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Design of Microstrip Patch Antenna on Flexible Substrate for BAN Applications

Trisha, Pramod Kumar, S K Sriwas, Mahendra Kumar

Abstract: ***Advancement in the wireless communication technologies, the Wireless Body Area Networks (WBANs) is the one of the most important networks in the healthcare applications. There are several advantages such as flexibility, efficiency and cost-effeteness of BAN system. In the BAN system sensors are implantable and wearable. In this paper, an overview of the 3-tier architecture of the BAN system explained. The design parameters and mathematical equations are explained to calculate the dimensions of a microstrip rectangular patch antenna on flexible denim substrate. The Gain, Return Loss, Directivity and Efficiency are simulated at two different frequencies and compared their performance.***

Index Terms: Body Area Network (BAN), wearable microstrip patch antenna, VSWR, Gain and Directivity.

I. INTRODUCTION

A Body Area Network is the interconnection of many computing devices worn on, affixed to or implanted in a person's body. BANs are categorized in various ways such as either implanted BAN or wearable BAN. A medical body area network (MBAN) is a special-purpose BAN that provides telehealth services through remote patient services through remote patient monitoring and can initiate alerts such as delivery of medication.

BAN follows a 3-tier architecture: Tier 1 (Intra- BAN communication), Tier 2 (inter- BAN communication) and Tier 3 (beyond BAN). The direct link between body sensors and BANs, the design of intra-BAN communications is difficult. In Tier-1, adaptable sensors are used to transfer signals to a Personal Server. Tier-2 network is used to interlink BANs with numerous networks that are used to obtain in daily life like cellular networks. The design of BAN beyond the tier it should accommodate the needs of user applications [1].

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***** Correspondence Author (s)
Trisha, Dept. of Electronics and Communication Engineering, BIET, Jhansi, UP, India.
Pramod Kumar, Dept. of Electronics and Communication Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, Karnataka, India. E-mail 79.pramod@gmail.com
S K Sriwas, Dept. of Electronics and Communication Engineering, BIET, Jhansi, UP, India.
Mahendra Kumar, Dept. of Electronics and Communication Engineering, BIET, Jhansi, UP, India.

Body Area Networks find numerous applications in the medical arena. These include medical sensors that monitor patients' health. For example, sensors attached to a patient can measure heart rate, blood pressure, temperature of a human body, electrical activity in muscles, electrical activity of the brain, CO_2 levels and oxygen concentration, blood glucose levels etc. Military applications of BAN include monitoring physical locations of field personnel and tracking of soldiers' vital signs such as monitoring their physical well-being.

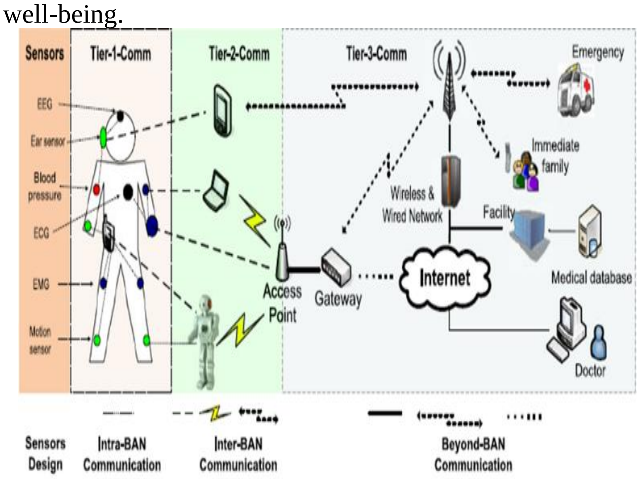

Figure 1: Architecture of BAN communication systems [1]

II. LITERATURE REVIEW

Wireless Body Area Networks have an edge over the conventional Wireless Sensor Networks due to the following reasons:

- BANs don't coop with the redundant failure nodes.
- BANs are used for registering physiological conditioners that occur more periodically so that the data obtained can be show stable rates.
- Replacement of nodes is easier in BANS over WSN
- BANs are mobile whereas WSNs are stationary

Advances in this technology include:

- With advances in MEMS, sensors are becoming smaller and smaller and are being manufactured for automatic drug delivery.
- The Charge coupled devices (CCD) and Complementary metal oxide semiconductor (CMOS) active pixel sensors, cameras can be made and can be embedded in eye glasses to help people going through eyesight problems.
- Accelerometers and gyroscopes are used for motion sensing.

On-Body wearable textile microstrip patch antennas are designed with probe-feed excitation to meet various requirements. Denim is used as the substrate with copper patch radiating element and ground plane to provide flexibility. Their dimensions have been calculated using the mathematical formulae discussed in the next section. Flexibility of the antenna is very significant so that it can be deformed over the skin. We go for using textiles since they have low dielectric constant that cuts down on surface wave losses and increases impedance bandwidth thus making it suitable for use [2-7].

In this paper, the structure of a typical BAN network and its applications described. The designs of a microstrip patch antenna using standard assumptions are simulated and analyzed their performance. The paper organized as follows;

An overview of BAN and it architecture, its advantages over WSNs and its applications and literature survey in section I and II, In section III described the design procedure of rectangular patch antennas and its simulation. Section IV describes the performance analysis of patch antenna at two different frequencies band C and X. Sections V conclude the paper.

III. *DESIGN* PROCEDURES *AND EQUATIONS*

The antenna designed for BAN application is a rectangular microstrip patch antenna. The various design parameters such as length and width have been calculated using the mathematical formulae with standard height of substrate and given resonance frequency. The standard relative permittivity and loss tangent values for the substrates have been used and shown in Table 1.

The following mathematical formulae used for calculating the dimensions are:

Width of the Patch: $$W_p = \frac{c}{2 * f_c * \sqrt{\varepsilon_r / 2}} \quad (1)$$

Effective Permittivity: $$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2 * \sqrt{1 + 12\frac{h}{w}}} \quad (2)$$

Differential Length: $$\Delta L = \frac{0.412 * h * (\varepsilon_{eff} + 0.3) * (\frac{w}{h} + 0.264)}{(\varepsilon_{eff} - 0.258) * (\frac{w}{h} + 0.8)} \quad (3)$$

Effective Length: $$L_{eff} = \frac{1}{2 * f_c * \sqrt{\varepsilon_{eff} * \varepsilon_0 * \mu_0}} \quad (4)$$

Actual Length: $$L_{actual} = L_p = L_{eff} - 2\Delta L \quad (5)$$

Length of Ground: $$L_g = 6h + L_p \quad (6)$$

Width of Ground: $$W_g = 6h + W_p \quad (7)$$

Where, fc is center frequency, “c” is speed of light, μ_0 is absolute permeability, ε_r relative permittivity and ε_0 is absolute permittivity [8].The design values of microstrip rectangular patch antennas at both the band of frequencies are shown in Table 2 and Table 3.

IV. RESULTS AND ANALYSIS

The result and analysis which includes tabular columns and graphs obtained based on the simulations carried out, along with the explanations of the results obtained. The software used for carrying out the simulations is HFSS at two different frequencies band.

The simulation results obtained include radiation patterns, return loss, gain and directivity which depend on the length, width, and height and center frequency of the antenna. A gain of less than -10 dB shows that the antenna is in working condition. The values for return loss, bandwidth, VSWR, gain and directivity are obtained from the graphical results obtained from the HFSS. Figure 2 and 3 represent the conventional design of rectangular microstrip antennas for the frequencies 5.9 GHz and 9.45 GHz respectively at for denim substrate. Figure 4 and 5 describes the simulation result of return loss for frequencies 5.9 GHz and 9.45 GHz respectively. The graph shows the return loss is less than -10 dB for both the cases at both the band of frequency. The antenna designs are in working condition and only 30% of the incident wave is being reflected. The simulation result of VSWR at the frequencies 5.9 GHz and 9.45 GHz shown in Figure 6 and 7 respectively. At magnitude 1, VSWR shows no reflection which is the ideal case and at magnitude 2, VSWR shows 33.33% reflection which should not be exceeded. Hence, the appropriate value of VSWR should lie in the range of 1 to 2. VSWR for both the designs lie in the same range, proving that the antennas are in working condition.

The 3D graphical representation of Directivity for frequencies 5.9 GHz and 9.45 GHz is shown in Figure 8 and 9 respectively. Figure 10 and 11 present the 3D graphical representation of Gain for frequencies 5.9 GHz and 9.45 GHz respectively. The value of Gain (G) and Directivity (D), gives the value of antenna efficiency (e) from the equation G=eD. The values of antenna efficiency for both the cases are above 85%. Figure 12 and 13 represent the graphical representation of radiation pattern for frequencies 5.9 GHz and 9.45 GHz respectively. The highest radiation intensity for 5.9 GHz is 1.2722 dB at θ=0° and ϕ=0°, i.e., at the centre of the antenna surface. The highest radiation intensity for 9.45 GHz is 3.6636 dB at θ=0° and ϕ=0°, i.e., at the centre of the antenna surface. Figure 14 represents a graphical representation of Radiation Pattern for -180 ° < θ<180° and (a) Ø =0° (b) Ø =90°. Figure 15 describe a graphical representation of Radiation Pattern for -180 ° < θ<180° and (a) Ø =0° (b) Ø =90°.

The simulation parameters and intermediate calculated values of microstrip patch antennas on denim substrate are shown in Table 1 to 3.The performance analysis of rectangular microstrip patch antennas are tabulated in Table 4. The all the parameters of antennas which are tabulated in Table 4 are describes that design of antennas are perfect.

The Denim substrate is more suitable for the X band frequency , the data which is presented in the Table 4 shows that all the parameters are upto the mark and this antennas designed on suitable substrate are suitable for the BANs applications, especially the efficiency is approximately ~ 90% at both the band of frequencies.

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TABLE 1. SIMULATION PARAMETERS OF THE DENIM SUBSTRATE

Parameters/Frequency(GHz)	f=5.9	f=9.45
Relative Permittivity (ε_r)	1.68	1.68
Loss Tangent (δ)	0.01	0.01
Height (h)	1 mm	1 mm

TABLE 2. INTERMEDIATRY CALCULATED VALUES

Parameters/Frequency (GHz)	f=5.9	f=9.45
Effective Permittivity (ε_{eff})	1.6134	1.588
Differential Length (ΔL)	0.5680 mm	0.5631 mm
Effective Length (L_{eff})	20.006 mm	12.59 mm

TABLE 3. FINAL CALCULATED DIMENSIONS OF ANTENNAS

Calculated dimensions(mm)/Frequency (GHz)	f=5.9	f=9.45
Width of Patch (W_p)	21.96	13.712
Length of Patch (L_p)	18.87	11.47
Width of Ground Plane (W_g)	24.87	19.712
Length of Ground Plane (L_g)	27.96	17.47

TABLE 4. A COMPARISON PARAMETERS OF THE DENIM SUBSTRATE

Simulated parameters/Frequency(GHz)	f=5.9	f=9.45
Return Loss	-14.5296 dB	-10.6730 dB
Bandwidth	191 MHz	140.7 MHz
VSWR	1.4629	1.8286
Directivity	4.2958 dB	6.9595 dB
Gain	3.6537 dB	6.3384 dB
Efficiency	85.05 %	91.07 %

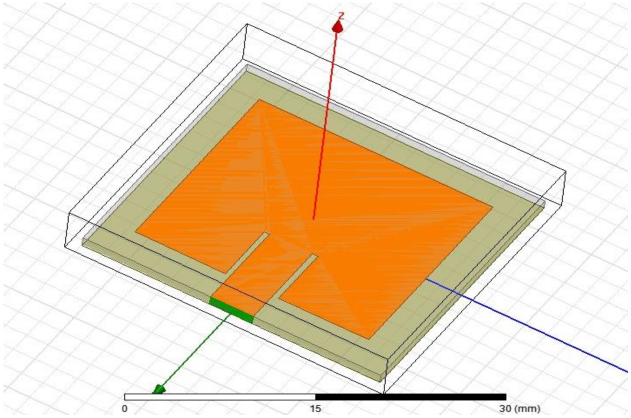

Figure 2. Denim Substrate Model in HFSS for f=5.9 GHz

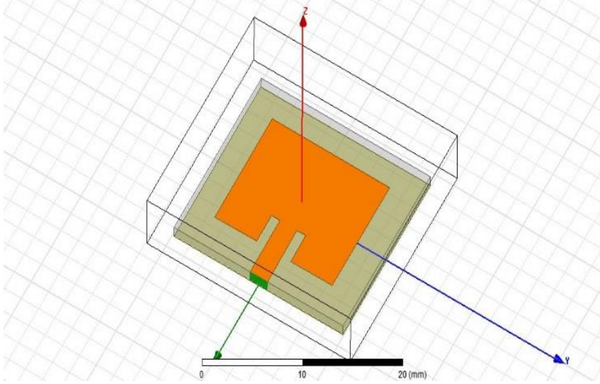

Figure 3. Denim Substrate Model in HFSS for f=9.45 GHz

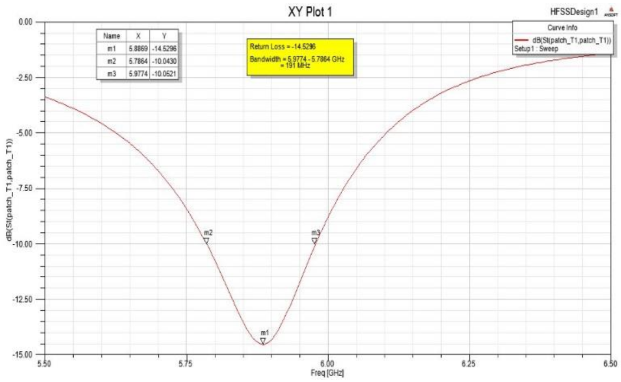

Figure 4. Return Loss (dB) versus Frequency (GHz) for Denim Substrate for f=5.9 GHz

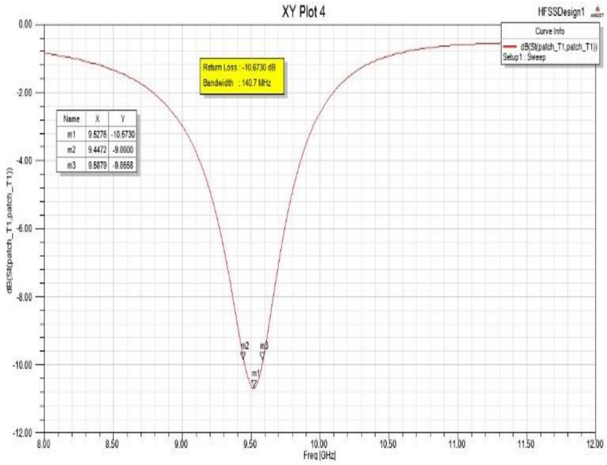

Figure 5. Return Loss (dB) v/s Frequency (GHz) for Denim Substrate for f=9.45 GHz

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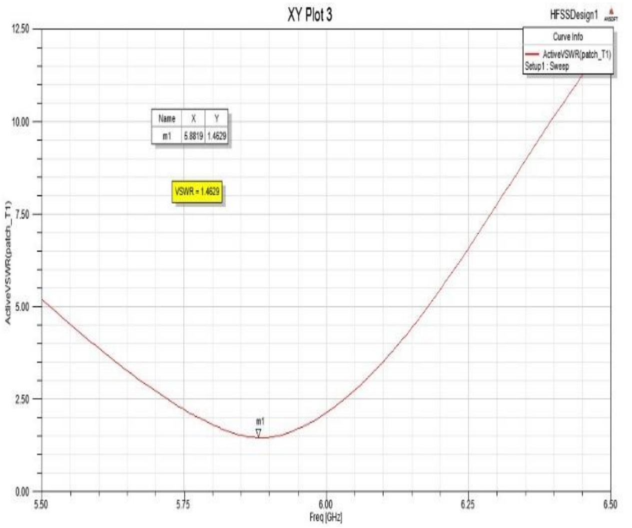

Figure 6. VSWR (mag) v/s Frequency (GHz) for Denim Substrate for f=5.9 GHz

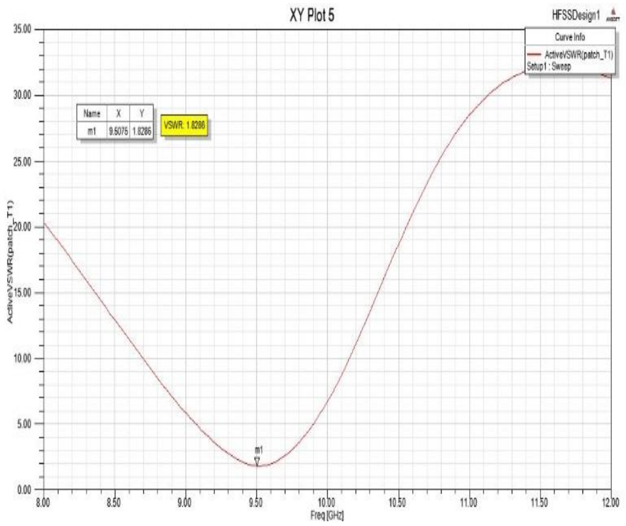

Figure 7. VSWR (mag) v/s Frequency (GHz) for Denim Substrate for f=9.45 GHz

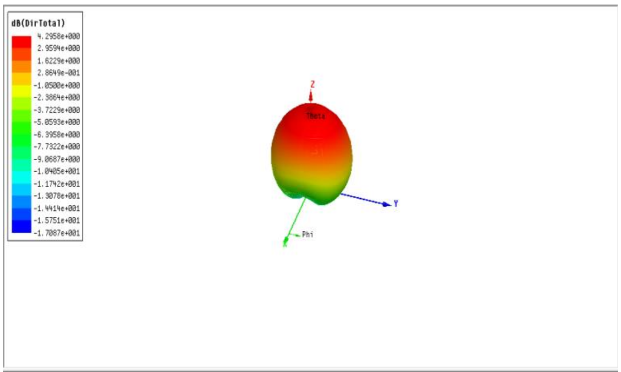

Figure 8. Directivity 3D Polar Plot for 0°<θ<360° and -180°<ϕ<180° of Denim Substrate for f=5.9 GHz

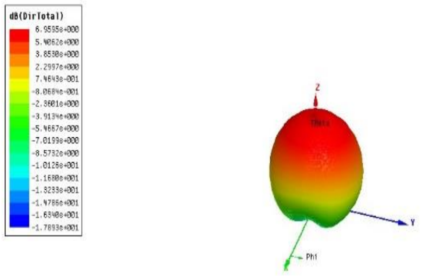

Figure 9. Directivity 3D Polar Plot for 0°<θ<360° and -180°<ϕ<180° of Denim Substrate for f=9.45 GHz

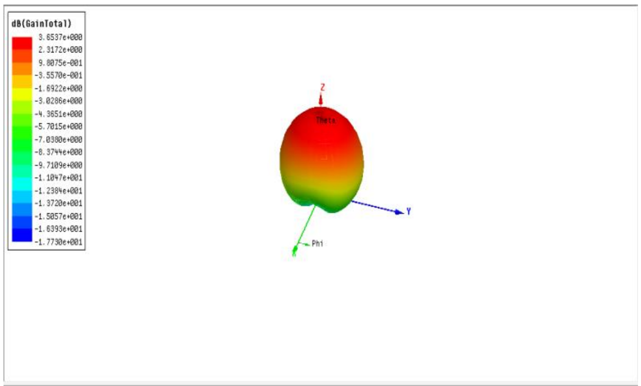

Figure 10. Gain 3D Polar Plot for 0°<θ<360° and -180°<ϕ<180° of Denim Substrate for f=5.9 GHz

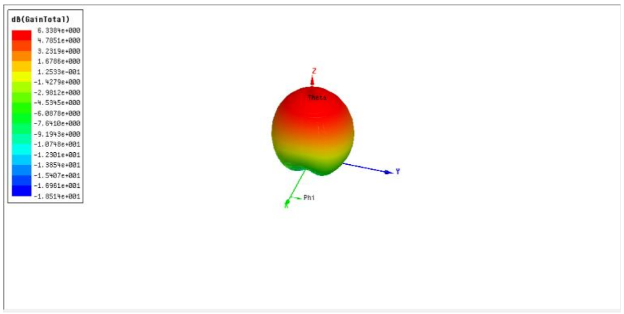

Figure 11. Gain 3D Polar Plot for 0°<θ<360° and -180°<ϕ<180° of Denim Substrate for f=9.45 GHz

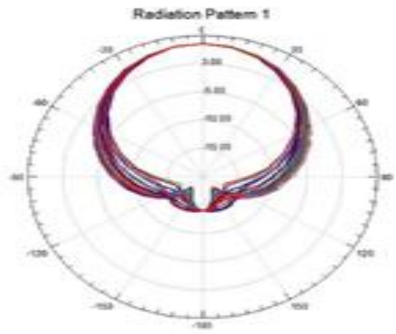

Figure 12. Radiation Pattern for 0 ° < Ø < 360° and -180 ° < θ<180° for Denim Substrate for f=5.9 GHz

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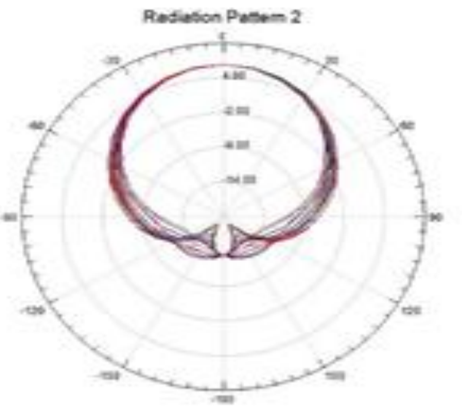
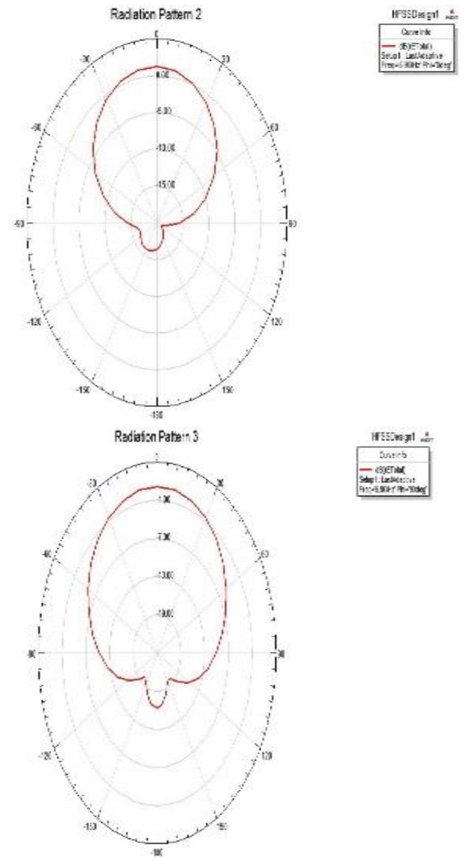
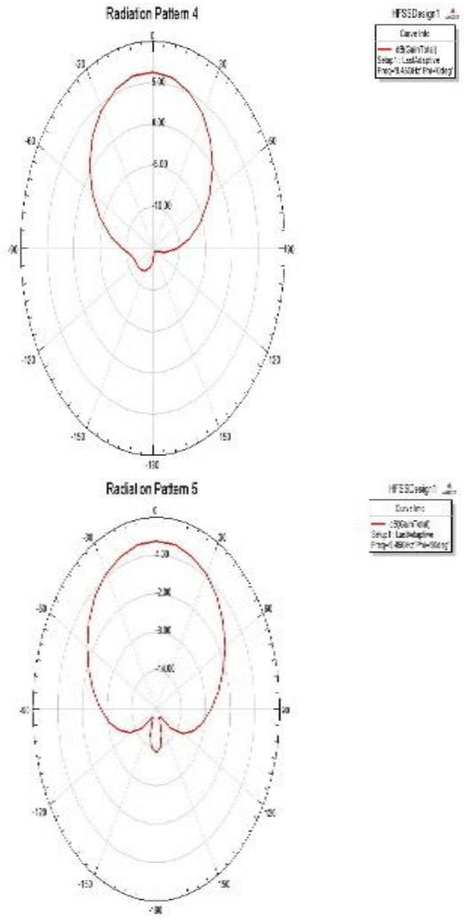


Figure 13. Radiation Pattern for 0 ° < Ø < 360° and -180 ° < θ<180° for Denim Substrate for f=9.45 GHz



(a) (b)

Figure 14. Radiation Pattern for -180 ° < θ<180° and (a) Ø =0° (b) Ø =90° for Denim Substrate for f=5.9 GHz



(a) (b)

Figure 15. Radiation Pattern for -180 ° < θ<180° and (a) Ø =0° (b) Ø =90° for Denim Substrate for f=9.45 GHz

V. CONCLUSION

The return loss for the substrate is less than -10 dB in both the cases. The bandwidth for the substrate is substantially high (greater than 100 MHz) in both the cases. The VSWR for the substrate lies between the required ranges, i.e. 1 to 2 in both the cases. We obtain high directivity, gain and efficiency for the substrate in both the cases. Hence, we infer that for both the frequencies, the substrate forms a feasible microstrip patch antenna for the given calculated dimensions. The comparison of the results for both the frequencies yields the conclusions that higher Radiation Intensity, Directivity, Gain and Efficiency are obtained for a higher frequency and higher Bandwidth and Lower Return Loss are obtained for a lower frequency.

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AUTHORS PROFILE

Trisha received her Bachelor of Engineering in Electronics and communication engineering from Meerut Institute of Engineering and Technology, Meerut, India in 2012. She is currently pursuing her M.Tech in Digital Communication (Electronics and Communication Engineering) from Bundelkhand Institute of Engineering and Technology, Jhansi, U.P. Her interests are in Antenna design for various applications, Digital Communication, Electronic Circuits and Microwave engineering.

Pramod Kumar received his B.E degree in Electronics and Communication Engineering from Visvesvaraya Technological University in 2002 and received his M.Tech degree in Microwave Engineering from Madhav Institute of Technology & Science; Gwalior, India in 2007.He obtained his PhD degree in Department of Electrical & Electronics Engineering at National Institute of Technology Karnataka, Mangalore, India. Currently, he is working as Associate Professor in the Department of Electronics & Communication Engineering at Manipal Institute of Technology, Manipal, India. He has published more than 40 papers in reputed peer reviewed international journal and conferences. E-mail 79.pramod@gmail.com

S K Sriwas received his Bachelor of Engineering in Electronics and communication engineering from Hindustan College of Science and Technology, Mathura, India in 2001. He received his M.Tech in Microwave Engineering (Electronics and Communication Engineering) from Madhav Institute of Technology and Science, Gwalior, M.P., India in 2007. He completed his PhD in the Dept. of ECE in AKTU, Lucknow, India. He is presently working as Assistant Professor in Electronics & Communication Engineering department, Bundelkhand Institute of Engineering and Technology (BIET), Jhansi (UP), India. His interests are in Multiple Access Schemes for Optical Channel, Coding Theory, Electronics Engineering, Electronic Circuits and microwave engineering. He has published 17 research papers in different international journals and conference.

Mahendra Kumar is presently working as Associate Professor in Electronics & Communication Engineering department, Bundelkhand Institute of Engineering and Technology (BIET), Jhansi (UP), India. His interests are in Multiple Access Schemes for area of research interest design of Microstrip Antennas for various applications. He has published many research papers in different international journals and conference.

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