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Performance Analysis of a Microstrip Patch Antenna for Biomedical Applications

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***Abstract*— A microstrip patch antenna's design and performance analysis for biomedical applications which operating at 2.45 GHz frequency range in ISM Band (2.4 GHz to 2.5 GHz) is represented in this paper. The antenna's good-looking feature is the proper thickness and suitable dimension. The special feature of this antenna is to make it perfect for On-body matched biomedical applications. FR4 material is used as the substrate to design the antenna. Individual properties of the Phantom model are perfectly maintained to get proper software simulated result. All the simulations, calculations and parameter results are fit for on-body matched conditions. To design the antenna CST Microwave Studio is used. Impressive S_{11} of more than -50 dB for off-body and on-body as well as Specific absorption rate (SAR) of 0.0005 W/kg in on-body make the antenna compatible for biomedical application.**

Keywords*— *microstrip antenna, ISM Band, biomedical applications, on-body, SAR.

I. INTRODUCTION

A great impact is created by microwave application in the field of biomedical in recent years. Antennas are widely considered for biomedical implementation because of the dynamic properties like higher bandwidth, low profile, portability, tiny dimensions with easy portability. It is going to be used in every stage of treatment in near future [1]. Diagnosing of complex and severe diseases, distance medical observation and instant monitoring system make its great attention to use widely in the biomedical sector [2]. The excellent advantage of the system is monitoring remotely despite the distance between doctor and patient [3-4]. The communication link between diagnosis devices and the human body in the biomedical sector is built by the use of an antenna [4]. The need for surgical operation and the complex situation will reduce in a large scale as an antenna can be used for monitoring, diagnosing and in the purpose of treatment [5-8]. Antennas are considered for telemetry [9-11] as well as biomedical applications. For this, the antenna based medical system will offer more benefit from the traditional system and on-demand service can easily be achieved by the patient from doctors.

Research on breast cancer and lung cancer is already done by many authors [1]-[8], [16]. Detecting cancer tissues using a biomedical antenna at on-body or off-body was the main concern of those researches. As cancer is spreading all over the world. Researchers need some more easy way to detect this. Among all of the types of cancers, lung cancer is one of them. Due to uncontrolled cell growth in tissues of the lung, it happened. Hundred thousand people around the world, are affecting by every year. Many of cancer, brain-disease patients cannot survive; because the disease diagnosed lately. The surgical operation can help to survive if it can be detected in the primary stage [12]. Design and shape of the antenna are mainly depending on where it is going to apply. Some antennas used for off-body communications, on-body purpose and some antennas used for the in-body purpose [12]-[14], [16].

In respect of Bangladesh, prominent research shows that almost 13 to 15 lakh cancer patients we have and every year near about 2 lakhs are being diagnosed with this fatal disease. Most males are affected by Lung cancer which is almost 13.1% and in case of a female, it is near about 2.0% as 41% of male and 1.8% of female in Bangladesh are addicted in smoking who are 15 years or more in age [15].

Microstrip antennas have been designed for biomedical purposes by many authors. Ultra-wideband (UWB) antenna is developed for lung cancer detection. Simple narrow band monopoles fabricated from coaxial cables, placed in a tank filled with matching liquid to emulate breast tissues, are used in an active microwave imaging system for noninvasive detection in breast cancer [17]. A variety of planner antennas have also been reported. The microstrip antenna array is also developed for biomedical as well as telemetry application [12], [16]. A microstrip patch antenna in the range of 4 to 9.5 GHz has been developed for breast cancer detection [18]. A planer on-body wide band slot-

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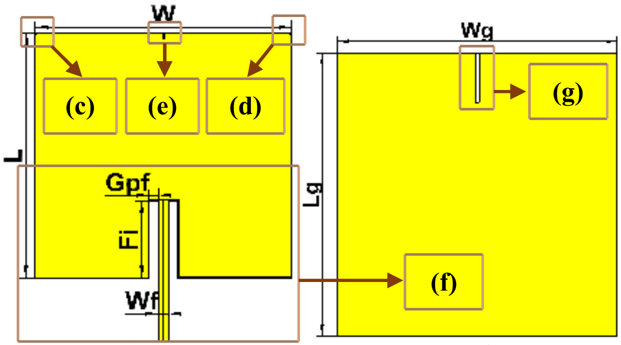
antenna biomedical application has been developed [19]. A simple triple-band antenna for implantable biomedical application shows the gains are -19.9 dB, -22.2 dB and -12.8 dB at multi-bands [20]. A flexible microstrip antenna for ISM band is also developed by authors where antenna-1 and antenna-2 give -26 dB and -31 dB return loss respectively [21]. To ensure patients' safety specific absorption rate (SAR) should be considered. This SAR value could be influenced by several parameters of antenna-like, radiated power, positions of the antenna relative to the human body, and radiation patterns of the antenna.

Here a microstrip antenna is designed with better return loss to make the diagnosis process easier; that is easy to fabricate, operational in low cost and consume low power than traditional diagnosis system. With the help of CST Microwave Studio, we simulated this antenna and determine the value of s-parameter, VSWR, SAR value, Far-Field region etc. The antenna is in ISM band as the operational frequency bands for medical applications according to FCC regulation are for Medical Device Radio Communications Service (Med-Radio), i.e. from 401 MHz to 406 MHz and for Industrial, Scientific and Medical Radio (ISM), i.e. from 2.4 GHz to 2.5 GHz respectively [22-23]. This work presents the design and performance analysis of a microstrip patch antenna used for the on-body purpose and may be used for detection of several types of cancer such as breast cancer, lung cancer, and brain tumor. Limitations from previously related researches are overcome in this literature such as higher bandwidth, impressive return loss, gain of the antenna, SAR values, and radiation pattern.

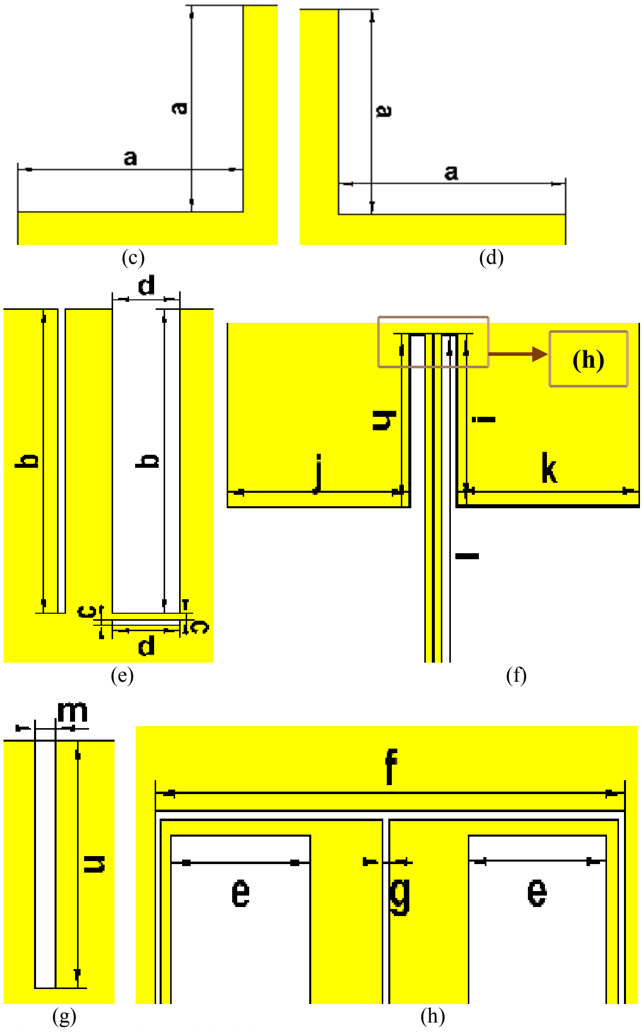
II. ANTENNA DESIGN AND MODELING

The antenna presented in this paper is a flexible microstrip patch antenna. The principal purpose of this antenna is to use for on-body applications. Proper dimensions are chosen to design the antenna to fulfill that purpose. Copper is used as the material for ground, patch, and feedline. FR4 lossy material is used as the substrate. The thickness of the ground is 0.035 mm. The substrate has a thickness of 1.60 mm and the thickness of patch and feedline are same which is 0.035 mm.

The geometric model is shown in Fig. 1. Here (a) and (b) are the front and back side respectively, (c) and (d) shows the slots of the patch in upper left and right corner respectively, (e) shows the slots in the upper middle portion of the patch, (f) shows the slots in lower patch and feedline, (g) shows the slots in upper middle portion of ground plane and (h) shows the slots in the connecting portion of feedline and patch.



(a) (b)



(c) (d)

(e) (f)

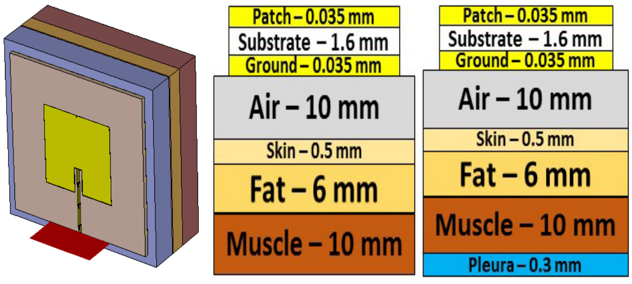
(g) (h)

Fig. 1. Geometric Model of the Antenna

All parameters used to design the antenna are given in TABLE I.

TABLE I. ANTENNA SIZE PARAMETERS

Parameter	Value (mm)		Parameter	Value (mm)
F_i	9		e	1.00
G_{pf}	1		f	3.38
L	28.45		g	0.05
L_g	56.90		h	9.04
W	28.45		i	9.00
W_g	56.90		j	12.55
W_f	1.137		k	12.53
a	0.13		l	23.18
b	0.54		m	0.80
c	0.10		n	9.95
d	0.01		-	-



(a) (b) (c)

Fig. 2. The antenna on human phantom Model: (a) antenna with the phantom model, (b) muscle phantom layers and (c) lung phantom layers

For biomedical on-body antennas, biocompatibility is the main concern while it is going to apply in practical life. Here two different phantom model (muscle phantom and lung phantom) are used to test the antenna. In Fig. 2 it shows.

III. ANTENNA SIMULATION AND RESULTS

To analyse the performance of the designed antenna, it's simulated in software in different environments such as off-body, on-body, and bend test. Fig. 3 shows the s-parameter value at off-body and comparison of s-parameters between off-body and on-body. From there 2.45 GHz is found as operating frequency for off-body, is in ISM band (2.4 GHz to 2.5 GHz). S-parameter of the antenna at that frequency is -63.062 dB. A horizontal mark line is drawn at -10 dB to determine the bandwidth of the antenna and it is 60.00 MHz (2.4797 – 2.4197).

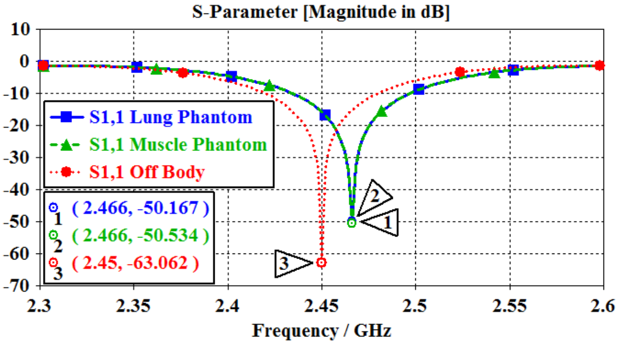


Fig. 3. S-parameter of the antenna and at off-body and on-body

Here, all parameters are also calculated respectively for muscle phantom to observe the biocompatibility of the antenna and it shows impressive performances. From Fig. 3 it is seen that at 2.466 GHz frequency which is in ISM band the return loss is -50.534 dB. All parameters are also calculated for Lung Phantom as like as muscle phantom. From Fig. 3 it is seen that at 2.466 GHz frequency the return loss is - 50.167 dB.

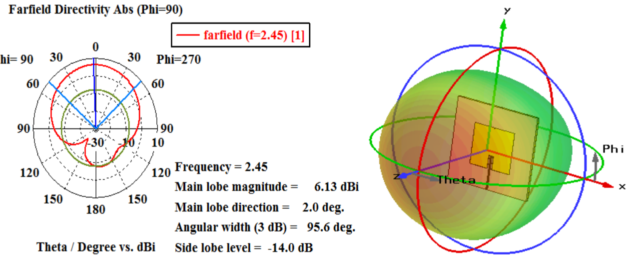


Fig. 4. Far-Field (polar & 3D) region at off-body

Polar and 3D view for off-body is shown in Fig. 4. Directional and focused accuracy of the antenna is shown at 2.45 GHz frequency. Here the magnitude of the main lobe is 6.13 dBi and positioned at 2.0° laterally through an angular width of 95.6° and the directivity value is 6.124 dBi.

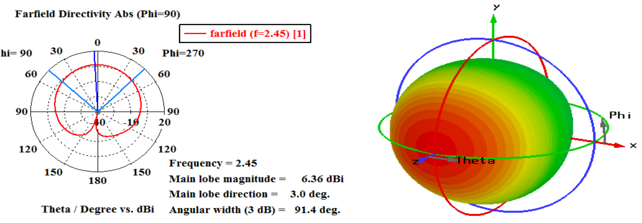


Fig. 5. Far-Field region (polar & 3D) at muscle phantom

Polar and 3D view in Fig. 5 shows for muscle phantom; here magnitude of the main lobe is 6.36 dBi and positioned at 3.0° laterally through an angular width of 91.4° and the directivity value of the antenna is 6.350 dBi.

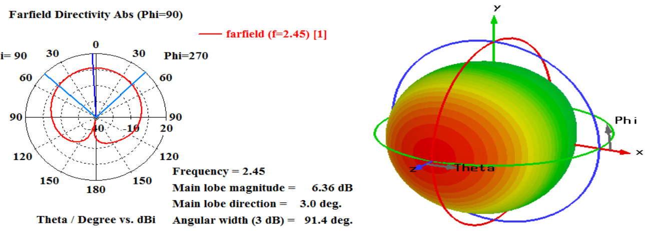


Fig. 6. Far-Field region (polar & 3D) at lung phantom

Polar and 3D view in Fig. 6 shows for lung phantom; here magnitude of the main lobe is 6.36 dBi and positioned at 3.0° laterally through an angular width of 91.4° and the directivity value of the antenna is 6.353 dBi.

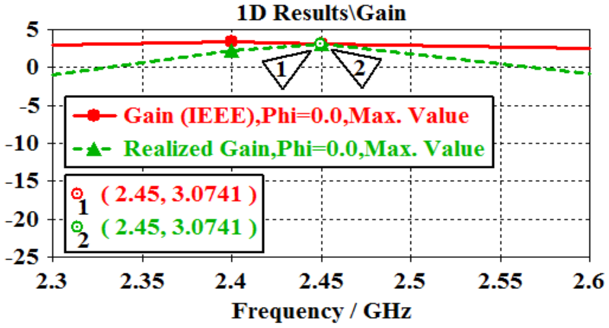


Fig. 7. Gain vs frequency at off-body

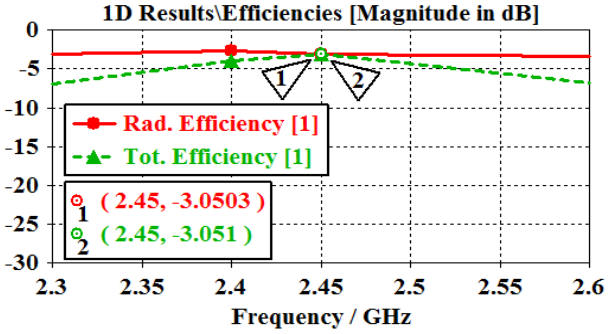


Fig. 8. Efficiency at off-body

Gain and Efficiency of the antenna for off-body are also determined by simulating in software is shown in Fig. 7 & Fig. 8. Gain (IEEE) and Realized Gain at 2.45 GHz frequency are respectively 3.0741 dB and 3.0741 dB. Radiation Efficiency and Total Efficiency at 2.45 GHz frequency are respectively -3.0503 dB and -3.051 dB.

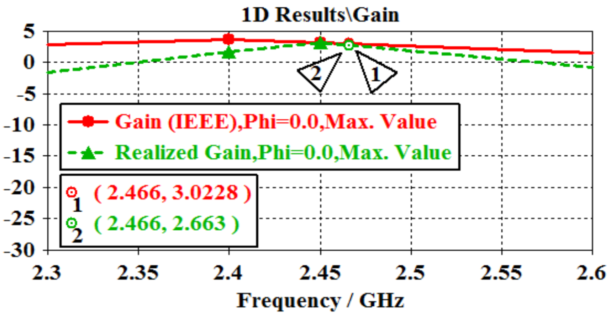


Fig. 9. Gain vs frequency at muscle phantom

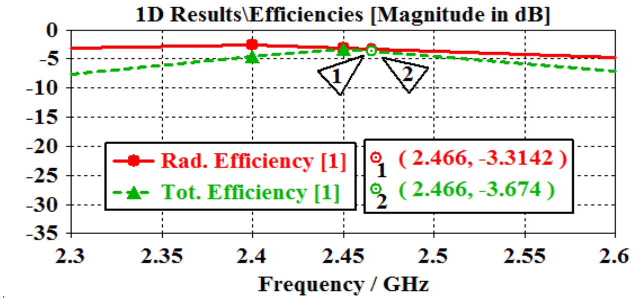


Fig. 10. Efficiency at muscle phantom

Gain, Realized Gain, Radiation Efficiency and Total Efficiency are shown in Fig. 9 and Fig. 10 for muscle phantom. Gain, Realized Gain, Radiation Efficiency and Total Efficiency are shown in Fig. 11 and Fig. 12 for lung phantom.

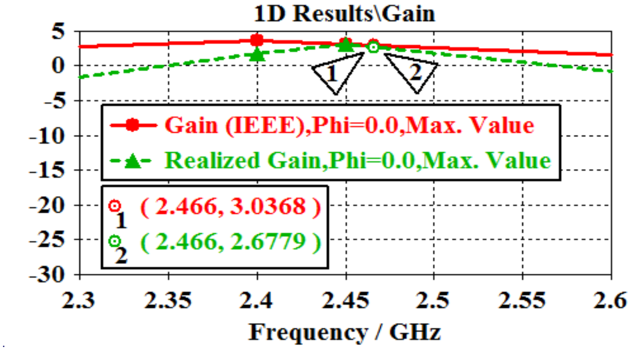


Fig. 11. Gain vs frequency at lung phantom

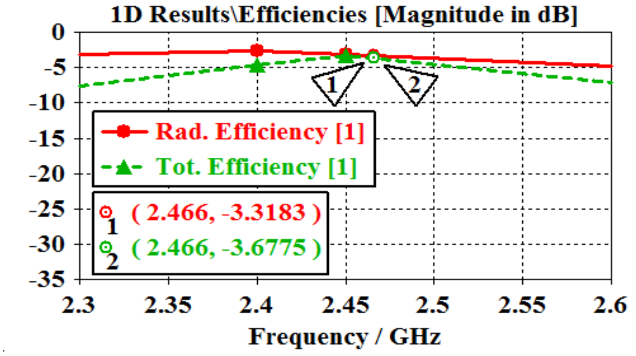


Fig. 12. Efficiency at lung phantom

In Fig. 8, radiation efficiency is 70.3857917% and total efficiency is 70.3801195%. In Fig. 10, radiation efficiency is 68.2794478% and total efficiency is 65.5088537%. In Fig. 12, radiation efficiency is 68.2472254% and total efficiency is 65.4824621%.

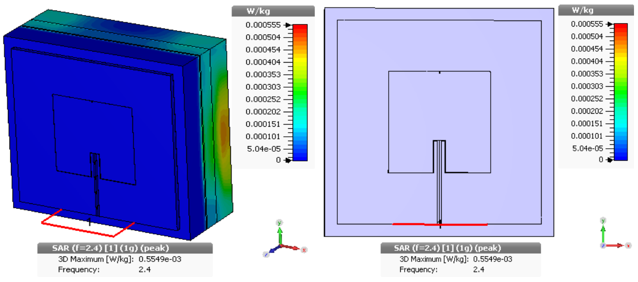


Fig. 13. SAR distribution result from two different perspectives at muscle phantom

SAR is a biomedical antenna parameter indicating the proper radiation amount, won't do any harm in human tissues. 0.467 W/kg (1g of muscle tissue) is the extreme tolerable value of SAR; determined by FCC and ICNIRP guidelines [24]. 3D view of SAR distribution shows for two different sides of the antenna in Fig. 13. Here the extreme SAR for muscle phantom is 0.0005 W/Kg (1g of muscle tissue) through an input power of 1mW which in maximum accepted value.

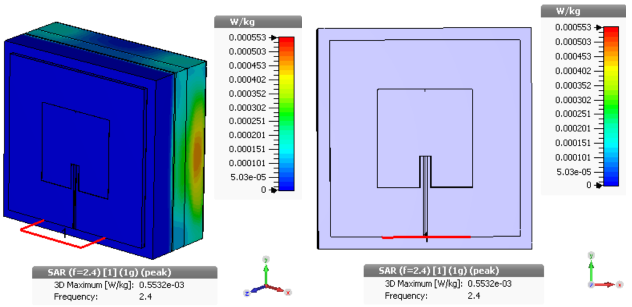


Fig. 14. SAR distribution result from two different perspectives at lung phantom

Here in Fig. 14; the maximum value of SAR for lung phantom is 0.0005 W/Kg (1g of muscle tissue).

IV. MATERIAL CHANGE AND BEND TEST PERFORMANCE ANALYSIS

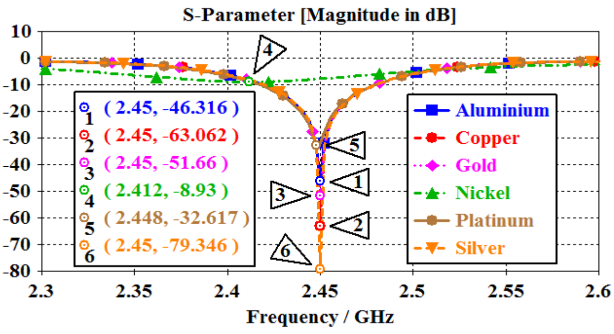


Fig. 15. Material change results of feedline, patch & ground at off-body

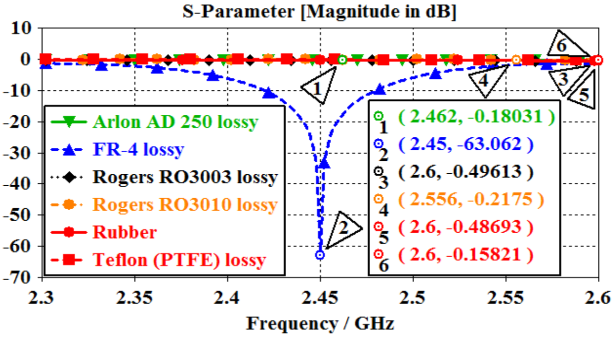


Fig. 16. Material change results of the substrate at off-body

Fig. 15 shows the s-parameter for off-body. From the figure, it is noticed that changing the material of feedline, patch, and ground keeping the substrate material unchanged will not affect the reflection coefficient in most cases. Though at 2.45 GHz, Silver gives better return loss (-79.346 dB) than Copper; Copper is used due to the huge availability.

From Fig. 16 it can be found that, if the material of the substrate will be changed keeping the material of feed-line, patch and ground unchanged will drastically change the reflection coefficient. Here it can be observed that FR-4 material gives a better result (-63.062 dB) than other materials.

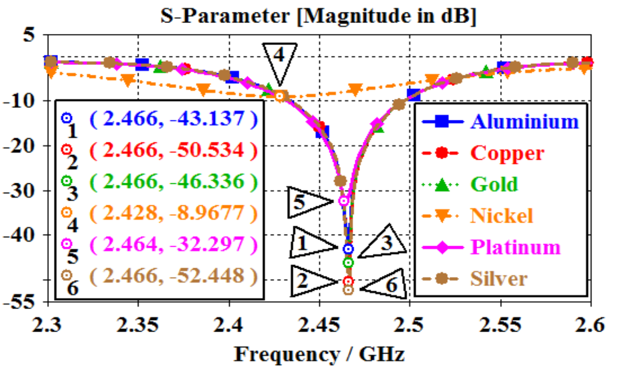


Fig. 17. Material change results of feedline, patch & ground at muscle phantom

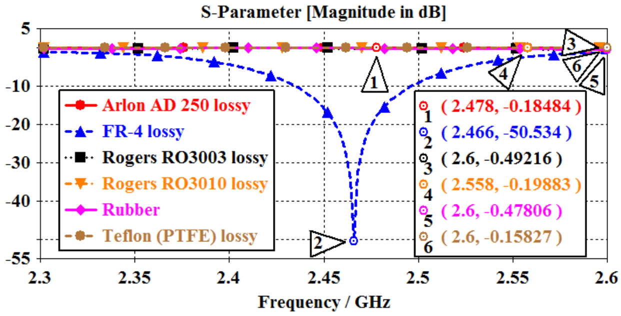


Fig. 18. Material change results of the substrate at muscle phantom

Effect of material change antenna results in muscle phantom is shown in Fig. 17 and Fig. 18

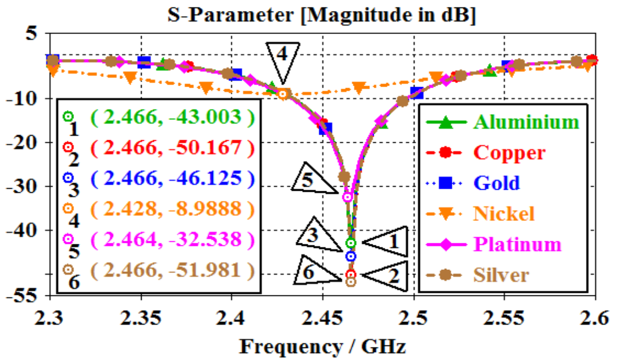


Fig. 19. Material change results of feedline, patch & ground at lung phantom

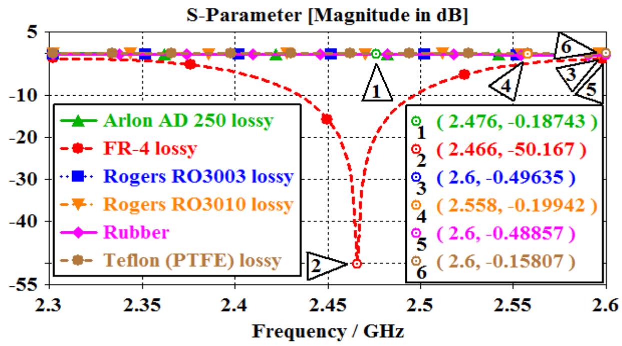


Fig. 20. Material change results of the substrate at lung phantom

Effect of material change antenna results in lung phantom is shown in Fig. 19 and Fig. 20

From the above figures, it is observed that there is a little difference in S_{11} parameter between the muscle Phantom and lung Phantom. The same kind of result also found for gain, efficiency, far-field, radiation pattern and SAR. So, this antenna may be applicable to the detection of the lung's and muscle's diseases.

As the human body is not a plain structure, the antenna needs to bend in several degrees without lagging its performance. Aimed at that purpose, the antenna goes into the test of bend capability. Fig. 21 shows the geometrical illustration of the antenna under the bend capability test.

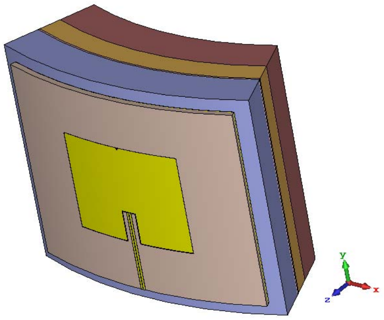


Fig. 21. Antenna undergoing bend test

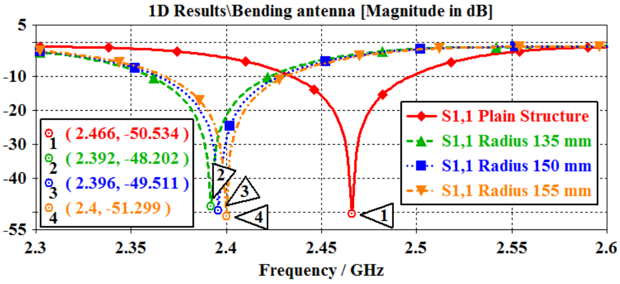


Fig. 22. The reflection coefficient of the antenna at different cylindrical bending for On-body

From Fig. 22 it can be found that on the human phantom model (Air, Skin, Fat, and Muscle); for plain structure and for bend structure it shows different result but all the resonance frequencies for different radius bending are in the ISM band.

V. CONCLUSION

The main goal of this paper is to design an antenna for on-body biomedical application. Here the designed antenna fulfilled the criteria. It works on 2.45 GHz frequency and has an impressive return loss which is -63.062 dB. If Silver is used instead of Copper as the material of Feedline, Patch and Ground it gives -79.346 dB as return loss. VSWR value is also acceptable for the antenna that is 1.0014067 dB. It also gives a better result when placed in the human phantom model. For muscle phantom model it gives -50.534 dB and for lung phantom model it gives -50.167 dB as return loss. It also gives better result in bending test for the different cylindrical radius. Far-Field region for both Polar and 3D, Gain (IEEE), Realized Gain, Radiation Efficiency and Total Efficiency for off-body and on-body are observed and compared. SAR values calculated for on-body shows the notable result. These outstanding results make the antenna suitable for use in practical life. As it gives improved return loss than previously designed antennas by many authors, it may be able to give fruitful result in real life application.

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