A COMPACT FAN SHAPED ANTENNA FOR WEARABLE APPLICATIONS

S. Chitti
ECE Department,
Aditya University,
Surampalem, India.
20A91A0449@aec.edu.in

M. Kalyani
ECE Department,
Aditya University,
Surampalem, India.
21A95A0402@aec.edu.in

B. P Mahalakshmi
ECE Department,
Aditya University,
Surampalem, India.
20A91A0406@aec.edu.in

K. Chaitanya Narayana
ECE Department,
Aditya University,
Surampalem, India.
20A91A0425@aec.edu.in

V N Koteswara Rao Devana
ECE Department,
Aditya University,
Surampalem, India.
koteswararaodevana@adityauniversity.in

Ch V Ravi Sankar
ECE Department,
Aditya University,
Surampalem, India.
venkataravisankarch@adityauniversity.in

Abstract-- This work presents the design of a flexible, low-profile radiator for wearable applications. The ability to put the antenna on the body is an essential requirement for on-body applications. Jeans material with 0.6 mm thickness, the tangent loss (tan δ) is 0.02, dielectric constant (ε_r) is 1.6 is used to design with a size of 23×25×0.6 mm^3. A fan shaped patch is integrated on the substrate with a defected ground structure (DGS) is printed on back of substrate, which is used to achieve a bandwidth from 3.4–4.2 GHz for magnitude of s_{11}< -10 dB with an efficiency 96%, operated for 3.3–3.6 GHz (WiMAX), and 3.7–4.2 GHz (C-band) applications.

Keywords— Wearable antenna, flexible substate, microstrip patch antenna, medical application, WiMAX, CST.

I. INTRODUCTION

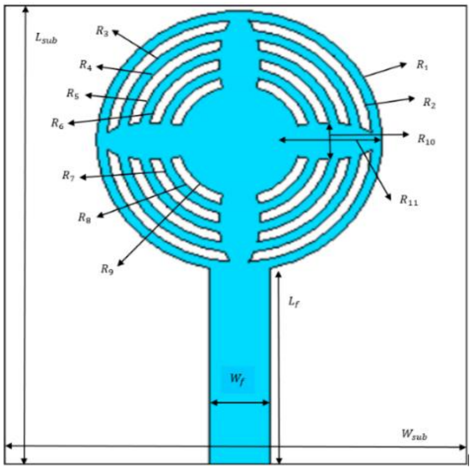
Body-Centric Wireless Communication (BCWC) indeed plays a vital role in various fields, especially in wearable technology applications such as telemetry and healthcare. The increasing demand for efficient wearable devices has led to a focus on wearable antennas, intended to function both off and on the body. Because they function so closely to the human body, fabric or textile antennas are an important field of study for body-centric communication.

One of the hot areas in body-centric communication research is wearable fabric/textile antenna. As a result of coupling and absorption by human tissues, these devices, in contrast to traditional antennas, function in close closeness to the body of an individual, which has an influence on performance parameters. These antennas are typically attached to clothing, though occasionally they are glued to people's skin [1]. A transmitting patch and the ground are placed on opposite ends of the dielectric substrate in a simple microstrip patch antenna [2].

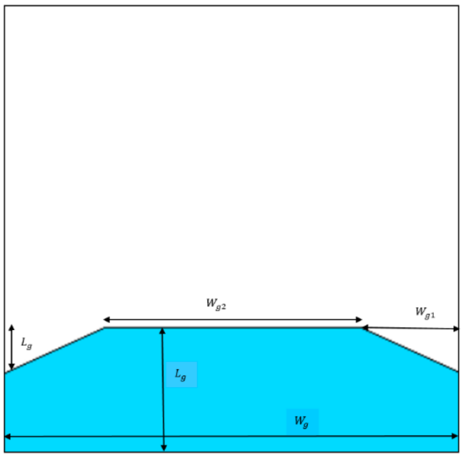
An UWB rectangular antenna designed for WLAN applications is mounted on a jean substrate. It operates across a wide frequency range, utilizing a 50-ohm microstrip line for feeding and 0.6 mm thick denim substrate is 0.6 mm having ε_r=1.6. The element displays notch characteristics and bandwidths of 5.86-10.7 GHz and 2.4-4.2 GHz [3]. The denim substrate is 0.6 mm thick and has a measured permittivity of 1.6. The antenna displays notch characteristics and bandwidths of 5.86-10.7 GHz and 2.4-4.2 GHz. It attains a radiation efficiency of at least 75% throughout the working frequency range [4]. CPW feeding is employed to attain a broad impedance bandwidth in wearable antennas [5], utilizing flexible substrates to ensure antenna flexibility. The UBW textile antenna performance for flexible antennas [6] is designed with a frequency range of operation between 3 and 12 GHz. The textile material used was jeans. A robust, wearable, high-impedance surface (HIS) combined measure 45 × 45 × 2.4 mm^3 antenna is reported in [7]. Both devices operate at 2.45 GHz frequency and are composed of a very stretchy textile. The antenna and HIS together provide exceptional performance, with a gain of 7.47 dB and an efficiency of 71.8% [8]. The flexible antenna composed of paper for wearable applications in telemedicine [9] is an investment that, under typical circumstances, runs at 2.33–2.53 GHz. The antenna demonstrated a feasible the layout of a flexible paper, that can operate in the 2.4 GHz ISM bands. Additionally, a tiny textile antenna is built for 2.4 gigahertz ISM band applications [10]. To be able to satisfy the needs of wearable applications, a sturdy, small, and low-profile solution has been demonstrated by a textile element with a unique downsized EBG structure operating at 2.4 GHz [11]. A tiny, foldable textile-based wearing monopole antenna [12] for lower SAR wrist applications offers an actual gain & overall efficiency of 4.06 dB & 44.39% in a flat scenario and 6.76 dB & 88.4% in free space, respectively. It keeps up its strong performance when it bends over an actual human hand model, SAR readings of 0.521 & 0.404 W/kg over 1 and 10 g of cells, respectively.

II. ANTENNA DESIGN

The suggested antenna's size is 23×25×0.6 mm^3. The three layers of the antenna are substrate, which is composed of denim material, patch, and copper, which are composed of copper material. The flexible Jean substrate used in the design of the suggested antenna has a constant of dielectric 1.6, tan δ=0.02 & 0.6 mm thickness. The patch has a fan-like shape [13]. The upper layer consists of four ellipses integrated with four circular slots and a feed of ($W_f \times L_f$) as delineated in Figure 1 (a). The bottom of substrate is initially designed with the rectangular shape of length (L_g) and width (W_g), further two bevel shaped slots [14] are subtracted at the edges shown in Figure 1(b). The optimized dimensions are in Table 1.



(a) Front view



(b) Back view

Figure 1: Antenna Design.

Table1: Antenna dimensions.

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
W_{sub}	23	R_4	5.5	R_{11}	1
L_{sub}	25	R_5	5	W_g	23
W_f	3	R_6	4.5	L_g	7
L_f	9	R_7	4	W_{g1}	5
R_1	7	R_8	3.5	W_{g2}	13
R_2	6.5	R_9	3	L_{g1}	2.5
R_3	6	R_{10}	2.5	--	--

III. SIMULATION RESULTS

The patch structure of the radiator is initially designed with a single circular slot and feed on top of the substrate and similar four circular slots are added to that initial one. Four ellipses are intersected with an angle of 90^0 one after one as Figure 2 (a)-(f).

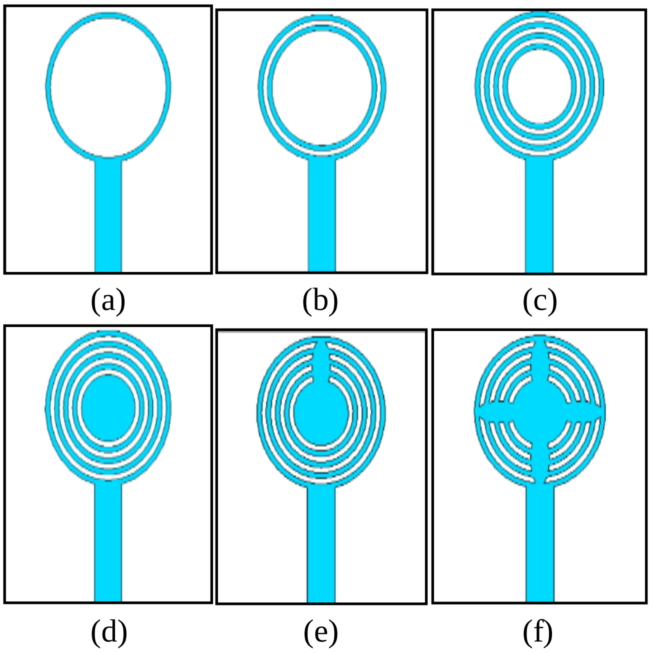
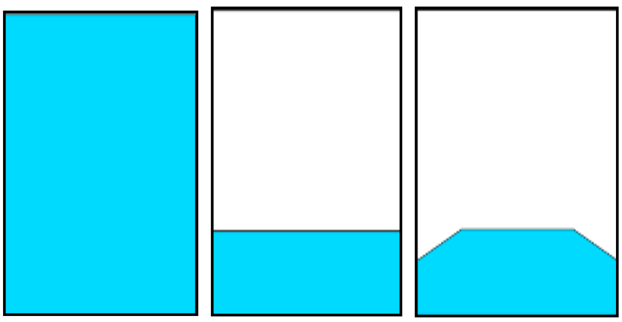


Figure 2: Evolution of patch structure.

The ground of the antenna is initially taken as full with respect to the size of the substrate. Further the size of the ground is minimized to the length 7 mm and simulated results are illustrated in Figure 3. A two-bevel formed openings are removed from the edges of the rectangular ground. The three steps design and simulated results of the ground are in Figure 3 (a)-(c).



(a) (b) (c)

Figure 3: Evolution of ground structure.

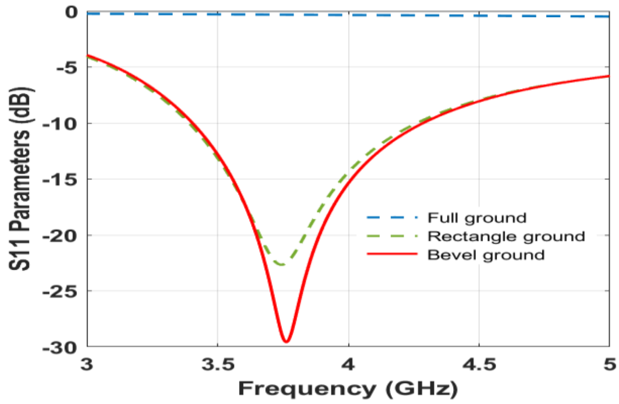
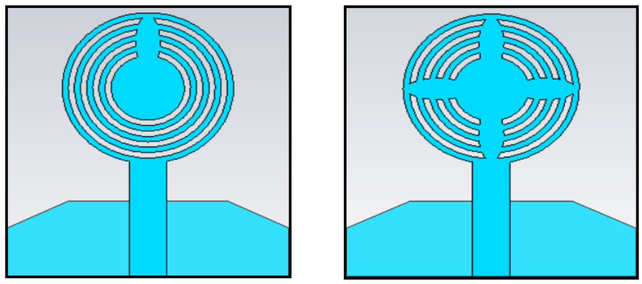


Figure 4: S_{11} plot with varying ground.

The variation of patch structure on the performance of the radiator is shown in Figure 5. The Ant#1 seen in Figure 5 (a) has a single elliptical patch and a bevel-shaped ground. For the structure, Ant#1, it is not providing the considerable resonances. So, to resonate the antenna, three elliptical patches are integrated into the Ant#1 with an angle of rotation of 90^0 and the final proposed antenna, Ant#2 looks like the fan shape with a bandwidth of 3.4–4.2 GHz. The simulated results are appeared in Figure 6. Thus, the radiator has 3.4–4.2 GHz of bandwidth and resonates at 3.76 GHz.



(a) Ant#1 (b) Ant#2

Figure 5: Patch implementation.

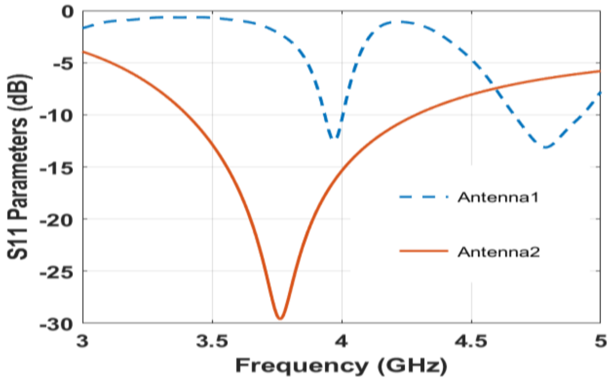
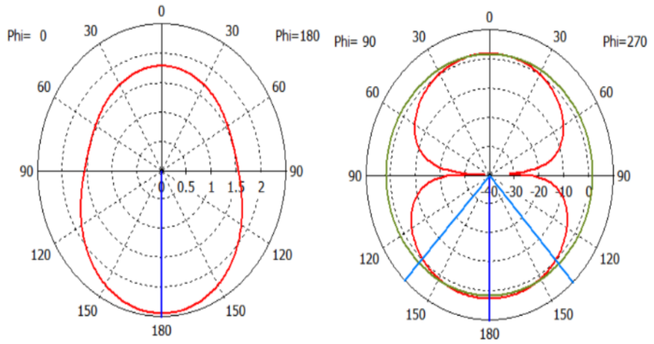


Figure 6: Simulated S_{11}.

The relative distribution of emitted electromagnetic fields in space is represented graphically by an antenna's radiation pattern as depicted in Figure 7, both in E and H planes at resonant frequency of 3.76 GHz.



E-plane H-plane

Figure 7: Radiation patterns at 3.76 GHz.

For any wearable antenna, it must satisfy the bending conditions on arm, chest, stomach, and other body parts to get better results. The radiator is simulated under bending conditions with bending angles of 20^0, 30^0, 40^0, and 50^0 and the results are compared with unbend condition as in Figure 8. From Figure 8, it is noticed that the suggested radiator operates in the 3.4–4.2 GHz range without bending and with the bending angle is increased, the resonant frequency is shifting towards right and the negative peak of S_{11} is also increasing. The SAR (Specific Absorption Rate) is a method for figuring out how quickly energy is taken in by the human body [15]. SAR measures the amount of radiofrequency energy absorbed by a 1g or 10g mass of body tissue and represented in W/kg. To prevent conflicts, the SAR value for a wearable element should be less than 1.6 W/kg. For SAR analysis, the three layers of a body phantom: skin (4 mm), fat (5 mm) and muscle (6 mm) are designed. The simulation set up of body phantom and the antenna's surface are separated by a 1 mm air gap and SAR plot are depicted in Figure 9 and 10. The dielectric properties of body phantom are represented in Table 2 and performance comparision is illustrated in Table 3.

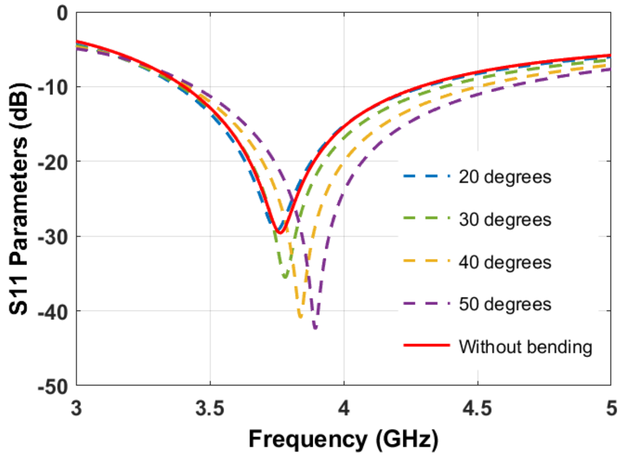


Figure 8: Proposed aantenna bending analysis.

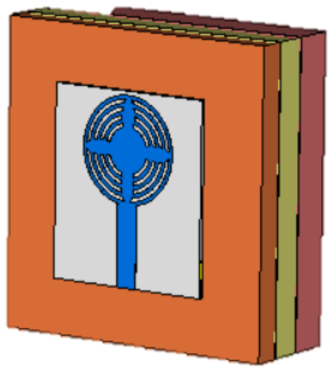


Figure 9: Simulation set up of body phantom with three layers.

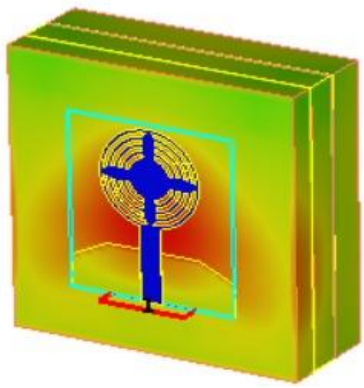


Figure 10: Simulated SAR Analysis.

Table 2: Dielectric properties of body phantom

Tissue	Dielectric constant, ε	Conductivity, S/m	Density, Kg/m^3
Skin	37.95	1.49	1001
Fat	5.27	011	900
Muscle	52.67	1.77	1006

Table 3: Performance comparision.

Ref.	Year	Size (mm^3)	material	Gain, dBi	R.E, %
16	2020	60×60×2.4	Jeans	6.45	–
17	2021	39×39×0.5	Rogers	2.06	75
18	2021	54×54×3.9	Fabric	6.49	84
19	2023	35× 32×0.5	Rogers	3.54	91
Prop.	2024	23×25× 0.6	Jeans	2.22	96

R.E- Radiation Efficiency

V. CONCLUSION

A compact flexible antenna is designed for wearable medical applications which is operated in the range 3.4-4.2 GHz is proposed. A flexible jeans substrate material having thickness of 0.6 mm with the combination of five circular slots and four ellipses with the microstrip line is etched on top and a beveled ground is deposited on back of substrate. The recommended radiator dimension is 23×25×0.6 mm^3 and achieved 96% efficiency. The radiator performance is also verified for bending angles of 20^0, 30^0, 40^0, and 50^0 to be used for wearable applications. The advantage of the proposed work is that the antenna is used for wearable applications that addresses the challenges of size reduction without compromising performance.

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