IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 16, Issue 3 Ser. II (May – June 2021), PP 17-24
www.iosrjournals.org

Design of Compact Ultra-wideband Flexible Monopole Antennas.

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Abstract:
In now-a-days trend of wearable antenna, Monopole antenna are good choice because of its simple structure, omnidirectional radiation pattern and ease of fabrication. The antenna#1 is designed using Polyamide substrate with thickness of 0.8mm having dielectric constant of 4.3 and dimension of 30mm X 20mm and antenna#2 is designed using Teslin substrate with thickness of 0.712mm having dielectric constant of 2.18 and dimension of 30mm X 20mm.Antenna designed have ultra-wideband of 12.4 GHz and 14.2 GHz. The antenna#1 operates over frequency range of 2 GHz to 14.4 GHz having bandwidth of 12.4 GHz and antenna#2 operates over frequency range of 2 GHz to 16.2 GHz having bandwidth of 14.2 GHz. The antenna designed are intended for ultra-wideband and Body Centric wearable Communication (BCWC). Ultra-wideband are becoming very popular in modern wireless communications systems because UWB antenna replaces multi narrow band antenna. Simulation of designed antenna was done on CST microwave studio 2016. The simulation results show that return loss of antenna is below -10 dB above mentioned frequency range. Efficiency and gain are also calculated and mentioned below. The designed and fabricated antennas reflection characteristics are measured using Anritsu MS2073C vector network analyzer (VNA).

Keywords: *Polyamide, Teslin, Rectangular Microstrip, Ultra-wide band.*

Date of Submission: 05-06-2021 Date of Acceptance: 18-06-2021

I. Introduction:

A flexible Monopole antenna are used for UWB and also considered good choice for wideband/UWB and EWB as it has simple structure, omnidirectional radiation pattern, which is used in mobile devices and it is easy to fabricate. In today's wireless communication world, Wearable antenna has gained importance in healthcare, tracking and navigation, mobile computing and public safety applications. Also increasing demand in field of WBAN has diverted researcher's mind to wearable textile antenna. Selection of textile material with proper dielectric constant and thickness is of utmost importance in wearable antenna.

The proposed antennas are designed on polyamide substrate having a dielectric constant of 4.3 and a loss tangent of 0.004 having thickness of 0.8mm, and Teslin paper with a dielectric constant of 2.18 and loss tangent of 0.02 having thickness of 0.712mm. Antenna Radiates at 2 GHz ,6 GHz and 10 GHz [1]. In this paper, technique for preparing soft and flexible substrates for antennas has been presented. This improved the low adhesion characteristic of PDMS. PDMS+glass antenna resonates at 2.8 GHz frequency with return loss of -19.0073 dB and VSWR of 1.2525. Antenna performance is also improved as values of relative permeability and loss tangents are reduced to great extent [2]. Wearable antennas are mostly microstrip patch antenna. Performance of wearable antenna are affected by dielectric constant, loss tangents, moisture, deformation, temperature etc. Also discussed various fabrication method of wearable antenna [3]. WBAN antenna is designed and analyzed. From results it is clear that textile materials have increased the efficiency, they are also flexible. This makes antenna suitable for on/off body application such as medical and military. As distance between human body and antenna reduces efficiency, directivity and gain. WBAN antenna reduces the shift in resonant frequency also there is not much reduction is efficiency, directivity and gain [4]. Here textile patch antenna is designed on leather substrate (dielectric constant = 1.8) for on-body wireless communication which radiates at 2.44 GHz. The antenna has gain of 5.59 dB and bandwidth of 56.6 MHz [5]. In this paper, UWB antenna on jeans substrate for wearable application is fabricated and presented. Here three different structures of antenna are designed all operating over frequency range of 3 GHz to 12 GHz [6]. This paper is study of characteristic of textile material for development of wearable antenna. Also, wearable antenna operating at 2.45 GHz is designed. While designing wearable antenna we have to take care of electromagnetic properties of textile material chosen. Other factors that directly affect antenna gain, bandwidth and efficiency are porosity, moisture content and homogeneity [7]. In this paper, MPA is designed on Rogers RT Duroid 5880 having dielectric constant of 2.2 (Height = 0.254mm) operating at 28 GHz for 5 G communication at LMDS band. The designed antenna has gain of 6.69 dB and bandwidth of 582 MHz with maximum reflection coefficient of -12.59 dB [8]. Proposed article is about design of triple wideband high directivity stacked textile antenna. Antenna has wide BW of 18.38 % covering 3.6667 GHz to 4.409 GHz frequency range, 7.76 % covering 7.2132 GHz to 7.795 GHz frequency range and 7.67 % covering 10.03 GHz to 10.83 GHz frequency range [9]. In this manuscript, textile antenna using jeans substrate operating at three different wide band with gain of 3.353 dBi, 4.237 dBi, 5.193 dBi suitable for various wireless communication systems is designed and fabricated [10]. In following experimentation, two different structures of antenna are designed -1) Rectangular microstrip patch antenna and 2) Rectangular with U-slots antenna with slits. antenna#1 resonates at 2.5 GHz with return loss of -16.86 dB and antenna#2 resonates at 2.2 GHz with return loss of -41.68 dB and 3.9 GHz with return loss of -16.16 dB [11].

1.1 Textile Material Selection:

Wearable antennas are becoming popular due to its vast applications in fields of wireless technology. While designing WBAN antenna selection textile material is very important. Textile substrate with proper dielectric constant and thickness must be chosen to enhance the band width. Textile material have low dielectric constant which reduces surface wave loss.

In this paper antenna#1 is designed using polyamide substrate having dielectric constant of 4.3 and thickness of 0.8mm and antenna#2 is designed using Teslin substrate having dielectric constant of 2.18 and thickness of 0.712mm.

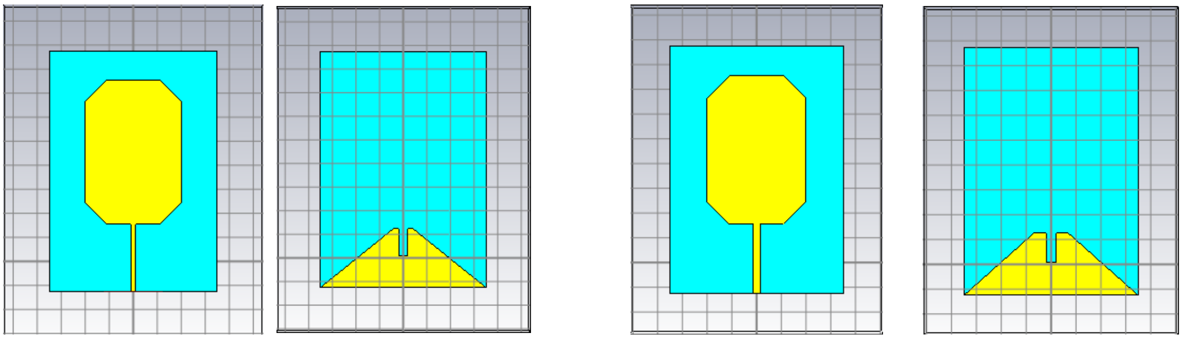
Ref. radiator	Substrate used	Flexible/ conformal	Operating range (GHz)	Size(mm^3)	Peak gain (dBi)
1	Leather	Yes	2.4,3.51,4.69	80x80x2	2.1
2	Polyamide	Yes	5.18-5.32	24x24x0.1	5.86
3	FR-4	No	0.4,2.4-2.5	32x50.3x1.8	NO
4	FR-4	No	2.9-11	15x25x1.6	3.5
5	FR-4	No	3.3-12	36.6x39x1.6	6
6	FR-4	No	2.4-2.7	30x40x1.6	NO
7	Felt	Yes	2.45	46x25x2	4.48
8	Liquid crystalline polymer (LCP)	Yes	2.5-11	40x22x0.1	4.2
9	Rogers RO4003C	Yes	2.2-3.8	80x60x0.2	6.3
12	Clear PVC	Yes	1.8-5,5.5-6.4	55x40x3	5.9
Proposed Antennas	Polyamide	Yes	1.8-13.3	50x40x0.8	5.53
	Teslin -paper	Yes	1.4-13.4	50x40x0.712	4.4

II. Antenna Design and Configuration:

In this article two wearable antenna are designed and fabricated. Antenna#1 is designed on polyamide substrate with dielectric constant of 4.3, loss tangent of 0.004 and thickness of 0.8mm and antenna#2 is designed on Teslin substrate with dielectric constant of 2.18, loss tangent of 0.002 and thickness of 0.712mm. Antenna#1 gives wide band of 2 GHz to 14.4 GHz with band width of 12.4 GHz and antenna#2 gives wide band of 2 GHz to 16.2 GHz with band width of 14.2 GHz. UWB has much application in the areas of defense, wireless communication. Wide band can be achieved by edge truncation (Change in radiator) and tapering ground plane and putting slots on ground plane. Design and dimension of antenna are shown in Fig. 1 (a-d). In planar monopole antennas, dimensions of the radiator and height of the radiator from ground plane influences the lower edge of the bandwidth. To radiate efficiently antenna input impedance must be match to output. So, impedance on antenna must be 50 ohms. To achieve this antenna#1 has feed line of 14 mm and feed width of 1.6mm and antenna#2 has feed line of 14 mm and feed width of 2.2 mm. The antenna is designed in four steps as shown in Fig. 1 (e-h). First design is simple rectangular patch antenna with partial ground plane of 12.5 mm. This reduces Q-factor and we get wide band characteristics (e). Partial ground plane aids to reduce the Q-factor, thereby a wideband characteristic is obtained. In second step ground plane is tapered exactly in middle with slot of width 2 mm and length of 5.8 mm (f). Proper dimension is chosen to get good impedance matching. Ground plane is cut with triangular slot as shown in fig.1-g, to enhance the impedance bandwidth through reduction in Q factor (g). Finally, radiating patch is modified by cutting the edge of radiating patch as shown in fig 1-g. Hence wideband is achieved and also better impedance matching (h).

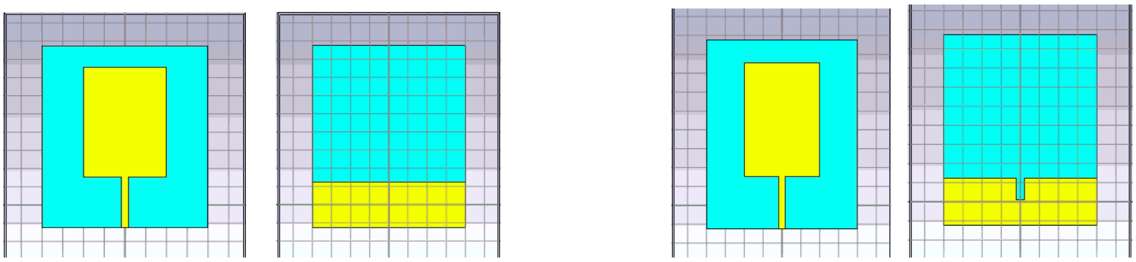
Parameters Value	Description	Value
W	Width of patch	20
L	Length of patch	30
Ls	Length of substrate	50

Ws	Width of substrate	40
Lg	Length of ground	12.5
Wg	Width of ground	40
Lfeed	Length of feed	14
Wfeed	Width of feed for antenna#1, antenna#2	1.1, 1.5

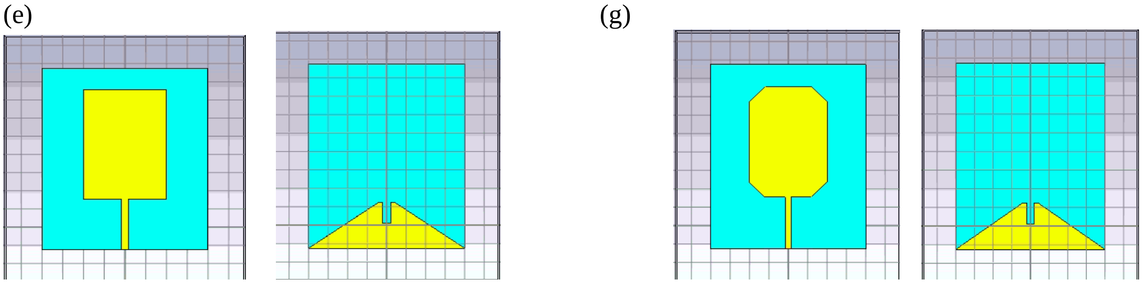


(a) Top view (b) Bottom view (c) Top view (d)Bottom view

Antenna#1 (Polyamide) Antenna#2 (Teslin)



(e) (g)



(g) (h)

Evolution of proposed antenna (e – h)

The dimensions of antenna are calculated for resonant frequency of 2 GHz, 6GHz and 10GHz.
Antenna#1 designed on polyamide substrate with dielectric constant of 4.3, height of 0.8 mm and antenna#2 designed on Teslin substrate with dielectric constant of 2.18, height of 0.712 mm as follows. The dimensions antenna are calculated as follows.

A) Effective width of patch:

$$Width = \frac{C}{2f0\sqrt{\frac{(\varepsilon r+1)}{2}}}$$

B) Effective dielectric constant:

$$\in eff = \frac{(\varepsilon r+1)}{2} + \frac{(\varepsilon r-1)}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{W}\right)}}\right]$$

C) Effective length of antenna:

$$Length = \frac{C}{2fo\sqrt{\varepsilon eff}} - 0.824h\left(\frac{(\varepsilon eff+0.3)(\frac{W}{h}+0.264)}{(\varepsilon eff-0.258)(\frac{W}{h}+0.8)}\right)$$

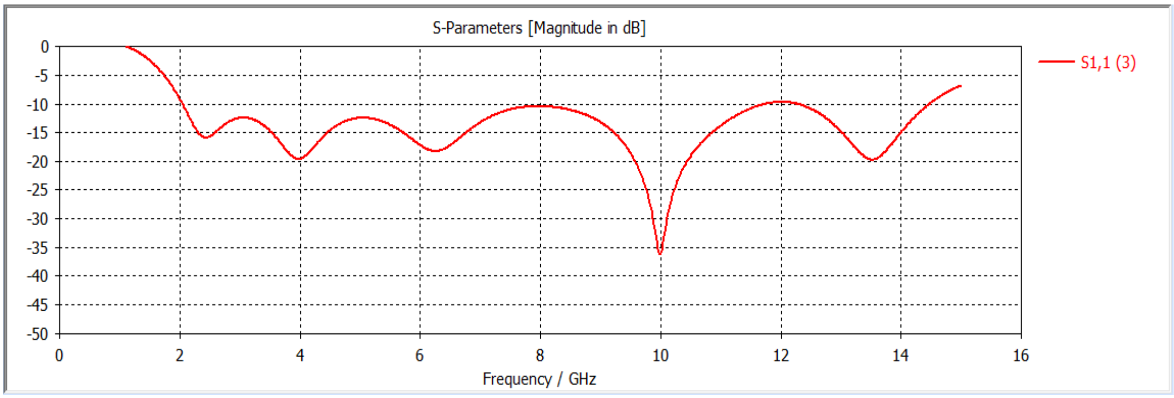
III. Result & Discussion:

The result of partial ground plane, deploying slot in middle and further modification to ground plane has reduce the Q-factor hence it broadens the resonance and improved impedance matching. Also, changes made to radiating patch and cutting the corner edges help in achieving wide band and increased the bandwidth.

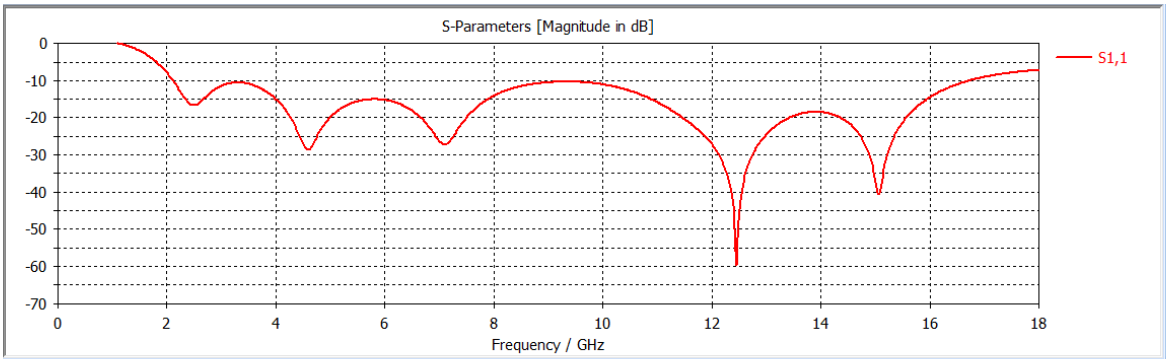
Hence finally proposed antenna#1 gives bandwidth of 12.4 GHz from 2 GHz to 14.4 GHz with maximum return loss of -35dB and antenna#2 gives bandwidth of 14.2 GHz from 2GHz to 16.2 GHz with maximum return loss of -60 dB. Conductive part such radiating patch and ground plane are made of copper tape. Reflection characteristics of fabricated antenna#1 and antenna#2 are measured using Anritsu MS2073 vector network analyzer (VNA).

3.1 Return loss:

To make antenna radiate efficiently return loss value must be kept below -10 dB. The measured S11 value matches with simulated results. But due to fabrication errors and losses in SMA connectors there is a small deviation between simulated and measured results but they are negligible. As shown in below fig (a) antenna#1 radiates over frequency range of 2 GHz to 14.4 GHz and fig (b) antenna#2 radiates over frequency range of 2GHz to 16.2 GHz.



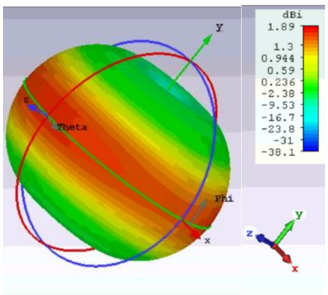
(a) Return loss (S11) for antenna#1



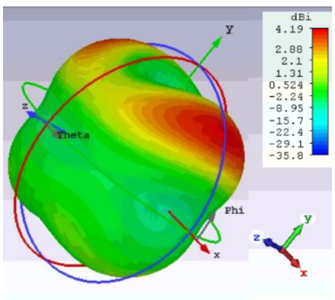
(b) Return loss (S11) for antenna#2

3.2 Radiation pattern of proposed antenna:

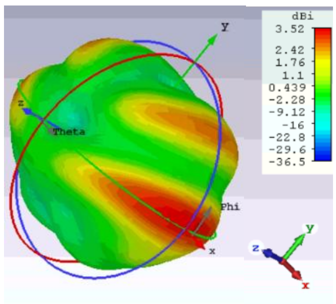
As designed antennas are planar monopole antenna, we get omnidirectional radiation pattern. Hence it radiates in all azimuthal directions perpendicular to antenna. Radiation pattern for antenna#1 is shown in fig below fig (a-c) and for antenna#2 is shown in fig (d-f).



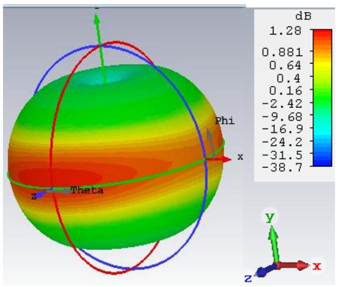
(a) 2 GHz

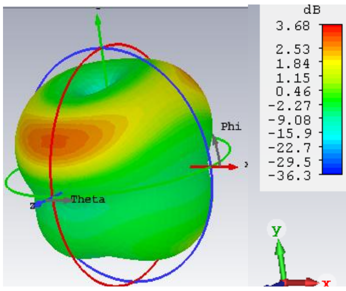


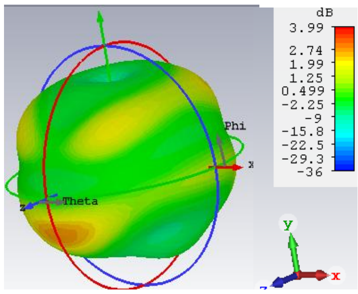
(b) 6 GHz



(c) 10 GHz





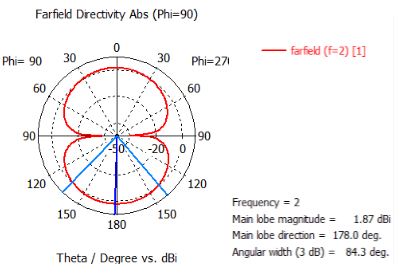


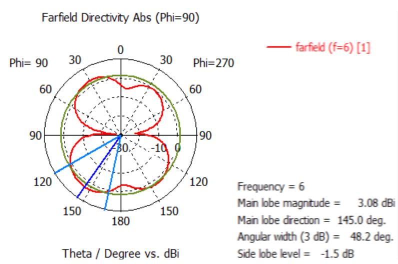
(d) 2 GHz (e) 6 GHz (f) 10 GHz

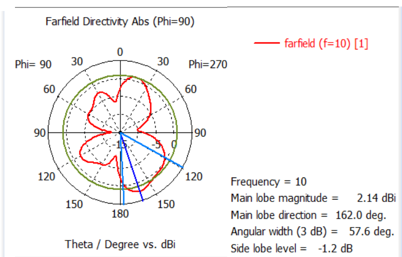
3.3 2D Radiation Pattern:

From figure below for antenna#1 (Polyamide antenna), it has been seen that the main lobe direction of 179˚& angular bandwidth of 84.9˚ with magnitude of 1.85 dBi at frequency of 2 GHz. The main lobe direction of 149˚and angular bandwidth of 51.7˚ with magnitude of 4.09 dBi at frequency of 6 GHz and side lobe level is of -0.7 dB. The main lobe direction of 159˚and angular bandwidth of 40.5˚ with magnitude of 4.25 dBi at frequency of 10 GHz with side lobe level is of -1.1 dB.

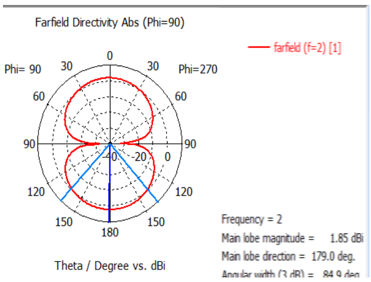
From figure below for antenna#2 (Teslin antenna), it has been seen that the main lobe direction of 179˚& angular bandwidth of 84.9 with magnitude of 1.85 dBi at frequency of 2 GHz. The main lobe direction of 149˚and angular bandwidth of 51.7˚ with magnitude of 4.09 dBi at frequency of 6 GHz and side lobe level is of -0.7 dB. The main lobe direction of 159˚and angular bandwidth of 40.5˚ with magnitude of 4.25 dBi at frequency of 10 GHz with side lobe level is of -1.1 dB.

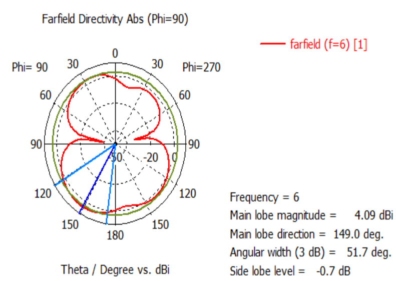


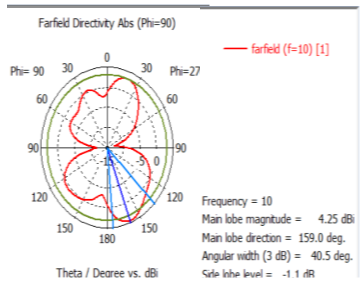




(a) 2 GHz (b) 6 GHz (c) 10 GHz







(d) 2 GHz (e) 6 GHz (f) 10 GHz

3.4 VSWR of antenna:

Figure below depicts the Voltage Standing Wave Ratio Vs Frequency curve for antenna#1 and antenna#2. VSWR should be less than 2. VSWR tells that how well antenna is impedance matched to transmission line to which antenna is connected. Figure a shows VSWR for antenna#1 and figure b shows VSWR for antenna#2. From results it is clear that VSWR is below 2 for both antenna.

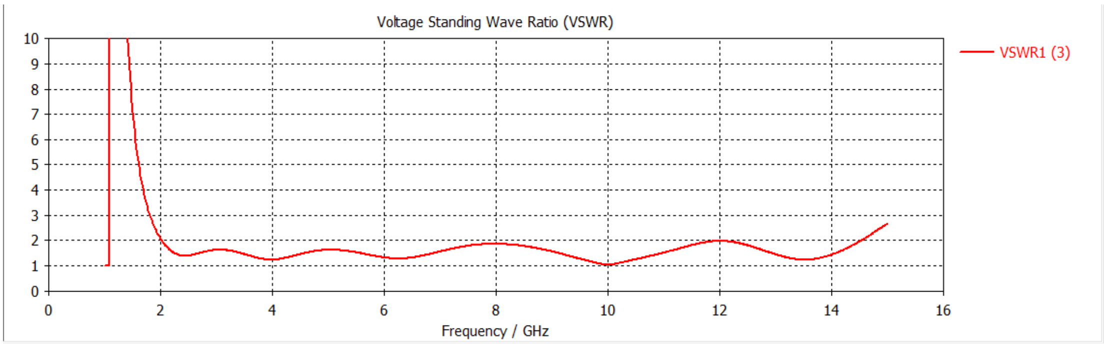


Fig a. VSWR of antennna#1 (Polyamide)

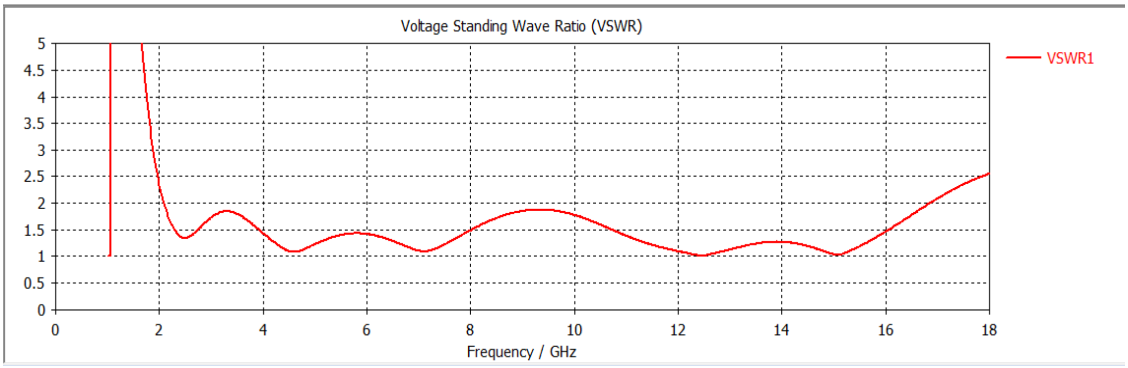


Fig b. VSWR of antenna #2 (Teslin)

3.4 Efficiency :

The efficiency of antenna is nothing but the ratio of radiated power to total incident power. Total efficiency of antenna is measure of radiation efficiency. From Figure it has been observed that the proposed antenna radiates over wideband of 12.4 GHz (antenna#1) and 14.2 GHz (antenna#2). The input power and radiated power is high all over band so radiation effiecieny is also high. For antenna#1 radiation efficiency above 93% from 2 GHz to 10 GHz and increases further from 10 GHz onwards. For antenna #2 radiaiton efficiency is 88 % at 2 GHz and it increases further all over the band.

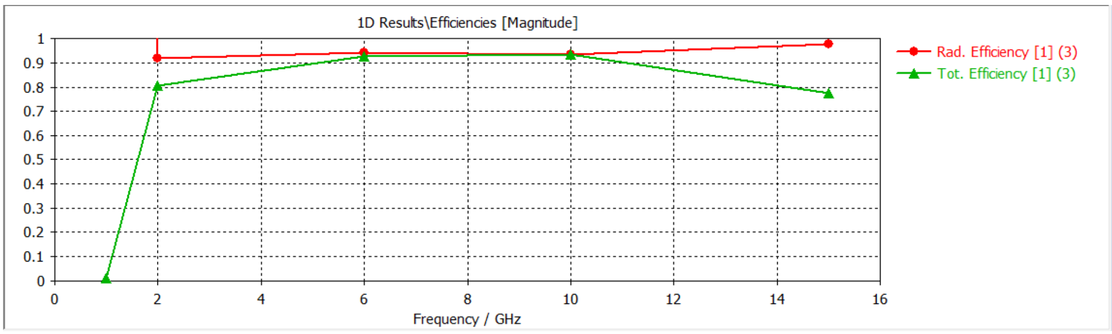


Fig a. Efficiency of antenna#1

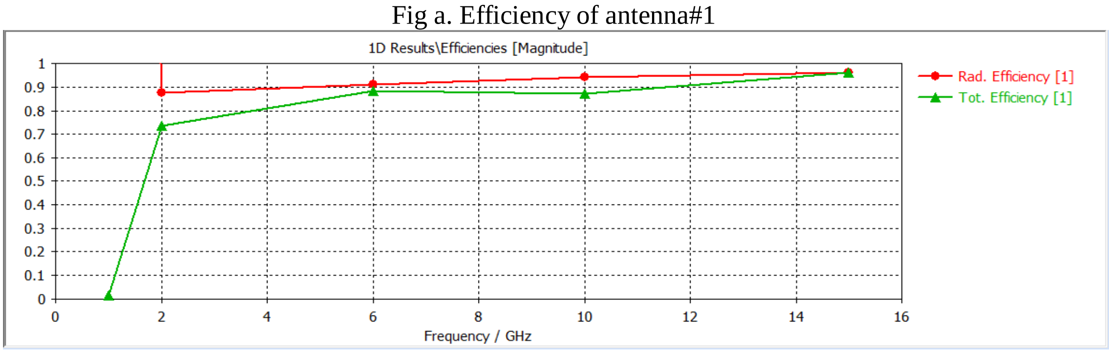


Fig a. Efficiency of antenna#2

3.5 Current Distribution:

Surface current of antenna is actual electrical current induced by an applied electromagnetic field. This induced current is 116.2 A/m, 66.62 A/m and 91.21 A/m at 2, 6, 10 GHz resp. for antenna#1(Fig a-c) and 115.3 A/m, 73.45 A/m, 97.64 A/m at 2, 6, 10 GHz resp. for antenna#2 (Fig d-f).

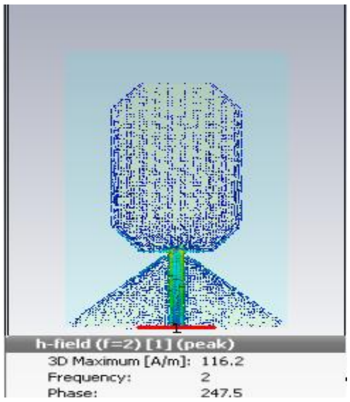


Fig a. 2 GHz

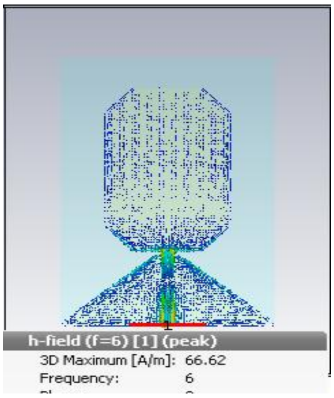


Fig b. 6 GHz

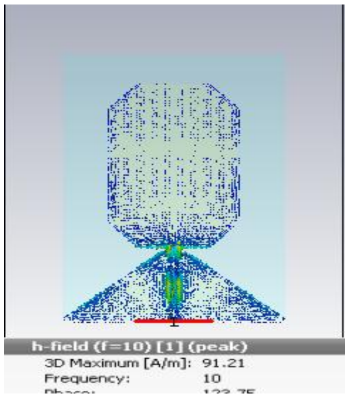


Fig c. 10 GHz

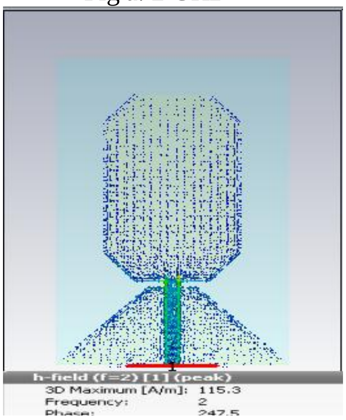


Fig d. 2 GHz

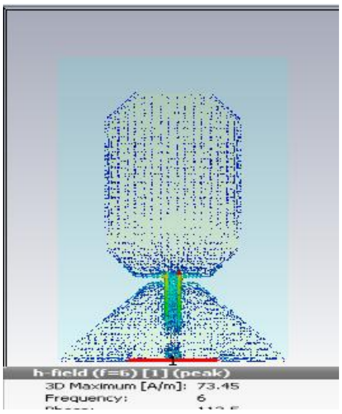


Fig e. 6 GHz

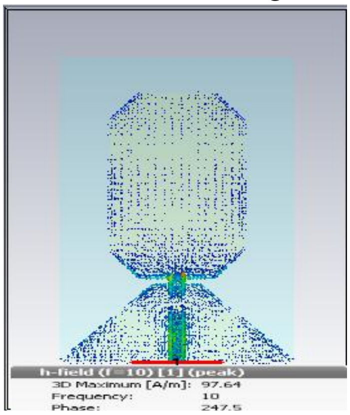


Fig f. 10 GHz

IV. Conclusion:

In this research work two antenna on two different substrates are designed and analyzed. Designed antennas have simple structure and are cost effective. Antenna#1 designed on Polyamide substrate having bandwidth of 12.4 GHz from 2 GHz to 14.4 GHz and maximum return loss of -35 dB and antenna#2 designed on Teslin substrate having band width of 14.2 GHz from 2 GHz to 16.2 GHz and maximum return loss of -60 dB. Measured results match with simulated results. This antenna can be used for on/off body wearable application with acceptable SAR value less than 1.6.

Acknowledgements:

The authors are thankful to the Mr. H.K. Bhaldar sir, Project guide and assistant professor, SVERI's COE Pandharpur for their assistance in execution of this research work. The author also thankful to SVERI's College of Engineering Pandharpur & My research center, Department of Electronics &Telecommunication.

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