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Staked T Lines Integrated Circular Microstrip Tri-band Wearable Antenna for GSM, ISM and NATO Applications

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***Abstract:** Antenna designed with fabrics as dielectric substrate find applications in health monitoring systems, fire-fighting, rescue operations, space, navigation and military personal communications. The aim of this paper is to design a flexible, microstrip antennas that will be mechanically robust and light weight. This type of antenna will find applications in Global System for Mobile communication (GSM), Wireless Fidelity (Wi-Fi) and North Atlantic Treaty Organization (NATO) bands. A tri – band microstrip antenna is designed and constructed with woolen felt as substrate. The dielectric constant of woolen substrate is 1.45, The thickness of the substrate is 1.588 mm. The gain and axial ratio are stable when bent and in presence of moisture. Also the operating band is compliant with specifications. The operating frequencies are 1800MHz (GSM), 3.5GHz (Wi-Fi) and 4-5GHz (NATO). The simulated result of S_{11} is measured as for all three bands are -13.399dB, -35.114dB and -36.254dB respectively. The tri-band wearable antenna is verified and validated using network analyzer. The testing of triband antenna also involves the calculation of Specific Absorption Rate (SAR) under the standards of IEEE and ICNIRP. The antennas with fabric as substrate allow hands free operation, comfortable and are also economically feasible.*

***Index Terms:** Global system for mobile communication (GSM), North Atlantic Treaty Organization (NATO), Wireless fidelity (Wi-Fi), Microstrip, Tri-Band, Wearable antenna, Woolen felt.*

I. INTRODUCTION

WIRELESS body area networks (WBAN) find diverse applications from health care to safety to defense. Hence it has become an important area of research and development. Antenna is an integral part of any communication systems as such as communication between sensors, with other off-body systems (e.g. GPS and GSM)., etc. The emerging technology of VLSI lead to the design of wearable electronic devices, combined with computer technology. This in turn has lead to the conception of a wide range of devices that can be carried in pockets and bags by the users in their pockets or embedded in the body or hidden in their dresses, assimilated into their body and much more to the innovation of the designer [1]– [4].

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This is due to the advancement in the field of designing mobile phones. Mobile phones have come smaller and smaller but with wide applications in recent future. This has made mobile phones more convenient for personalized operations in the last decade. The challenge in mobile communication is the design of antenna since it operates in a highly challenging atmosphere, in close proximity of the human body. Also the antenna performance is affected by deformation, especially if incorporated directly into clothing. Examples are smart clothes for applications including sports, emergency rescue workers, navigation, military, medical and space applications or even in casual daily clothes. Designing antennas for such applications are thus exciting. One such antenna is proposed in this paper.

Research has been done to study the effects of different fabric material for various wearable applications. The distinct feature of wearable patch is that the textile fabric substrate can be effortlessly be integrated in the clothes. Woolen felt is used as the substrate in this work, since it offers better flexibility than other textile materials such as jean, fleece, polyester, cotton etc. Also the low dielectric constant of felt material reduces the loss created due to the surface wave. In this paper a tri-band monopole antenna is designed for GSM-1800MHz, Wi-Fi-3.5GHz and NATO-4-5GHz bands. This design provides multiple services for wireless applications using single antenna structure. This design proposed for tri-band antenna prototype, provides improved performance in terms of bandwidth when compared to the literature with similar applications [5]. Antenna for wearable applications requires Specific absorption rate (SAR) analysis to study the on-body measurement of human tissue. Section II deals with the design consideration for the proposed tri-band antenna. In Section III, S parameter and radiation characteristics are presented and explained. This section also includes the effects of bending and crumpling of the substrate. Section IV nalyzes SAR and in Section V, fabrication and validation of the prototype are explained.

II. DESIGN CONSIDERATIONS

The microstrip patch antennas structure have three layers. The top and the bottom layers are of conducting material such as PEC, copper foil tape, etc,. A dielectric substrate is sandwiched between the conducting layers. According to the design copper foil tape (CFT) of thickness 0.05mm is used as the radiating patch and the ground plane. Woolen felt is used as substrate with a thickness (h) of 1.588m. The relative permittivity (Ɛr) of the substrate is 1.45 and the loss tangent is 0.025.

The antenna is connected with a transmission line whose characteristic impedance is 50Ω.

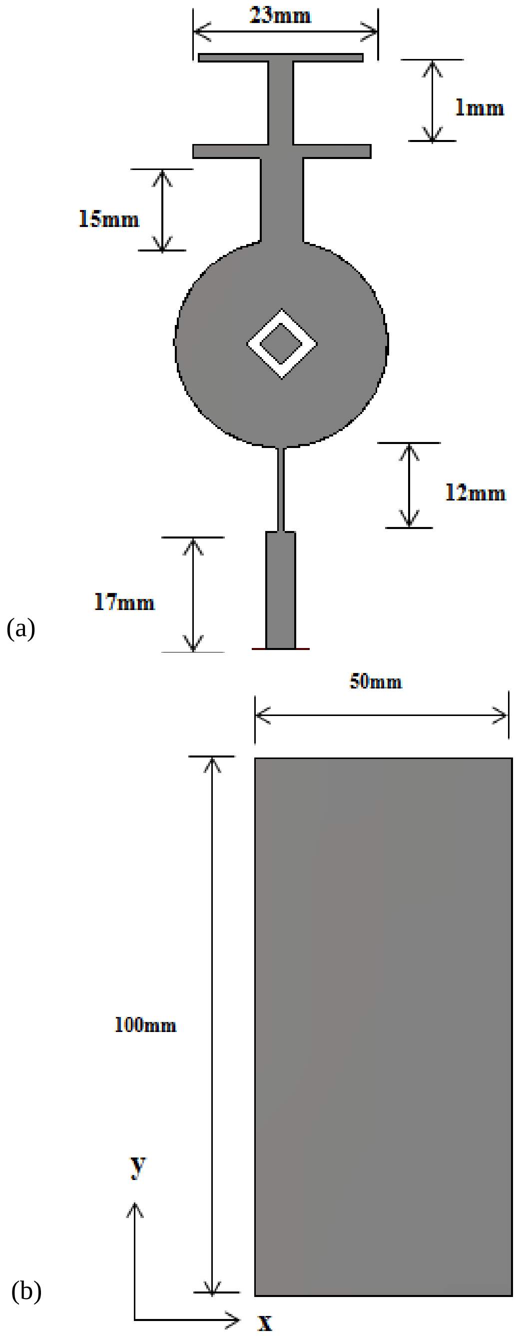


Fig.1. Geometry Tri-band Microstrip wearable antenna (a) Front view (b) Back view

Proposed antenna is designed to operate on the frequencies of 1800MHz Global System for Mobile communication (GSM), 3.5GHz Wireless Fidelity (Wi-Fi) and 4.75GHz North Atlantic Treaty Organization (NATO) bands. Size of the existing wearable antenna [9], are large. This makes it inconvenient to the user. The patch is subject to unpredictable crumples that lead to change in the electromagnetic properties thereby influencing the performance of the antenna. The designed wearable antenna must have minimum back lobe and if placed near the heart it should have zero back lobe rejections mechanisms. Since the conductivity of conductor is high, the ground plane avoids any back lobes that may tend to enter the human body of the person wearing it.

III. TRI-BAND ANTENNA

The best way to enrich an antenna design is to make use of single structure for multi-band communications required for different wireless technology networks. It has been accomplished by proposed tri-band wearable antenna. The length (L) and width (W) of the monopole tri-band antenna is calculated using the well-known theory of transmission line model [10]. i.e. L=90mm and W=50mm. Fig.1 shows the detailed geometry of tri-band monopole antenna. Fig.2 shows the simulated results of $S_{11.}$ The reflection coefficients (S_{11}) of all three bands are -13.399dB, -35.114dB and -36.254dB at the frequencies of 1.76GHz, 3.5GHz and 4.75 GHz for GSM, Wi-Fi and NATO bands respectively.

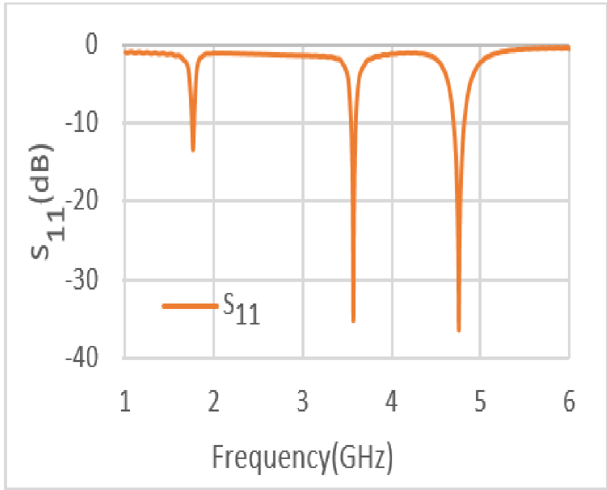


Fig. 2. Simulated results of Reflection coefficient S11.

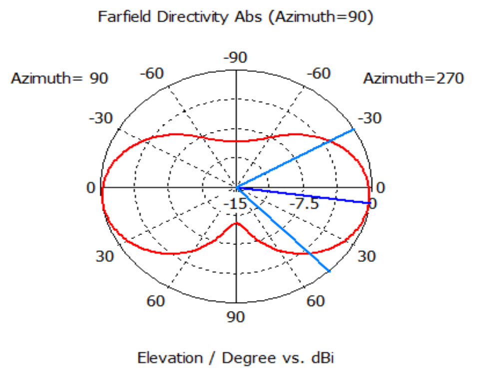
The radiation pattern of the design triband antenna is shown in the Fig.3. The radiation pattern for three bands are shown in Fig.3 (a), (b) and (c). The directivity at the three band frequencies (1.76GHz, 3.56GHz and 4.75GHz) with directivity of 6.823dB, 7.344dB and 7.820dB respectively.

The current distribution characteristics of the proposed antenna are shown in fig. 4 for all three bands of operation. From the current distribution analysis, it is evident that the antenna aperture is utilized effectively for radiation.

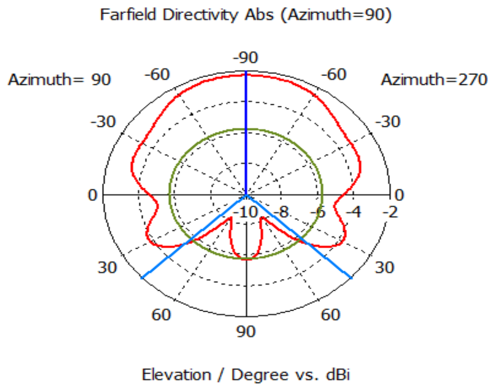
IV. SAR ANALYSIS

Specific absorption rate is used to evaluate the radiation effect on humans. This measure the electromagnetic energy absorbed by the biological tissues of the human body when exposed to electromagnetic radiations (e.g. mobile phone) in a field. SAR is generally an average value either over the whole body or over a sample volume (typically 1g or 10 g of tissue). Since SAR is expressed as the power absorbed per mass of tissue its unit is watts per kilogram (W/Kg). Mathematically SAR can be expressed as,

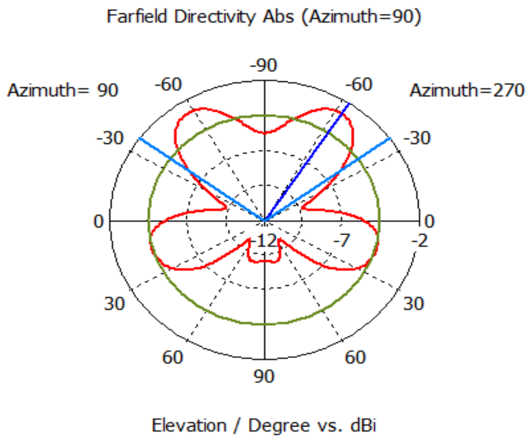
$$SAR = (\sigma \times E_{rms}^{2}) / \rho \qquad (1)$$



(a)

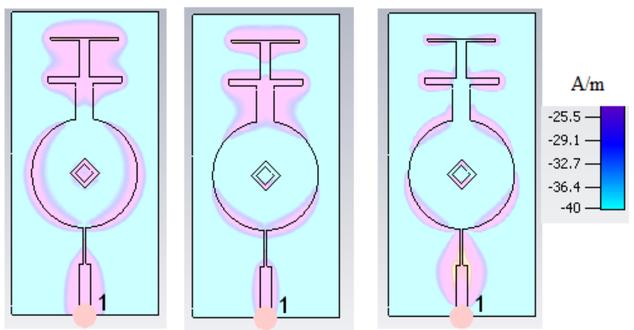


(b)



(c)

Fig. 3. Simulated radiation pattern of new tri-band antenna (a) 1.759 GHz, (b) 3.56GHz, and (c) 4.76GHz.



(a) (b) (c)

Fig. 4. Current Distribution Characteristics of Fabricated Prototype of Tri-Band Antenna at (a)1.8GHz, (b) 3.5GHz and (c) 4.75GHz.

IEEE 1.6W/kg for any 1g of tissue, and ICNIRP (International Commission on Non-Ionizing Radiation Protection) 2W/kg for any 10g of tissue are the two most commonly used limits for safe SAR. In order to measure the SAR a sample of 1g and 10g of sphere of body tissue is taken as sample. The CST simulation software calculates of SAR using the averaging method of IEEE/IEC 62704-1with the skin specification at the power of 0.25W.

TABLE-I: comparison between SAR values

Frequency (GHz)	1g of tissue (W/Kg)	10g of tissue (W/Kg)
1.8	1.63	2.112
3.5	1.569	1.989
4.75	1.59	2.066

Table I show a comparison of specific absorption rate of 1g and 10g tissue at the different resonant frequencies. All the results are calculated with the power value of 0.25W and compliance with the standardized value of SAR.

V. FABRICATION AND TESTING

The fabrication and validation of the proposed wearable tri-band antenna is described here. Fig.5 shows the fabricated design of tri-band monopole antenna with the woolen felt substrate and copper foil tape with the thickness of 0.05mm. Fig.6 shows the measurement setup with vector network analyzer.

Fig. 5. Fabricated Prototype of Tri-Band Antenna.

In order to analyze the antennas parameters such as VSWR, reflection coefficient S_{11}, impedance, etc., is calculated using the vector network analyzer.

Fig. 7 shows the measured S_{11} characteristics of the proposed tri-band wearable antenna using network analyzer along with simulated values.

The measured response from the resonant frequencies 1.8 GHz, 3.5 GHz and 4.75 GHz as -17.1318 dB, -12.628 dB and -22.448 dB respectively.

Fig. 6. Validation of Fabricated tri-band antenna with Vector Network Analyzer.

Table II shows a comparison of simulated and tested results of scattering parameter S_{11}. Measured results show slight deviation from the simulated results. The property of cooper foil tape, woolen felt material, bending and connector losses may account for the deviation in the resonant frequency of the fabricated antenna.

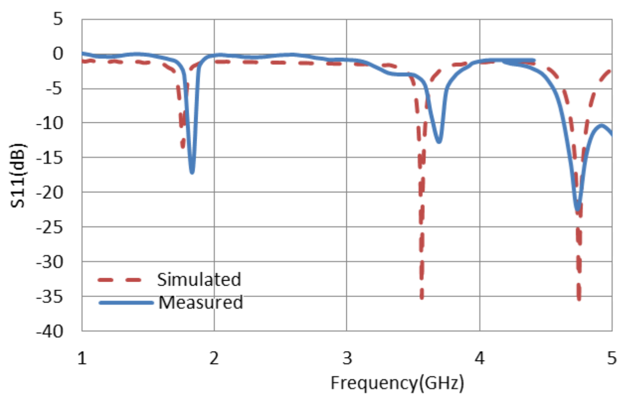


Fig. 7. Measured response of scattering parameter S11.

TABLE-II: Comparison between simulated and tested results

Frequency (GHz)	Simulated S_{11} (dB)	Measured S_{11} (dB)
1.8	-13.399	-17.1318
3.5	-35.114	-12.628
4.75	-36.254	-22.448

VI. RESULTS & DISCUSSION

The design and fabrication of tri-band antenna based on woolen felt material is proposed for the purpose of GSM, ISM and NATO Bands of frequencies 1.8GHz, 3.5GHz and 4.75GHz respectively. Simple circular patch antenna is designed for 1.8GHz frequency and to induce 3.5GHz band in the antenna a slot is introduced in the design. For the NATO band stacked T line are connected with the circular patch antenna. The return loss at the design frequencies are -17.13 dB at 1.8GHz, -12.628 dB at 3.5GHz and -22.448 dB at 4.75GHz which are well below the -10 D impedance bandwidth considered for the antenna elements. To access the usability of the proposed antenna structure, the SAR value is calculated using simulations for 1g and 10g tissue model as per IEEE/IEC 62704-1 standard. The maximum SAR values are 1.63 W/kg for 1g tissue model which is near the IEEE guideline of 1.6 W/kg.

VII. CONCLUSION

This article proposes tri-band antenna for wearable applications using woolen felt material. The proposed Woolen felt based tri-band microstrip wearable antenna is fabricated and validated using Vector Networks analyzer in terms of S parameters. Further the SAR analysis of proposed antenna is evaluated and confirms with international guidelines. As the proposed antenna is simple to make and cost-effective, can be easily integrated with cloths for multiband applications. The bending, crumpling, wetness, and off-body measurements can be done in future to validate the structure.

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