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Dual-Band Antenna design for Energy Harvesting

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Abstract: Harvesting energy from radiofrequency (RF) signals presents a promising avenue for powering wireless sensor network (WSN) electronic circuits with low power demands. Designing the reception antenna for RF Energy Harvesting (EH) systems poses significant challenges and complexity. Consequently, extensive efforts are devoted to optimizing the performance of these antennas. In this study, we develop a dual-band antenna tailored for RF EH applications, operating across the 2.6 GHz, and 3.6 GHz frequency bands. To obtain an optimal performance, we carried out a comparison that shows the effect of changing dimensions on the antenna performance. Numerical simulations demonstrate the efficacy of our proposed design as a receiver antenna in RF EH setups.

Keywords : Energy harvesting, dual-band, antenna design.

1. INTRODUCTION

Managing waste batteries is an urgent concern due to their potential for environmental harm. Improper disposal contributes to land and water pollution, posing significant risks to ecosystems and human health. Minimizing battery usage is crucial and adopting Wireless Power Transfer (WPH) technology can reduce battery dependence, thereby mitigating the negative impacts of disposal. WPH technology enables devices to be powered wirelessly, reducing the need for disposable batteries and promoting eco-friendly practices by generating clean energy without producing harmful waste. The Internet of Things (IoT) has revolutionized connectivity, with Wireless Sensor Network (WSN) devices operating on minimal power [1]. Given the often harsh environments in which WSNs are deployed, maximizing their longevity is essential. Numerous methodologies have been developed to reduce the frequency of battery replacements [2, 3], and RF Energy Harvesting (RF EH) has emerged as a leading approach by harnessing ambient energy to power WSN devices, reducing their dependency on conventional batteries [4, 5]. Despite its recent introduction, RF EH has quickly gained recognition as a pivotal technology within the IoT landscape [6].

Research efforts are focused on extending battery life by reducing device usage, while other teams explore using ambient energy as a renewable power source in MEMS. RF EH offers promising solutions for powering wireless sensor nodes in remote or inaccessible locations, reducing reliance on traditional battery charging methods.

The microstrip patch antenna is a cornerstone in RF EH systems, widely applied across various frequency bands due to its simplicity, affordability, and compact design relative to wavelength [6-13]. However, optimizing energy extraction requires careful consideration of key performance metrics such as the reflection coefficient (S11 parameter), gain, and efficiency [12, 13]. Achieving multi-band functionality in antennas presents significant engineering challenges [8].

Rectennas, fundamental to RF EH systems, combine antenna and rectifier functionalities to collect and process ambient RF energy from sources like FM broadcasts, TV signals, and mobile networks [8]. The advent of 5G and beyond (B5G) is expected to become a predominant energy source in urban areas, reflecting ongoing research into RF EH systems for both outdoor and indoor environments [14-16].

Designing compact, multi-band antennas for RF EH is complex and challenging. Numerous studies, such as those on L-probe microstrip antennas and tri-band differential antennas, highlight the research community's efforts to advance multi-band antenna designs for RF EH applications. This paper introduces a dual-band microstrip patch antenna design to address the growing demand for efficient RF EH solutions across multiple frequency bands. Section II explores the design principles and methodologies employed, Section III analyzes the antenna's performance through simulations and experiments, and Section IV synthesizes the findings and implications of the study.

II. ANTENNA CONFIGURATION

The illustration in Fig. 1 showcases the proposed structure of a dual band antenna tailored for applications in the 2.6, and 3.6 GHz frequency bands, specifically designed for EH purposes. The antenna's design comprises a rectangular patch resembling the shape of the letter E, complemented by a suitable feeding line. It is constructed using FR-4 substrate material characterized by a relative dielectric constant of 4.4 and a loss tangent of 0.017. The initial dimensions of the antenna include a substrate length (L_sub) of 53 mm and a width (W_sub) of 58.1 mm, as detailed in Table 1. To analyze and optimize the proposed antenna, Ansoft simulation tools, particularly the High Frequency Structure Simulator (HFSS), are employed. Section 3 of this study presents the outcomes and insights derived from these

Table 1: Variables describing antenna geometry.

Variable	Value (mm)	Variable	Value (mm)
W_{sub}	58.01	L_{sub}	53.00
W_{ant}	23.92	L_{ant}	26.50
W_{slot1}	1.70	L_{slot1}	8.40
W_{slot2}	2.65	L_{slot2}	14.51
W_{feed}	3.35	L_{feed}	22.13
D_{slot1}	3.40	D_{slot2}	14.59
D_{feed}	4.55		

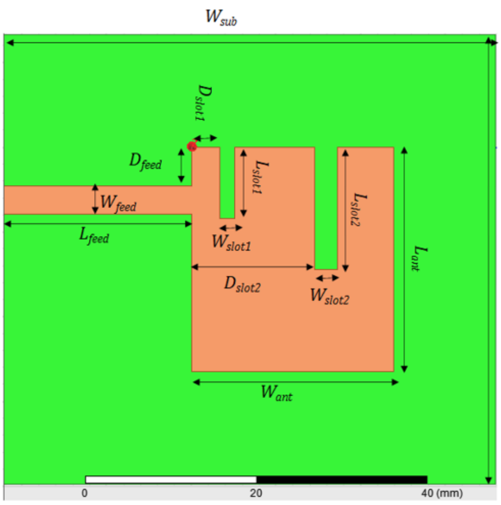


Fig 1: Configuration of proposed dual-band antenna

III. SIMULATION RESULTS

This study introduces and enhances a dual-band patch antenna intended for RF EH applications within urban environments. The antenna design is meticulously adjusted to operate across the 2.6, and 3.6 GHz frequency bands. Optimization of the antenna structure is conducted using the HFSS, renowned for its capability to analyze the electromagnetic properties of structures. HFSS serves as a versatile electromagnetic modeling tool widely employed not only in antenna design but also in crafting intricate RF electrical circuit components like filters and transmission lines.

Fig. 2 presents the visual representation of the reflection coefficient (S11) plotted against frequency for the dual-band patch antenna under consideration. Analysis of the graph reveals the antenna's proficiency in capturing ambient energy across two distinct frequency bands. The first band spans from 2.6 GHz to 2.67 GHz, exhibiting a reflection coefficient of -32 dB at 2.64 GHz. The second band covers the frequency range of 3.47 GHz to 3.58 GHz, with S11 of -41 dB observed at 3.53 GHz.

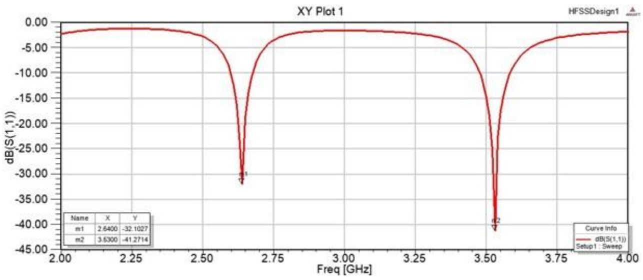


Fig 2:return loss S11proposed design

Fig. 3 displays the 3D polar plot simulation results of the proposed patch antenna operating within the 2.6 GHz frequency band. In Fig. 3, the radiation pattern is depicted, with a notable maximum value of 2.43e1 dBm observed. It is noteworthy to mention that while the proposed antenna demonstrates relatively modest gain values, these values remain adequate for facilitating the reception module within a rectenna system to effectively capture ambient energy from its surroundings [13, 16].

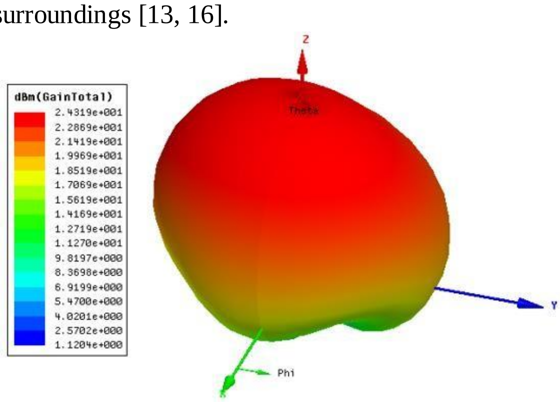
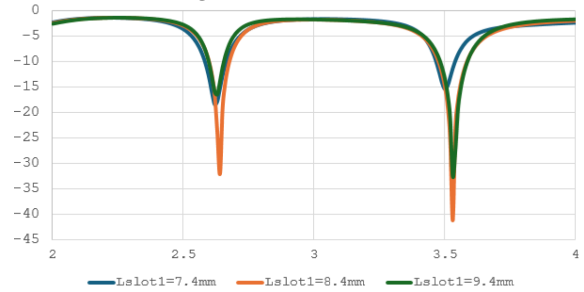
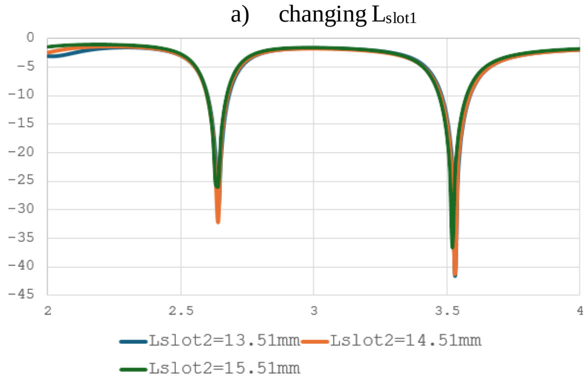


Fig 3: proposed antenna 3D far-field

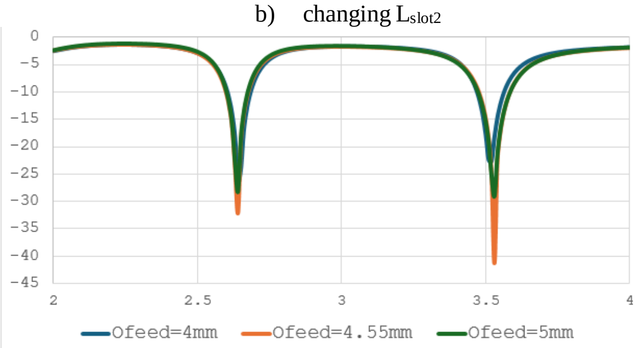
To verify the optimality of the proposed design, we carried out a comparison by changing the dimensions of the proposed antenna and recorded the effect of this change on the value of S11 in Figure 4. The figure shows the effect of changing three lengths; L_{slot1}, L_{slot2}, and D_{feed}; on the value of S11. In Figure 4-a, we can notice that changing L_{slot1} has a notable effect on the of S11 in both operating bands. And it is also clear that the optimal value of L_{slot1} is 8.4 mm. Similarly, the effect of L_{slot2} is depicted in Figure 4-b. The figure illustrates that the optimal value of L_{slot2} is 14.51 mm. Finally, the change of D_{feed} was studied in Figure 4-c. The figure concludes that the optimal value of D_{feed} is 4.55 mm. From these three sub figures, we can easily notice that any change by increase or decrease causes a degradation on the value of S11.



a) changing L_{slot1}



b) changing L_{slot2}



c) changing D_{feed}

Fig. 4. Effect of changing different dimensions of the proposed antenna.

IV .CONCLUSION

The fast advancement of WSN and IoT has spurred significant breakthroughs in the design of RF EH antennas. As these technologies continue to evolve and find diverse applications, the demand for antennas operating across specific frequency ranges has grown exponentially. In response to this demand, this paper introduces a novel approach by proposing a modified E-shaped antenna capable of operating at dual-band frequencies. Through meticulous analysis and optimization using the HFSS, the performance of the proposed antenna is thoroughly evaluated. The simulation results unequivocally demonstrate that the designed antenna meets the stringent requirements of contemporary applications, signaling its potential to address the burgeoning needs of the rapidly expanding WSN and IoT landscape.

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