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Research paper

Mobile Application SAR Analysis in Human Head Model Using a Dual Frequency Triple Slotted Patch, Inset feed, Flexible Softwear Antenna

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Abstract

A triple slotted softwear antenna with an inset feed working in dual frequency was introduced for mobile and any wearable electronics application. This is flexible and has the textile and wearable properties bending in 2D plane. This uses various substrates like Velcro, fleece and polystyrene foam and by using scaling technique these substrates have made to operate with a frequency of 5.8-8 GHz. The main objective is to appraise the antenna parameters (free space and human phantom model interaction).A good S_{11} of -17.7 and -29.66dB was obtained. The directivity of 6-7dB and a gain of 6dB were obtained for almost all the substrates in the designed antenna for free space propagation. Polystyrene foam is chosen finally due to its less SAR value and flexibility for fabrication. The proposed antenna is then positioned on various locations such as left ear, right ear and an Occipital position of the human head phantom. This softwear antenna is excited a gap excitation of maintaining a distance between the antenna and human head model, which is a superior way to achieve a significant reduction. Since the distance is relative to SAR, it has been reduced proficiently and the left ear in human interface gives a reduced SAR in simulation. Hence this proposed antenna is suitable for any wearable applications. The simulated results, fabricated softwear antenna and the measured result using Network analyzer were compared and tabulated.

Key words: Head Phantom model, Softwear antenna, soft fabric substrates, specific absorption Rate (SAR)

1. Introduction

The combination of textile and wearable antenna properties are called softwear antenna, patch in planar structure, flexible in 2D can bend simultaneously along 2 planes, optimized in proximity to human body substantiate to attachment surfaces [13]. Softwear Patch antennas are reduced cost, with low profile and are easily fabricated which uses soft substrate and ground plane in two dimension and flexible [19]. They are mostly used at microwave frequencies [14].Antenna engineers were able to expand designs based on individual specifications and requirements before the evolution of portable wireless devices and mobile handsets. The modern prominence plummeting the size, improved power efficiency and summit FCC Requirements for mobile handset are some of the additional imperative rudiments of the antenna design. The efficiency of the antenna and controlling SAR are the main factors focusing in this investigation. The present research analyze the performance of a single antenna with different substrates having slot patch in free space and also in the presence of the human head model, Further Specific Absorption Rate has been depicted for various distance and location when this antenna is used in mobile phones, wearable electronics and headsets. [4,5,7] Proposed a Ground Plane Effects on SAR for Human Head Model Exposed to a Dual-Band PIFA found the effects of ground plane on the Specific absorption rate (SAR) in SAM head model exposed PIFA antenna. The dual-band PIFA working at 900 MHz and 1800 MHz was designed to operate with a ground plane. Systematic biases on SAR in SAM head model resulting from shape effect of the ground was investigated as both the average SAR over a mass of 1g and 10g in the head models exposed to a dual band PIFA were determined [16]. The variations of 1g averaged SAR and 10g averaged SAR have been calculated, the ground size has significant influence on SAR in head model when ground plane size L<0.8λ, and it has little effect on SAR in head model when L>0.8λ When the radiator interacts near to head model, a change in the resonant frequency was observed. SAM head model provided only a conservative estimation in peak spatial-average SAR for mobile phones. Different soft textile materials have been compared for wearable applications [2, 6].

In addition, the cases of using cellular phones in enclosed areas were studied. Moreover, the effect of distance between source and head model was investigated. At the same levels of radiated power, SAR levels in the tissues are less than the safety limit recommendations, except in skin and CSF tissues. The effect of age on dielectric properties of tissues, and head size in SAR measurement was studied [1]. The results show a very small difference in temperature elevation because of age. For children, temperature increases by ~2% than adults'. This means that the dielectric properties for the child head models do not significantly affect the temperature elevation [17]. This could be explained as a cancellation of the increased conductivity and decreased electric field penetrating into the tissue [11, 12]. It is found that the induced temperature elevation in the brain never exceeds 0.48C. This value is well below the threshold for the induction of adverse thermal effects to the neurons. SAR values were compared for 3D head models [3].

Since the dielectric permittivity of the soft textile substrate is much less than the hard substrate, designing an antenna over those substrates and making them work on par with hard substrates is much more challenging. The antenna design on the patch and the ground is kept constant and various substrates and antenna parameters were introduced and compared. The main objective behind choosing four different substrates is based on the fact that these substrates represent different range of dielectric permittivity such as Velcro represents low level dielectric permittivity 1.34 and Fleece and Polystyrene Foam represents much lower dielectric permittivity 1.17, 1.02 respectively. Rogers Duroid RT5880 represents higher level dielectric permittivity (2.2). Since four different substrates of varying dielectric permittivity were used, an optimum substrate thickness for each substrate is considered for designing the proposed patch [20].

Various antenna parameters such as radiation pattern, VSWR, gain, directivity which describes various aspect of the designed antenna were obtained. These parameters are then recorded which in turn is used for further analysis. Then the tabulated parameters are compared with parameters obtained from other substrates. In order to reduce the SAR, it is essential to bring changes in the antenna current distribution which is achieved by introducing two large rectangular box slots and an elliptical slot in the ground plane of the antenna. Similarly, slots were also set in the radiating patch but two strip slots and a rectangular box slot each of which are designed in the same length. The occurrence of the health risk caused by wearable devices due to absorption of thermal power on the human tissue should be investigated. The proposed antenna was then oriented on the left and right human head model also it was placed at a distance, where a separation of λ distance was maintained and observations were made for further analysis. Below Figure.1.shows the human head model analysis.

The Industrial, Scientific and Medical (ISM) bands are radio bands reserved internationally for the use of radio frequency (RF) energy for industrial, scientific and medical purpose other than telecommunication.

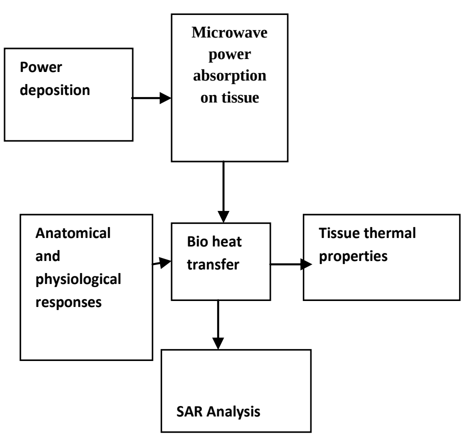


Fig. 1:. Human Head model analysis process

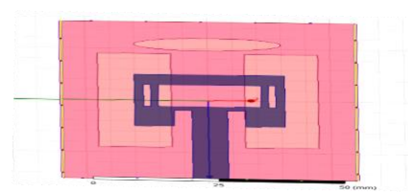
The proposed softwear patch antenna is operational in 5.72-5.82 GHz as per worldwide ISM band. These bands are used in low power communication systems and medical application. Proposed antenna plays a crucial role in Body Centric Wireless Communications (BCWN) and Wireless Body Area network (WBAN) application [18].

2. Ii. Softwear Antenna Specification

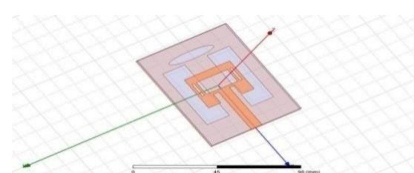
Table1: .Softwear antenna Design Specification

Design Parameters	Rogers Rt/Duroid 5880	Velcro	Fleece	Polystyrene Foam
Dielectric constant	2.2	1.34	1.17	1.02
Scaling Factor(units)	1.5	1.7	1.74	1.82
Patch Size Along X Axis(mm)	30.67	34.76	35.58	37.21
Patch Size Along Y Axis(mm)	24.75	28.05	28.71	30.03
Substrate Size Along X Axis(mm)	60.15	68.17	69.774	72.982
Substrate Size Along Y Axis(mm)	75.61	85.69	87.71	91.74
Substrate Thickness(mm)	2.3622	2.67	2.677	2.866
Inset Distance(mm)	7.56	8.56	8.76	9.17
Inset Gap(mm)	3.63	4.12	4.22	4.41
Feed Width(mm)	7.27	8.248	8.44	8.83
Feed Length(mm)	25.62	28.84	29.50	30.85

The design specification of the proposed softwear patch antenna has been shown in above table: 1.Substrates like Rogers, Velcro, Fleece, polystyrene foam has been introduced and the Performances of the proposed antenna has been shown below



(a)



(b)

Fig. 2: Proposed Softwear antenna

Above Figure.2. (a, b) shows the design of the proposed softwear patch antenna using HFSS.

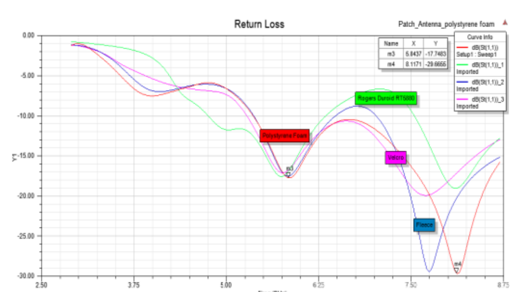


Fig.3:. Simulated S_{11} in free space for various substrates

Figure.3 shows the S_{11} parameter of the proposed antenna. Below Figure.4 shows the SAR, temperature and E, H fields of the antenna on different substrates.

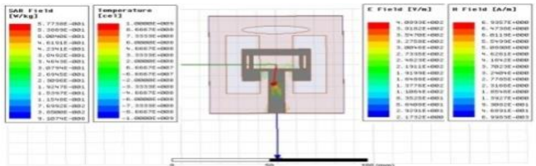


Fig.4:.: Simulated Results of SAR, Temperature, E-Field & H-field

Since the Slotted softwear Patch antenna on all four substrates has a return loss value less than-10dB at 5.8GHz, it is clearly evident that the Polystyrene Foam has the highest Return loss value which means only a negligible power is lost.

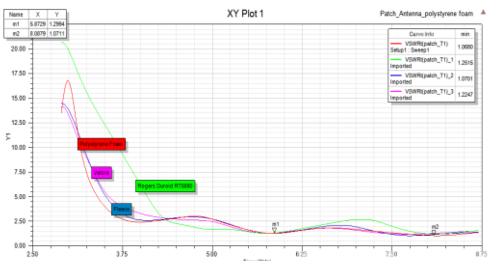


Fig.5:.VSWR of softwear antenna on different Substrates

Higher the VSWR means higher the reflection coefficient which causes maximum reflection loss. VSWR incorporates insertion loss as well. Above Fig: 5. Illustrate the comparison graph, it is concluded that the VSWR of softwear antenna on Polystyrene Foam shows the best figures of 1.0680 and the VSWR of Rectangular Patch in Rogers Duroid RT 5880 shows highest VSWR of1.2515.

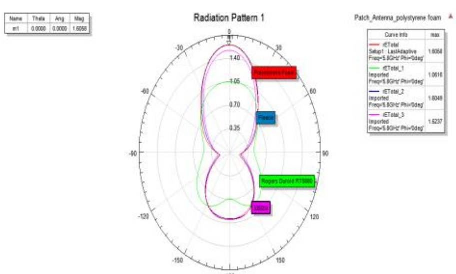


Fig.6:. Radiation pattern Comparison of softwear antenna on different substrates

As the graph Fig.6.Indicates, almost all the substrates are having the same identical Radiation pattern. Above Fig: 6.shows the Radiation pattern on different substrates, the identical pattern obtained here is a Bi-directional Radiation obtained along the 0 degree and -180 degree respectively. By comparing, it is clearly evident that the magnitude of the Radiation pattern of Polystyrene Foam is higher than other substrates respectively.

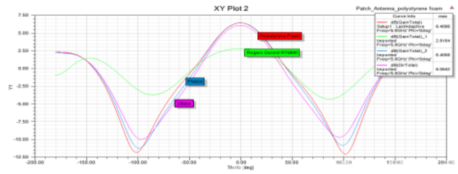


Fig. 7:. Variation in Gain of softwear antenna on different

In this proposed antenna on Polystyrene Foam i

In Fig: 7 shows the highest antenna gain of 6.4095 dB whereas in Rogers, Duroid shows the lowest antenna gain of 2.8184 db. The antenna gain of Rectangular Patch on Velcro and Fleece is 6.0542 dB and 6.4058 dB respectively. An antenna that radiates equally in all directions would have effectively zero directionality, and the directivity of this type of antenna would be 0dB. Increased directivity implies a more focused or directed antenna.

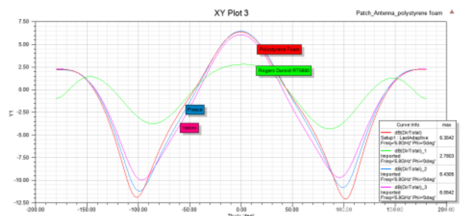


Fig.8:. Directivity of softwear antenna on different substrates performance

Directivity of patch antenna ranges from 2 to 10dB. Here the softwear antenna on Polystyrene Foam in Fig: 8 shows the highest directivity value of 6.3542 dB on Rogers,Duroid substrate shows the lowest directivity of 2.7803 dB. Even Velcro and Fleece show good directivity values in the order of about 6 dB.

Table 2: Comparison of the various parametric Observations of the softwear antenna for different substrates

Antenna Parameters	Rogers Rt/Duroid 5880	Velcro	Fleece	Polystyrene Foam
Working (Dual)Frequency (GHz)	5.8	5.8	5.8	5.8
	8	7.7	7.7	8
Return Loss(dB)	-17	-17	-17	-17
	-19	-19	-29	-29
Gain(dB)	6.13	6.88	6.99	6.70
Directivity(dB)	6.09	6.97	7.01	6.64
VSWR	1.30	1.22	1.07	1.06
SAR(W/kg)	0.60	0.76	0.57	0.01
Mismatch Loss	0.08	0.04	0	0
Reflection Coefficient	0.13	0.1	0.03	0.03
E-Field(V/m)	962.92	475.29	408.93	393.68
H-Field(A/m)	4.527	6.151	6.935	4.016
Z0 Input Impedance(Ω)	16.37	20.49	21.33	23.09
Dielectric Constant	2.2	1.34	1.17	1.02

Designed softwear antenna was kept constant and various parametric observations for different substrates were obtained and were tabulated in the above table .2.

3. Assortment Techniques in Reduction of SAR

Reducing the electric and magnetic field of the softwear antenna will effect to reduce the value of SAR in human head that can be made by using the RF shield. SAR can also be reduced by changing in the antenna surface current distribution, using suitable Metamaterial also by changing the antenna physical structure or feeding network. By bringing changes in the radiation edges or by introducing geometric changes such as embedding slots, SAR can be reduced effectively. A slot is being introduced, then there is a significant difference in the antenna performance, the size of the slot differs, or small slots are introduced in the antenna structure, it improves the gain and directivity of the antenna but there was also an increase in the SAR value which most of the times surpass the SAR limit to above 1.6 W/Kg. When bigger slots are introduced in the antenna structure although there was a slight drop in the peak gain and directivity, there was a significant drop in the SAR value which exceeds the country limit which leads to unbearable radiations, which affects health of the human head.

$$SAR_{(X,\,Y,\,Z)} = \frac{\sigma(X,Y,Z)|E(X,Y,Z)|^2}{\rho(X,Y,Z)} \text{(W/Kg)} \quad (1)$$

E = root mean square value of the E-Field, (Volt/m), σ = conductivity of the head (Siemens/m) and ρ= mass density of the head (Kg/m^3)

$$SAR = \frac{\sigma|Ex^2|}{\rho} \quad (2)$$

Where σ is the conductivity of the tissue S/m
ρ is the density and E_x is the tissue rms electric field strength

Maximum value of SAR (X, Y, Z) for the whole head model is obtained as shown in equation (1)Specific absorption rate is computed from the induced electric field strength, electrical conductivity of the medium and the mass density. The amount of RF power engrossed in a unit mass of human body tissue, measured in watts per kilogram. It can be calculated by integrating over a specific volume. SAR limit is varied in different countries based on standardization. The physical quantity of SAR causes heating of tissues due to RF exposure a bio heat equation solves temperature elevation and timing effect exposure, Penne's[3] projected a model for blood perfusion within the tissues which is given in the below expression

$$C_P(z)\rho(z)\frac{\partial T(z,t)}{\partial t} = k(z)\nabla^2 T(z,t) + \rho(z)SAR(z) - B(z)(T(z,t) - T_b) \quad (3)$$

Where C_p is the specific heat in tissue, thermal conductivity, T_b is the blood temperature is the tissue temperature is related to blood perfusion. The geometrical parameters and thermal properties the heating device which is connected externally should be considered for SAR distribution. Moreover the size of the head the Fresnel zone and Fraunhofer zone around the head also considered. In general, in the adjacent region is reactive field E and Fields are 90° out of phase commonly given as $R < 0.62\sqrt{\frac{D^3}{\lambda}}$ Fresnel region lies between near and far field ,shape of the pattern may vary with distance given as $0.62\sqrt{\frac{D^3}{\lambda}} < R < \frac{2D^2}{\lambda}$ therefore a compact size antenna is needed to reduce SAR.This softwear patch antenna with slots will reduce SAR, the efficiency of this proposed antenna is more effective and SAR is reduced by placing it on various positions and gap excitement is maintained for various distances, as distance varies SAR is also varied accordingly. Also SAR is reduced when the antenna is placed on left ear. Hence this antenna is well suited for other wearable devices also.

4. Analysis of Placing the Softwear Antenna in Different Positions of Human Head Phantom Model

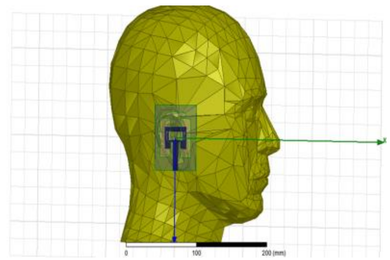


Fig.9:. Softwear Antenna positioned on left ear

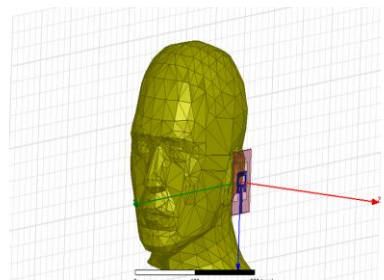


Fig. 10:. Softwear Antenna positioned on Right ear

Figure.9, 10, 11 shows the different positions on the human head model analysis when the softwear antenna was placed on various positions including Right ear, Left earand Occipitalpositions. Polystyrene foam and Fleece are the soft substrate material which gives better performance over other substrates. This gives the flexibility and can bend concurrently along two planes and optimized in propinquity to human head.

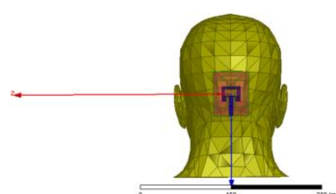


Fig. 11:. Antenna placed on Occipital position

It is clearly seen that when the antenna is brought near the human head there is a significant change in the antenna performance. Below table shows the change in performance of the antenna after placing the softwear antenna on the human head phantom model.

Table 3:.Performance of the softwear antenna after placement on human head phantom model in different positions

Antenna place	Operating Frequency(GHz)	Peak Gain(dB)	E-field(V/m)	H-field(A/m)	SAR(W/Kg)	VSWR

ment on						
Left Ear	5.8 & 4.4	6.8950	5758	39.29	0.5804	1.0824
Right Ear	5.8 & 4.4	6.8950	5749	39.27	0.5930	1.0824
On Occipital position	5.6	7.0516	5202	55.88	1.5397	0.941

Above table .3.shows the change in antenna performance after placing on human head phantom model. The simulation result shows the variation in working frequency when it is placed very near to the phantom model. Similarly other parameters like VSWR, gain, have been changed which shows the on body and free space performance. Also, it is noted that their exist a small difference in the value of SAR between Left ear, right ear respectively. It states, that the SAR value obtained at the left ear is slightly less than the SAR value obtained at the right ear. Hence reduction in SAR is given as SAR reduction factor,

$$SRF=\frac{P_{absorbed}-P_{dissipated}}{P_{absorbed}} \quad (4)$$

It can be concluded that it is safer to use this softwear antenna, when it is used in mobile or any other wearable electronics at the left ear rather than keeping it in right ear.

5. Orientation of Antenna with Various Distances

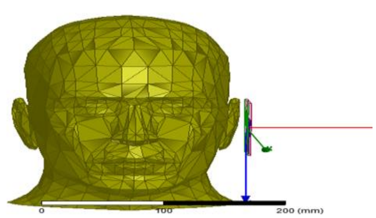


Fig. 12:. Antenna placement at a gap excitement of 4mm from the head model

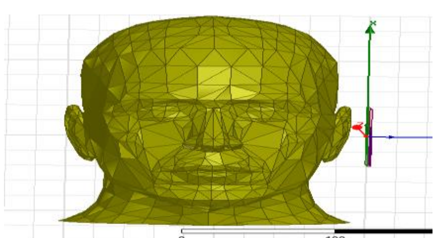


Fig. 13:. Antenna placement at a gap excitement of 6mm from the head model

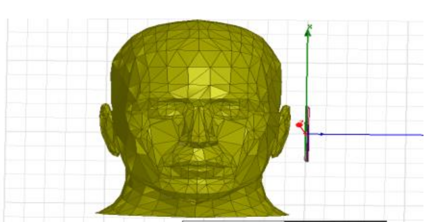


Fig. 14 : Antenna placement at a gap excitement of 8mm from the head model

An optimum distance between the softwear antenna and the human head model is shown in Fig.12, 13, 14. In order to avoid the radiation as much as possible and also to get the antenna working with an optimum performance. Due to its novel design in softwear antenna a significant reduction of the Fresnel field is achieved.

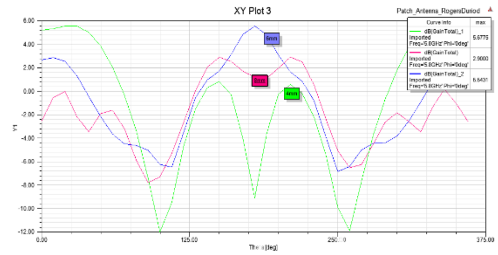


Fig. 15:. Distance Analysis between softwear antenna and human head

Figure. 15, 16show the simulated results of Gain, directivity when positioned in various distances like 4mm, 6mm, and 8mm respectively.

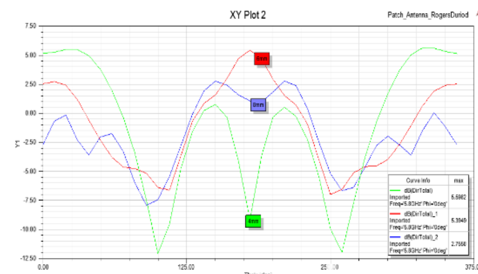


Fig. 16:. Distance Analysis between softwear antenna and human head model based on Directivity

Table4:. Performance Analysis of Antenna when kept at different distance from the head

Distance between softwear antenna &head model	Performance					
	Operating Frequency (GHz)	Gain(dB)	E-Field(V/m)	H-Field (A/m)	SAR (W/Kg)	VSWR
4mm	5.8	6.8950	5758	39.29	0.5904	1.082
	4.4					
6mm	3.4	6.0924	3850	55.24	1.5502	0.053
8mm	6	5.8800	3368	63.151	1.6599	4.4

Table.3 illustrates, the distance between the softwear antenna and human skin interaction on the human head model analysis, only at an optimum distance of 4mm, the antenna is resonating perfectly at designed frequency of 5.8GHz. At 4mm, the VSWR of the antenna is only 1.0824 which suggests that there is less reflection loss respectively. SAR is also reduced at 4 mm distance. Maximum linear dimension D of the proposed antenna satisfies R> $\frac{2D^2}{\lambda}$, where $R > D$ and R> λ.in the far field since in the far field at 4mm and 8mm the field behaves like a plane waves.

Fig.17:.Fabricated softwear Antenna

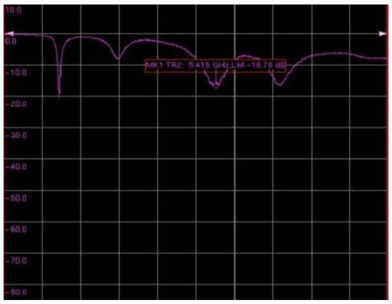


Fig: 18: Measured S_{11} of the Proposed Softwear antenna

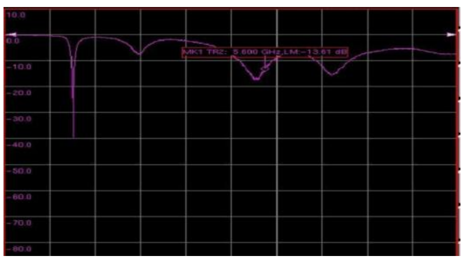


Fig: 19 :S_{11} of the Proposed Softwear antenna

Figure .17. Shows the fabricated softwear antenna. And the measured S_{11} result using Network Analyzer was shown in figure.18.It shows the multiband frequencies of5.6GHz & -13.61dB.Also 5.415GHz & -16.78dB is shown in Figure: 19 respectively. And Figure: 20 shows the voltage standing wave ratio of the proposed fabricated antenna

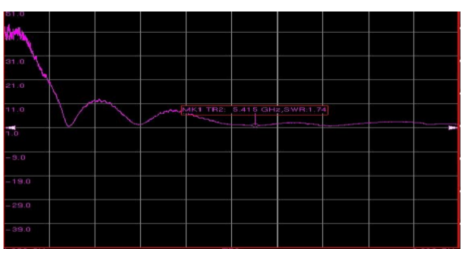


Fig: 20: Measured VSWR of the Proposed Softwear antenna

Table5: Measured Result of the proposed Antenna

parameters	Simulated Result	Measured Result
Working frequency	5.8 GHz	5.6 GHz
	8GHz	5.4 GHz
Return Loss	-17dB	-13.61 dB
	-29dB	-16.78 dB
VSWR	1.06	1.0

Above Table:5 shows the measured result using Network Analyzer in which the simulated results have been compared with measured results.

6. Conclusion

A comprehensive investigation has been performed and softwear patch antenna with an innovative design slots, operating in dual frequency of various substrates has been analyzed. Inferences obtained by simulation after placing the antenna close to a high relative permittivity structure such as human head phantom, considerable performance changes has been achieved. The amount of radiation experienced at right ear is slightly more than the left ear respectively. Human head antenna was alienated the performance analysis were made and at 4mm distance between antenna and human head analysis SAR reduction was achieved. The measured results are approximately equivalent to its simulated result. Therefore, the soft substrate like polystyrene and the distance maintained between the human head and antenna interface are very significant in reduction of SAR and the flexibility needed for any wearable and mobile applications was achieved by the proposed antenna.

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