[1]Mehaboob Mujawar,
[2]T. Gunasekaran,
[3]Kanchan Wagh,
[4]Subuh Pramono

Wearable T – Shaped Metamaterial Microstrip Patch Antenna with Split Ring Resonators for Wi-Fi Applications

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Abstract: - This paper presents the design of a T-shaped metamaterial microstrip patch antenna integrated with split ring resonators, tailored for IEEE 802.11a Wi-Fi applications. The antenna utilizes a non-woven polypropylene geotextile substrate, measuring 1.9 mm thick with a dielectric constant of 2.2, while the copper sheet thickness is 0.1 mm. Performance metrics such as reflection coefficient, antenna gain, and VSWR are evaluated. Simulated results show a reflection coefficient of -21 dB at 5 GHz, which closely matches the measured value of -22 dB. VSWR values of 1.5 and 1.3 are obtained through simulation and measurement respectively. Additionally, SAR analysis indicates suitability for wearable applications, with the SAR value exceeding 10 grams of tissue falling within acceptable limits.

Keywords: acceptable, Simulated, evaluated, measurement, coefficient

INTRODUCTION:

Antennas play a vital role in wireless communication systems, serving as both transmitters and receivers. They facilitate the conversion of electric signals into electromagnetic waves for transmission and vice versa for reception. Flexible antennas are particularly essential in the growing market of wearable electronic devices, which demand lightweight and compact designs for user comfort and convenience. Wearable antennas, integrated into clothing, offer hands-free operation and enhanced comfort, finding applications in emergency services, security, military, athlete monitoring, medical tracking, and fashion. Typically fabricated from conductive materials, textile antennas are becoming increasingly popular due to their versatility and adaptability. An antenna serves as the interface between free space and guiding structures in communication systems, transmitting and receiving radio waves across various applications such as cellular communication, wireless networking, GPS, and more. Body-centric wireless communication, a cornerstone of 4th and 5th generation wireless systems, operates within personal and body area networks, as defined by IEEE 802.15.6 standards [11]. It encompasses off-body, on-body, and in-body communication modes, enabling diverse applications including medical diagnostics and external monitoring devices. Textile antennas, integrated seamlessly into clothing, ensure wireless connectivity without compromising comfort or durability. The choice of textile substrate and conductive materials is crucial, necessitating wearable, robust, and flexible fabrics. By leveraging materials with low dielectric constants, textile antennas [10] minimize surface wave losses, thereby enhancing impedance bandwidth and overall performance.

Various factors impact the performance of wearable antennas:

1). Dielectric property: The antenna designer first needs to check the dielectric property of the textile material. The dielectric property is derived from the permittivity (ε_r) of the material.

$$\varepsilon_r : \ \varepsilon = \varepsilon_o \, \varepsilon_r = \varepsilon_o \, (\varepsilon_{r1} - j \, \varepsilon_{r2})$$

The dielectric constant, denoted as ε_o , is the permittivity of vacuum which is 8.854×10^{-12} F/m and is a critical factor in antenna design, representing the real part of the permittivity of a material. It's a fundamental consideration when selecting textile materials for antennas. The dielectric properties of a material are influenced by several factors including frequency, temperature, surface roughness, moisture content, purity, and homogeneity. These factors collectively affect the performance and efficiency of wearable antennas.

[1]Bearys Institute of Technology, Mangalore, Karnataka, India,
[2]University of Technology and Applied Sciences, Muscat, Oman,
[3]Cummins College of Engineering for Women, Nagpur, Maharashtra, India,
[4]Department of Electrical Engineering, Universitas Sebelas Maret, Surakarta, Indonesia.

2). Loss tangent: It is the ratio of imaginary part to the real part in the permittivity.

$$tan\delta = \frac{-\varepsilon_{r2}}{\varepsilon_{r1}}$$

For the flexible antennas both the loss tangent and dielectric constant value should be as minimum as possible. Depending on the application the substrate material can be selected. We can conclude from the above discussion that low dielectric constant and low loss tangent material should be selected for wearable applications, in order to get the good performance as well as the good bandwidth.

3). The thickness of the dielectric fabric is a crucial factor affecting the performance of planar microstrip antennas. The bandwidth and efficiency of these antennas are primarily determined by the dielectric constant and thickness of the substrate [8]. Textile materials typically have low permittivity values. Increasing the substrate thickness can enhance bandwidth, but this can also lead to increased losses, thus reducing antenna efficiency. Therefore, antenna designers must strike a balance between maximizing bandwidth and maintaining efficiency to achieve optimal performance.

LITERATURE REVIEW:

In the referenced paper [1], a T-shaped microstrip patch antenna augmented with Split Ring Resonators (SRR) is employed. The antenna configuration is tailored for applications in the public safety band, catering to use cases such as fire-fighting, police vehicles, and offshore operations. Utilizing a Polypropylene (PR-30) substrate with a thickness of 1.9mm and a dielectric constant of 2.2, the antenna is meticulously designed. The feedpoint is positioned at coordinates -7.2 mm along the X-axis and 0 mm along the Y-axis. Copper tape is used with a thickness of 0.1mm. The overall size of the antenna is 69×36. There is formation of two capacitors (one capacitor between the two rings) at the slots. The reflection coefficient obtained under unloaded condition is -5.5 dB at 5 GHz and the reflection coefficient obtained under loaded condition is -16 dB at 4.99 GHz and hence the antenna after loading was suitable for public safety band applications (4.94 GHz to 4.99 GHz). The measured return loss is -21dB at 4.2GHz. The paper [2] introduces a wearable microstrip patch antenna featuring an interdigital capacitor and rectangular stub. The inclusion of the rectangular stub provides inductance, while the interdigital capacitor contributes capacitance. Fabrication involves mounting the antenna on a polyester substrate, with a ground plane soldered on the opposite side. The polyester substrate measures 3.14mm thick and possesses a dielectric constant of 1.39, while the copper tape used is 0.1 mm thick. The feedpoint is situated at coordinates 13mm along the X-axis and 7mm along the Y-axis. Under unloaded conditions, the simulated reflection coefficient of the antenna is recorded at -25 dB at 2.45 GHz, with a measured reflection coefficient of -32 dB at 2.54 GHz. Filters are employed to eliminate unwanted frequency bands. The antenna design demonstrates commendable gain performance.

Table.1: Comparative study of Literature review techniques with proposed design

Reference	Technique	Substrate	Operating frequency GHz	Dimensions	Return loss	VSWR
[1]	T – shaped microstrip patch antenna	Polypropylene	4.94 to 4.99	69×36	-21	1.46
[2]	MPA using interdigital capacitor and rectangular stub	Polyester	2.45 to 2.54	45×55	-32	1.3
[3]	Wearable MIMO Antenna	Liquid Crystal Polymer (LCP)	2.9 to 10.86	65×65	-22	1.2
[4]	E-Shape Fractal	FR4	2.66 to 7.42	55×65	-23.7	1.05
[5]	Circular Monopole UWB Antenna with Reconfigurable Band-Notched Characteristics	FR4	3.3-3.7, 5.15-5.825, 3.1-10.6	30×30	-28	1.26

[6]	UWB U-Shaped Slot Etched on a Circular Patch Antenna with Notch Band Characteristics	FR4	2.9 to 20	44 × 34	-30	1.07
[7]	Fork-Shaped Monopole Antenna	FR4	2.4-2.484, 3.1-10.6	42 × 24	-15	1.2
Proposed design		Polypropylene	2.4 , 5 , and 6	29 × 29	-22	1.3

Antenna Design:

The first step in the flexible antenna design is the selection of material. The materials involved in the flexible antennas or the wearable antennas are substrate materials and conductive materials used for the patch as well as ground. In the material selection, we need to choose the conductive material as well as the substrate material. The next step is to check the property of characterization that is conductivity as well as the resistivity. The conductivity should be as high as possible for conductive materials and the resistivity should be as low as possible because if the conductivity is more, it will radiate or receive more power. If the resistivity is lower, then losses will be minimum. The next step is the antenna design. Usually in the simulation part, the antenna has been designed using the formulas and then will be simulated and optimized. CST, HFSS software can be used for simulation purpose. In the simulation part, optimization of the antenna has been done in order to satisfy the requirements such as return loss, bandwidth requirements, radiation pattern, SAR value as well as the bending characteristics. If any of the parameters are not matching with the desired standard requirements, then the antenna has to be optimized in the simulation itself to avoid the fabrication error. The antenna can be fabricated only after obtaining simulation parameters matching with the desired standard requirements for proper functioning of the antenna. The antenna measurement can be done of the parameters such as SAR, bending effect, human body effect and environmental effect using Vector Network Analyzer (VNA) and anechoic chamber. A T-shaped microstrip patch is created by overlapping two rectangular microstrips to create the proposed antenna. The T-shaped configuration was selected to enhance the antenna's resonant length and minimize its overall size. Additionally, the design integrates metamaterial Split Ring Resonators (SRRs) to further reduce the antenna's footprint. Specific dimensions for the proposed antenna are outlined in Table 1. For feeding, the antenna employs a coaxial arrangement with coordinates set at x=-6.3 mm and y=0 mm.

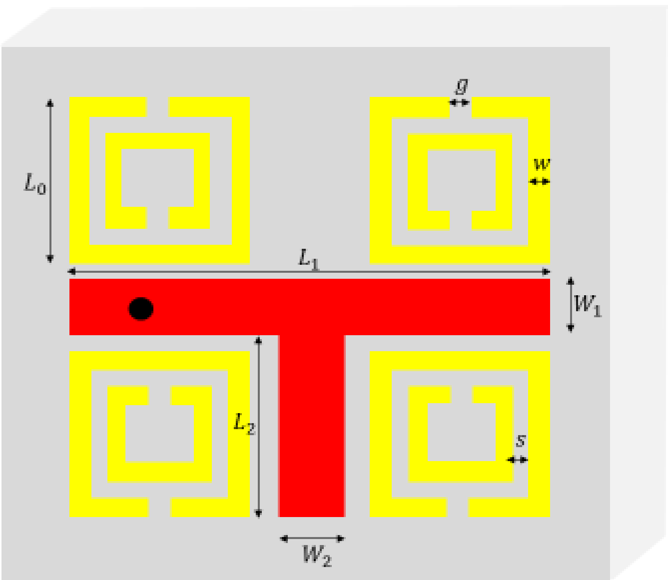


Fig.1: The proposed antenna structure

Table.2: The proposed antenna's dimensions are outlined as follows:

Dimensions	Unit (mm)
Length of MPA 1 (L_1)	23
Length of MPA 2 (L_2)	11
Width of MPA 1 (W_1)	3
Width of MPA 2 (W_2)	3
Length of outer split ring (L_0)	9
Gap in the ring (g)	1
Width of the ring (w)	1
Separation between rings (s)	0.8

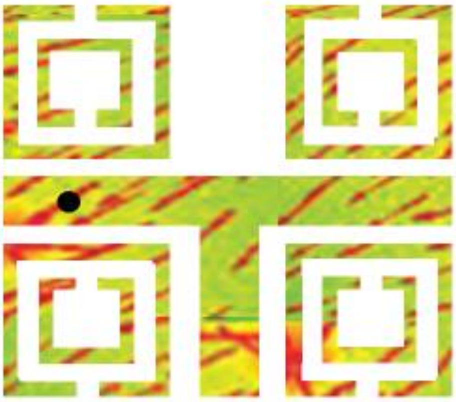


Fig.2: Surface current distribution at 5 GHz

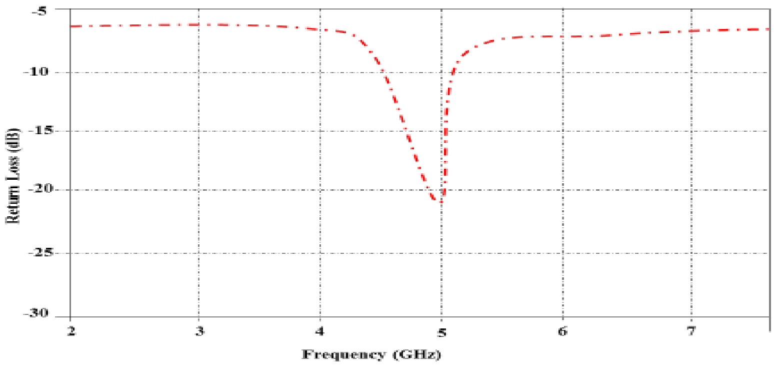


Fig.3: Simulated Reflection coefficient

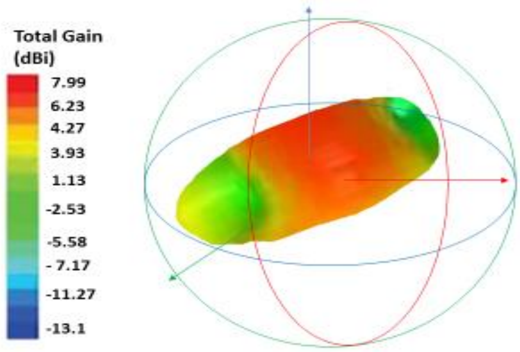


Fig.4: Simulated Antenna gain

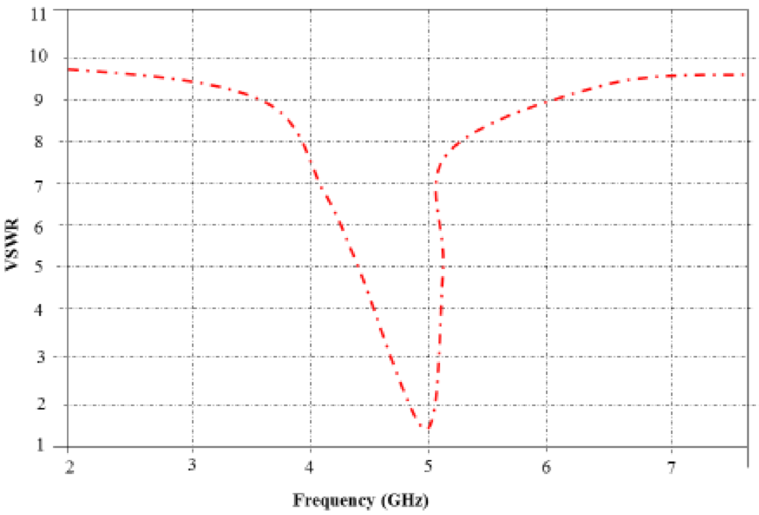


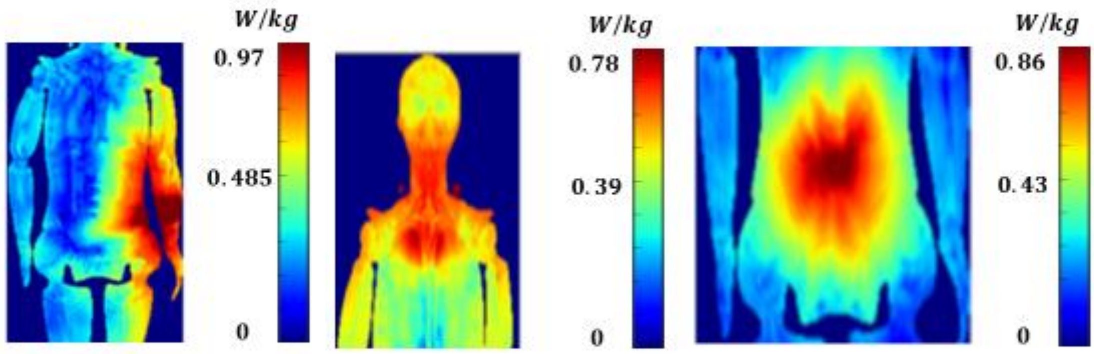
Fig.5: Simulated VSWR

Table.3: Simulation results for the proposed antenna

Frequency	IEEE 802.11a Wi-Fi
Return loss	-21 dB
Gain	7.99
VSWR	1.5

SAR (Specific Absorption Rate) Analysis

SAR, measured in watts per kilogram (W/kg), signifies the rate at which the human body absorbs energy from electromagnetic radio frequencies. To ensure safety, a threshold of 2 W/kg is typically observed over 10 grams of tissue [9]. In assessing the SAR for the suggested antenna design, placements were made on the arm, neck, and abdomen. The following table presents the SAR values recorded for the proposed antenna across different body areas.



(a) Arm (b) Neck (c) Abdomen

Fig.6: SAR Value Analysis of the proposed antenna [a] Arm, [b] Neck, [c] Abdomen

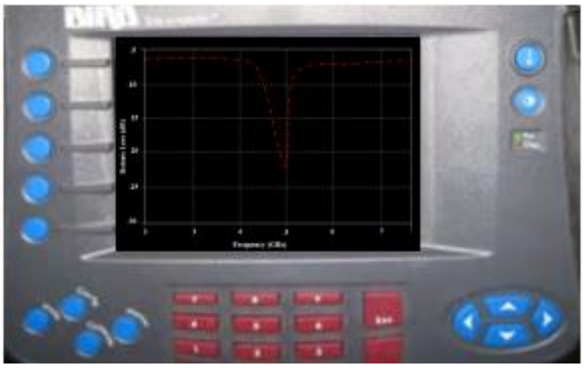


Fig.7: Measured Return loss

Fig.8: Measured VSWR

Table.4: Measured results for fabricated antenna

Frequency	IEEE 802.11a Wi-Fi
Return loss	-22 dB
VSWR	1.3

Table 5: Simulated SAR values and Measured reflection coefficients on different parts of human body

Human body part	Simulated SAR value over 10g of tissue	Measured reflection coefficient
Arm	0.97	-22 dB
Neck	0.78	-28 dB
Abdomen	0.86	-25 dB

CONCLUSION:

The proposed antenna, a T-shaped metamaterial microstrip patch antenna with split ring resonators, has undergone extensive performance evaluation. The reflection coefficient, antenna gain, and VSWR were assessed, yielding promising results. Simulated reflection coefficient at 5 GHz stands at -21 dB, closely matching the measured value of -22 dB. Similarly, the simulated and measured VSWR values are 1.5 and 1.3 respectively, indicative of excellent impedance matching. Fabricated using a 0.1mm thick copper sheet, the antenna is suitable for IEEE 802.11a Wi-Fi applications. Furthermore, SAR analysis demonstrates its compatibility with wearable applications, with SAR values meeting safety thresholds over 10 grams of tissue.

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