Fabric-Based Multiband Spike Antenna for Wearable Applications

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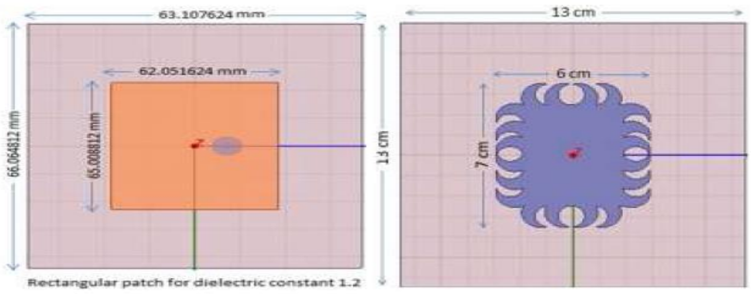
Abstract

The research places particular emphasis on assessing the antenna's performance in both the S and L bands, shedding light on its versatility across various frequency ranges. To comprehensively evaluate the antenna's effectiveness, a combination of simulation and measurement techniques is employed, with meticulous documentation and presentation of the results throughout this study. It's worth highlighting that all antennas subjected to evaluation yield promising results, effectively meeting the practical demands of real-world applications. The fusion of innovative multiband spike antenna designs with the utilization of fabric substrates underscores their potential for seamless integration into wearable technology. This research significantly contributes to the advancement of wearable communication systems by offering antenna solutions that are versatile, efficient, and adaptable, thus catering to the evolving needs of this rapidly growing field.

Introduction

In recent years, the realm of body-centric communications has been significantly influenced by the compelling research focus on wearable and fabric-based antennas. These antennas find applications in diverse fields such as tracking, navigation, computing, and safety protocols. Their utility extends to sectors like medicine, firefighting, military operations, elder care, and sports [1]. Wearable antennas are expected to fulfill several key criteria, including lightweight construction, cost-effectiveness, portability, and minimal maintenance requirements. The design of textile antennas necessitates a comprehensive understanding of electromagnetic characteristics, including parameters like loss tangent and permittivity of the fabric material (Rais et al., 2009) [2]. The electromagnetic traits of fabric substrates can be assessed through methods such as transmission or reflection waveguide techniques (Sankaralingam et al., 2009). Copper and conductive textiles like polyester and taffeta fabrics are pivotal materials for constructing radiating elements [3]. The primary objective of wearable antennas is to seamlessly integrate electronic systems into fabrics, enhancing convenience and intelligence (Tanaka and Jang, 2003). These wearable electronics should seamlessly blend with the user's experience in all situations while ensuring easy integration with fabric materials. Wireless Personal Area Networks (WPAN) play a pivotal role in such antenna configurations (Madhav et al., 2013). Textile antennas prove valuable in this context, as they enable seamless integration into clothing. This integration poses challenges such as maintaining minimal bending radii, especially at joints where bending is more pronounced. For Bluetooth applications, we intend to design patch antennas operating within the 2.4 GHz range, aiming for a return loss of <-10 dB [4].



(a) (b)

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

Materials methods

Patch width:

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

where,
'c' = The light speed in free space
'ε_r' = The relative permittivity of the material (Fabric Material):

Patch length:

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

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

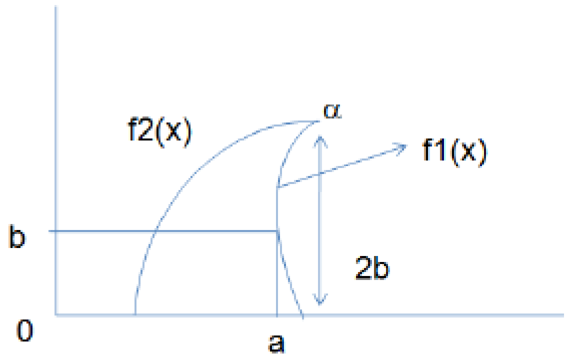


Fig. 2: Unit cell serrated spike model

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

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

$$F_1(x) = (y\text{-}b)^2 = (x-a) \qquad (2)$$

The intersection point:

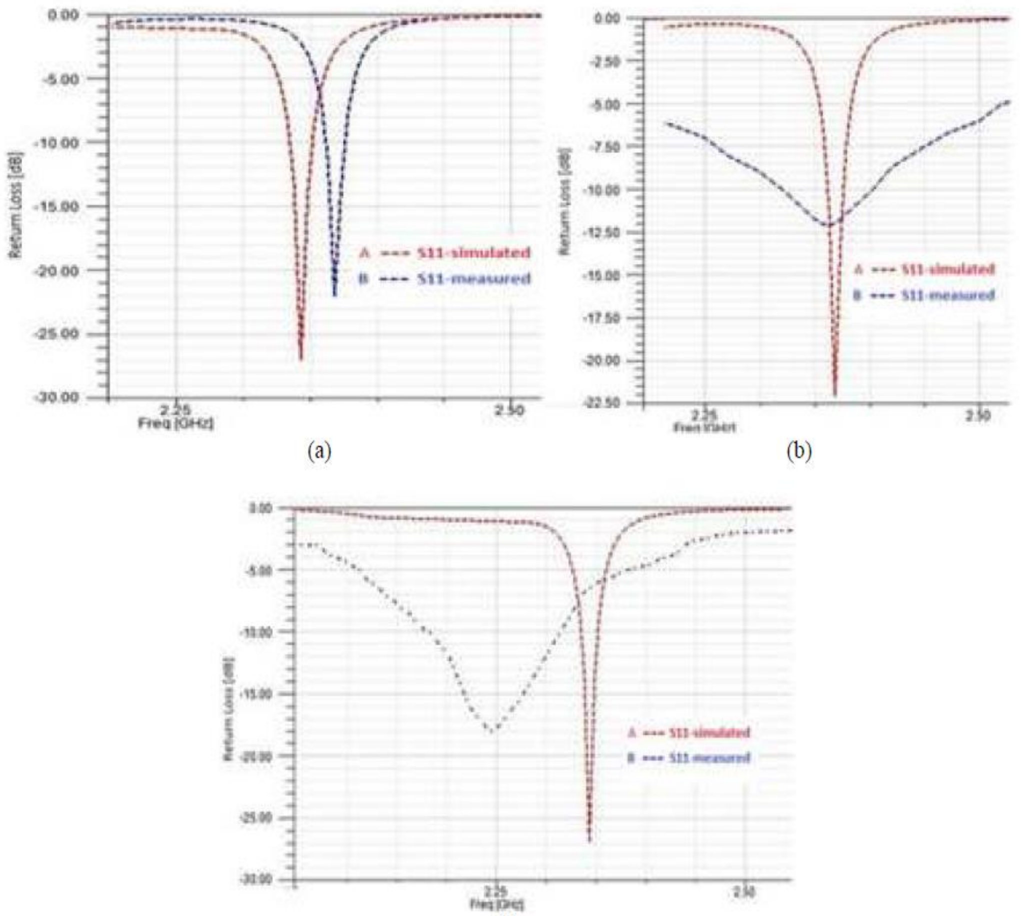
$$A= ((b/2\text{-}a/2b)^2+a,\ |\mathrm{sqrt}((b/2\text{-}a/2b)\ 2+a)\ |) \qquad (3)$$

The two functions are discontinued after A.

Results

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

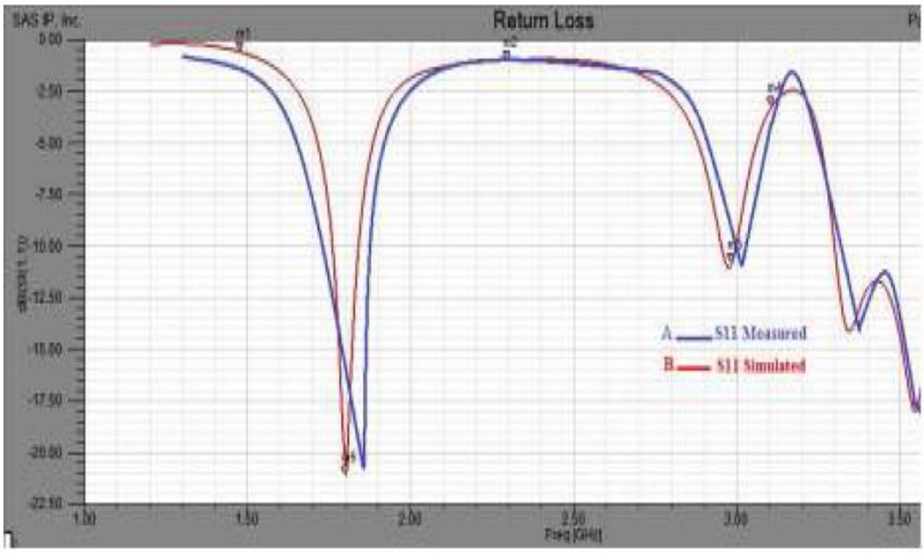
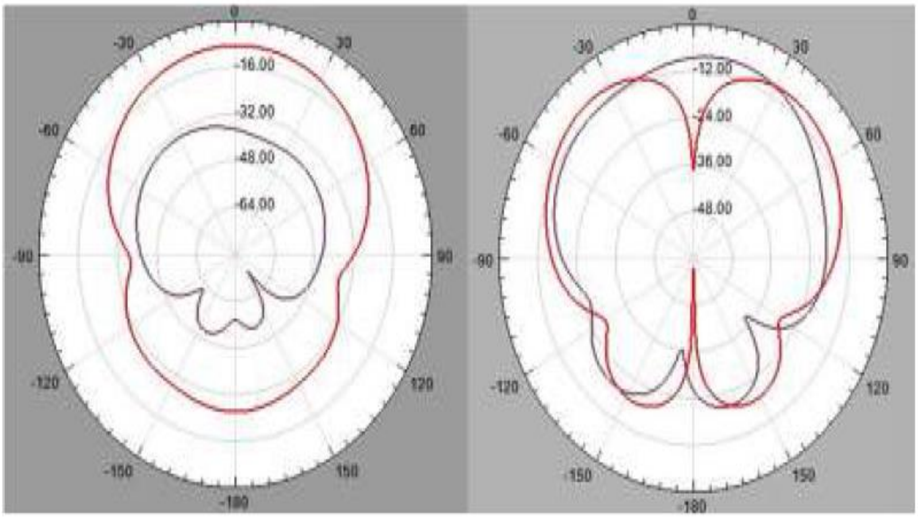
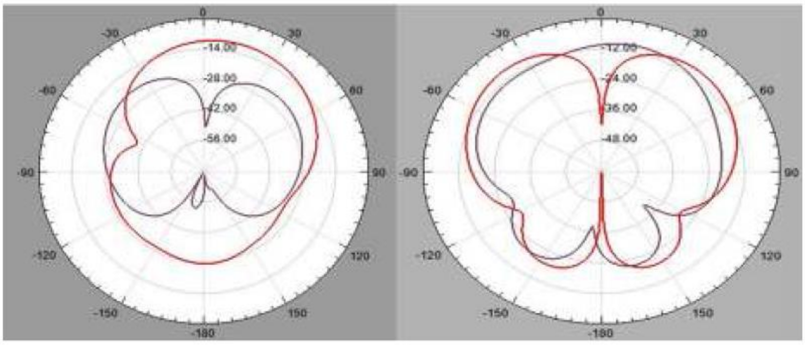


Fig. 4: Frequency vs return loss for rectangular spike antenna



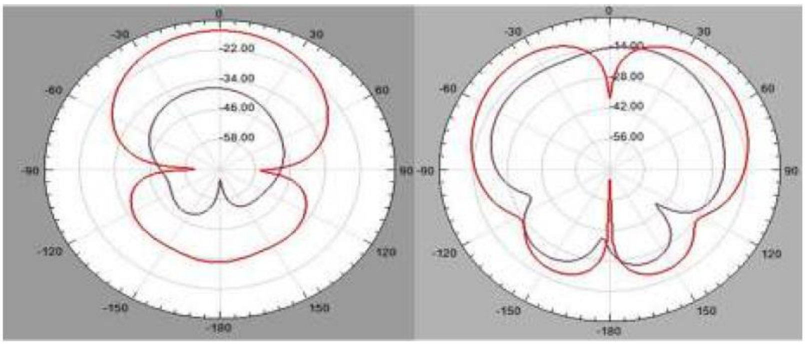
(a) (b)

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



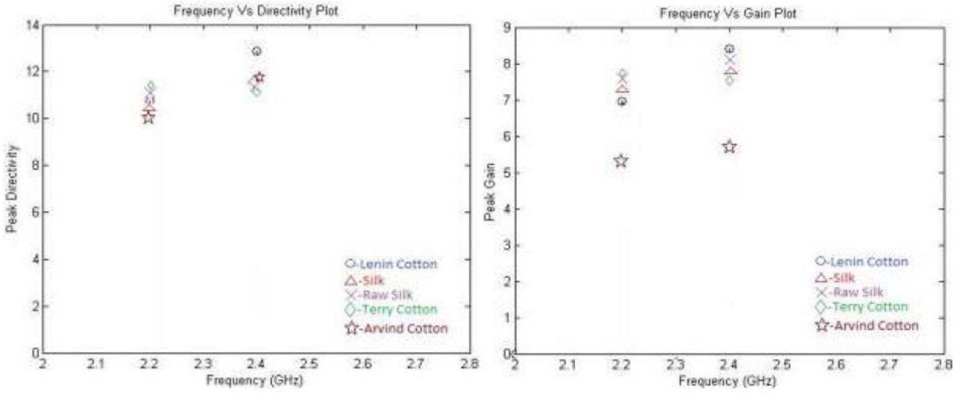
(a) (b)

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



(a) (b)

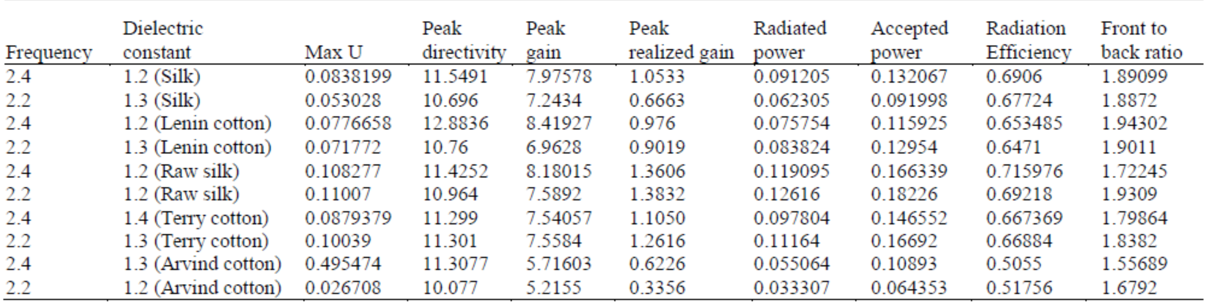
Fig. 7: (a) Radiation pattern in E-plane for bed sheet and (b) Radiation pattern in H-plane for bed sheet



(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

Conclusion

Minor fluctuations in the dielectric constant can result in significant shifts in the antenna's resonant frequency. This study is aimed at elucidating the performance characteristics of antennas when different substrate materials are utilized in their design. While this investigation does not specifically delve into the effects of bending, it offers valuable insights for designers who need to choose appropriate materials for specific applications. Furthermore, the emerging domain of textile micro strip antennas holds the promise of replacing traditional patch antennas mounted on conventional PCB substrates. This innovation has the potential to find applications across a broad spectrum of industries and use cases, making it a noteworthy area of exploration.

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