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Wearable Antenna for Wireless Body Area Network Applications Using HFSS

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Abstract: *This paper presents a wearable antenna that is low cost, low profile, and flexible for Wireless Body Area Network (WBAN) applications. The antenna is multi-band: 2.4 GHz (Medical Body Area Network (MBAN)), 2.45 GHz (international & domestic industrial, scientific, and medical (ISM) band), 3.5 GHz (WiMAX), and 5.2 GHz (WLAN). Microstrip radiating patch is hexagonal and is on low-cost photo paper substrate with a defected ground plane to improve impedance matching and bandwidth. The antenna is 30 × 40 mm², and has a wide operational bandwidth of 3 GHz (2.30–5.30 GHz). Performance analysis shows radiation efficiency (greater than 91%) and that gain remains consistent across frequency bands with limited impairment from bending radius. Specific Absorption Rate (SAR) was completed, to assure safety if anticipated usage with humans. Deemed suitable for wearable healthcare monitoring, and Internet of Things (IoT) applications, and will provide a low-cost solution for the communications sector, this study provide potential avenue for next-generation wireless communication systems.*

Key Word: *Wearable Antenna, Low-cost, Low-profile, Flexible, Wireless Body Area Network (WBAN), Frequency Bands: 2.4 GHz (MBAN), 2.45 GHz (ISM), 3.5 GHz (WiMAX), 5.2 GHz (WLAN), Hexagonal microstrip, Photo paper substrate, Defected ground plane, Impedance matching, Bandwidth, Size: 30 × 40 mm², Operational Bandwidth: 3 GHz (2.30–5.30 GHz), Radiation Efficiency (>91%) Stable, Gain, Bending resilience, Specific Absorption Rate (SAR), Safety Compliance, Healthcare Monitoring, IoT Applications, Next Generation Wireless Communication*

I.INTRODUCTION

The growth of wireless communication technology has activated the development of small, efficient, and low-profile antennas, particularly in wearable applications. Wearable antennas are crucial in Wireless Body Area Networks (WBANs) which enable real-time health monitoring, GPS navigation, and secure military communication as they enable connection to other devices via wireless signals. Microstrip patch antennas are typically preferred to utilize in WBAN applications due to its lightweight, low profile, and conformal characteristics. Smart textiles provide an integration method that allows microstrip patch antennas to achieve new levels of wearability which is desired for next-generation telemedicine and body-centric communication networks.

This study presents a flexible, wideband wearable microstrip patch antenna, which has a reported radiating efficiency of 91% The antenna has achieved a design that allows frequency operation in more than one essential radiated band, including but not limited to slightly different operating frequencies based on MBAN, ISM, WiMAX, and WLAN. A flexible substrate allowed for the antenna to be completely wearable, either on fabric or directly mounted to the surface of a body.

The designs were simulated then optimized in High Frequency Structure Simulator (HFSS) software, and the primary antenna performance measurements (return loss, gain, med-bandwidth, and radiation pattern) were considered in a number of different bending applications in order ensure durability and maximum performance. Results demonstrated that the antenna would consistently provide impedance matching and maintained stable radiation characteristics, even under deformation. The design also kept Specific Absorption Rate (SAR) levels very low and acceptable for exposure in humans. The antenna was also advantageous in regards to wide bandwidth and overall performance.

II.METHODOLOGY

Antenna Proposed Topology

This research proposes an antenna topography that embodies a compact, flexible, wideband wearable antenna for Wireless Body Area Network (WBAN) applications. The specific antenna topography utilizes a hexagonal microstrip patch framework with utilization of geometric compactness and better current distribution than normal rectangular patches. It uses a flexible and cost-effective photo paper substrate which allows it to be lightweight, conformal, and suitable for ingestion into smart textiles or directly on a human body. To do this effectively we have utilized a Defected Ground Structure, which improves the characteristics of the wearable antenna. By improving significant parameters such as radiation directivity and gain, overall impedance matching and response, as well as a wide operating bandwidth (2.30–5.30 GHz) exceeding WBAN parameters.

The implemented operating frequencies effectively cover the desired WBAN communication bands such as ISM (2.45 GHz, largest one), WiMAX (3.5 GHz, middle frequency) and WLAN (5.2 GHz, highest frequency). We optimized the antenna using software HFSS in under different bending conditions (30°, 60° and 90°), to replicate bending conditions from real life scenarios that use wearable's (ex. long sleeve shirt).

Also, and importantly the antenna characteristics such as return loss and radiation were relatively unaffected under the bending conditions as is still guaranteed communication was possible as well. In short, our antenna topology constructed spacing of the antennas design achieved 91% radiation directivity and compliant with SAR values for safety. When comparing existing wearable antennas, the proposed antenna design has greater gain, bandwidth, mechanical flexibility, and on body safety. These related topics will be discussed individually.

Antenna Structure Details and Substrate

The proposed antenna has a small and compliant structure specifically designed for wearable use in Wireless Body Area Networks (WBANs). The antenna design is a hexagonal microstrip patch due to its compact size and better rotating current distribution, which provide improved radiation characteristics. The overall dimensions of the antenna are 40 mm × 30 mm, and the substrate thickness is 0.27 mm which makes the design very conformable and lightweight to integrate into a t-shirt, wristband, or other type of wearable. The material used for the substrate is photopaper, a flexible, inexpensive, and electromagnetic property compatible material.

Slightly rare from the plastic counterpart for antenna research, when using a dielectric constant (εr) of 3.2 functions well as a radiation and impedance matching material and allows the broadband performance necessary for multi-frequency operation. Lower dielectric loss on the substrate material, with a loss tangent (tan δ) of 0.05, aids the antenna's high radiation efficiency and stable performance when bent or deformed.

The correct operational frequency range is at 2.4 GHz (MBAN), 2.45 GHz (ISM), 3.5 GHz (WiMAX), and 5.2 GHz (WLAN), while the bandwidth is exceeding or greater than 100 MHz for lower bands and 200-300 MHz for higher bands which all supports data reliability and some speed. The antennas overall gain has a range of 2 dBi to 6 dBi which is sufficient for ensuring the integrity of the wearable system communication needs continuously remain within range. This structural configuration and material option affords a solid construction.

III.MODELING AND ANALYSIS

TABLE 1: Single element antenna dimensions

parameter	Readings in mm
SL	40
SW	30
FW	0.8
FL	14.8
PW	24.5
PE	12
GH	3.5
GW	4

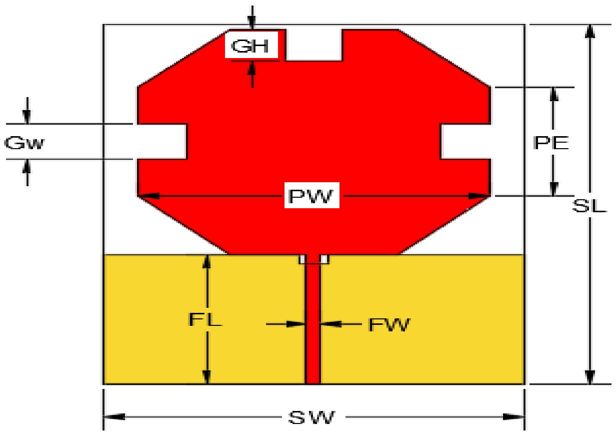


Figure 1: Design Diagram

Designed Antenna Models:

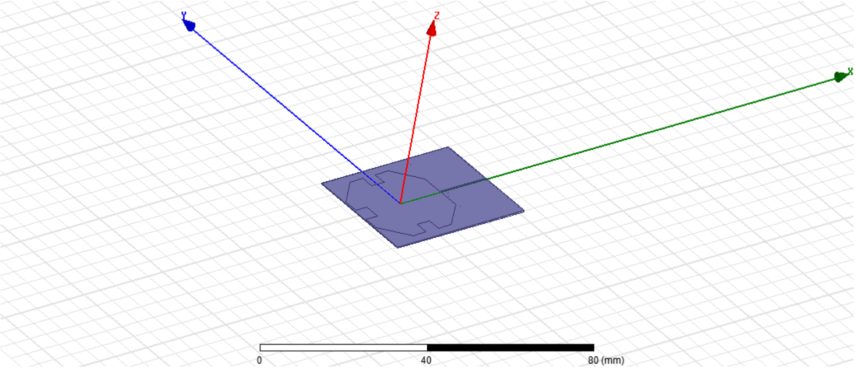


Fig1: Flat model

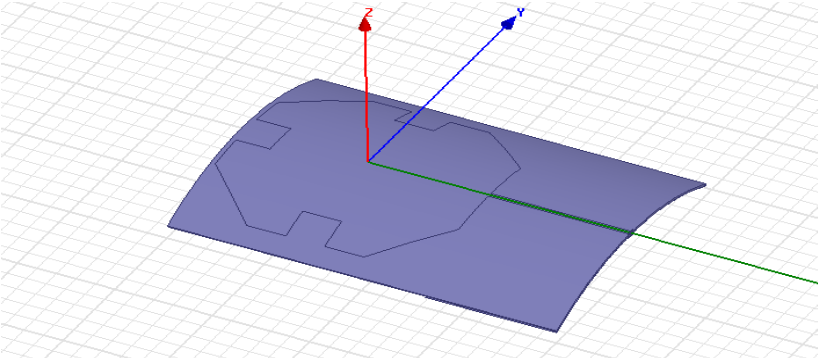


Fig2: 30mm bend model

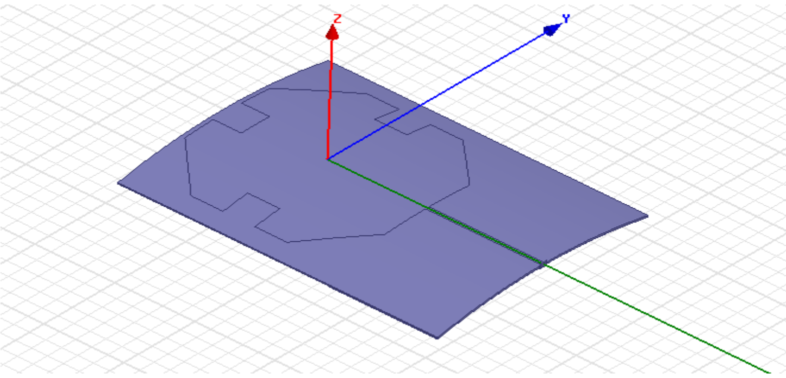


Fig3: 60mm bend model

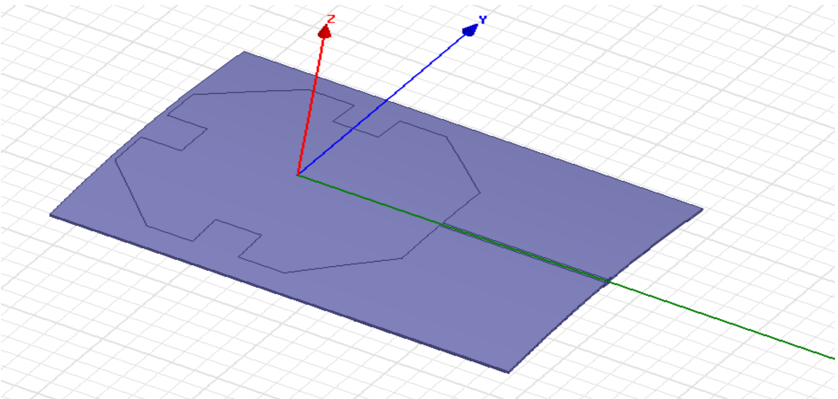


Fig4: 90mm bend model

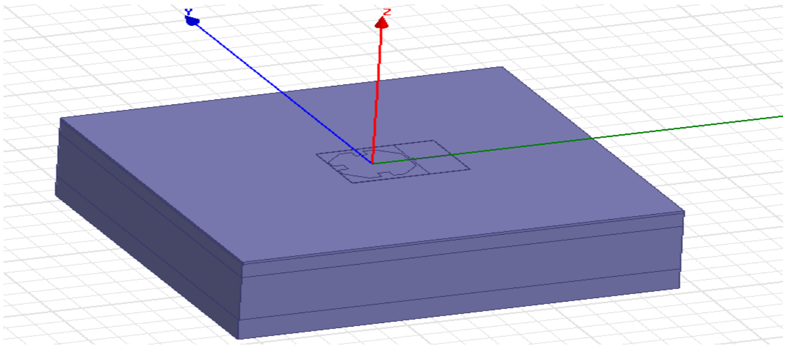


Fig5: Human tissue model

IV.RESULTS AND DISCUSSION

In broad terms, a detailed comparison of the proposed wearable antenna's performance is through the simulations' results focusing on parameters such as S11 (return loss), gain, efficiency, and SAR distribution. The S11 parameter indicates the performance of the antenna's impedance matching or resonance at the intended frequency bands. The S11 results show that the antenna is working well in the 2.4 GHz band (MBAN), 2.45 GHz (ISM), 3.5 GHz band (WiMAX), and 5.2 GHz (WLAN) with return loss results less than -10 dB so reflected power is at a minimum and thus performing efficiently transmitting power. The results also show a small shift to the resonance frequency when the antenna is placed on human body biological tissues changes dielectric properties. The gain performance of the antenna is reported for both the free-space condition, as well as where the antenna is placed on a body. The antenna's peak gain for free-space is reported to be acceptable for WBAN applications and consistently stable radiation characteristics were observed. The performance of the antenna when placed on the human tissue model does produce a very small reduction in gain due to some degree of acceptance of the electromagnetic energy by the biological layers, as the directional radiation pattern is maintained, assuring efficient propagated energy. The bending simulations at 30 mm, 60 mm, and 90 mm radius demonstrate some very minor variations in gain and efficiency suggesting the antenna's performance is stable when placed in use in real-world applications.

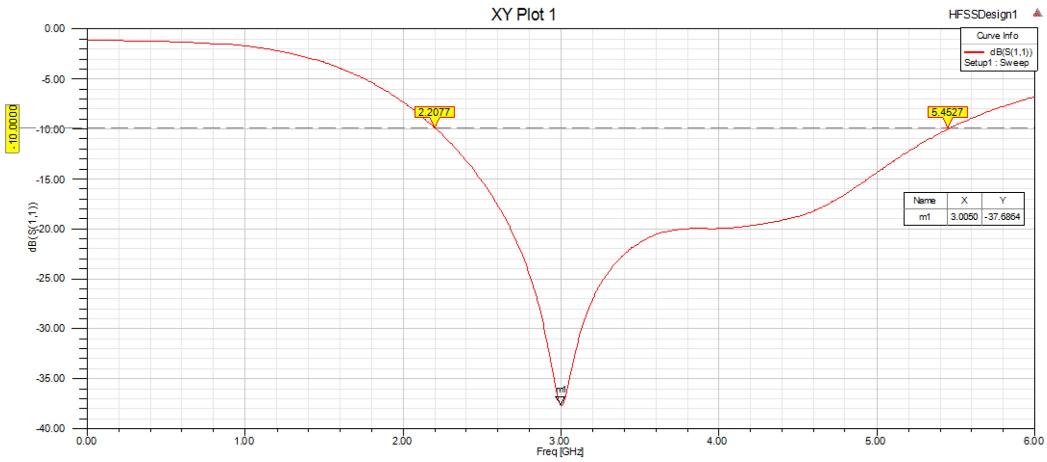


Figure 4.1: S11 for the flat type model

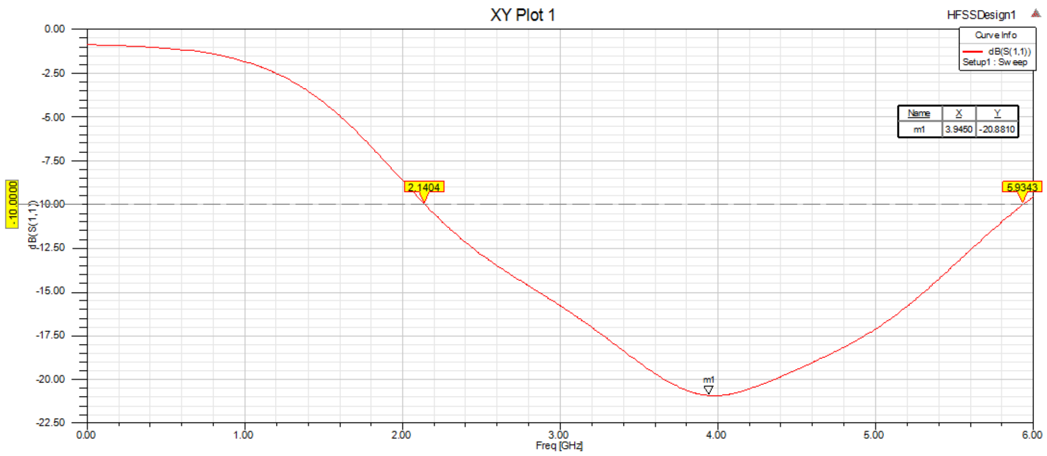


Figure 4.2: S11 for 30 mm bend radius model

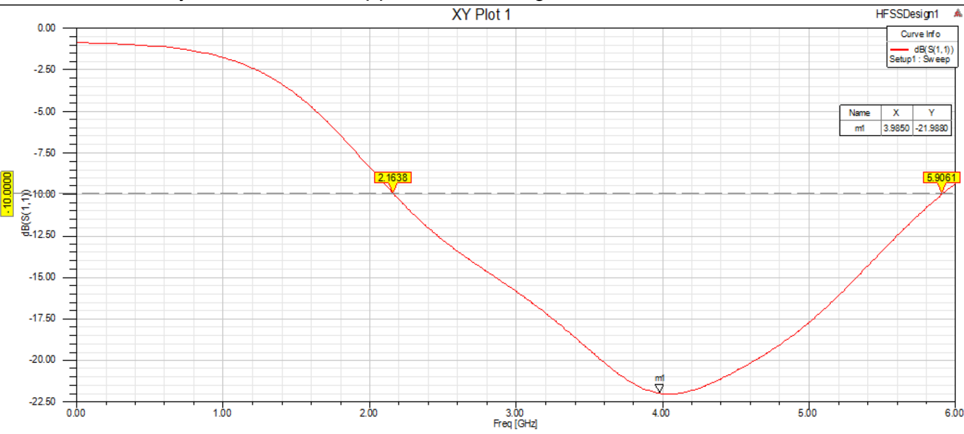


Figure 4.3: S11 for 60 mm bend radius model

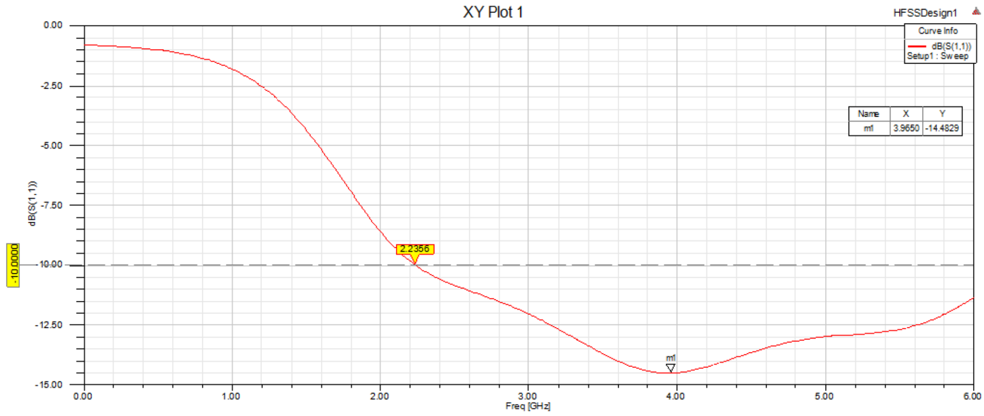


Figure 4.4: S11 for 90 mm bend radius model

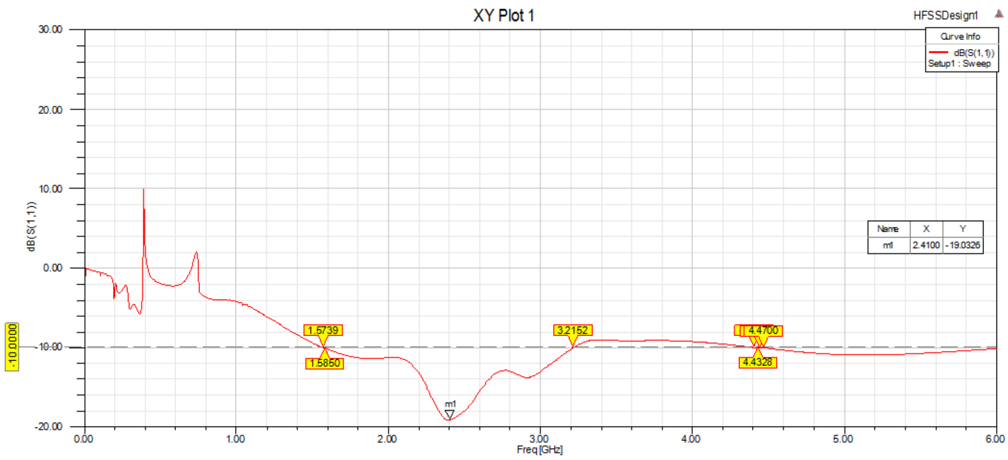


Figure 4.5: S11 for human model

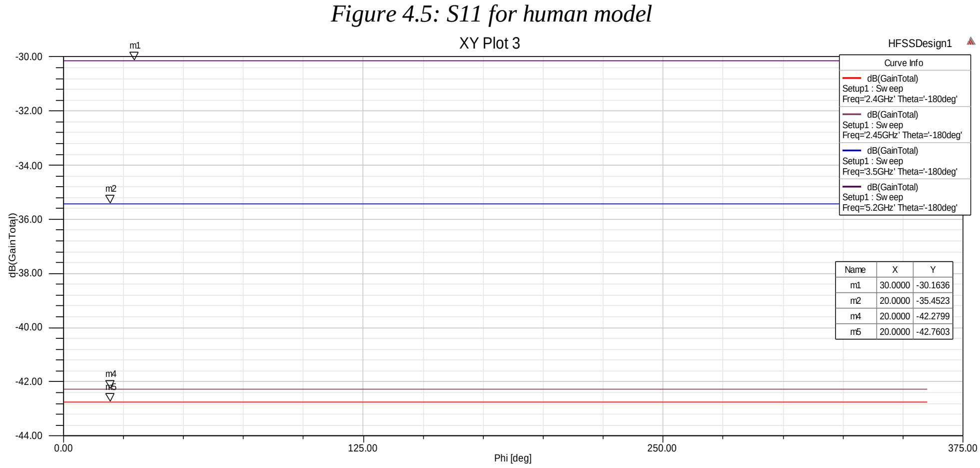


Figure 4.6: Gain for flat type model

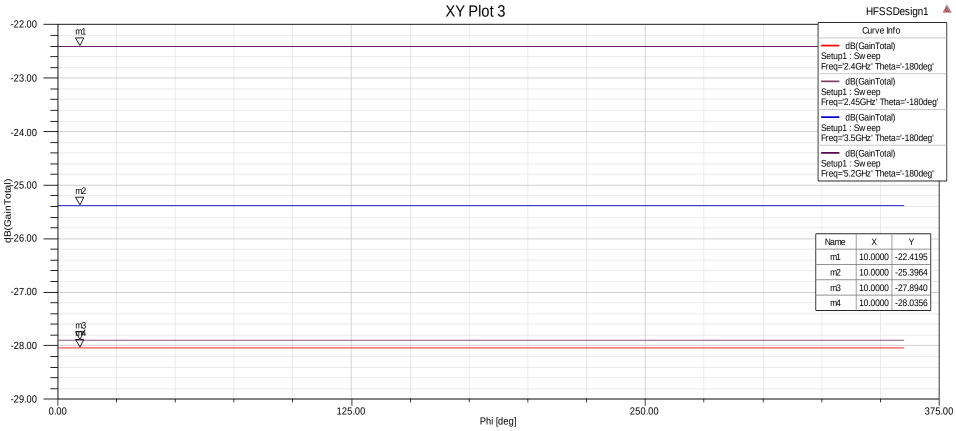


Figure 4.7: Gain for 30 mm radius type model

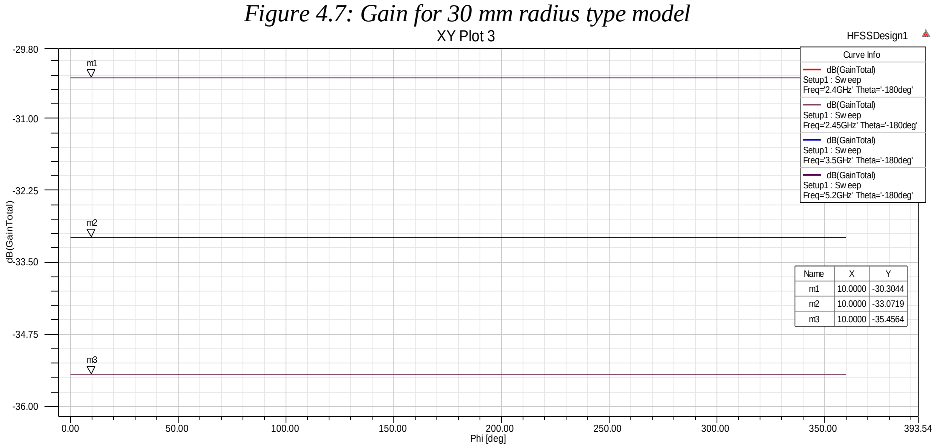


Figure 4.8: Gain for 60 mm radius type model

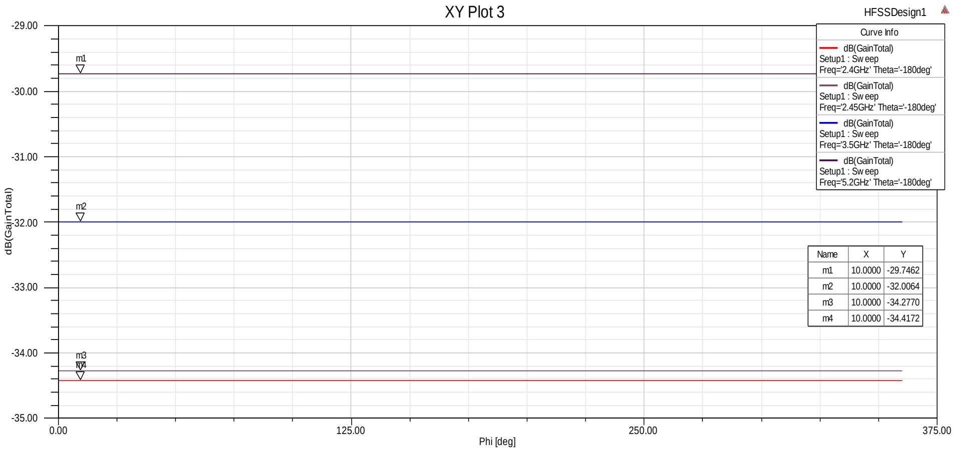


Figure 4.9: Gain for 90 mm radius type model

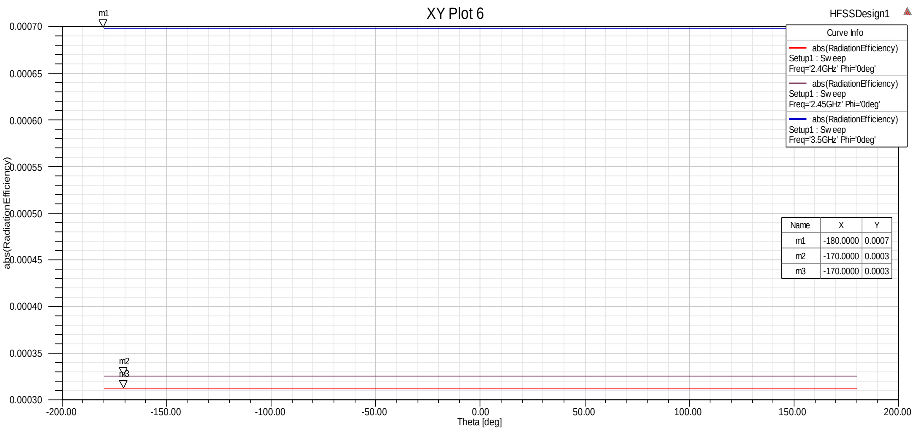
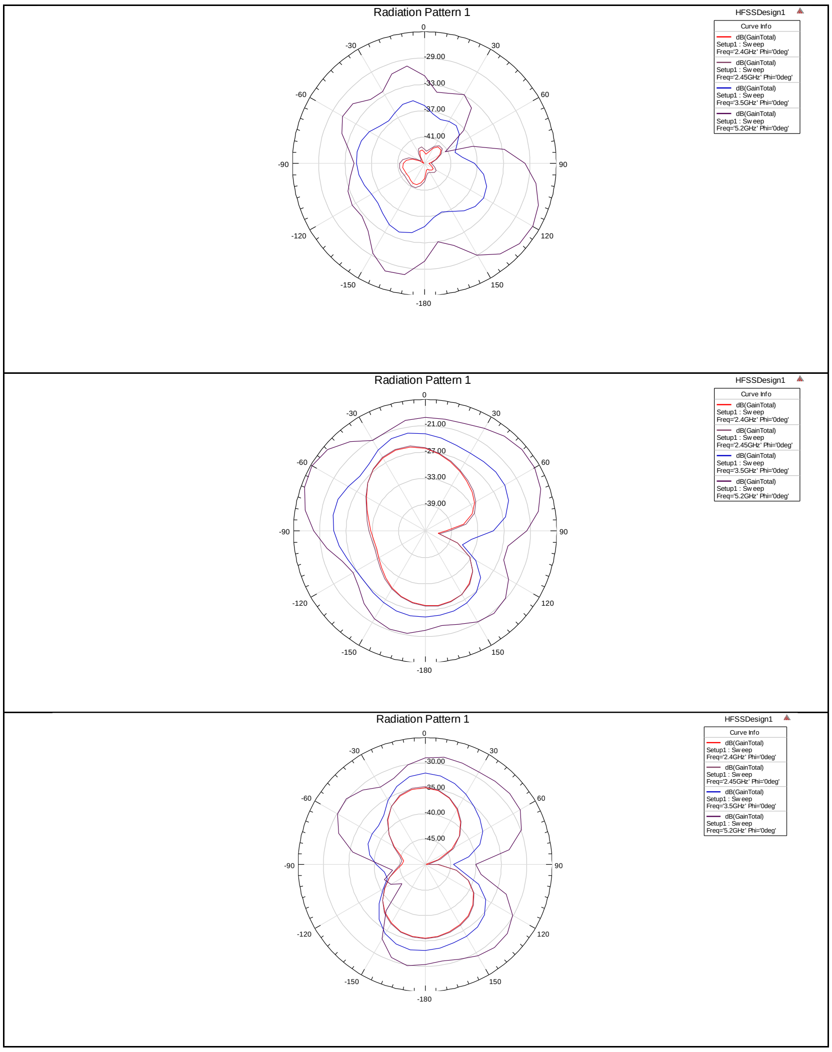


Figure 4.10: Antenna efficiency of flat type model



Figures 4.11: Radiation pattern for flat, 30mm, 60mm, 90mm, flat body

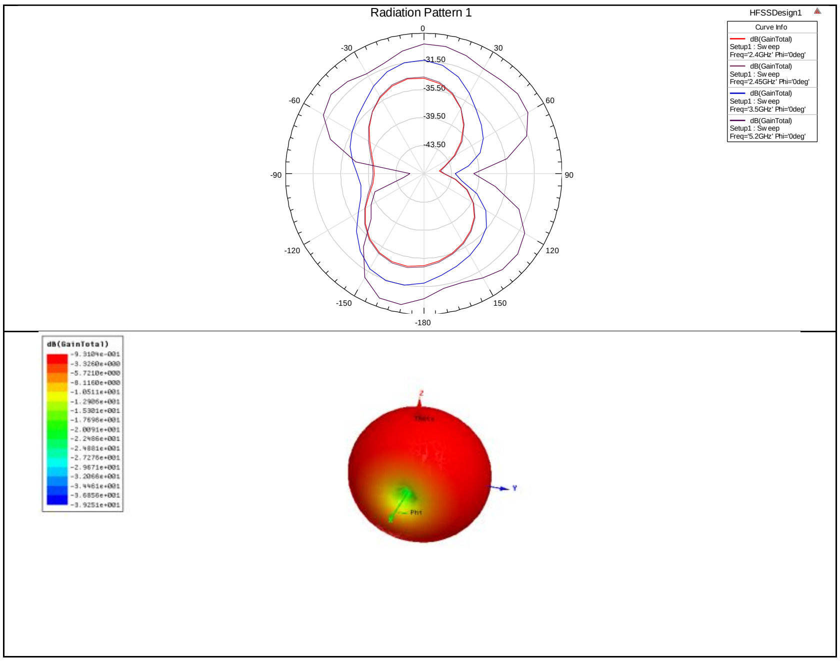


Figure 4.12: 3D polar plot

V.CONCLUSION

This research introduces the design and assessment of a compact, flexible and wideband wearable antenna for Wireless Body Area Network (WBAN) usage. By employing a low-cost photopaper substrate with a thickness of about 0.27 mm, a dielectric constant equal to 3.2 and a loss tangent of about 0.05, the antenna exhibits very good mechanical and electrical characteristics that are suitable for on-body usage. This antenna access multiple frequency bands such as 2.4 GHz (MBAN), 2.45 GHz (ISM), 3.5 GHz (WiMAX) and 5.2 GHz (WLAN), enabling an array of healthcare, IoT and personal communication systems. The antenna was shown to obtain a flat performance gain of 2.12 dBi and a radiation efficiency of 93.09%, and a gain of 2.18 dBi and a radiation efficiency of 94.8%, under a 60 mm bending radius, illustrating the ability of the antenna to withstand mechanical stress and maintain performance characteristics for dynamic wearability. The return loss (S11) was lower than –10 dB for all operating bands with a partial ground plane on the antenna, providing good impedance matching and good performance with minimal power loss. In addition, the SAR analysis showed a violation causing it to be compliant with IEEE/FCC safety standards further delineating the antenna's suitability to be worn in proximity to the human body. Taken together, the presented antenna solution is an effective and multi-band solution for body-worn communication systems that offer, mechanical flexibility, high efficiency, and safety of users, which makes it a suitable product for next meilleures alternatives.

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