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Performance Evaluation of a Microstrip Patch Antenna for On-body Communication in ISM Band

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Abstract: *A microstrip patch antenna is designed for on-body communication in this paper. The designed antenna's performance is evaluated to operate in the Industrial, Scientific and Medical (ISM) band (2.4-2.5 GHz). The antenna's performance parameters such as impressive return loss, miniaturization, higher bandwidth, polarization make it appropriate for on-body application. The performance of the antenna is assessed using a three-layered human phantom environment. To ensure biocompatibility of the antenna, Specific Absorption Rate (SAR) along with bending test are considered using CST Microwave Studio software to check its feasibility in wireless medical applications.*

Keywords: *Biocompatibility, miniaturization, polarization, SAR, return loss.*

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I. Introduction

In this age of the advanced world, communication has transformed into the elementary segment of our life. Antenna has cogently involved unreplaceable position in finding the applications in biomedical [1], Satellite communications [2]-[4], GPS [5]-[6], for its favorable dimension, compactness, low profile, cost-adequacy, better fabrication result as well as simplicity of printing competence on the circuit board. Scientists have been using microstrip antenna in millimeter and microwave for different applications for its low multifaceted nature, miniaturization, light-weight. Exceptional development has acquired the field of microstrip antenna which prompts promising communications.

Design and shape of the antenna is mainly depending on where it is going to apply. Biomedical antennas are widely used for on-body, off-body communications as well as implantable devices [7]-[9]. Recently, an incredible effect is made by microwave application in the field of biomedical. Antennas are mostly considered for biomedical enactment because of the vigorous properties like higher data transmission, low power consumption, compactness. It will be utilized in each phase of treatment in upcoming time [10]. Diagnosing of intricate and extreme ailments, wireless medical annotations and portable monitoring system [11] make it extraordinary thoughtfulness regarding use generally in the biomedical area [12]-[13]. The outstanding benefit of the system is inspecting remotely notwithstanding of the distance among specialist and patient [14]-[15]. Antennas make it easier to link up the diagnosis devices and human body in the field of biomedical engineering. The need of a careful activity and the unpredictable circumstance will decrease in a substantial scale as a biomedical antenna can be utilized for diagnosing and monitoring and in the motivation behind treatment. The antenna based biomedical system will offer more proceeds by the conventional framework and continuous monitoring is possible with the help of these biomedical devices. Medical imaging [16] techniques are also appreciated by the researchers along with microwave imaging methods.

Microstrip antennas have been developed for biomedical purposes. 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. Which is easy to fabricate and 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 functioning frequency bands for medical applications as per FCC regulation are for Industrial, Scientific and Medical Radio (ISM), (2.4-2.5 GHz) and for Medical Device Radio Communications Service (Med-Radio), (401-406 MHz) respectively [1`4-16].This work presents the design and performance analysis of a microstrip patch antenna used for the on-body purpose. Which may be used for observing of several types medical applications. 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's Geometry

Computer Simulation Technology Microwave Studio (CST MWS) simulation tool is utilized to design & simulate the antenna. The proposed antenna is designed to operate it in the ISM band and the resonant frequency is 2.45 GHz. The antenna is designed with the free space (Off-body). After the initial design it is designed with the human phantom model environment to check its performance in the human tissue characteristics which is considered as On-body communications. The antenna dimension is a significant part that should be remembered as the miniaturization of the antennas defeat the challenges of functional usage. Despite the fact that having an on-body communication, maintaining a compact size of the antenna as low as conceivable without having a disparity in execution, was the main apprehension of this simulation. ISM band is selected as the resonant frequency of the antenna, considering its advanced bit rate execution after employment with a high transmission capacity, which makes it an ideal fit for applications such as biomedical telemetry. Considering the applications and the performance parameters and also, to circumvent the cross polarization, the following six equations [17] are used to calculate the length and width of the patch.

Patch width (W):

$$W = \frac{c}{2f_r\sqrt{\frac{\epsilon_r+1}{2}}} \tag{1}$$

Where, f_r = frequency of resonance, c = the velocity of light, ε_r = the constant of dielectric substrate.

Effective Dielectric Constant (ϵ_{reff}):

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{-\frac{1}{2}}, \frac{w}{h} > 1 \tag{2}$$

where, h = height (thickness) of the dielectric substrate, ε_r =dielectric constant of the dielectric substrate, W = patch width.

Length of the patch:

$$\frac{\Delta L}{h} = 0.412\frac{(\epsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\epsilon_{eff}-0.258)(\frac{W}{h}+0.8)} \tag{3}$$

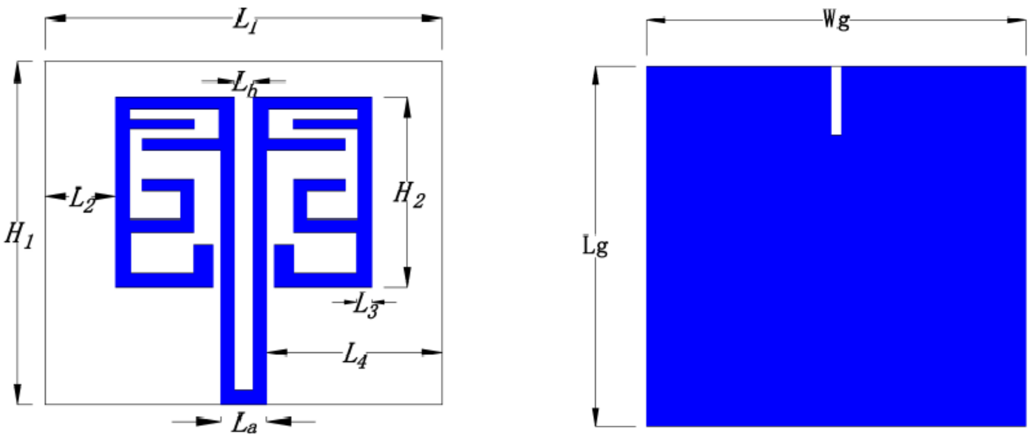
$$L = \frac{c}{2f_r\sqrt{\epsilon_{eff}}} - 2\Delta L \tag{4}$$

Length (Lg) and Width (Wg) of ground plane:

$$Lg = 6h + L \tag{5}$$

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

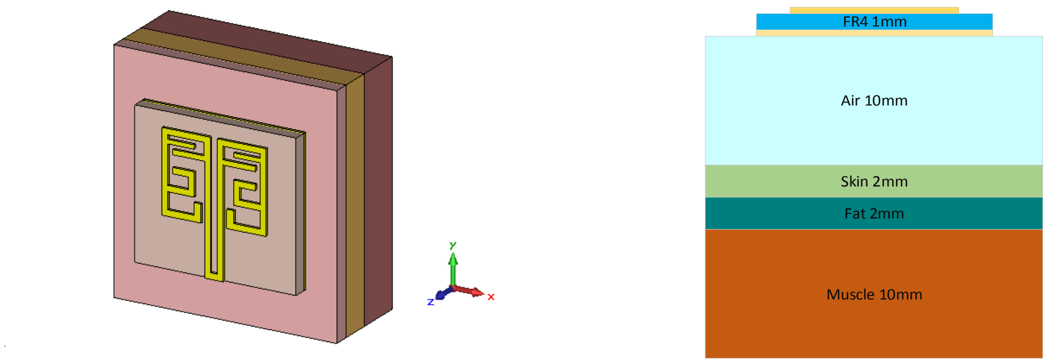
A three-layer of the human phantom model is introduced after finalizing the design with free space for on-body communication. The antenna substrate measurement is 30mmx20mmx0.8mm. The tanδ estimation is 0.002. The thickness of the ground plane and the radiation patch is 0.08mm. Copper is utilized for ground and emanating patch. In this recommended model, a rectangular shape has been picked in light of the fact that a rectangular model has some inalienable focal points. Each side comprises of two arms. The arm is so long to build the current conveying way. Parasitic area is utilized to expand the execution. In the center point of the arm, there is a rectangular shaped patch with measurement 10.50mm x 8.40mm x 0.845.



(a)Radiating Patch of the Antenna (b) Ground Plane

Fig. 1. Geometry Model of The Antenna

Initially, this is a micro-strip antenna with open end space feed line with width 1 mm. Fig. 1(a) demonstrates transmitting patch and 1(b) presents to the ground structure of the antenna. In literatures, there are numerous methods for streamlining. Be that as it may, various simulations are performed to improve the proposed model until achieving a superior outcome. Improvement of the antenna is finished by presenting a slot in the ground plane and emanating patch. A three-layered apparition demonstrate comprises of muscle (10.00mm), fat (2.00mm) and skin (2.00mm) are put underneath the antenna to perform on body communication. The front perspective on the phantom model is appeared in Fig 2.



(a) (b)

Fig. 2. (a) Antenna on Human Phantom Model,
(b) Cross sectional view of the antenna placed on human phantom model

TABLE-I presents antenna's parameters which are utilized during the design procedure. As the emanating patch, just as the ground plane material, Copper is utilized with a thickness of 0.08mm. With a dielectric constant of 4.3, FR4 is utilized as a substrate material that has a thickness of 1.06mm.

TABLE I Antenna's Dimensions

Parameter	Value(mm)		Parameter	Value(mm)
L_1	10.50		H_1	8.40
L_2	1.20		H_2	4.80
L_3	0.40		W_g	*10.50*
L_4	9.5		L_a	0.95
L_g	*8.40*		L_b	0.30

III. Simulation Result Analysis

The Extensive simulation and analysis has to be done to a newly designed antenna so that it can perform almost exactly the same way in real implementation as it is in the computer simulation.

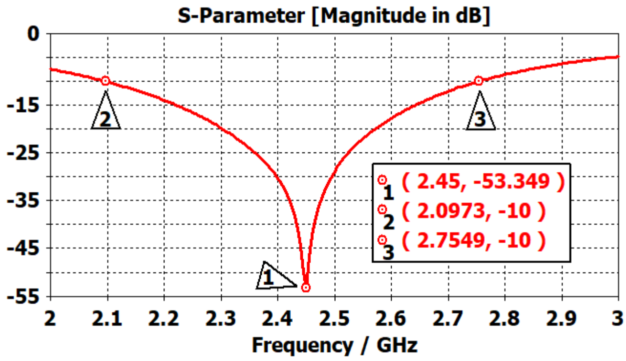


Fig. 3. Return loss of the proposed antenna on a human phantom environment

For this situation, the previously mentioned apparition model of human body with three layer of skin fat and muscle with various thickness are integrated. The proposed antenna is then reenacted on the apparition model to reproduce the practically precise execution. Fig. 2, presents the cross sectional perspective of the antenna on the top of the phantom model. In the event of antenna, the measure of reflected power is one of the key concerns, which is known as reflection coefficient and delineated by S11 parameter. Moreover, as the antenna cannot be set specifically on the uncovered surface of the human body, a small gap of 10mm air is presented in the recreation condition and watched the reenactment results.

Fig. 3 shows the antenna's S 1,1 parameter additionally the resonant frequency is unequivocally 2.45 GHz that is the center frequency of ISM band. The return loss of the antenna is -53.349 dB which is low considering the similar type of antenna in ISM band. The bandwidth (BW) is located between 2.097 GHz-2.755 GHz that denotes a BW of 657.6 MHz.

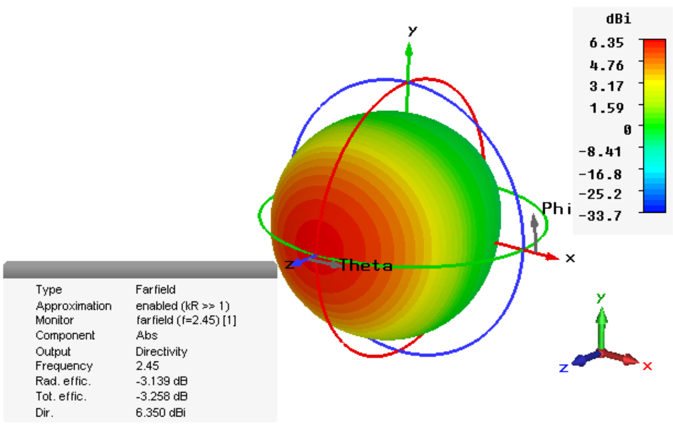
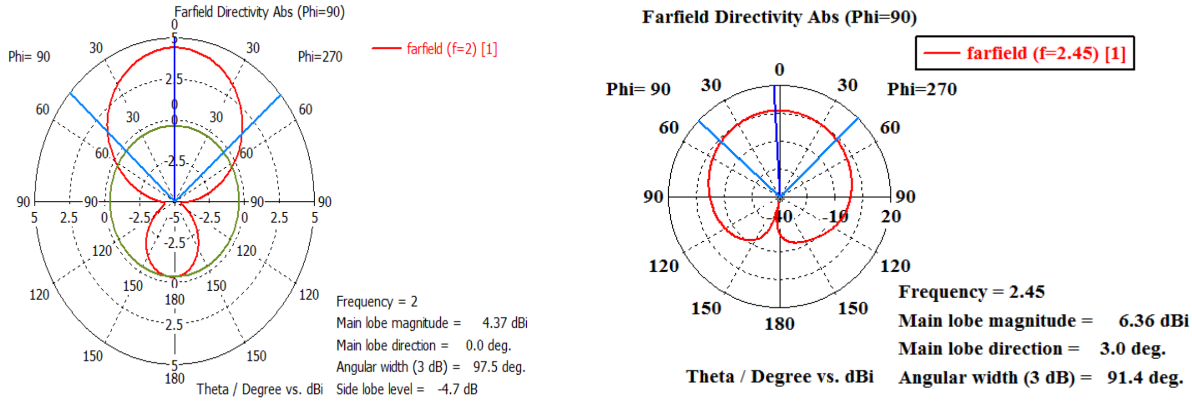
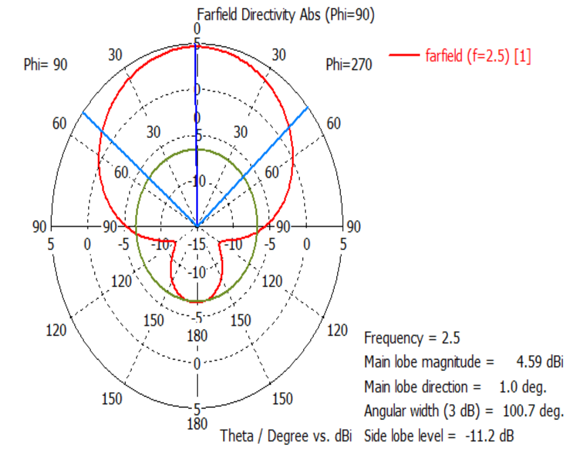


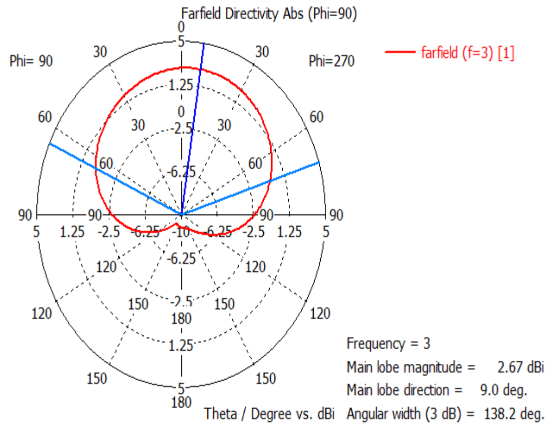
Fig. 4. 3D view of the Far-Field



(a) (b)



(c)



(d)

Fig.5. Far field analysis for different frequencies: (a) 2 GHz, (b) 2.45 GHz, (c) 2.5 GHz and (d) 3 GHz

The directivity of the antenna represents the antenna's radiation focus and directional properties and it can be found by analyzing the Far-field. The antenna is designed and performance was analyzed through iteration technique to achieve a better result. Far-field analysis is observed at four different frequencies such as 2, 2.45, 2.5 and 3 GHz. The detailed data are tabularized in TABLE II which indicates the parameters like main lobe magnitude, main lobe direction, side lobe level and angular width direction. Equating the far-field characteristics for these four frequencies, it can be concluded that the resonant frequency designates a better result.

TABLE II. Far-Field Analysis at Different Frequencies

Frequency (GHz)	Main Lobe Magnitude (dBi)	Main Lobe Direction (degree)	Angular width (3 dB) degree	Side Lobe Level (dB)
2	4.37	0.0	97.5	-4.7
2.45	6.36	3.0	91.4	0
2.5	4.59	1.0	100.7	-11.2
3	2.67	9.0	138.2	0

Power analysis graph shown in Fig. 6 signifies losses in metal as well as dielectrics. Also, it indicates the simulated power, radiated power and accepted power

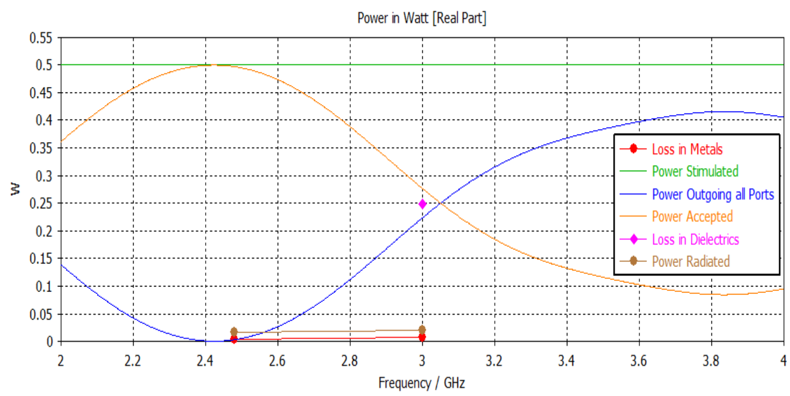
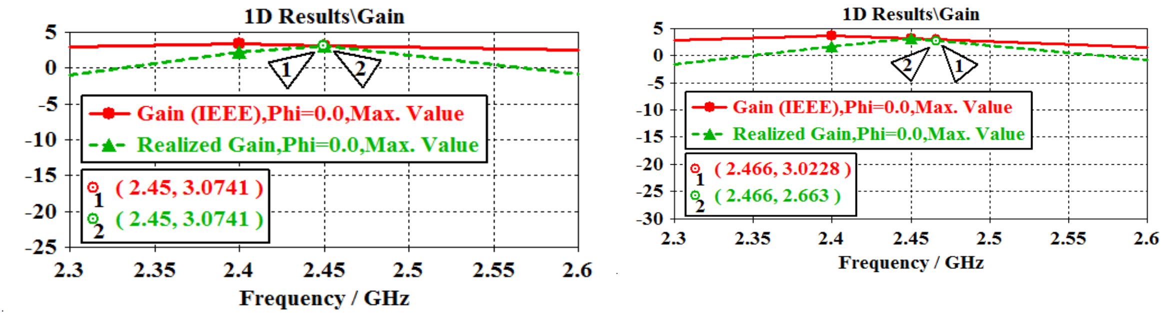


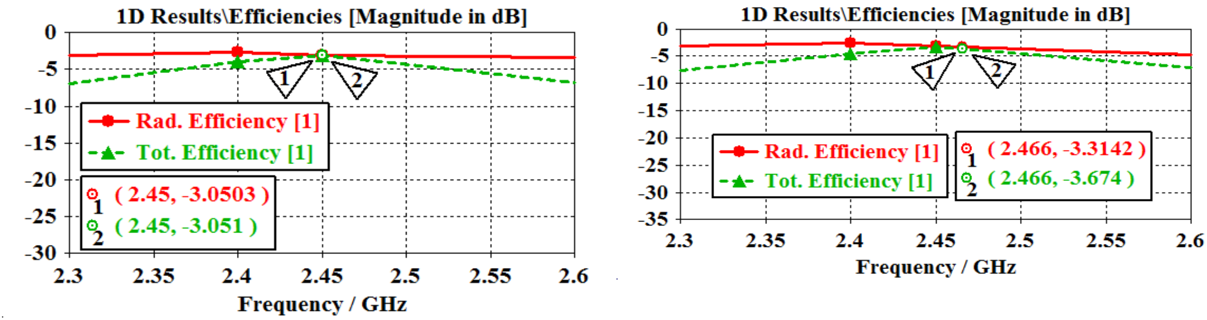
Fig.6. Power Analysis of the Antenna

Gain, Realized Gain, Radiation Efficiency and Total Efficiency are shown in Fig. 7 and Fig. 8 for free space (off-body) and on-body. Gain and Efficiency of the antenna for Off Body are also determined by simulating in software which is shown in Fig. 7 (a) & (b). Gain (IEEE) and Realized Gain at 2.45 GHz frequency are respectively 3.0741 and 3.0741 for off-body and 3.0228 and 2.663 for on-body communication. Radiation Efficiency and Total Efficiency at 2.45 GHz frequency are respectively -3.0503 and -3.051 for off-body and -3.3142 and -3.674 for on-body communication are shown in Fig. 8 (a) & (b)



(a) (b)

Fig. 7. Gain (a)Off body (b) On-body



(a) (b)

Fig. 8. Efficiency (a)Off body (b) On-body

Additionally, we have compared different parameters of some of the references used in this paper and presented in TABLE III.

	Return Loss dB	**Volume mm^3**	**Directivity dBi**	**SAR W/Kg (1 g Tissue)**
Proposed Antenna	-53.35	75.32	6.36	0.470
Ref [1]	-38.42	4.6125	0.319	0.846
Ref [7]	-52.808	3034.9	4.17	0.06435
Ref [8]	-53.349	65.439	4.64	0.467
Ref [10]	-29.856	189.36	3.3	0.328
Ref [12]	-41.44	2304	5.36	0.264
Ref [13]	-40.04	65.57	0.321	1.02
Ref [14]	-69.812	62.4	2.97	0.325
Ref [15]	Off -64.625	254.66	3.96	-
	On -30.492		6.91	0.0293
	In -39.821		4.1	0.280

IV. Study Of Biocompatibility

Biocompatibility examination is dissected by taking the estimations of Specific Absorption Rate (SAR) and bowing limit of the proposed antenna to be companionable with the human body. To sidestep detrimental intricacies or debilitation of human tissue by the radiation of the antenna, SAR discernment is executed. FCC and ICNIRP rules chose the most extraordinary satisfactory estimation of SAR that is 0.470 W/kg (1g tissue) [10]. The SAR figuring of the structured radio wire is presented in Fig.9 from two exchange perspectives. The most outrageous estimation of the SAR here is found 0.328 W/kg (1g tissue) while 1mW power is used as data which double dealings under the extraordinary recognized regard. Thusly, it might be said that the gathering mechanical assembly will work unequivocally without making any kind of damage to human tissue.

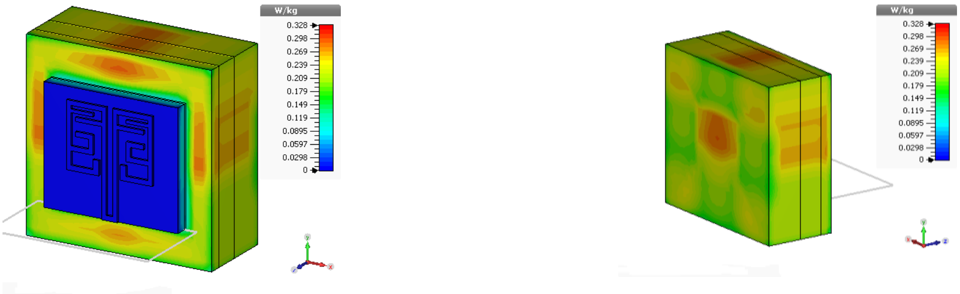


Fig.9. SAR distribution result from different perspectives

Since the use of the proposed reception apparatus is of on-body composed and human body surface isn't organizer, the structured antenna must most likely twist somewhat without arranging its execution. For the bowing limit test, a 30 mm barrel is used to twist the radio wire in x-hub. The geometric delineation of the reception apparatus under twist test is showed up in Fig.10.

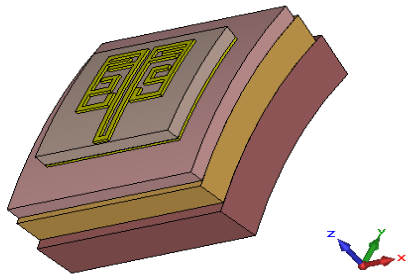


Fig. 10. Antenna Performance during Bend Test

To check the execution capacity so the antenna fits well with the human body surface, the antenna is tried under bending condition with a 30 mm cylinder beneath the muscle layer that is signified to in Fig. 10. Fig. 11 delineates S 1,1 parameters which is return loss correlation among plain and bend conditions. The antenna shows better result in both the conditions and ensures its feasibility when positioned on the human body surface.

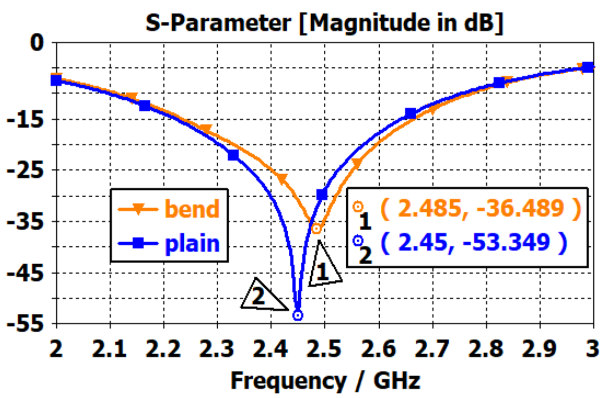


Fig. 11. Comparison result of S11 parameter between plain and bent structure of the antenna

V. Conclusion

In this research, an on-body match ISM band antenna is proposed for wireless medical applications. The antenna's parameters like return loss, size of the antenna, far-field regions, directivity, gain, power analysis confirm its feasibility for the above mentioned applications. To compatible with the human body SAR calculations, bending performance are also utilized to confirm its workability and further research can be utilized by fabricating the antenna and test it with network analyzer.

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