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Dual band dual mode triangular textile antenna for body-centric communications

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Abstract

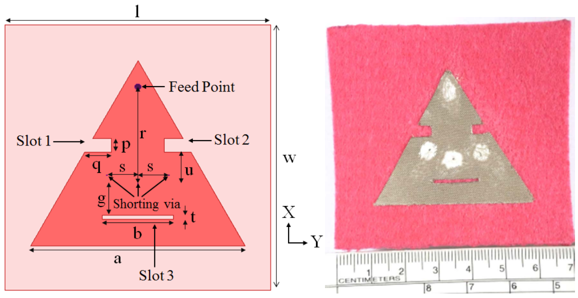
A dual band dual mode triangular textile patch antenna is proposed for body-centric communication. The antenna has a broadside radiation pattern at 2.5GHz for supporting OFF body link whereas a conical-like radiation pattern at 5.8GHz for ON body link. Tuning of both broadside and conical radiating modes to the specific frequencies is achieved by loading three shorting pins and two symmetrical open-ended slots. This approach has resulted in the realization of the dual band- dual mode antenna using a single radiator with a simple structure. An all textile design further enhances the practicability of the antenna for wearable applications respectively.

1. Introduction

The research over body wearable devices has accelerated in recent times due to the wide range of services ranging from patient monitoring, sports, military and rescue operations etc. [1]. Various ON body sensor devices mounted over human body senses numerous physical phenomena like temperature, pressure, pH, blood glucose levels inside the body and then transmits this information to the nearby base station for further processing. An antenna is a crucial part of the WBAN system which not only collects information from ON body devices; also it transmits that information to an external base station [2]. In this case, a dual band antenna is required with specific radiation pattern in each band for facilitating easy exchange of data from other sensor devices as well as with the base station. Initial researches over ON body communication mostly reported with single band antenna operation only [3-4]. Later on, several techniques have been implemented with single as well as double radiators to realize dual band-dual mode antenna characteristics. Some of them are a half ring antenna with slot and pins on the ground plane [5], T- shaped patch shorted with a circular patch and some parasitic patches [6] and Circular patch on PDMS substrate with reactive loadings [7]. A wearable triangular textile antenna for ON/ OFF body communication have been reported recently [8]. But in that work, the frequency ratio between the two modes is quite low and only supports 3.5 GHz WLAN and 5.8 GHz ISM bands only. The first two techniques utilize multiple radiators and the latter two uses a single radiator only for the generation of dual modes. With the use of two or more radiators for generating dual modes, the overall profile of the antenna also increases which is a constraint from the wearable point of view. The prime requirements of antennas for this type of applications are lightweight, flexibility, low profile, easy fabrication methodology and a lesser effect of radiation on the body.
In this work, a dual band dual mode wearable antenna for ON/OFF body communications has been proposed by using an equilateral triangular patch radiator. The TM_{10} mode is mostly broadside directed whereas the TM_{11} mode has a null in the broadside and has a conical pattern. To maintain proper frequency ratio between the two modes and to prevent unwanted mode excitations, suitable reactive loading technique has been employed. The proposed antenna has merit in terms of generation of dual modes using a single radiator only unlike previous designs. A full ground plane beneath the antenna has resulted in the minimum impact of radiation on the human body. User comfort is taken into care with the use of all textile materials to fabricate the antenna. In addition, bending sensitivity study is also performed to measure the level of detuning under robust conditions.

2. 2. Antenna Design and Characteristics

The structure of the proposed antenna is shown in Fig.1 (a). A flexible substrate with dielectric constant value (ε_r) of 1.63 and loss tangent value (tan δ) 0.04 is taken. The dielectric parameter of the substrate is measured using Agilent 85070E Dielectric Probe Kit. The patch and the ground is fabricated using woven conductive silver fabric of thickness 0.12 mm and sheet resistance less than 0.01 Ω/ sq. The fabricated antenna is shown in Fig. 1(b). The antenna is co-axially fed for laboratory purpose however for real life application a micro SMA connector can be substituted for a flat garment layer. The thickness of each layer of the substrate is 1mm respectively. Three such layers were stacked for the antenna. The substrate has an overall thickness of 3mm. Shorting vias is realized using stainless steel thread of radius 0.11mm. The upper two open-ended slots, slot 1 (s_1) and slot 2 (s_2) are symmetrical to the centroid of the triangle whereas the lower closed one (s_3) is placed at a distance of g from the centroid. One of the shorting pins is placed directly over the centroid point (p_1) and the other two were symmetrical with the centroid on both sides at a distance of 2mm from the centroid (p_2 and p_3). The overall volume of the antenna is 70 × 65 × 3.24 mm^3. Optimized dimensions of different sections of the proposed antenna are shown in Table 1. A full ground plane has been employed to provide a higher degree of isolation to the human body.



(a) (b)

Figure 1 (a). Schematic diagram of the proposed antenna (b). Fabricated antenna prototype

Table 1 Dimensions of different sections

Symbol	l	w	a	b	p	q	r	s	g	t
Dimensions in mm	70	65	48.5	16	3	6	22	7	7	1

3. Analysis and Results

In order to excite the TM_{10} and TM_{11} modes, feeding point is adjusted near to the top vertex of the equilateral triangular radiator. The basic patch i.e. the simple triangular patch antenna without any type of loadings is initially resonating at 2.9 GHz (f_1) in TM_{10} mode and at 5.1 GHz (f_2) in TM_{11} mode. But in this case, poor impedance matching is obtained with the two modes.
The resonant frequency f_{mn} of the triangular patch antenna can be calculated using the formula in [9] as:

$$f_{mn}=\frac{2c\left(m^2+mn+n^2\right)^{1/2}}{3s_e\sqrt{\varepsilon_e}}$$

(1) Where s_e is the effective side length, ε_e is the effective permittivity; c is the speed of light.
To attain resonance at desired operating frequency i.e. 2.45 and 5.8GHz with the preferred modes, reactive loading technique is employed [10]. For this purpose, three shorting pins and two open-ended rectangular slots have been employed. The E-field and H-field distribution of the antenna at 2.9 and 5.1GHz without any type of loadings is shown in Fig.2 (a-d). Two shorting pins symmetrical to the y-axis were placed at a distance (s) horizontally and for vertical variation, distance is represented by 'd'.

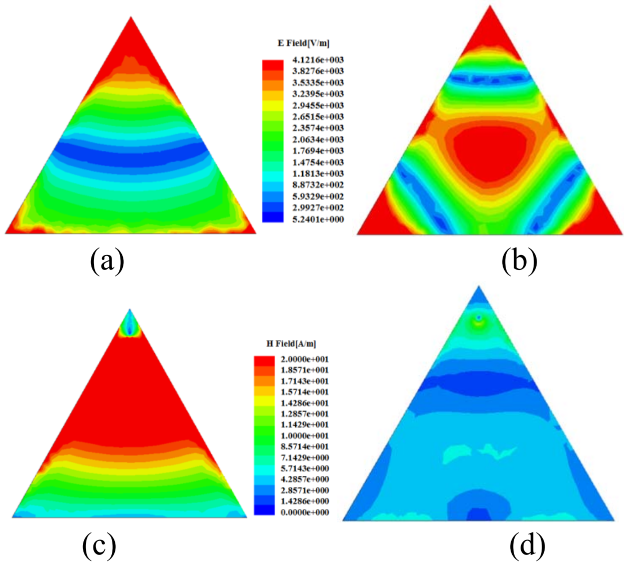
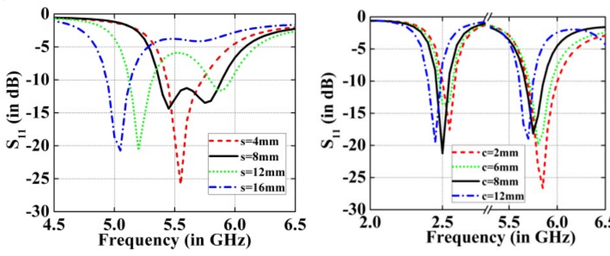


Figure 2 E-field distribution at (a). 2.9GHz (b). 5.1GHz and H –Field distribution at (c).2.9GHz (d). 5.1GHz

The third shorting pin has been placed at the centroid position of the triangle and its vertical position variation is designated as 'c'. By placing the shorting pins in positions of minimum E- field of 1st resonating frequency (f_1) and maximum E- field position of 2nd resonating frequency (f_2), the higher order mode gets affected. In the meantime, placing the slots in positions of the maximum H-field position of 1st resonating frequency (f_1) and minimum H-field position of 2nd resonating frequency (f_2), lower order mode gets affected. The open-ended slots have a length 'q' and width 'p' while the closed slot has a length 'b' and width 't' respectively. The parametric analysis results of slot dimensions and number of pins as well as position variation are discussed in the next section.

3.1. Effect of shorting pins

Shorting pins p_2 and p_3 were placed symmetrically to the y-axis and the centroid.



(a) (b)

Figure 3 Variation in S_{11} with symmetrical (a).Horizontal variation of pin p_1 and p_2 position (b). Pin p_3 variation along the vertical direction

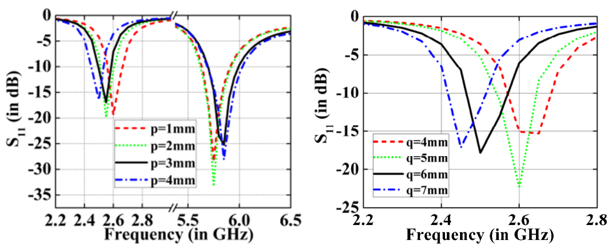
By reducing the separation (s) between them uniformly along the y-axis, f_2 shifts towards the right as shown in Fig. 3 (a). The higher order mode is not affected in this case. Variation in the position of shorting pin (p_3) at the centroid position of the triangle along the vertical direction (c) is used for improving impedance matching for both the bands as shown in Fig. 3(b). Varying the position of the pins (p_1 and p_2) along the vertical direction (d) i.e. x-axis affects the frequency ratio between the operating bands as given in Table no.2. It can be observed that initially, the frequency ratio increases when moving from negative x-axis near to the origin. While moving to the positive x-axis, frequency ratio again reduces. Thus vertical pin position variation affects the frequency ratio between the two modes respectively.

Table 2 Parametric analysis results with vertical pin position variation

Pin position (in mm)	***f_{r1}***	***f_{r2}***	***Frequency Ratio (f_{r1}/f_{r2})***	***S_{11} (1^{st} band)***	***S_{11} (2^{nd} band)***
-12	2.85	5	1.75	-24.3	-22.3
-6	2.8	5.1	1.82	-16	-22.93
0	2.7	5.3	1.96	-22.3	-20.4
6	2.75	5.25	1.91	-18.2	-14.3
12	2.95	5.1	1.73	-12.5	-17.26

3.2. Effect of rectangular Slots

Two open-ended slots have been carved, symmetrical to the feed axis (s_1 and s_2); width of the slots (p) affects both f_1 and f_2.



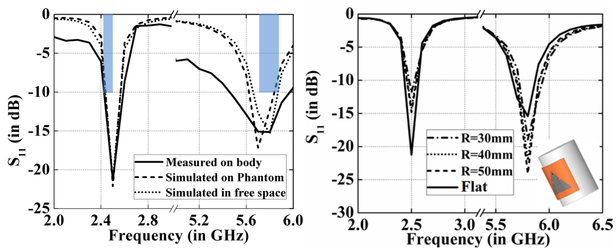
(a) (b)

Figure 4 Variations in S_{11} with (a). Width of the slots (b). Length of slots

Increase in width of the slots (p) increases the frequency ratio between them as shown in Fig.4 (a). Increasing the length of the slots (q) equally results in a leftward shift of the f_1, as shown in Fig. 4 (b), whereas the higher frequency (f_2) remains unaffected in this case. Closed rectangular slot 3 (s_3) below the center of the patch affects the impedance matching of the 1st band while the 2nd band is not found to be too much affected. Increase in length of the slot (b) improves the impedance of 1st band while the 2nd band shows almost constant impedance.

4. ON Body Antenna Performance

During parametric analysis, the performance of the antenna has been tested in free space condition only. For practical considerations, the antenna has to be tested over equivalent phantom model and ON body. A box having dimensions of 150 × 100 × 10 mm^3 is placed under the antenna which has the given dielectric properties (ε_r = 54.2, σ = 1.52 S/m, tanδ = 0.205 at 2.45 GHz and ε_r = 48, σ = 5.56S/m, tanδ = 0.354 at 5.8 GHz) close to the human body tissue as obtained from [7] is shown in Fig. 6(a). Two types of muscle-mimicking phantoms were prepared one at 2.5 and the other at 5.8 GHz frequency. The phantoms has been prepared using standardized sucrose powder, de-ionized water and agar powder with proper proportions. To mimic the practical thickness of garments, the antenna is placed at a height of 5 mm over the box during simulations as well using foam spacers during measurements. The measured, as well as simulated S_{11} values of the antenna are shown in Fig. 6 (a). A good agreement is obtained between the simulated and measured results. The measured -10dB return loss bandwidth under on body conditions is 180 MHz (2.4-2.58GHz) in the 1st band and in the 2nd band, it is 500 MHz (5.48-5.98GHz). There is a little mismatch which might be due to the constraints involved while fabricating manually.



(a) (b)

Figure 6 (a). Measured and Simulated S_{11} Results (b). Variation in S_{11} with bending

Bending sensitivity study is done to assess the robustness of the antenna when practically worn over the human body. Fig. 6 (b) depicts the results when it is wrapped on a cylinder of radii 30, 40 and 50 mm. It can be observed that bending has affected the matching of the antenna but -10dB impedance bandwidth of the antenna still it covers the application bands efficiently. The higher resonating frequency shifts little to the right with an increase in bending radii and the matching of the antenna deteriorates with increase in bending radii. The radiation patterns are plotted in Fig.7 (a-d) at frequencies of 2.5and 5.8GHz. Both on the body and free space results are shown. The radiation pattern is mostly broadside directed at 2.5 GHz whereas, at 5.8GHz, it has a conical radiation pattern thus satisfying the criteria for ON/OFF body communications. Although the radiation pattern is not fully Omnidirectional in the horizontal plane still the conical pattern supports ON body communication respectively.

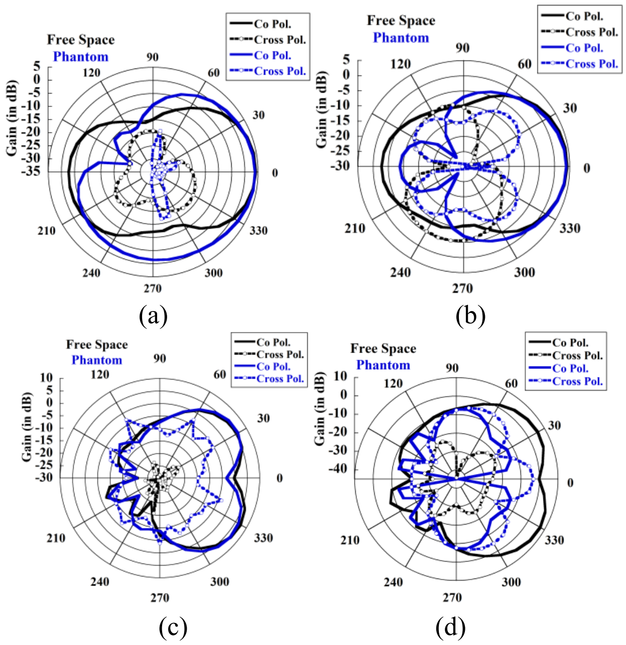


Figure 8 Radiation Patterns at 2.5GHz (a). XZ- Plane (b). YZ -plane and at 5.8GHz (c). XZ -Plane (d). YZ-Plane

Maximum gains in free space conditions are 4dB and 7.2 dB in lower and upper bands and in ON phantom the corresponding gain values are 3.8dB and 6.8 dB respectively. A reduction in gain can be observed when the antenna is placed on phantom over free space condition which is due to the lossy nature of human tissue where the near field of the antenna strongly couples.

Finally, SAR levels have been investigated based on the IEEE C95.1-1999 standard averaged over 1 gm of tissue with the input power of 1 W. Maximum 1 gm average SAR at 2.5 and 5.8GHz are 1.01 and 1.19 W/kg respectively at a separation distance of 5mm from the phantom, which is below the threshold of 1.6 W/kg

5. Conclusion

In this paper, a compact dual-band dual-mode textile antenna is proposed for ON/OFF body communications. Tuning of the antenna in the designated bands with desired modes is achieved with slot and pin loadings within a single radiator. The antenna is light weighted, compact in size and has a simple design topology in addition to less backward radiation characteristics. The achieved bandwidth and gain of the antenna is found to be quite high in both the bands. Further, the level of detuning of the antenna when placed over the phantom model and under the bending conditions is found to be very minimal which signifies high robusticity of the antenna and optimal for wearable applications.

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7. References

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