioned antenna so that it could witness bend condition if required for medical using purposes. This antenna can be tuned at 2.415 GHz frequency that means this is an ISM (Industrial, Scientific and Medical) banded antenna [16].



(a)



(b)

Fig. 2. (a) side view and (b) back view of the proposed antenna

TABLE I. ANTENNA LAYERS' FEATURES LIST

Layer	Material	Total length (mm)	Total width (mm)	Total thickness (mm)
Patch	Copper	12	12	1
Substrate	Rogger R03010	14	14	0.5
Ground	Copper	14	14	1

TABLE I is showing that the three layer antenna (Fig. 2 (a)) has patch and ground of copper [17] and the substrate of Rogger R03010 (dielectric constant = 10.2 and tan δ = 0.0035), which is used as substrate material to design the antenna due to its flexibility [16]. Proposed antenna has a meandered line patch as shown in Fig. 1. Operating frequency of the antenna can be changed or varied by changing the dimension of the patch slots and slot numbers.

Designing parameters' dimension of the antenna layers also can be visualised from TABLE I.

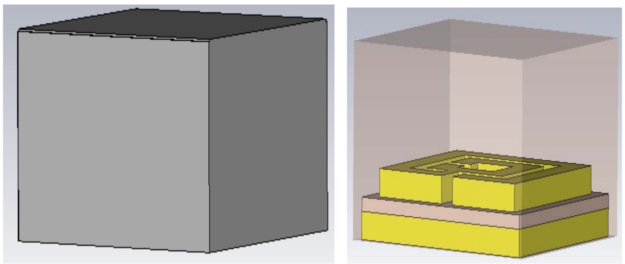
TABLE II. ANTENNA PARAMETERS' DIMENSION LIST

Parameter	Size (mm)
TL	14
TW	14
SSP	2.06
LP	12
WP	1.70
SP	1.00
CP	3.20
LP1	12
LP3	6.60

TABLE II is showing the antenna parameters' value according to Fig. 1.

B. Modelling of Pacemaker Casing and Body Phantom

Choosing of biomaterial to design any implantable device is very important agreement because the chosen material must be harmless to human body. According to the biomedical engineering there are several numbers of biomaterials such as alloplastic [18], titanium or titanium alloy [19], Teflon [20], polyamide [21] those can be used to construct implantable devices.



(a) (b)

Fig. 3. (a) solid view (b) transparent view of the designed pacemaker casing with inserted antenna

In our case, polymide (tan δ = 0.004, dielectric constant = 4.3 and thickness = 0.0025 mm) is used to illustrate the pacemaker casing [21]. Total size of the pacemaker is 15mm x 15mm x 7mm whereat the antenna is placed inside, on the floor of it with total size of 14mm x 14mm x 2.5mm (Fig. 3). The proposed antenna occupies only 31% of the pacemaker. Although, a traditional pacemaker size (30.7mm x 41mm x 9.5mm) [20] is far larger than the designed one. Pacemakers' size can vary with the requirements.

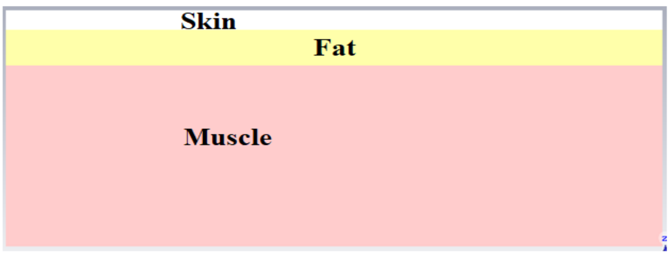


Fig. 4. Human body phantom model

Fig. 4 is demonstrated the human body phantom layers such as: skin, fat and muscle. Several articles such as [22], [23], [24] have been studied to come up with the agreement of human body layers' thickness. In this study, the human phantom model is designed with skin thickness of 4 mm, fat thickness of 7 mm and muscle thickness of 35 mm by maintaining proper electrical properties of skin, fat and muscle, which is shown in TABLE III [25].

TABLE III. DIELECTRIC PROPERTIES OF TISSUES FOR ISM BAND

Tissue	Density (kg\m^3)	Conductivity (s\m)	Dielectric constant
Skin	1100	1.59	42.85
Fat	1850	0.27	10.82
Muscle	1040	1.81	53.6

C. Bio-Environmental Arrangement for antenna testing

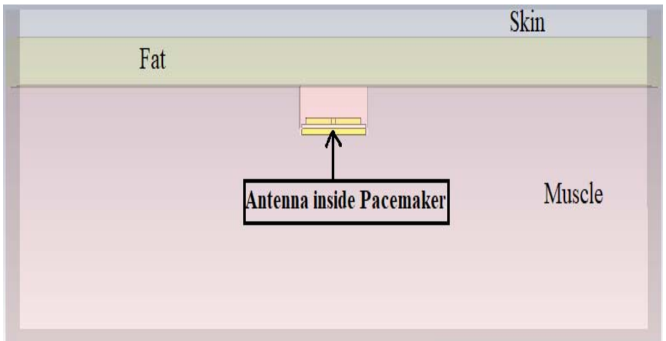


Fig. 5. Pacemaker inside the human body tissue with the inserted antenna

A pacemaker is usually placed under the skin and subcutaneous fat tissues but it varies where to implant with the patient's health [11-12]. Fig. 5 is showing that the pacemaker is buried inside the phantom model at beneath of the fat along with the inserted antenna.

III. PERFORMANCE ANALYSIS OF THE DESIGNED ANTENNA

Proposed antenna's performances are investigated in free space and also after the placement inside the body. In this part several antenna parameters are discussed to confirm the credibility of the proposed patch antenna as a bio-medical antenna.

A. Impedance Matching of the Proposed Patch Antenna

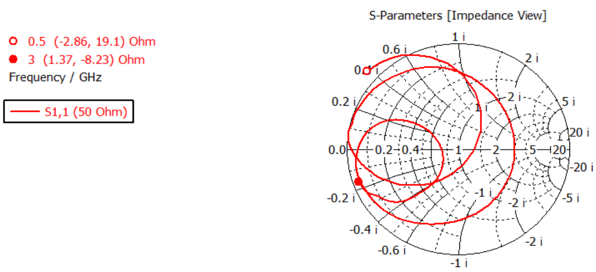


Fig. 6. Impedance matching of the antenna at implanted condition

After completing the analysis, impedance of the antenna is found 50 ohm (Ω) by using smith chart (Fig. 6).

B. S11 or return loss Results

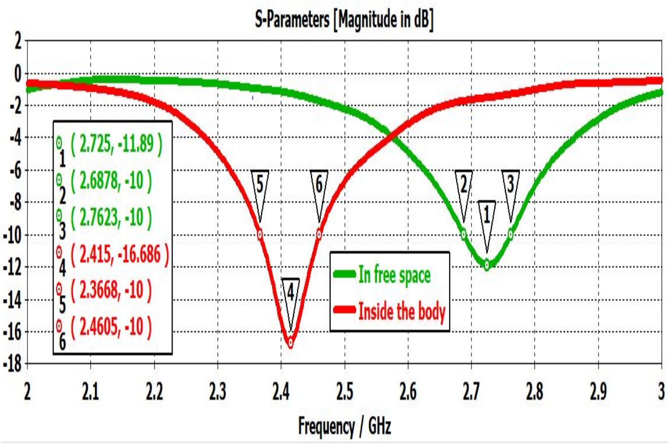


Fig. 7. Comparison of S11 or return loss of the proposed antenna between free space and inside the body

S11 or return loss of the proposed antenna is examined for both in free space and in-side the human tissue model as shown in Fig. 7. According to the antenna theory, return loss value should be less than -10 dB, more than that would be a cause of 90% radiated energy from the transmission system , which is not desired [26]. In our case, s11 value in free space (Green line) is around -11.89 dB at resonance frequency of 2.725 GHz and s11 value of the antenna inside the tissue model (Red line) is -16.69 dB at operating frequency of 2.415 GHz (ISM band), means the antenna performance is much better at impalnted condition than in free space, which is clearly shown in Fig. 7. Bandwidth of the antenna found to be 93.7 MHz (2.4505 GHz to 2.3668 GHz) at horizontal level of -10 dB, while the antenna is at buried condition. As, this type of communication usually transmits ASCII data so, there is no need of a large bandwidth [27].

C. VSWR Results of the Proposed Antenna

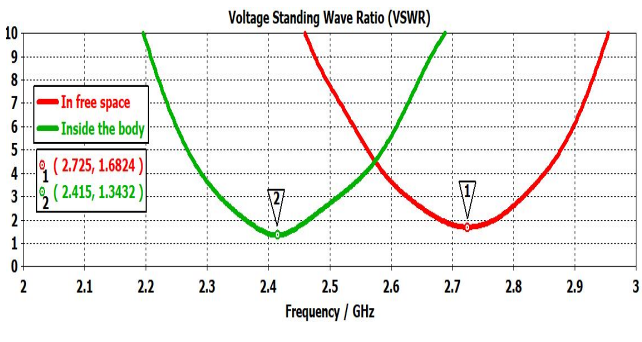


Fig. 8. Comparison of VSWR of the proposed antenna between free space and inside the body

1 is the ideal VSWR (Voltage Standing Wave Ratio) value and this value must be less than 2, to be a matched and well-performed antenna for the in-body telemetry system [28-29]. Fig. 8 is showing the variation of VSWR at free space and inside the body tissue. For this study observed VSWR value of the antenna at free space is around 1.68 (red line) and for inside the phantom model VSWR value is 1.34 (Green line).

D. Far-Field Radiation Patterns

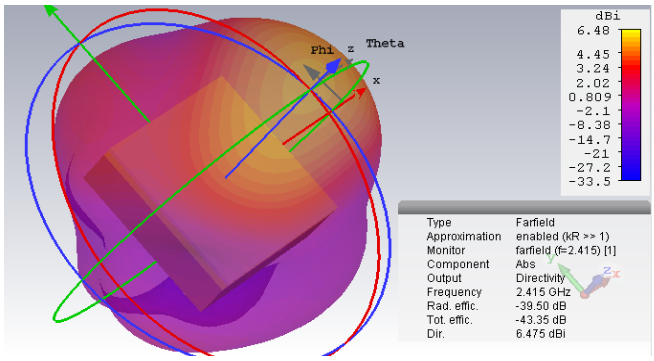
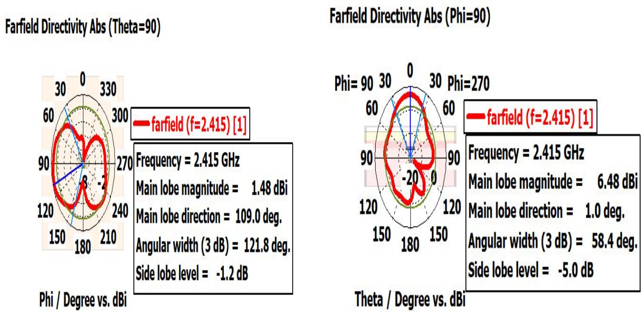


Fig. 9. 3D far-field radiation pattern of the antenna at impalnted condition, inside the phantom model.

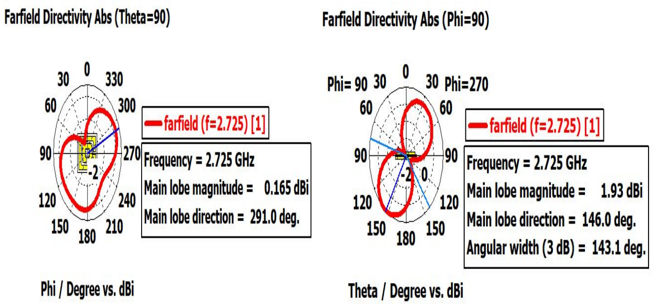
This antenna's maximum directivity is 6.48 dBi at frequency of 2.415 GHz as it is shown in the Fig. 9. Total efficiency and radiation efficiency of the antenna are equal to -43.35 dB and -39.50 dB, respectively.



(a) (b)

Fig. 10. 2D radiation (a) Azimuth & (b) Elevation, pattern of the proposed antenna at implanted condition

2D far field view is analysed at 2.415 GHz for both azimuth and elevation angle of this antenna, which can be observed from Fig. 10. For all the phi (φ) values, theta (θ) is fixed at 90 degree to observe azimuth pattern, which main lobe magnitude is equal to 1.48 dBi and it is centred at 109.0 degree. Its angular width of the main lobe is 121.8 degree. On the other side, For all the theta (θ) values, phi (φ) is fixed at 90 degree to observe elevation pattern, where 6.48 dBi is found as its main lobe magnitude, which is centred at 1 degree and its main lobe angular width is 58.4 degree. Although the elevation pattern is almost omni-directional but the azimuth pattern is bi-directional.



(a) (b)

Fig. 11. 2D radiation (a) Azimuth (b) Elevation, pattern of the proposed antenna in free space

In the aspect of main lobe magnitude, radiation performance of the antenna is better inside body condition compare to free space condition, while free space tuning frquency is 2.725 GHz Fig. 11.

E. SAR Analysis of the proposed Patch Antenna

The full form of SAR is "Specific Absorption Rate". It is the amount of measured electromagnetic energy that is being consumed by the near-side body tissue of the antenna due to its radiation. Because of this a Pacemaker's wall must be capable to protect the surrounding tissue from the antenna radiation. According to IEC (International electro-technical commission) SAR value should not be more than 2 W\kg for 10 gram tissue [30].

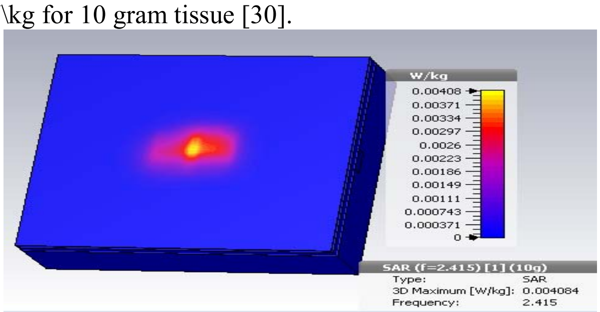


Fig. 12. Measured SAR values of the antenna for 10 gram body tissue

Proposed patch antenna has maximum SAR value = 0.00408 W/kg (10 gram), (Fig. 12) this rate absolutely comply with IEC requirement. During this SAR calculation input power is fixed at 1 mW.

IV. Comparison Analysis

TABLE IV. PARAMETERS' COMPARISON OF THE ANTENNA FOR TWO DIFFERENT CONDITIONS

Condition / Parameter	Free space	Inside the body
Resonance frequency	2.725 GHz	2.415 GHz
Return loss	-11.89 dB	-16.69 dB
Bandwidth	74.5 MHz	93.7 MHz
VSWR	1.68	1.34
Main lobe magnitude (azimuth)	0.168 dBi	1.48 dBi
Main lobe magnitude (elevation)	1.93 dBi	6.48 dBi

TABLE IV. Depicts the parameters' comparison of the antenna for two different conditions – free space and inside body phantom where it can be commented that antenna performance is much better inside body phantom compare to free space condition.

TABLE V. PARAMETERS' COMPARISON OF THE ANTENNA WITH BODY IMPLANTABLE ANTENNAS

Ref. / Parameter	This work	Ref. [17]	Ref. [28]	Ref. [31]	Ref. [32]
Frequency (GHz)	2.415	2.46	0.405	0.404	0.4025
VSWR	1.34	1.4549	1.072	1.188	1.428
Return loss (dB)	-16.69	-14.64	-29.2	-21.28	-15.071
Total Efficiency (dB)	-43.35	-177.0	-44.79	-45.74	-44.57
Radiation Efficiency (dB)	-39.50	-176.94	-43.92	-45.71	-43.51
SAR (W/kg) (1 mwatt) (10 gram)	0.0041	Not given	0.662	0.588	0.548
Directivity (dBi)	6.475	-200	2.178	2.750	1.582

Here, full form of Ref. = Reference

TABLE V illustrates the data of parameter comparison of the antenna with some implanted bio-antennas, those are published recently. It can be clearly seen from the table that proposed work has desired results compared to other similar works in severel aspects. All of those compared references are representing their corresponding antenna for in-body telemetry system and all in-body antennas should maintain the same ideal findings in terms of resonance frequency, VSWR, Return loss, SAR, efficiencies, directivity etc. However, this work shows poor results of VSWR and return loss compare to Ref. [28] and Ref. [31] but the other results such as efficiencies, directivity show this antenna performance is worthier compare to them. Compare to other references (Ref. [17] & Ref. [32]), all of the presented parameters of this work are desired. Specially, the maximum SAR value of this work ensures that this is probably one of the safest antennas for body implantation compare to any other existing antennas in bio-medical sector, which can be considered as the main feature of this design.

V. Conclusion

A bio-antenna's parameters can be influenced by several body factors such as: antenna's surrounding tissues' dielectric properties, antenna's placement location (how depth the antenna is placed) and tissue thickness etc. So, throughout the study, proposed patch antenna's parameters have been discussed at implanted condition as well as in free space with proper care of those major factors. Finally, the antenna parameters at implanted condition have been found much worthier than in the free space condition as it was discussed in S11, VSWR, 2D farfield section and comparison section. This antenna tuning frequency has been found 2.4125 GHz (ISM band and body granted band) at buried condition. Furthermore, SAR is another important parameter for an implantable antenna, which has been found in the safest region for the proposed patch antenna compared to other related works. So, from the whole study it can be summarised that the propounded patch antenna is a bio-compatible antenna and it can be used in a pacemaker for wireless monitoring purpose. As future work, enhancement of the antenna bandwidth and placement of the antenna inside a practical body for measuring the data will be focused.

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