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Research Article

Fabric Substrate Material Based Multiband Spike Antenna for Wearable Applications

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Abstract: A different multiband spike antenna with fabric material as substrate for wearable applications is presented in this study. Five fabric materials, including Silk, Aravind Cotton, Lenin, Raw Silk and Terry-Cotton are been used in this study. The performance characteristics, like gain, impedance bandwidth, efficiency and radiation characteristics are simulated and measured. The performance characteristics of the wearable antennas in the S and L band are observed and presented in this study. Generally, all the evaluated antennas are giving estimated outputs and meeting the requirements of practical aspects.

Keywords: Fabric substrate material, impedance bandwidth, multiband spike antenna, performance characteristics, wearable applications

INTRODUCTION

In recent years, the most attractive research topics in body-centric communications are utilization of wearable and fabric based antennas. The applications of wearable antenna is used for tracking, map-reading, computing and for the safety measures. Wearable antennas can also be applied for medical, fire men, military soldiers, elders and sportsmen. The main requirements of wearable antennas include low weight, less cost, easily portable, less maintenance with less equipment. To design the textile antenna we require the information about electromagnetic characteristics such as loss tangent and permittivity of the fabric material (Rais *et al*., 2009). Electromagnetic characteristics of fabric substrate can be measured using transmission or reflection waveguide method (Sankaralingam *et al*., 2009). The materials required for radiating elements like copper and conductive textile such as polyester, taffeta fabrics.

The main objective of wearable antennas is to describe the integration of electronic systems into fabrics to assist intelligently (Tanaka and Jang, 2003). These wearable electronics will not create any disturbance or problem to the user in any situation and facilitates easy integration with fabrics. WPAN is one of the most important components in such fabrication antennas (Madhav *et al*., 2013). Textile antennas are used for this purpose, which facilitates feasible integration to clothing. This integration is important, radii at the bending should be very small (10 mm), more at the joints. For Bluetooth, we will design a patch antennas in the range of 2.4 GHz with return loss of <-10 dB on average. Bluetooth features can be obtained with bent of around 37.5 mm radius placed on upper arm of human body. With a maximum thickness of 6 mm, we can maintain comfortable wearing which when integrated to textiles. Comparing with probe feed microstrip occupies more height to the patch antennas. Microstrip feed assures flat structure and also its integration to electronic components directly on the fabric with in its proximity. With antenna design we have also carried experiments regarding electrical performances of various materials such as substrates of fabrics (Hall and Hao, 2006).

The main purpose of fabric material based antennas is for the usage in WBAN's applications (Zhu and Langley, 2009), which includes:

- Supports cops in emergency situations
- Applications including tracking locations and low level systems
- Assistance in real world environment
- Recognising systems by identification of independent secondary systems
- Guiding route maps in journey (Park and Jayaraman, 2003)

The minimum level of interference, low level interference must be obtained through WBAN. An antenna which can be wearable is an important part of body-centric wireless network. We can use microstrip patch antenna for wearable applications which can be fused into clothing. The main goal of this article is to find the performance parameters of the microstrip spike patch antenna on different fabric materials and comparative study with conventional rectangular patch antennas.

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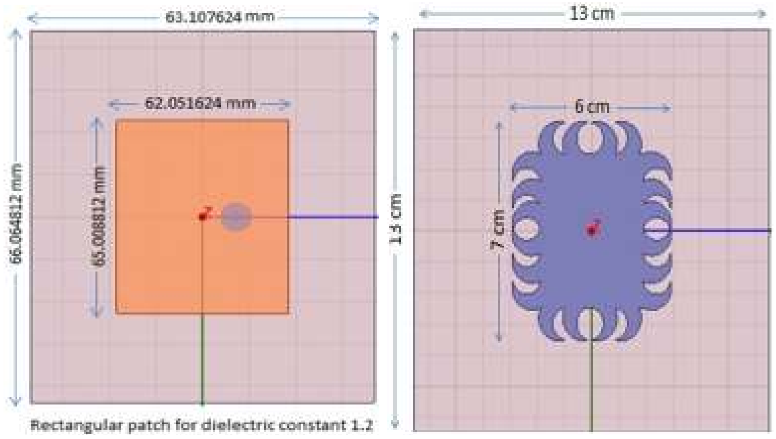


(a) (b)

Fig. 1: (a) Conventional rectangular patch antenna and (b) Serrated spike antenna

MATERIALS AND METHODS

Antenna geometry: Figure 1a shows the basic structure and dimensions of conventional antenna operating at 2.2 GHz with substrate permittivity of 1.2 and thickness of 0.176 mm. Figure 1b shows the serrated spike antenna, which will operate at multiband.

The design of conventional microstrip patch antenna involves the calculation of patch and ground dimensions and thickness of the substrate (Madhav *et al*., 2014). The patch width and length are formulated as below:

Patch width:

$$W = \frac{c}{(2f_r)}\sqrt{\frac{2}{(\varepsilon_r+1)}}$$

where,

'c' = The light speed in free space

'ε_r' = The relative permittivity of the material (Fabric Material):

Patch length:

$$L = \left[\frac{c}{(2f_r\sqrt{\varepsilon_{reff}})}\right] - 2\Delta L$$

where,

'ε_{rf}' = The effective permittivity of the fabric dielectric material:

$$\varepsilon_{reff} = \left[\frac{\varepsilon_r+1}{2}\right] + \left[\frac{\varepsilon_r-1}{2}\right]\left[1+\frac{12h}{W}\right]^{\frac{-1}{2}}$$

The ground width and length are formulated as below:

Ground Length = L+6*h

Ground Width = W+6*h

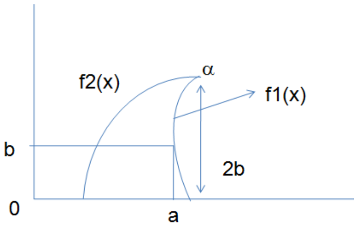


Fig. 2: Unit cell serrated spike model

where, 'h' is the height of the substrate.

The spike model presented Fig. 1b is constructed from conventional patch by placing serrated shapes around the edges. Figure 2 shows the unit cell of the serrated spike model of Fig. 1b. Here regarding the spike model, we are presenting the required function in two seperate functions. The function F2(x) is a parabola with equation:

$$F2\ (x) = y = |\mathrm{sqrt}\ (x)| \text{ lies in range 0 to } A_x. \quad (1)$$

Here 'A' is the intersection point of two functions F1(x) and F2(x) shifted to a point (a, b):

$$F_1(x) = (y-b)^2 = (x–a) \quad (2)$$

The intersection point:

$$A= ((b/2-a/2b)^2+a,\ |\mathrm{sqrt}((b/2-a/2b)\ 2+a)\ |) \quad (3)$$

The two functions are discontinued after A.

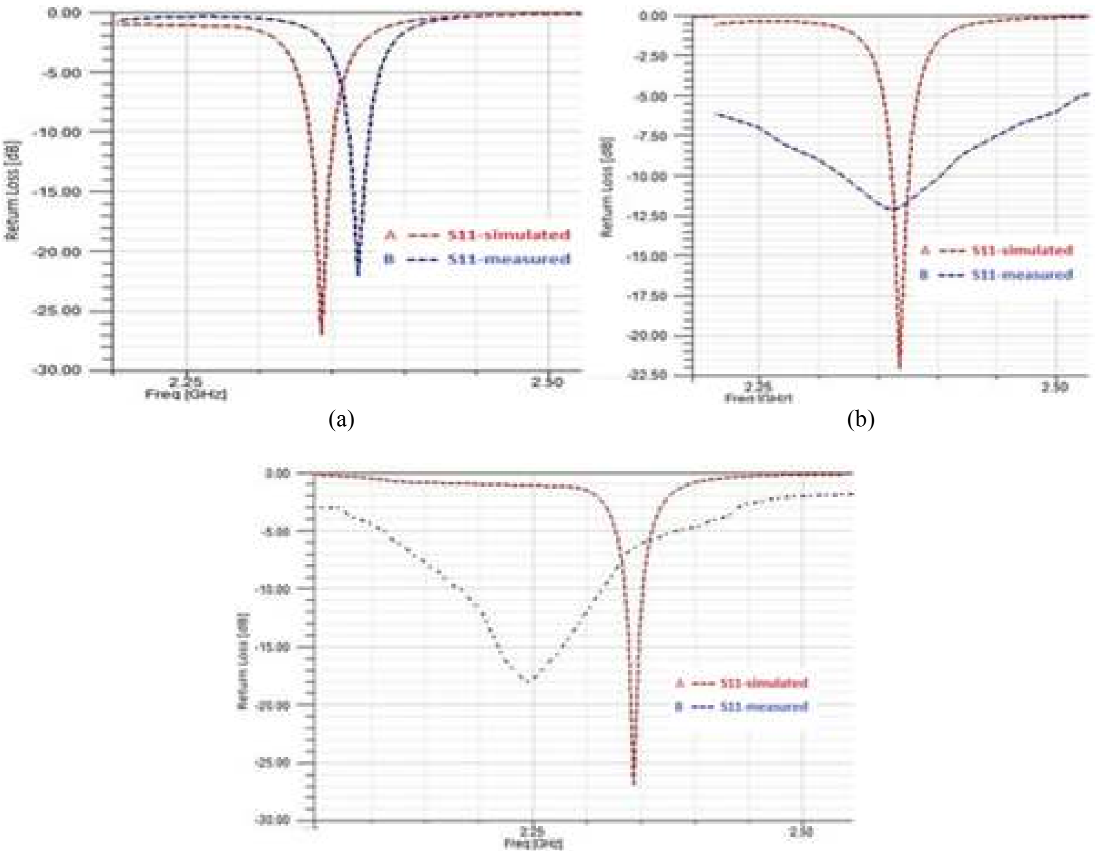
Fabric materials based antenna characterization: Table 1 shows the conventional antenna dimensional characteristics with change in substrate material and its resonating frequencies. With change in dielectric constant of the material, the antenna dimension is depended and it is presented in the Table 1. The spike model is having the dimension of 13×13 cm in dimension and its performance characteristics are examined by varying the different fabric materials using HFSS 15. The simulated results are giving the confidence for the applicability of the antenna in real time environment.

RESULTS AND DISCUSSION

The design of microstrip rectangular patch antenna is done with the reference to multiband spike antenna and its operational characteristics are verified with respect to the change in the fabric materials. The following steps indicate the procedure for determination

Table 1: Dimensions for conventional antenna with respect to material used

S. No	Substrate material used	Dielectric constant	Frequency of operation (ghz)	Antenna dimensions (mm)	Feed location	Patch length and width (mm)
1.	Material1	1.2	2.2, 2.4, 5.2	63.19*66.17*0.29 (2.2 GHz)	28.33, 32.50	62.03*65.00
2.	Polycot	1.3	2.2, 2.4, 5.2	60.78*64.74*0.29 (2.2 GHz)	26.17, 31.78	59.61*63.57
3.	Polyester	1.4	2.2, 2.4, 5.2	53.82*58.22*0.29 (2.4 GHz)	22.28, 28.52	52.65*57.05
4.	Material 2	1.5	2.2, 2.4, 5.2	52.05*57.06*0.29 (2.4 GHz)	20.80, 27.94	50.88*55.90
5.	Wash cotton	1.6	2.2, 2.4, 5.2	54.93*60.96*0.29 (2.2 GHz)	21.29, 29.89	53.77*59.79
6.	Material 3	1.7	2.2, 2.4, 5.2	48.98*54.95*0.29 (2.4GHz)	18.37, 26.89	47.81*53.79
7.	Bed sheet	1.8	2.2, 2.4, 5.2	47.64*53.98*0.29 (2.4GHz)	17.36, 26.41	46.47*52.82
8.	Material 4	1.9	2.2, 2.4, 5.2	50.53*57.78*0.29 (2.2GHz)	17.94, 28.31	49.36*56.62
9.	Material 5	2.0	2.2, 2.4, 5.2	49.22*56.83*0.29 (2.2GHz)	17.03, 27.33	48.12*55.67



(a) (b)

(c)

Fig. 3: (a) Frequency vs return loss for polycot material, (b) Frequency Vs Return loss for Material 2 and (c) Frequency vs return loss for wash cotton

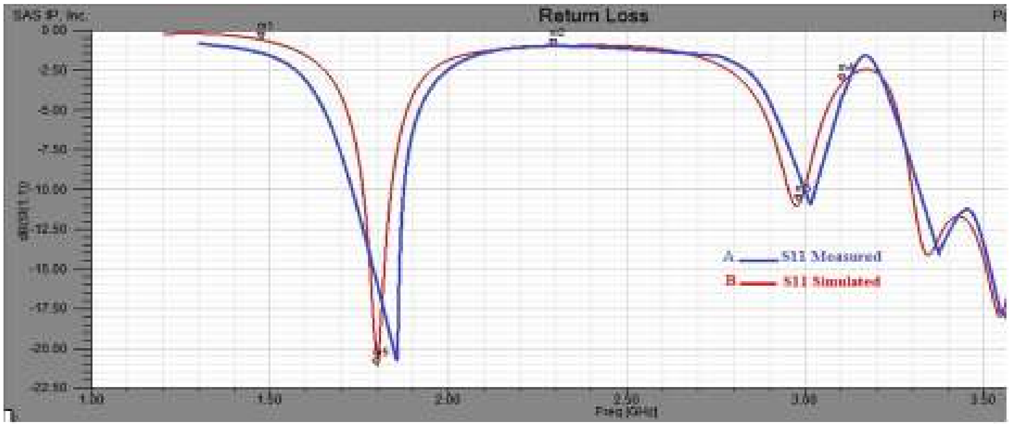
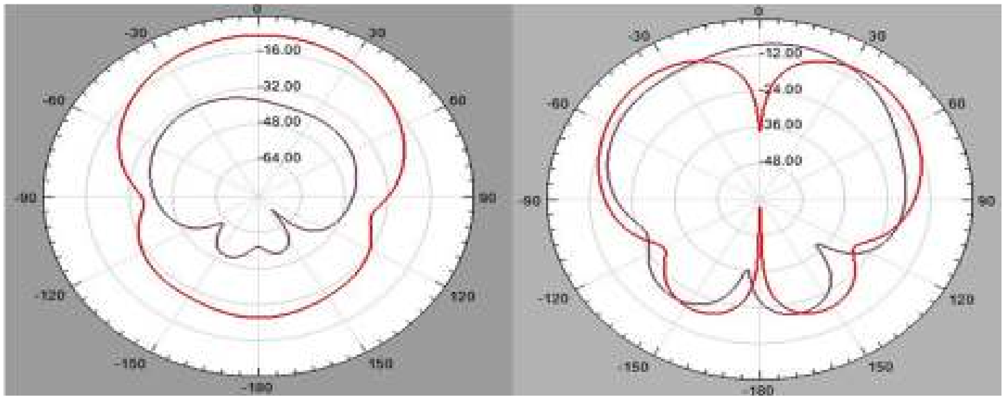


Fig. 4: Frequency vs return loss for rectangular spike antenna



(a)

(b)

Fig. 5: (a) Radiation pattern in E-plane for polycot and (b) Radiation pattern in H-plane for polycot

of substrate permittivity and other parameters related to the antenna model:

- Design of conventional microstrip antenna for a particular resonant frequency by assuming appropriate dielectric constant values of the fabric materials (Table 1).
- Design of the spike model is done by placing sharp edged objects at the corners of conventional patch antenna.

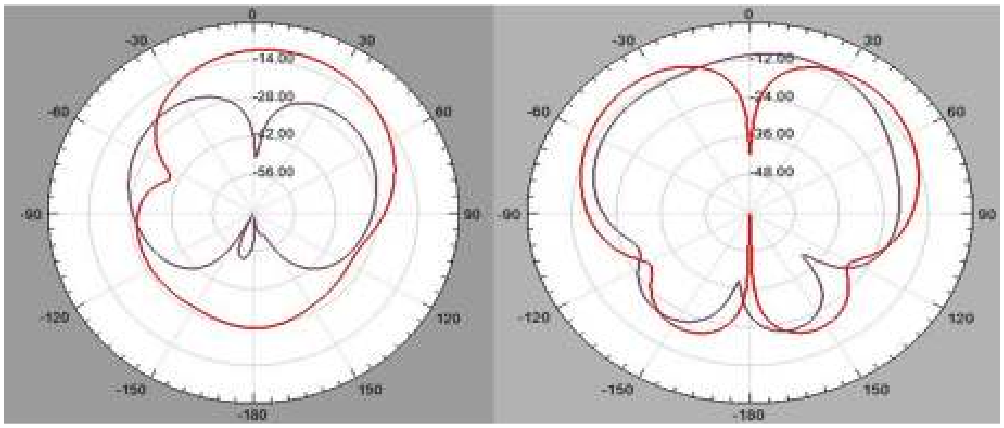
Simulated the antenna structures using HFSS 15.0 and results of both conventional antenna and spike model are presented in this study.

For polycot, material2 and wash cotton models are fabricated and measurement results comparison with simulated results hence is placed in Fig. 3. The simulation results are in very good agreement and almost identical to the measured results. A special care is taken in the design of the models in such a way that the area of ground plane and the fabric material to be measured is at least 3 times larger than that of the rectangular patch to avoid back lobes in the radiation and to reduce scattering effects at the edges of ground.

Considering wash cotton fabric material to illustrate the process in this technique, Rectangular microstrip spike antenna is designed at 2.4 GHz frequency with a substrate thickness of 0.7 mm. The dielectric constant for this fabric material is assumed to be 1.6. The patch length and width for this fabric material are 60 mm and 70 mm, respectively. The measured resonant frequency is found at 2.36 GHz while it is designed at 2.4 GHz as shown in Fig. 4. The same procedure is used for the remaining 8 fabric materials and the corresponding dimensions are tabulated above.

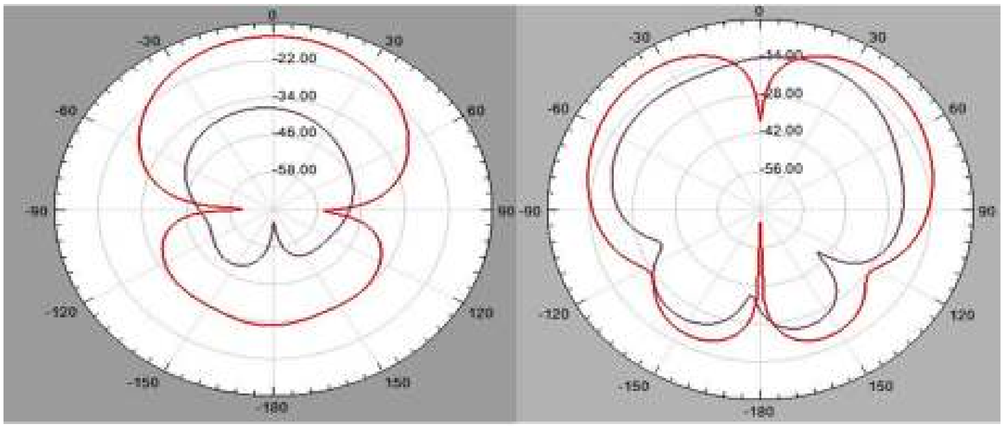
The radiation patterns plotted in E plane and H plane for poly cot, polyester and bed sheet materials are as shown in Fig. 5 to 7, respectively. From the radiation patterns it is observed that all the plots are simulated at 2.4 GHz of proposed spike antenna. The H plane radiation patterns are looking like a butterfly model and which covers almost all the directions with considerable gain and directivity. The E plane patterns are also giving confidence for the applicability of the antenna for the desired operation.

Simulations are done for the range of frequencies of 2-2.8 GHz for all the five models. The variations of



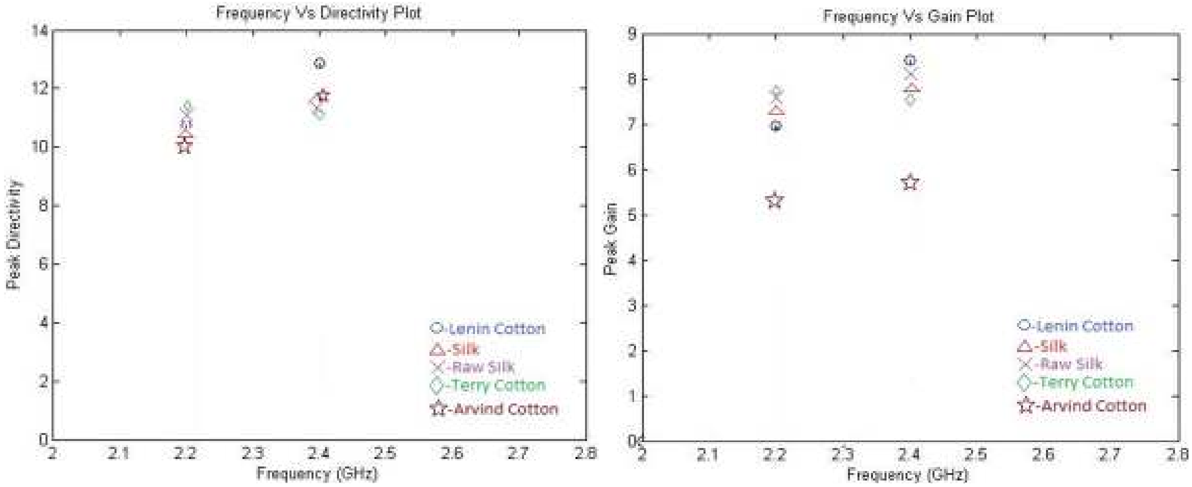
(a) (b)

Fig. 6: (a) Radiation pattern in E-plane for polyester and (b) Radiation pattern in H-plane for polyester



(a) (b)

Fig. 7: (a) Radiation pattern in E-plane for bed sheet and (b) Radiation pattern in H-plane for bed sheet



(a) (b)

Fig. 8: (a) Frequency vs directivity plot and (b) Frequency vs gain plot

Table 2: Antenna parameters

Frequency	Dielectric constant	Max U	Peak directivity	Peak gain	Peak realized gain	Radiated power	Accepted power	Radiation Efficiency	Front to back ratio
2.4	1.2 (Silk)	0.0838199	11.5491	7.97578	1.0533	0.091205	0.132067	0.6906	1.89099
2.2	1.3 (Silk)	0.053028	10.696	7.2434	0.6663	0.062305	0.091998	0.67724	1.8872
2.4	1.2 (Lenin cotton)	0.0776658	12.8836	8.41927	0.976	0.075754	0.115925	0.653485	1.94302
2.2	1.3 (Lenin cotton)	0.071772	10.76	6.9628	0.9019	0.083824	0.12954	0.6471	1.9011
2.4	1.2 (Raw silk)	0.108277	11.4252	8.18015	1.3606	0.119095	0.166339	0.715976	1.72245
2.2	1.2 (Raw silk)	0.11007	10.964	7.5892	1.3832	0.12616	0.18226	0.69218	1.9309
2.4	1.4 (Terry cotton)	0.0879379	11.299	7.54057	1.1050	0.097804	0.146552	0.667369	1.79864
2.2	1.3 (Terry cotton)	0.10039	11.301	7.5584	1.2616	0.11164	0.16692	0.66884	1.8382
2.4	1.3 (Arvind cotton)	0.495474	11.3077	5.71603	0.6226	0.055064	0.10893	0.5055	1.55689
2.2	1.2 (Arvind cotton)	0.026708	10.077	5.2155	0.3356	0.033307	0.064353	0.51756	1.6792

directivity and gain as a function of frequency, are obtained from the simulation of these models are presented in Fig. 8. From the results it is observed that a minimum gain of 5 dB and minimum directivity of 10 dB maintained by all the models. Along with the materials used, the size of the ground plane also effects marginally the radiation characteristics of the antenna. Among all the materials used here, the Lenin cotton is showing best results compared with the other models (Table 2).

CONCLUSION

The antenna performance characteristics mainly depend on the substrate, shape of the patch and feeding method. The current study is giving an idea to find the dielectric constant of fabric substrate material, once it is fabricated and tested then by finding its resonant frequency. By knowing the resonant frequency of the antenna, we can find the dielectric constant of the material that is used in that model. Even a small change in the dielectric constant of the material will produce considerable shift in the resonant frequency of the antenna. Form this study we communicated the antenna performance characteristics, if different substrate materials are used in the design. The textile microstrip antennas may eventually replace patch antennas on standard PCB substrates for various applications. The bending effects are not studied in this study, but that will help the designers to choose particular material for particular application. We are in the search of electro textiles instead of copper patches on the antenna surface.

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