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DESIGN OF WEARABLE ANTENNA FOR ISM BAND APPLICATION

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ABSTRACT

A crescent-shaped wearable antenna is designed at 5.4 GHz for ISM (Industrial, Scientific, and Medical) band application and it is presented in this paper. The crescent shape is a combination of two circles and then the inner circle is removed from the outer circle for achieving a crescent shape. The crescent-shaped wearable antenna used jeans fabric as a substrate and it provides comfort and greater flexibility to wear on the human body. The proposed wearable antenna has a small thickness. The measured radiation parameters of wearable antenna-like return loss and VSWR are agreed well with performance evaluation simulations. It is simulated using HFSS software.

Keywords: wearable antenna, ISM band, crescent-shaped.

1. INTRODUCTION

Conventional radio equipment is bulky and uncomfortable to wear on the human body and also conventional antennas make easy targets for enemies. Hence, invisible, lightweight, and embedded wearable electronic systems have become more popular to secure soldiers and improve their combat utility. Wearable antennas are part of an intelligent wearable system that can support different applications like emergency workers, athletics outfits, medical, military, and entertainment applications. In addition, integrating additional hardware components into smart clothes can provide other functions such as call assistance and patients' medical condition [1] - [2].

The body-worn wireless communication is possible using wearable antennas. It provides on and off-body communication between wearable devices using wearable antennas. These belong to a different class manufactured entirely/partially with textile material, unlike regular antennas made with rigid materials. Wearable antennas are fabricated from textiles that are integrated into clothing [3] - [5].

In [6], the authors examined the diversity of wearable antennas for different fabrics and applications. In contrast to constructing a conventional antenna, conductive fabric like a flectron is used for ground and patch. The non-conductive materials like cotton and silk are used for the Substrate, which provides more flexibility and comfort to wearables.

In [7], to make it more protective against environmental effects like corrosive and fluid absorption, an antenna that can be washable is designed to cover the inbuilt textile antenna by Coating it with a breathable material like thermoplastic polyurethane. For durability and consistent performance of the washable antenna even after rigorous washing, the screen printing technique is used.

A Hilbert-shaped meta material is used for the miniaturization of the wearable antenna and also reduces the SAR value. The shadowing effects can be reduced by antennas integrated with met material [8]-[9].

Horizontal, vertical, and circular stitch configurations suggested evaluating the designed antenna's performance and observed that circular stitch configuration gives some edge in performance compared to the two other stitch configurations as circular stitch follows leaf shape. The Radiation property of textile antenna changes depending on the fold and bends of textile fabric. In addition, moisture affects antenna behavior [10].

Based on PIFA topology [11], the textile antenna is designed for different bands like single, dual, and UW bands. For the designed antenna, conductive materials like conventional copper foil, plain copper polyester taffeta fabric, and shield are super used. A non-conductive felt substrate preferred to have dielectric permittivity of 1.45 and a dielectric loss is 0.044.

A wearable antenna designed for wearable applications using sensors [12]. It can be used for medical applications with a miniaturized structure. Here two methods are proposed: In the first method, adhesive-backed nonwoven conductive fabric, and in the second technique, embroidery of conductive threads is used for the wearable antenna.

For WiMAX an application, a wearable E-shape patch antenna was designed, which follows the process of PVB (polyvinyl butyral) coated polyester fabric. It was enabled to perform at 3.37 GHz frequency and provided a return loss of -21dB. In addition, the PVB-coated polyester fabric has several characteristics as being thin, flexible, and water-resistant. Therefore, it is allowed to be used in wearable applications [13].

The circular polarization of the MIMO wearable antenna is designed for different wireless wearable applications on felt Substrate. Here, CP can be reached by erecting an L shape slot on the ground plane [14]. The brace wearable antenna is proposed for the detection of damaged tissues of the knee. It is designed on wool fabric because it is comfortable to wear on the human body. The early detection of Ligament tears reduces major knee injury then it can save more than six million lacerations per year [15] - [16]. The UWB textile antenna is proposed for the detection of breast cancer and is also designed on wearable fabric [17]. In papers, some authors designed wearable antennas partially with fabric, and others proposed fabric wearable antennas fully.

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2. WEARABLE ANTENNA DESIGN

Initially, the circular patch dimensions are determined by applying the subsequent Eq. [18]. Next, the design values are analyzed for more results that are reliable. For a circular patch, the effective radius is

$$a_e = a\left\{1 + \frac{2h}{\pi a \varepsilon_r}\left[\ln\left(\frac{\pi a}{2h}\right) + 1.7726\right]\right\}^{1/2} \tag{1}$$

The resonant frequency is

$$f_r = \frac{1.84 * c}{2\pi a_e \sqrt{\varepsilon_r}} \tag{2}$$

Where, f_r is the resonant frequency,

ε_r is relative permittivity of fabric,
h is the thickness of fabric,
a_e is the effective radius,
a is the circular patch radius, and
c is the velocity of light.

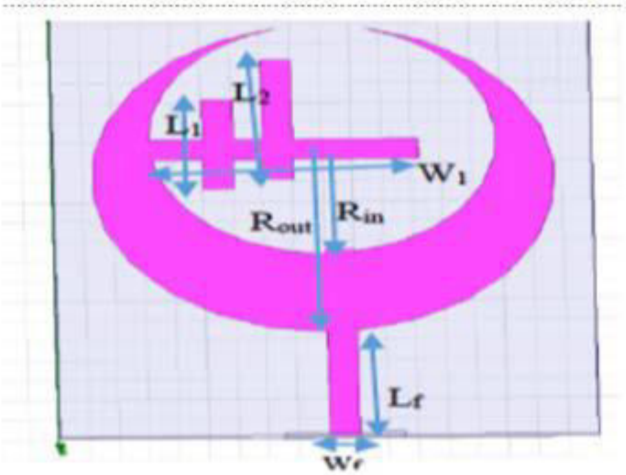


Figure-1. Illustrative of crescent wearable antenna.

The schematic structure features of the crescent-shaped wearable antenna are presented in Figure-1 above. The recommended wearable antenna is configured on jeans cloth with a relative permittivity is 1.67 [19] - [20]. Its thickness is 0.8 mm. The design parameters of the Substrate are 22 mm x 18 mm. A microstrip line feeds it, and its length (L_f), and width (W_f) are 9.4 mm and 1 mm. The inner and outer circle radius is R_{in}=5.8mm, R_{out} =8.2mm. Both circles are overlaid, and then the inner circle is removed from the outer circle, so the patch's shape is crescent. The length of the horizontal strip (W_1) is 6mm, the size of vertical strip L_1 is 4.5mm, and the length of vertical strip L_2 is 6mm. The position of three strips on the patch is affected the radiation characteristics of the crescent wearable antenna.

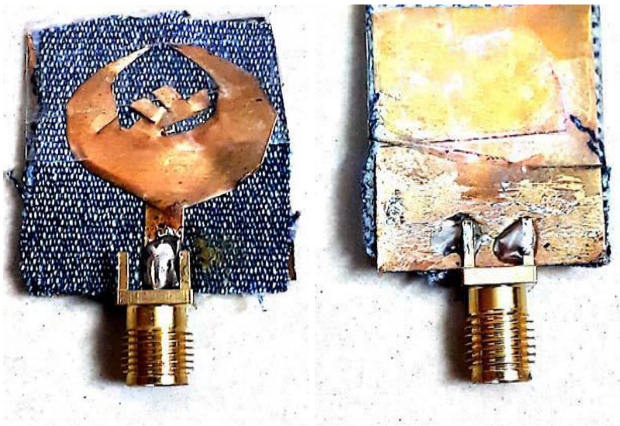
2.1 The Step by Step Procedures for the Design of the Crescent Wearable Antenna are Shown Below

Step 1: Initially, the ground plane was created with copper material.

Step 2: Jean substrate positioned on the ground plane.

Step 3: For the patch, two circles are overlaid from the outer circle diminishes the inner circle, which gives a crescent shape. The patch is made of copper material.

Step 4: Two vertical and one horizontal rectangular patch are created and connected to the crescent shape. Finally, it is positioned on the jeans substrate.



(a) (b)

Figure-2. Fabrication of crescent wearable antenna (a) Front (b) Back view.

The fabricated model front view of a crescent-shaped wearable antenna is given in Figure-2 (a), and another view with the full ground is given in Figure-2(b). Here patches are made with copper material, and Substrate is made with jeans fabric. The microstrip line feed is attached to the SMA connector, and it is suitable for the excitation of crescent shaped wearable antenna. Here, the inner pin is connected to the patch and the outer pins are attached to the ground.

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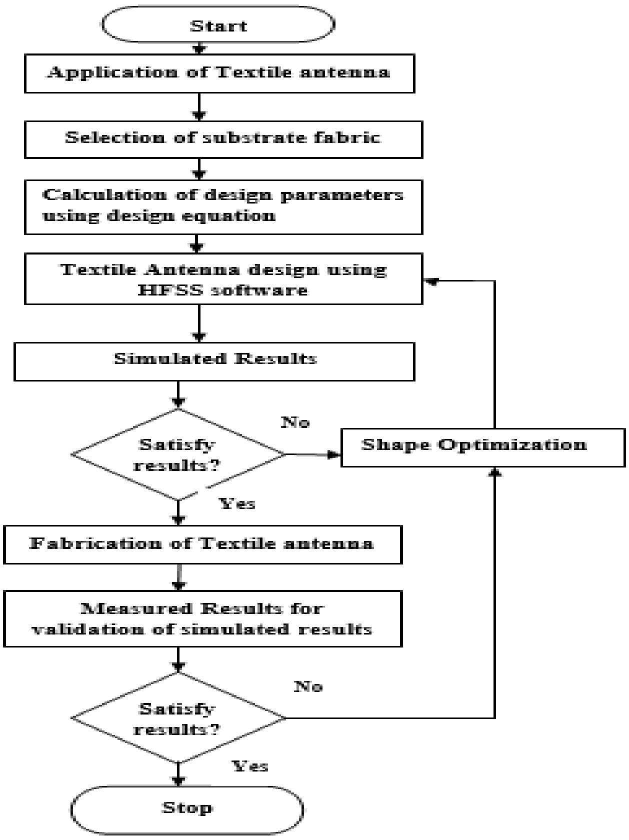

Figure-3. Flow chart for design of UWB wearable antenna.

Figure-3 shows the flow chart for the design of the crescent wearable antenna. The flow chart shows the procedure for the simulation and measurement of the crescent wearable antenna. If the simulated or measured results are not good, then the wearable antenna is optimized for better results using parametric analysis. The flow chart is suitable for analyzing the crescent wearable antenna at different levels.

3. RESULTS OF WEARABLE ANTENNA

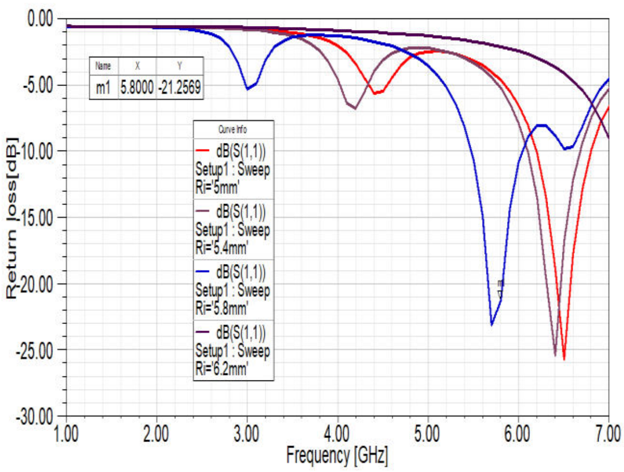

Figure-4. Parametric analysis of inner circle radius of crescent wearable antenna.

The inner-circle radius (R_{in}) is simulated using a parametric technique, and it is changed from 5mm to 6.2 mm. Then the 5.8mm was chosen as the optimum value because it resonates at 5.8 GHz frequency, as presented in Figure-4. The resonance frequency of the crescent-shaped wearable antenna is influenced by a change in the inner circle radius and also depends on the substrate thickness. The distribution of current on patch changes depends on the slot position of the inner circle.

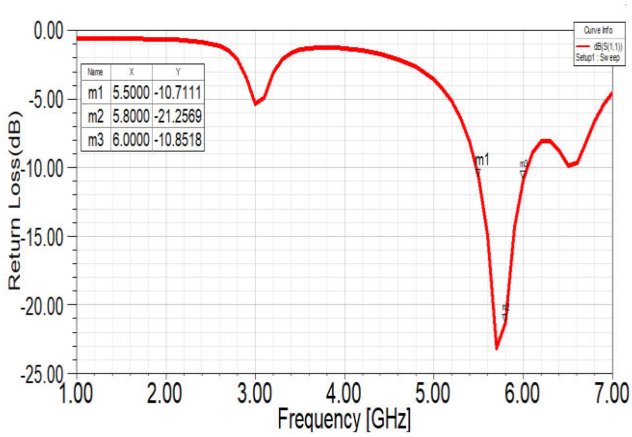

Figure-5. Return loss of the crescent wearable antenna.

Above Figure-5 presents the return loss of the crescent shape wearable antenna. The wearable antenna's return loss is -21.2 dB at 5.8 GHz, and the impedance bandwidth range between 5.5 GHz and 6.0 GHz is 500 MHz. It is calculated using a -10 dB line as a reference.

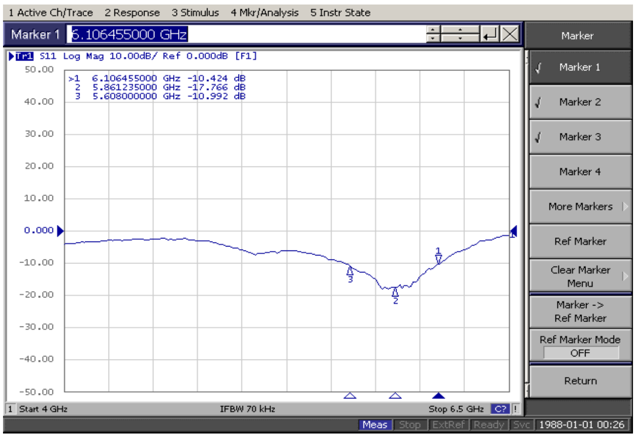

Figure-6. The measured return loss of the crescent shape wearable antenna.

Figure-6 above presents the practical return loss of the crescent shape wearable antenna. The fabricated wearable antenna's return loss is -17.7 dB at 5.8GHz, and the corresponding impedance bandwidth is 500 MHz between 5.6 GHz and 6.1 GHz. It is calculated based on the -10dB line. The fabricated and simulated crescent shape wearable antenna resonates at the same frequency. The resonance frequency of the wearable antenna changes depending on the bending condition of the antenna.

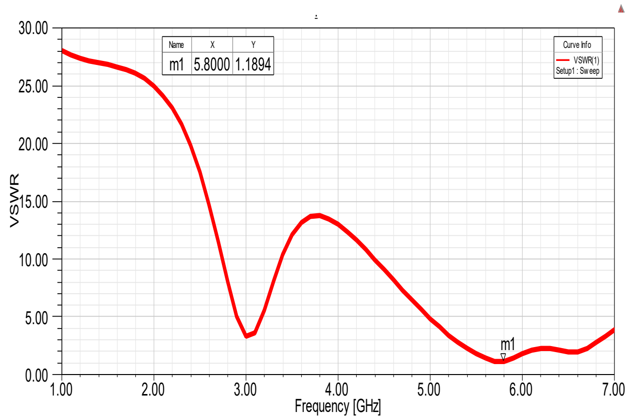

Figure-7. Simulated VSWR of crescent wearable antenna.

The simulated VSWR of the crescent shape wearable antenna is given in Figure-7. The simulated VSWR value is 1.18 at 5.8 GHz frequency, and this value is below the reference value (VSWR<2).

The measured VSWR value of the crescent wearable antenna is presented in Figure-8. The measured VSWR value at 5.8 GHz frequency is 1.29. The measured and simulated VSWR values are almost equal. But, this variation is due to the air gap between the patch and the jeans substrate.

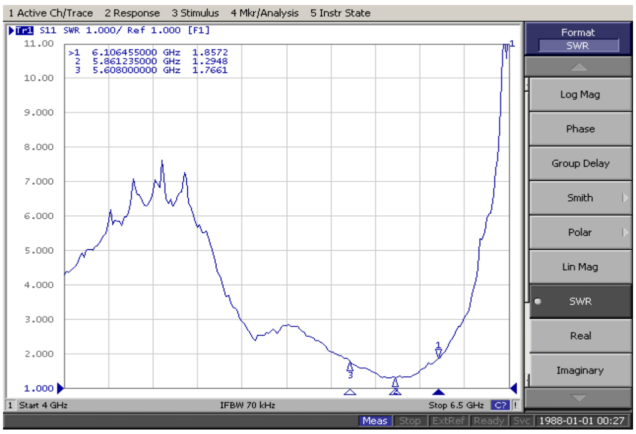

Figure-8. Measured VSWR of crescent shape wearable antenna.

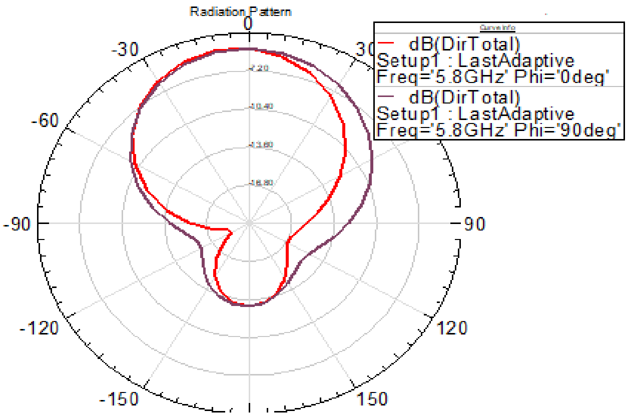

Figure-9. Radiation pattern of crescent wearable antenna.

Figure-9 above shows the radiation pattern of a crescent-shaped wearable antenna at 5.8GHz frequency. Depends on antenna bending position and due to human body, radiation pattern will affect.

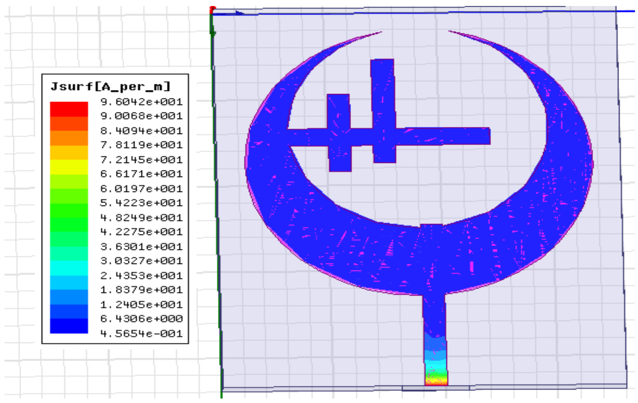

Figure-10. Current distribution of crescent textile antenna at 5.8 GHz.

The flow of current for the crescent shape wearable antenna is shown in Figure-10. The distribution of current changes depends on the creation of slots on the patch. At 5.8 GHz frequency, the maximum current is allocated to the patch antenna and along the feed line also.

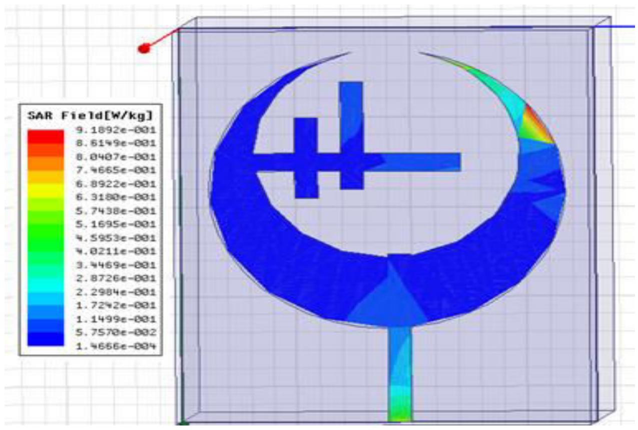

Figure-11. SAR of crescent textile antenna at 5.8 GHz.

For the wearable antenna, the SAR value is an important parameter. It must be below the 1.6 w/kg over 10g tissue as per IEEE standards. Figure-11 shows the SAR value for the proposed textile antenna. Here, the SAR value is 0.9 w/kg over 10g of tissue at an input power of 0.5 watts.

Table-1. Results of the crescent shaped wearable antenna.

Parameters	Simulated	Measured
Frequency(GHz)	5.8	5.8
Return loss(dB)	-21.2	-17.7
Bandwidth(MHz)	500 (5.5 to 6.0GHz)	500 (5.6 to 6.1GHz)
VSWR	1.18	1.29

The summary of obtained simulated and measured crescent shaped wearable antenna results are presented in Table-1.

4. CONCLUSIONS

A single band crescent shape wearable antenna designed for ISM band wearable application. The fabricated crescent shape wearable antenna resonates at a 5.8 GHz frequency. The fabricated wearable antenna's return loss is -17.7dB, and the corresponding impedance bandwidth is 500 MHz which is from 5.6GHz to 6.1GHz. The VSWR value (<2) is 1.29 at 5.8 GHz frequency. Here, the Substrate is a jeans fabric.

Future scope: Radiation characteristics of the wearable antenna change depending on the bending condition of the antenna and also calculates SAR value.

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