2024 IEEE International Symposium on Antennas and Propagation and INC/USNC-URSI Radio Science Meeting (AP-S/INC-USNC-URSI) | 979-8-3503-6990-8/24/$31.00 ©2024 IEEE | DOI: 10.1109/AP-S/INC-USNC-URSI52054.2024.10686944

Smart-Watch Integrated Flexible Strap Antenna for Enhanced WiFi and Bluetooth Connectivity Applications

Karthik Kakaraparty and Ifana Mahbub
The University of Texas at Dallas, Richardson, TX 75080, USA

Abstract*—This paper presents a smartwatch strap-embedded antenna tailored for WiFi and Bluetooth-based applications within the 2.4 GHz frequency bands. Placing the antenna within the smartwatch strap rather than the watch's housing with other electronic components mitigates electromagnetic interference, ensuring optimal antenna performance in wireless communication applications. The antenna exhibits a realized gain of 10.21 dBi in the unbent case and 7.23 dBi when bent at an angle of 125°. The input power of 50 mW (17 dBm) is utilized for specific absorption rate (SAR) analysis when averaged over 10g of human tissue. The SAR result indicates a safe radiation level of 0.90 W/kg, well within the ICNIRP-specified limit of 2 W/kg over 10g of tissue. This research contributes to the enhancement of smartwatch communication capabilities by facilitating the provision for an antenna to be embedded while ensuring compliance with rigorous safety standards.

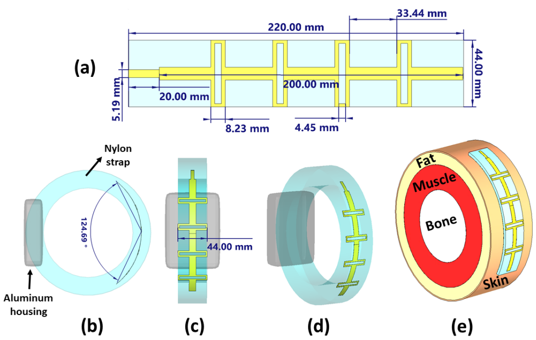

Fig. 1. Proposed smart watch strap antenna (a) antenna structure, antenna embedded within the watch (b) Side view (c) Back view, (d) Trimetric view, and (e) Curved body model with antenna bent 125°.

I. Introduction

In the exponentially growing landscape of smartwatch utilization, the embedded antennas within the smartwatch play a pivotal role in facilitating seamless wireless communication. The integration of antennas into the limited space of smartwatch housings, amidst a myriad of electronic components, introduces challenges such as signal interference, degradation of antenna gain, impact on the operating bandwidth, and other intricacies related to compliance with Specific Absorption Rate (SAR) regulatory standards. These challenges collectively influence both the performance and user experience of the smartwatch. Prior works have underscored the significance of antenna size miniaturization, achieving high gain, and mitigating specific absorption rate (SAR) issues, and these aspects are identified as strengths [1]–[5]. Kakaraparty et al. have demonstrated a series-fed antenna array with material deformation analysis, and such designs are best fit for smartwatch strap embedded antennas as they are compact and possess high gain [6]. However, the design demonstrated in [6] is for a 24 GHz frequency of operation. Nevertheless, challenges arise in the form of a potential trade-off between size and performance and bending-induced gain degradation, which affects the overall performance of the antenna. This study contributes to the advancement of smartwatch communication capabilities by addressing these challenges.

Embedding the WiFi antenna within a smartwatch's housing poses formidable challenges. Proximity to electronic components and the metallic structure introduces significant signal interference, potentially undermining WiFi performance and range. This configuration also compromises antenna efficiency, as nearby electronic elements may detrimentally impact overall functionality. Moreover, internal placement raises concerns regarding heat dissipation, posing risks to both the antenna and sensitive electronic components within the smartwatch. These pivotal issues underscore the intricacies and drawbacks associated with internally housing the WiFi antenna, necessitating meticulous consideration for optimal smartwatch design and operational excellence.

The novelty of the proposed work lies in our compact antenna design with high gain, specifically tailored for embedding in smartwatch straps rather than the traditional metal housing. This design envisions an external connection between the proposed antenna and the electronics board that is situated in the watch's housing, effectively isolating the antenna from the housing electronics to mitigate the aforementioned issues.

II. Design Methodology

The proposed flexible strap antenna design, the human body layer model, and the watch model are presented in Fig. 1. The computer simulation technology suite (CST) suite is utilized to design the antenna and aforementioned models. The human body model consists of four layers, namely, skin, fat, muscle, and bone. The material properties for these layers were assigned as mentioned in [2]. The watch model consists of an aluminum housing and a 6 mm thick nylon strap, and the materials and corresponding material properties were chosen from the pre-defined materials available in CST. The chosen substrate material for the proposed antenna is nylon, aligning with the prevalent use of this material in the manufacturing of smartwatch straps. The patch material utilized is copper

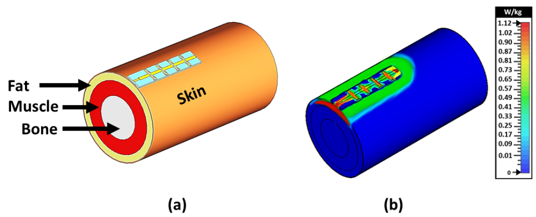

Fig. 2. SAR analysis (a) Model setup (b) SAR output.

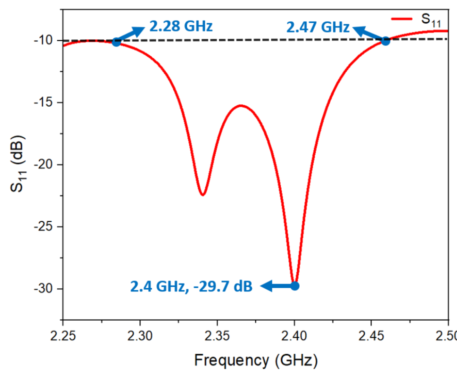

Fig. 3. S_{11} versus frequency plot.

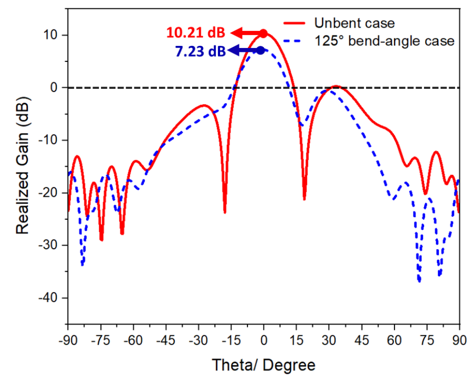

Fig. 4. Gain versus theta plots for the unbent case and bend case scenarios.

TABLE I
COMPARISON WITH PRIOR WORKS

	[1]	[2]	[3]	This Work*
Antenna dimension (mm^2)	42 × 72.5	30 × 30	30 × 30	44 × 220
Gain (dBi)	6.25	7.5	6.43	10.21
Frequency bands covered	2.4 GHz ISM	2.4 GHz ISM	2.4 GHz ISM	2.4 GHz ISM
SAR (W/kg)	0.9	0.174	0.147	1.1
HPBW (in degrees)	80°	77.8°	97.8°	30°

* This work is based on simulation

with a 1 Oz (0.035 mm) thickness. Copper is selected for its cost-effectiveness and commendable performance, particularly in terms of antenna gain. The proposed design consists of four slotted patch arrays connected and edge-fed in a series fashion. The dimensions of the patch elements are optimized to contribute to favorable radiation patterns.

III. Results and Discussion

The simulated return loss versus frequency result is presented in Fig. 3. It is observed that the magnitude of S_{11} is -29.7 dB at 2.4 GHz. The proposed antenna's radiation pattern with gain versus theta plot, as shown in Fig. 4, has portrayed an absolute gain of 10.21 dBi and a half-power beamwidth (HPBW) of 45 degrees at 2.4 GHz in the unbent case. The antenna bend case exhibited a gain of 7.23 dBi with an HPBW of 30 degrees. The high gain, HPBW, and design compatibility with watch strap performance characteristics highlight the suitability of the proposed flexible strap antenna for smart-watch applications. The performance comparison among similar prior works is presented in Table 1. The design presented in this study demonstrates superior performance in terms of gain and half-power beamwidth (HPBW). It exhibits low and safe Specific Absorption Rate (SAR) output while maintaining a relatively large size compared to previous designs.

IV. Conclusion

In conclusion, our work successfully presents and evaluates a smartwatch strap-embedded antenna tailored for 2.4 GHz WiFi and Bluetooth applications. Strategically embedding the antenna within the smartwatch strap mitigates potential electromagnetic interference due to other electronic components and metal structures within the aluminum housing of the smartwatch. The antenna's realized gain of 10.21 dBi in the unbent configuration and 7.23 dBi when bent at an angle of 125° demonstrates its adaptability to different usage scenarios. Moreover, our rigorous SAR analysis indicates a safe radiation level of 1.1 W/kg, well within the established ICNIRP safety limit of 2 W/kg over 10g of tissue. This adherence to safety standards is crucial for the widespread adoption and integration of such smartwatch antennas.

Acknowledgment

This work is based upon work supported by the National Science Foundation (NSF) under Grant No. ECCS 2246559.

References

[1] Karthik Kakaraparty and Ifana Mahbub. Design and sar analysis of a meander slot antenna for backscattering rfid applications. In *2023 United States National Committee of URSI National Radio Science Meeting (USNC-URSI NRSM)*, pages 141–142, 2023.

[2] Karthik Kakaraparty and Ifana Mahbub. The design and sar analysis of a uwb bow-tie antenna for wireless wearable sensors. In *2022 United States National Committee of URSI National Radio Science Meeting (USNC-URSI NRSM)*, pages 204–205, 2022.

[3] Karthik Kakaraparty and Ifana Mahbub. The design and sar analysis of wearable uwb antenna for radiative near-field wireless power transfer. In *2022 IEEE MTT-S International Microwave Biomedical Conference (IMBioC)*, pages 141–143, 2022.

[4] Sima Noghanian. A dual-band wearable mimo wifi antenna. In *2022 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (AP-S/URSI)*, pages 1170–1171, 2022.

[5] Buyun Wang and Sen Yan. Design of smartwatch integrated antenna with polarization diversity. *IEEE Access*, 8:123440–123448, 2020.

[6] Karthik Kakaraparty and Ifana Mahbub. Design and performance analysis of a 24 ghz series-fed 1×5 antenna array with material deformation for d2d applications. In *2023 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (USNC-URSI)*, pages 1575–1576, 2023.