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Antenna design and fabrication for biotelemetry applications

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ABSTRACT

This research work assumes the role of designing a Micro-strip patch antenna that exists within the band range of 402 MHz to 405 MHz, which was considered as medical implantable communication systems (MICS) band and can be possibly implanted at human body phantom model because of its flexibility and lower radiation characteristics. CST microwave studio was used for designing the patch antenna and the human body phantom model with the existence of homogeneous layers (fat, skin and muscle) and the final version was fabricated. Being highly flexible, FR4 was chosen as a substrate to maintain 0.5 mm thickness throughout. For the ground and patch, copper material was selected having thickness of 0.018 mm. For the ease of fabrication and biocompatibility, silicon was selected with the thickness of being 8 mm. Maximum specific absorption rate of the proposed antenna was obtained 0.588 W/Kg for 10 g tissue. Various Parameters such as VSWR, S11, Radiation efficiency, Total efficiency were found 1.1889, -21.28 dB, -45.71 dB, -45.74 dB respectively inside body phantom that ensure the antenna design was efficiently and effectively suitable for biotelemetry system which is body implantable. After fabrication the value of S11 is found -12.43 dB in open space with 453 MHz frequency.

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1. INTRODUCTION

A study of the signal transmission at the sector of biomedical with the remote record of various parameters that would not occur any embodied disturbances and can protect the lives monitored, is known as Biotelemetry system [1]. Many organizations come up with distinctive features, such as wireless communication and monitoring assistance [2]. The assesment of a biological signal at a space that has been done along with the biotelemetry system by external monitoring. The signal is transmitted for monitoring the patient condition, which is placed at a negligible distance from the patient body [3].

In 1970s microstrip patch antennas became immensely famous because of space-borne application and widely used in biotelemetry due to some major charactieristics such as lower profile, agreeable to planar, non-planar exterior, simple and uncomplicated fabrication and vigorous design [4]. In present days, a number of antenna designs have been proposed on several researches for the different applications [5]. With many advantages, this antenna can communicate with others wireless system spontaneously [6, 7]. With ease of manufacturing, replacement facility and being light weight, low profile, low cost, and high efficiency are possible in such advances [8, 9]. The popularity of patch antenna in microwave communication is increased nowadays that requires semispherical coverage [10] A microstrip patch antenna's geometric shape contains a radiating patch on one side of the dielectric substrate with a ground plane on the other. Radiating element can be square, circular, semicircular, and triangular [11]. Communication with other devices is much easier with this antennas and contains more advantages [12]. The main concerns and requirements to design an antenna are to maintain patient safety, wider bandwidth, radiation efficiency as well as compact size [13, 14]. Various types of antenna have been developed, e.g. meander line, monopole, and loop antenna for wireless monitoring [15, 16].

Though it is economical, the International Telecommunication Union-Radio communication permited the medical implantable communication systems (MICS) is in between the range of 402 MHz-405 MHz frequency band because of having the quality of less power consumption, higher-data-rate-transmission and lower noise portion of the spectrum [17]. U.S. Federal Communications Commission (FCC) and the European Radio Communications Committee (ERC) regulated the MICS band [18].

In this paper, a fabricated design of microstrip patch antenna with the three parts of ground, substrate and patch is presented which operates in MICS band (402 MHz to 405 MHz) inside body phantom. A human phantom model is schemed by using the CST microwave studio for the investigation of the performance of antenna while placing it inside the human tissue. Before implanting the antenna inside the human body phantom, it is let into silicon for biocompatibility. The final material is resultantly chosen for the proper performance through the observation and analyzation of all the paramerts value by changing the material used in patch.

2. STRUCTURE AND DESIGN METHOD

2.1. Equations

The following equations are used to calculated the values of different parameters for designing the microstrip patch antenna [19].

$$\text{Width, W} = \frac{c}{2f_r\sqrt{\frac{\varepsilon r+1}{2}}} \tag{1}$$

Here,
fr=Resonance frequency (404 MHz); c=Light speed (3*108 m/s); εr=Relative permittivity of the dielectric substrate (3.5)

$$\text{Effective Dielectric Constant, } \varepsilon eff = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+12(\frac{h}{w})}}\right] \tag{2}$$

W=Patch width; h=Thickness (0.5 mm)

$$\text{The Effective length, } L_{eff} = \frac{C}{2f_{\circ}\sqrt{\varepsilon_{eff}}} \tag{3}$$

$$\text{Length extension, } \Delta L = \frac{C}{2f_r\sqrt{\varepsilon_{rff}}} - 0.824h\left(\frac{(\varepsilon_{rff}+0.3)(\frac{W}{h}+0.264}{(\varepsilon_{rff}-0.258)(\frac{W}{h}+0.8)}\right) \tag{4}$$

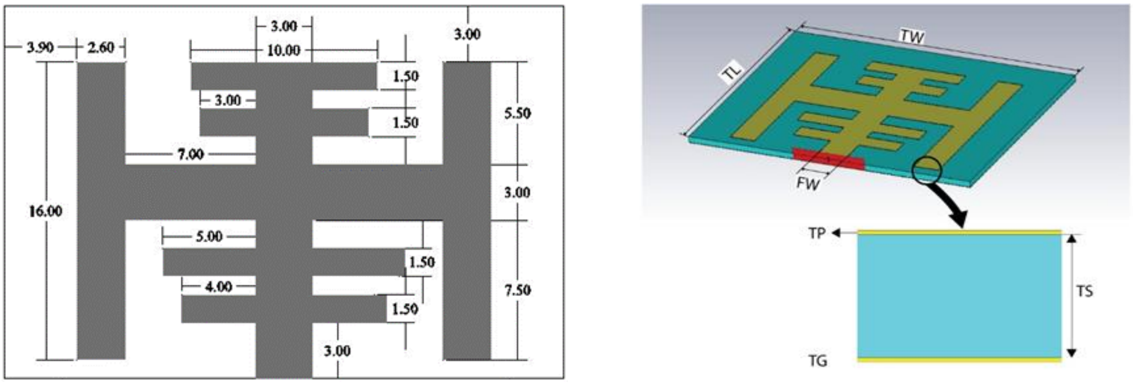
$$\text{Actual length of the patch, } L = L_{eff} - 2\Delta L \tag{5}$$

After calculating the parameters the length (L) and width (W) were found 199.14 mm and 248.45 mm individually. Dividing the length and width, it can be possible to maintain the ratio for achieving the goal and it can be modified until the operating frequency was found at MICS band.

2.2. Antenna model

A rectangular shaped microstrip-patch antenna with the 20 mm length and 30 mm width is designed by using CST is described in this article. Ground, substrate and patch are used for creating the proposed antenna where the copper is used to make the ground and the flexible FR4 material is used as substrate maintaing 0.5 mm thickness. When the antenna is designed the total thickness is maintained 0.536 mm (0.5 mm+0.018 mm+0.018 mm) and the dimension is 20×30×0.536 mm (321 mm^3) in order to reduce the effects of a high conductive human tissue as well as to avoid shortening the antenna [20]. The biocompatibility and the size are the main objections to design the proposed antenna. A body phantom model is created along with the designed antenna because of checking its biocompatibility property by locating the antenna in the pronouned model where the values are kept in millimeter range to design the antenna. In

Figure 1(a) the geometrical view of the proposed patch antenna has been shown, which can be operated in MICS band. Figure 1(b) shows the substrate and waveguide port positioning at the antenna with a feed line (3 mm) which is placed in the central part of the antenna. The waveguide port is linked with input power which is in the downward of the feed line. The waveguide port is indicated by the red segment in Figure 1(b) at Table 1, the size of all the parameters is tabulated.



(a) (b)

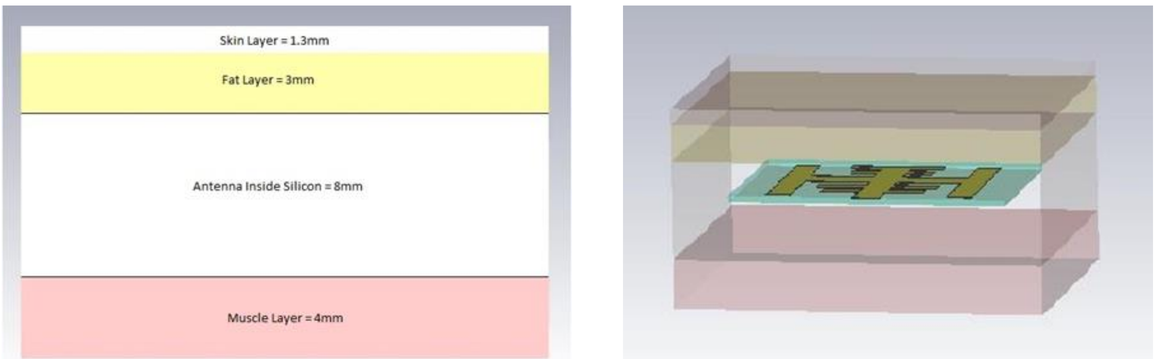
Figure 1. Proposed antenna; (a) geometrical view, (b) design with dimension

Table 1. The parameters of the antenna

Parameters	Symbol	Size (mm)
Length	TL	30
Width	TW	20
Patch thickness	TP	0.018
Substrate thickness	TS	0.5
Ground thickness	TG	0.018
Feedline width	FW	3

2.3. Human body phantom

To analysis the biocompatibility of mentioned antenna, a human body phantom model is designed with the help of CST microwave studio where the antenna has been created for biotelemetry system. Before implanting the pronouned antenna antenna inside the human body phantom model, silicon has been used to create biocompatible weather with thickness of 8 mm [21]. The human body phantom model is consisting skin, fat and muscle maintaining the thickness of 1.3mm, 3 mm and 4 mm respectively with the appropriate electric and dielectric constant which are shown in Figure 2(a). The antenna containing silicon layer is placed in between the fat and muscle layer to examine the proposed antenna. Figure 2(b) represents the antenna which is overlapped with silicon inside human phantom model. All these procedures have been followed for making this designed antenna biocompatible.



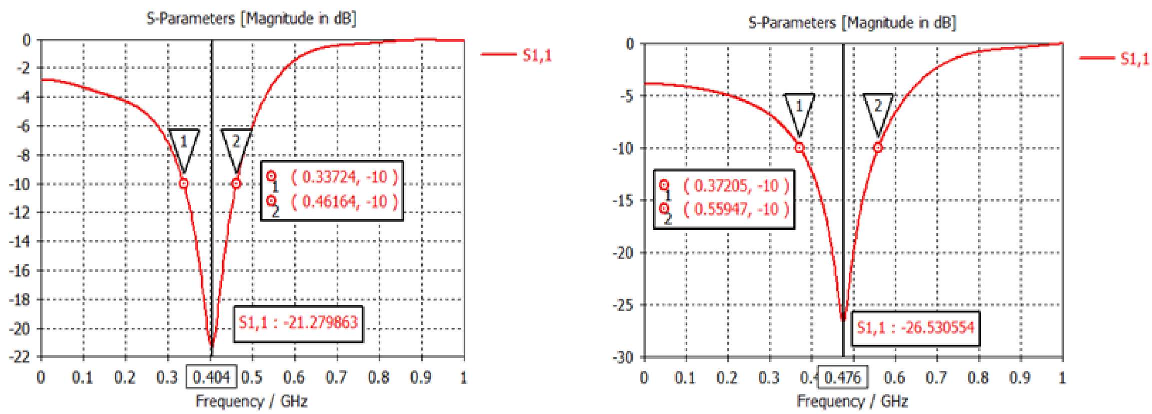
(a) (b)

Figure 2. Human body phantom; (a) layers, (b) antenna position

3. ANTENNA CHARACTERISTICS

3.1. Reflection coefficient or S11 parameter

The S11 parameter which is known as reflection coefficient or return loss is the measurement of the power from an antenna which is radiated or reflected [22]. At resonant frequency, the return loss is noticed while implanting the pronouned antenna inside the designed phantom model and free space. In Figure 3, the X-axis is indicated the frequency at the range of GHz & the Y-axis is indicated the return loss in dB scale. The return loss is observed -21.27986 dB by maintaing the MICS band range with the resonant frequency of 404 MHz for ensuring the biocompatibility inside the phantom. And in free space, the return loss is observed -26.53 dB in resonace frequency of 476 MHz. The free space return loss is shown in Figure 3(b) while the return loss inside body phantom is shown in Figure 3(a). The maximum radiation can be shown in return loss with a better output of the proposed antenna [23]. The antenna's bandwidth is observed 124.4 MHz (337.24 MHz to 461.64 MHz) inside the phantom and 187.4 MHz (372.05 MHz to 559.47 MHz) in free space by framing up a linear line towards the -10 dB can assure the compatibility of the implantion of proposed antenna inside the human body [24].

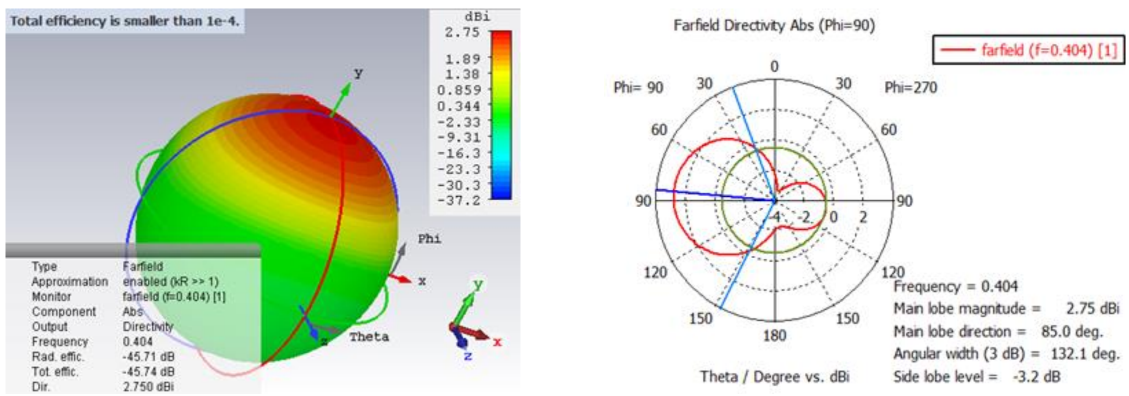


(a) (b)

Figure 3. Return loss or S11 parameter; (a) inside body phantom, (b) in free space

3.2. Far-field radiation pattern

The radiation characteristics of the proposed antenna inside human body phantom has been shown in Figure 4. While impleting inside body phantom model then it is observed that, 2.75 dBi is the directivity and -45.74 dB is the total efficiency of the antenna and at resonance frequency (404 MHz), the radiation efficiency is found -45.71 dB. The radiation pattern is unidirectional as seen in the Figure 4. From Figure 4(b), the far-field radiation pattern with the polar view of the mentioned antenna is explained from where it can be said that the magnitude of the main lobe is 2.75 dBi.



(a) (b)

Figure 4. Far-field radiation pattern; (a) 3D view, (b) polar view

3.3. Specific absorption rate (SAR)

The radiation pattern is noticed by the adjacent tissues which is measured by using specific absorption ratio (SAR) for maintain safety [25]. Depending on the measurement of Federal Communications Commission (FCC), SAR might be lower than 2 W/Kg for 10 gm tissue to assure the higher safety [26-28]. Figure 5 represents the maximum specific absorption rate for the antenna at resonant frequency that is obtained for 10 g tissue. The SAR is 0.588 W/kg putting 1 mW input power for 10 g tissue.

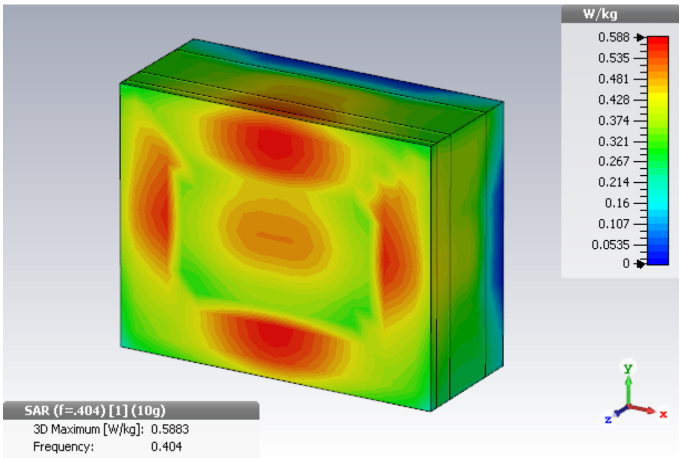
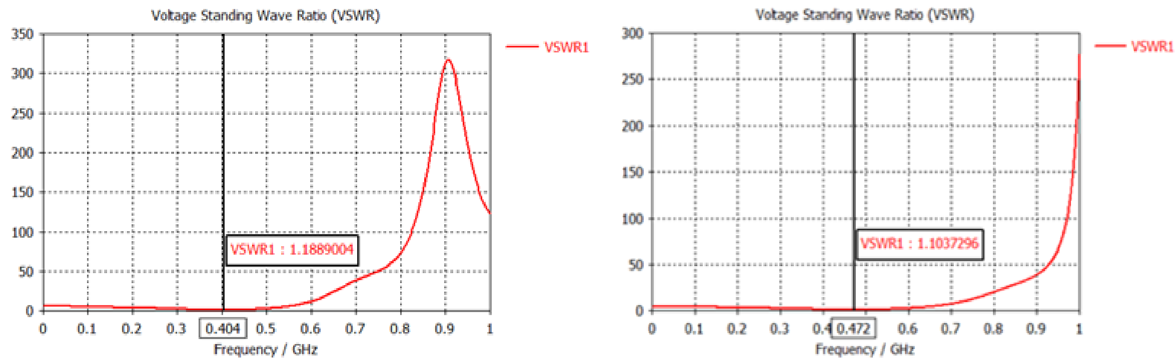


Figure 5. SAR distribution for 1 mW of input power

3.4. Voltage standing wave ratio (VSWR)

The function of reflection coefficient is known as voltage standing wave ratio (VSWR) which is measured by the power reflected from the antenna [29]. Due to ensuring the favourable performance of the antenna, the value of voltage standing wave ratio should be present in between the range of 1 to 2 [30]. In Figure 6, the X-axis is represented the frequency (GHz range) and the Y-axis is represented VSWR that is found 1.1889 inside human phantom model and 1.1037296 in free space at resonant frequency (404 MHz & 472 MHz) which is desired for the designed antenna.



(a) (b)

Figure 6. VSWR of the proposed antenna (a) inside human body phantom model (b) in free space

4. ANTENNA FABRICATION AND TESTING

The designed antenna has been fabricated by using PCB printing technology and in the case of free space analyzation, ENA network analyzer was used for testing from where the return loss was found -12.430 dB at 453.71 MHz which is prity much close result comparing with our simulated results in free space. The small differences in values shows due to perfection in printing and in thickness. Figure 7 shows the fabricated antenna and Figure 8 shows the return loss or S11 in free space measured by ENA network analyzer.

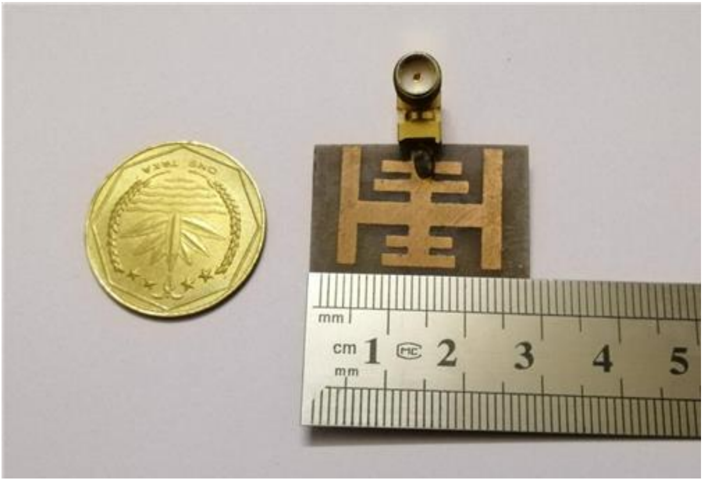


Figure 7. Fabricated antenna for bio-telemetry applications

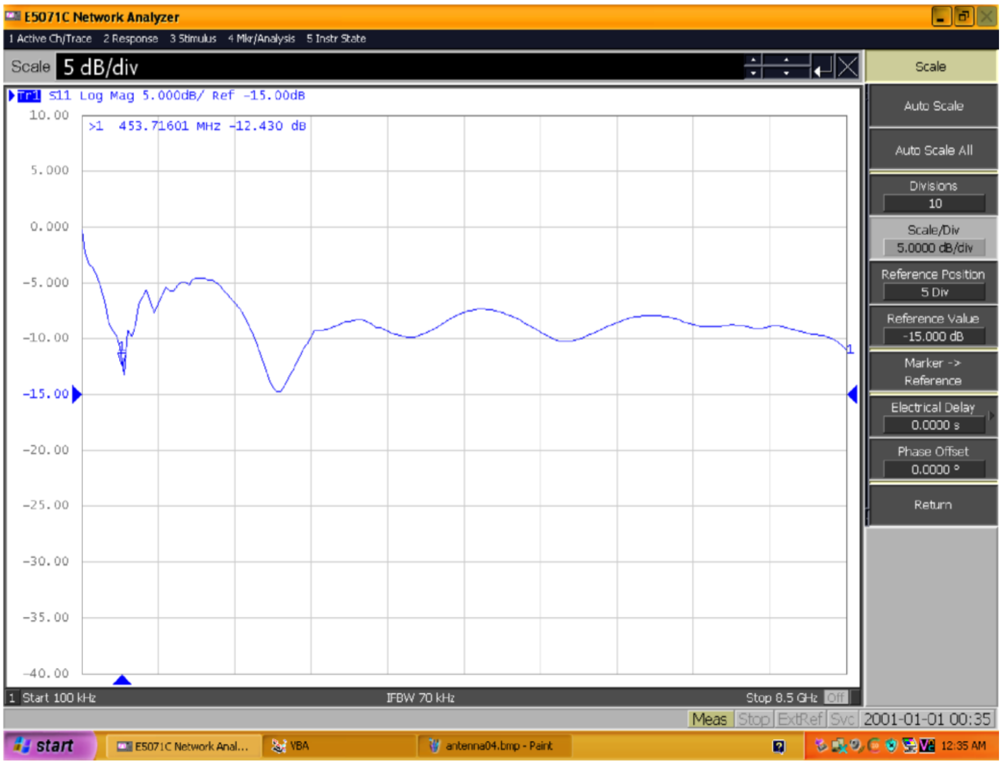
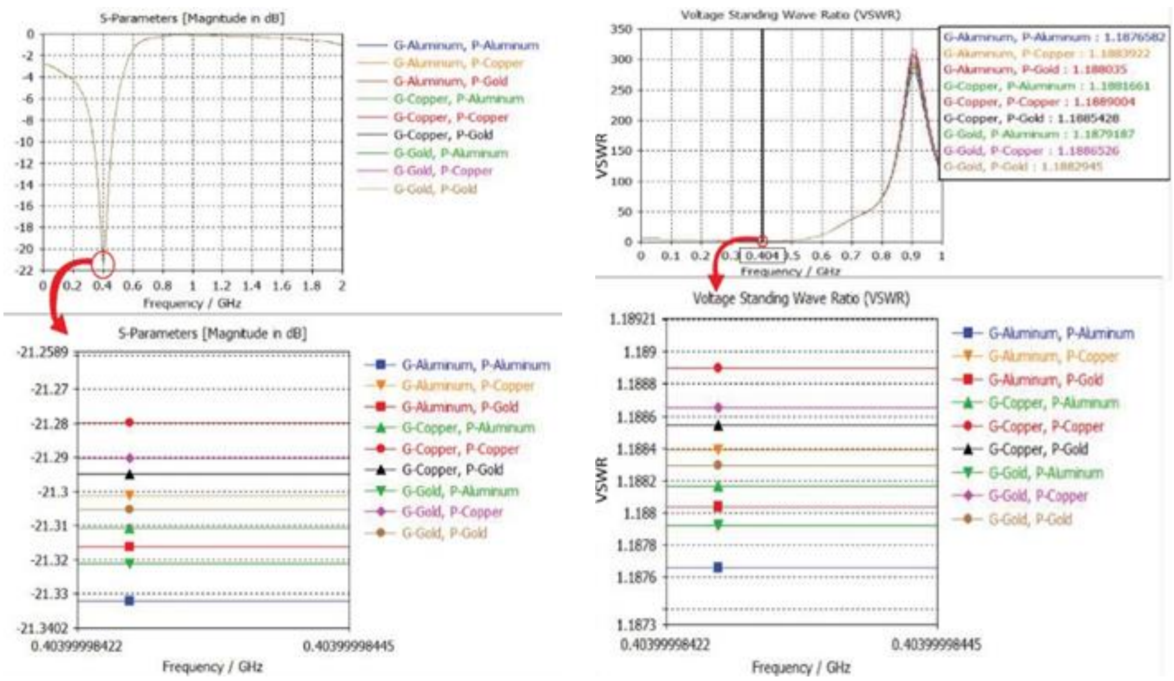


Figure 8. Tested S11 parameter by ENA network analyzer

5. COMPARISON ANALYSIS

By alternating the materials (aluminum, gold and copper) of ground and patch with their dissimilarities, the mentioned antenna is also explored after implanting inside the human body phantom model. As par as shown in Figure 9, It can be said that the ground and patch of aluminum combination is provided the best return loss and VSWR which are obtained -21.33 dB and 1.1876582 respectively. Specific absorption rate (SAR) of aluminum ground and aluminum patch combination is also obtained 0.589 W/kg which is higher than the value of copper ground and copper patch. In copper ground and gold patch combination, gold ground and gold patch combination and aluminum ground and gold patch combination in these three case the specific absorption rate is found 0.586 W/kg. For all the abbreviations, the operating frequency, directivity, total and radiation efficiency are standing in the same position.



(a) (b)

Figure 9. The variation of; (a) S11, and (b) VSWR analysis for the difference in ground and patch of the pronouned antenna

6. CONCLUSION

The performance of a in body microstrip patch antenna is observed in this research by designing an antenna for biotelemetry system which is operating in MICS band. Various parameters of the designed antenna such as resonant frequency, bandwidth and return loss are observed 404 MHz, 124.4 MHz and -21.28 dB respectively inside the phantom which indicate the better performance of the designed antenna. SAR is also calculated at 404 MHz for ensuring the safety which is obtained 0.586 W/kg for 10 g tissues. While the use of different types of materials as patch and ground are occured then it has been observed that use of Gold as patch and ground gives the better performance of S11 with the value of -21.31 dB and VSWR with the value of 1.1882945. All these simulated results are justified when the antenna parameters are compared with the fabricated results done by the PCB printing technology and tested the values by using ENA network analyzer and the return loss was found -12.430 dB at 453.71601 MHz which is nearabout similar with the simulated result. After completing all these analyzation of parameters values and comparison, it is expected that the propounded antenna can be used as the implanted antenna for biotelemetry applications.

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