# Optimized Design of Low-Profile Wearable Antennas for Electronic Devices

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***Abstract— This study investigates the design and performance analysis of low-profile wearable microstrip patch antennas using three different substrate materials: FR-4, polyimide, and polystyrene. As wearable electronic devices continue to evolve, the demand for compact, flexible, and efficient antenna solutions has grown significantly. Each substrate offers distinct advantages—FR-4 provides mechanical strength and cost-effectiveness, polyimide ensures flexibility and thermal stability, while polystyrene contributes lightweight characteristics and a low dielectric constant. The antennas are modeled and simulated using electromagnetic design tools to evaluate key performance parameters such as return loss, bandwidth, gain, and radiation pattern. Comparative analysis highlights the influence of substrate properties on overall antenna performance, guiding the selection of suitable materials for specific wearable and wireless communication applications.***

***Keywords: Microstrip patch antenna, wearable antenna, FR-4 substrate, polyimide substrate, polystyrene substrate, low-profile design, flexible electronics, wireless communication, antenna performance, substrate comparison.***

## I.INTRODUCTION

With the growing demand for wearable electronics, there's an accelerating need for compact, effective antennas that can be fluently integrated into ultramodern bias. Microstrip patch antennas are well- suited for similar operations due to their thin profile, light weight, and ease of manufacturing. FR-4, a generally used and cost-effective substrate, offers mechanical continuity, although it comes with certain electrical limitations. This work presents the development of a low- profile wearable microstrip patch antenna grounded on the FR- 4 substrate, accommodated for electronic device integration. The design aims to deliver a practical accommodation between electrical performance, physical size, and affordability, making it ideal for wearable technologies similar as wireless communication systems and health- monitoring appliances.

The development of flexible and wearable electronics has accelerated the need for antennas that are n't only effective and compact but also adaptable tonon-rigid shells. Microstrip patch antennas, with their planar structure and ease of fabrication, are ideal campaigners for similar operations. Polyimide, a high- performance polymer, stands out as a flexible substrate material due to its excellent thermal stability, mechanical elasticity, and favorable dielectric parcels. These characteristics make it largely suitable for wearable and conformal antenna designs. This study explores the design and perpetration of a low- profile wearable microstrip patch antenna using polyimide substrate, aimed at enhancing the integration of wireless functionality in coming- generation wearable electronic bias.

The integration of antennas into wearable electronics has brought forward the need for featherlight, low-cost, and flexible outfit that can support effective wireless communication. Microstrip patch antennas are a high choice for similar operations due to their compact design, ease of fabrication, and peace with polychrome substrates. Polystyrene, known for its low dielectric constant, affordability, and feathery parcels, presents a promising substrate option for wearable antenna designs. Although traditionally used in packaging and segregation, its potentiality in RF operations is being explored for cost-sensitive and featherlight systems. This work focuses on the design and optimization of a low- profile wearable microstrip patch antenna using a polystyrene substrate, aiming to balance performance, manufacturability, and integration into compact electronic devices.

## II. LITERATURE SURVEY

Sankaralingam and Gupta [1] have worked on textile based rectangular microstrip patch antennas with different fabrics such as cotton and polyester intended for use on the body at 2.45 GHz WLAN band. It was tested in flat and bent conditions, and there was a marginal degradation in performance in bending condition but it ensured sufficiency for wearable use. It also introduced an innovative method for experimental determination of dielectric constant of fabric substrates, which is crucial for reliable antenna design. Chen and Ku [2] addressed smartwatch antenna design challenges by proposing a low-profile antenna that was incorporated with a miniature HIS. With 2.4 GHz operation, their miniature antenna (38 × 38 × 3 mm³) showed excellent directivity (6.3 dBi) and low SAR value (0.29 W/kg), and proved robust in impedance matching even with wrist-tissue loading. Their innovative use of fractional factorial designs (FFD) in adjusting HIS dimensions for wearable usage is a significant step forward for wrist-worn communication systems. A biomedical application was undertaken by Soni et al. [3], who developed a wearable, flexible microstrip patch antenna for tumor detection, using a polyimide substrate (εr = 3.5) and targeted towards 2.45 GHz operation. Their simulation involved a multi-layer model of human tissue with tumor structures embedded, and they received insight into reflection coefficient, SAR, radiation patterns, and directivity gain, thereby showing promise for non invasive, real-time tumor monitoring. Under the scenario of dynamic communication needs, Salameh and Qubaia [4] provided a comprehensive review of reconfigurable antennas. The paper presented some tuning mechanisms, including switches and varactors, for achieving frequency, polarization, and radiation pattern agility that forms the backbone of wearable and body centric networks with multiple environments adaptability. Further work from Sankaralingam and Gupta [5] included a detailed dielectric characterization study in which six textile materials were tested using a microstrip patch resonance technique. This work confirmed that polyester was a suitable substrate for wearable antennas due to its high efficiency and radiation characteristics, and reaffirmed the need for precise dielectric constant measurement in the design of textile antennas.

## III. SYSTEM MODEL

To accurately design a microstrip patch antenna, it is essential to determine the precise dielectric constant (εr) of the substrate material selected.

Step 1: Determining the Width (W):
The width of the patch antenna can be computed using the formula:

$$W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}}$$

Effective Length Correction (ΔL):

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\left(\frac{h}{w}\right)\right]^{\frac{-1}{2}}$$

Owing to the fringing effects at the edges of the patch, the antenna's electrical length appears slightly longer than its physical length. The extension in length (ΔL) due to fringing can be estimated using the following expression:

$$\Delta L = 0.412(h)\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+\ 0.264)}{(\varepsilon_{reff}-\ 0.258)(\frac{W}{h}+0.8)}$$

where h represents the thickness of the substrate.
Calculating Patch Length (L):
Once ΔL is known, the actual physical length of the patch can be obtained from the effective length:
Ground Plane Dimensions:
The ground plane must be larger than the patch and is generally assumed to have the same dimensions as the substrate. The length and width of the ground plane can be calculated as follows:

Ground Plane Length (Lg) = $L_g = 6(h) + L$

Ground Plane Width (Wg) = $W_g = 6(h) + W$

(Insert the respective equations here)

Design Example Using HFSS:
A microstrip patch antenna designed to operate at a resonant frequency of 2.45 GHz was analyzed using HFSS (High Frequency Structure Simulator) software to evaluate its performance. Several design parameters were investigated to optimize the antenna for the desired frequency

## IV. POLYMIDE SUBSTRATE ANTENNA

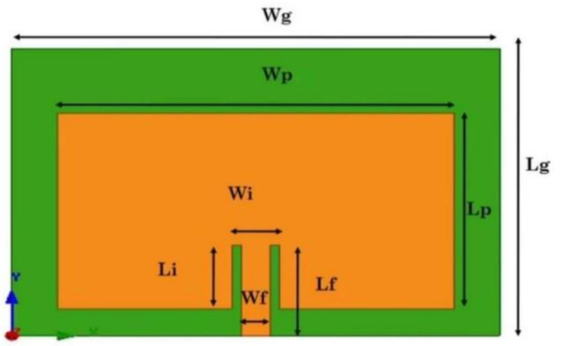

Figure 1: Microstrip Patch antenna

| Parameter | Description | Value (mm) |
|---|---|---|
| L | Antenna length | 38.75 |
| W | Antenna width | 51.76 |
| h | Thickness | 1.6 |
| PL | Patch length | 29.15 |
| PW | Patch width | 42.16 |
| FL | Feed Line Length | 13.546 |
| | Feed width | 3.061 |
| IL | Feed Insert Length | 9.5 |
| | Feed Insert Width(insert gap) | 5 |

Table 1: Parameter use in this antenna

## V. PERFORMANCE EVALUATION

The antenna is designed and simulated with the High- Frequency Structure Simulator (HFSS). The antenna in question is a microstrip patch antenna, and it is designed on the basis of its resonant frequency. The design is done in multiple steps beginning with the choice of polyamide as the substrate material, whose thickness is 1.6 mm. The antenna uses an inset feed method for excitation. The dimensions of the patch are computed using standard microstrip antenna equations as a function of the selected resonant frequency at 2.45GHz. After calculating the geometrical parameters, the structure of the antenna is simulated in HFSS by specifying the substrate, ground plane, and patch geometry. Excitation is applied via a wave port, and proper boundary conditions are specified to simulate free-space conditions. Once the simulation setup is completed, a frequency sweep is done around the operating band of interest. When the simulation is run, the antenna yields an S11 parameter of -26.24 dB, representing impedance matching, and a Voltage Standing Wave Ratio (VSWR) of 1.19, demonstrating effective power transfer. The final design is verified via analysis of return loss and VSWR values.

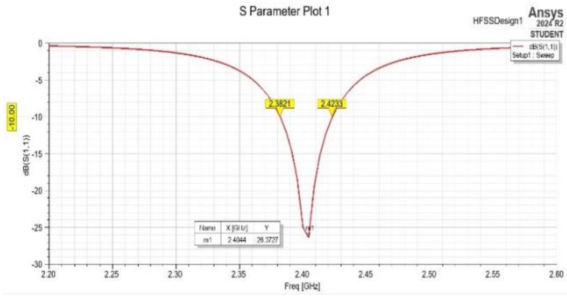

Figure 1.1:Retun loss (S11) of the presented antenna

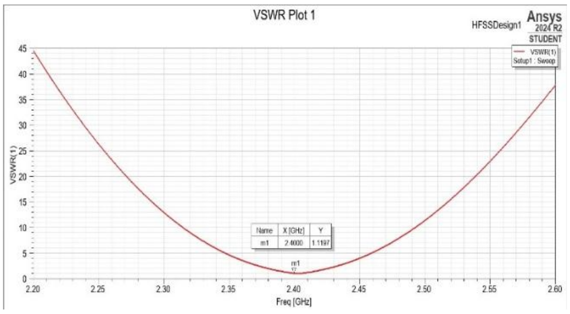

Figure 1.2:VSWR Plot of the presented antenna

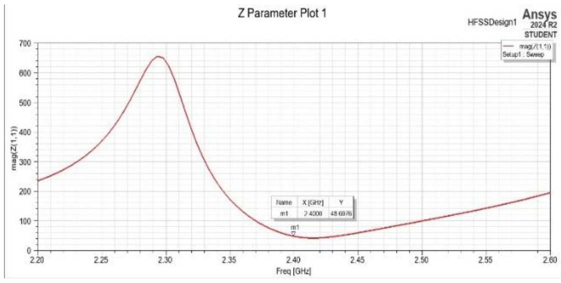

Figure 1.3:Z Parameter of the presented antenna

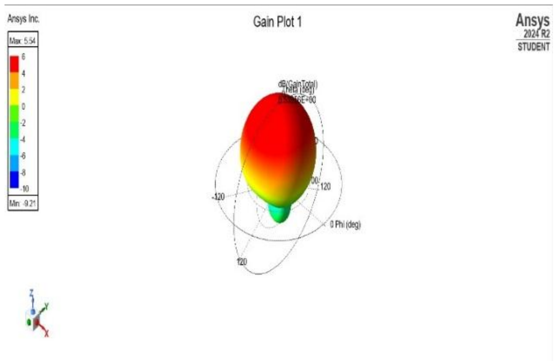

Figure 1.4:Gain Plot of the presented antenna

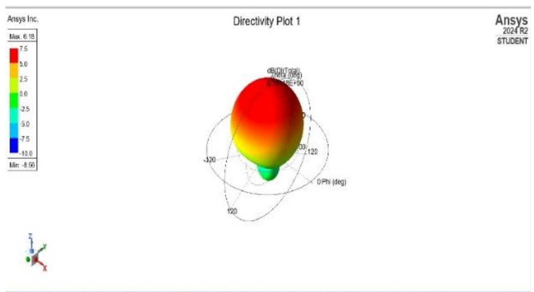

Figure 1.5: Directivity Plot of the presented antenna

## VI. FR-4 SUBSTRATE

| Parameter | Description | Value (mm) |
|---|---|---|
| L | Antenna length | 45 |
| W | Antenna width | 45 |
| h | Thickness | 1.6 |
| PL | Patch length | 30 |
| PW | Patch width | 30 |
| FL | Feed Line Length | 22.5 |
| | Feed width | 3.25 |
| IL | Feed Insert Length | 10 |
| | Feed Insert Width(insert gap) | 5 |

Table 2: Parameter use in this antenna

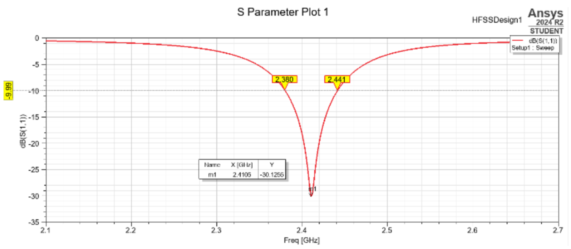


Figure 2.1: Retun loss (S11) of the presented antenna

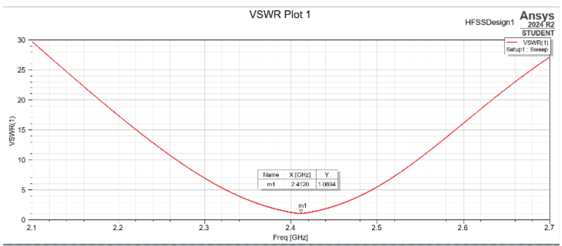


Figure 2.2: VSWR Plot of the presented antenna

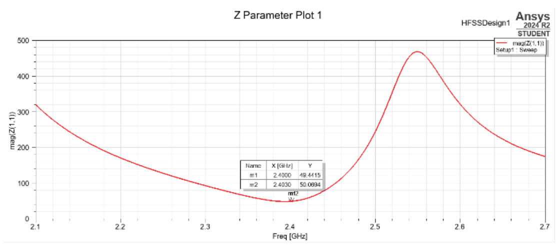


Figure 2.3: Z Parameter of the presented antenna

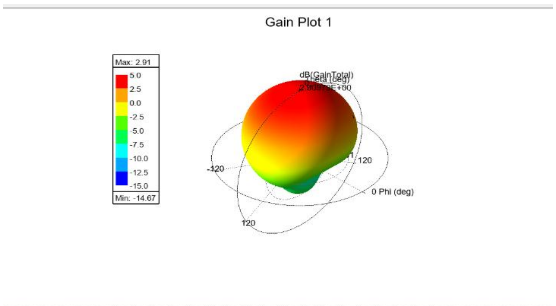


Figure 2.4: Gain Plot of the presented antenna

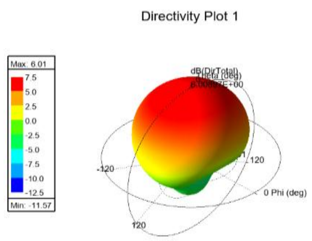


Figure 2.5: Directivity Plot of the presented antenna

## VII. POLYSTYRENE SUBSTRATE

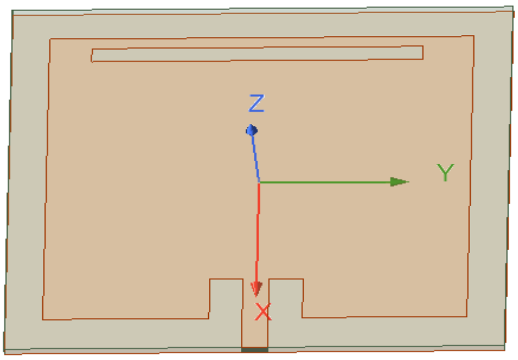


Figure 3: Microstrip Patch antenna

| Parameter | Description | Value (mm) |
|---|---|---|
| L | Ground Antenna length | 52 |
| W | Ground Antenna width | 59 |
| h | Thickness | 1.90 |
| PL | Patch length | 43 |
| PW | Patch width | 50 |
| FL | Feed Line Length | 14.724 |
| | Feed width | 3.066 |
| IL | Feed Insert Length | 9.5 |
| | Feed Insert Width(insert gap) | 11 |
| Slot | Slot Length | 2 |
| | Slot width | 39 |

Table 3:Parameter use in this antenna

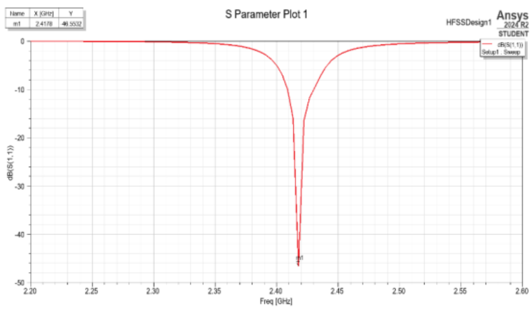


Figure 3.1:Retun loss (S11) of the presented antenna

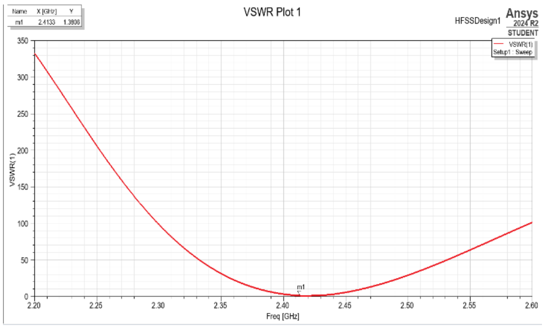

Figure 3.2: VSWR Plot of the presented antenna

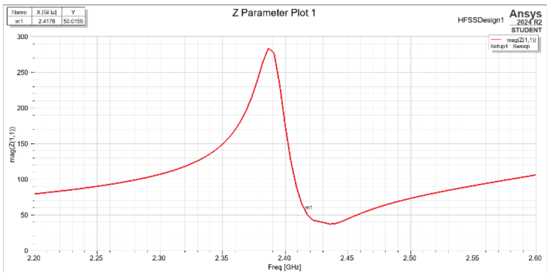

Figure 3.3: Z Parameter of the presented antenna

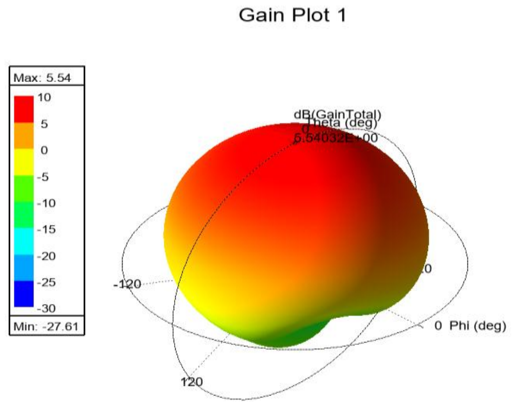

Figure 3.4.: Gain Plot of the presented antenna

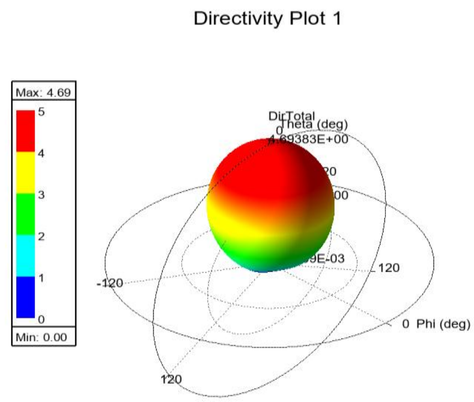

Figure 3.5: Directivity Plot of the presented antenna

## VIII. CONCLUSION

This research highlights the design and optimization of a low-profile wearable microstrip patch antenna for wireless applications. By selecting suitable substrate materials, optimizing antenna geometry, and employing advanced impedance matching techniques, high efficiency and low SAR can be achieved. Future work will focus on multi- band and reconfigurable antenna designs to further enhance wearable communication technologies.

## IX. REFRENCESES


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