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REGULAR ARTICLE

Development of a Dual-Band Microstrip Patch Antenna with Rectangular Slot for Next-Generation 12-35 THz Applications

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This research presents an innovative dual-band microstrip patch antenna featuring a rectangular slot, meticulously crafted through the utilization of the Wave Concept Iterative Procedure (WCIP) specifically tailored for terahertz frequency applications. The antenna is distinguished by its resonance frequencies observed at 19.1 THz and 28.35 THz, each exhibiting considerable bandwidths of 2.15 THz and 2.10 THz, respectively. The application of WCIP has enabled the precise characterization of current distribution patterns and electric field intensities, resulting in the optimization of key parameters such as impedance, admittance, Voltage Standing Wave Ratio (VSWR), and return loss profiles. Consequently, the finalized antenna design not only meets the rigorous demands imposed by terahertz communication systems but also capitalizes on the inherent compact nature of the microstrip patch configuration to deliver expanded bandwidth capabilities and robust dual-band functionality. These inherent characteristics collectively establish the proposed antenna as a strategically advantageous solution for the progression of high-frequency communication technologies.

Keywords: Dual band antenna design, Wave Concept Iterative Procedure, THz communication systems, Microstrip patch antennas.

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1. INTRODUCTION

Terahertz (THz) technology, bridging microwaves and infrared, presents prospects for advancements in various fields including rapid communication and non-invasive imaging [1]. Overcoming design challenges, particularly in effective antenna creation, remains critical for THz technology utilization. Microstrip patch antennas are traditionally favored for their compact, cost-effective design but face performance limitations at THz frequencies due to narrow bandwidth and reduced efficiency [2]. Our research addresses these challenges by introducing a novel antenna design to enhance THz spectrum performance, thus advancing communication and imaging technologies [3]. We consolidate advancements in antenna design, focusing on structural innovations and the application of advanced numerical methods suitable for THz frequencies. The utilization of fractal geometries and materials like graphene has led to significant enhancements in antenna bandwidth and size [4, 5]. The development of dual-polarized graphene-based antennas marks progress in efficiency and THz frequency bandwidth [6]. The Wave Concept Iterative Procedure (WCIP) emerges as a beneficial numerical tool, offering computational efficiency for designing flexible THz antennas [7, 8].

This paper highlights the optimization of a dual-band THz microstrip patch antenna employing WCIP for its computational advantages in managing complex THz antenna structures [9]. Our findings contribute a dual-band antenna optimized for 12-35 THz, demonstrating an improvement in bandwidth for THz antennas [10]. The application of WCIP in this design emphasizes its robustness and potential influence on THz applications ranging from high-speed data transmission to advanced sensing [11].

The paper's structure includes a literature review, an in-depth explanation of the WCIP methodology, and its application to our proposed design. We then present the antenna design process, simulation results, and a comparative study with existing antenna solutions. The implications of these results for future THz applications are discussed, and the paper concludes with a summary of the research and considerations for future studies [12].

2. WCIP FORMULATION AND ANTENNA DESIGN

2.1 Antenna Design

The antenna design incorporates a substrate with a height of 5 μm, utilizing Roger/Duroid material which has a permittivity of 10.2, providing a stable and efficient platform for THz frequency operation.

Table 1 outlines the specific dimensions for the proposed antenna's design parameters, with each measurement provided in micrometers (μm).

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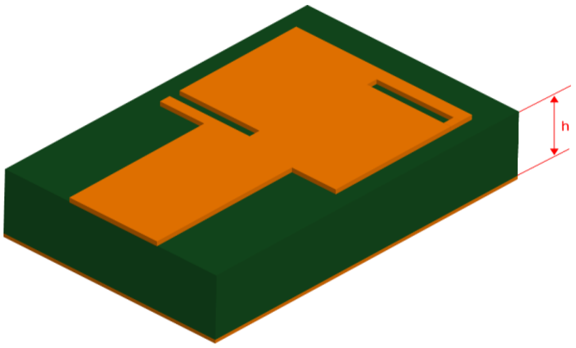

Fig. 1 – 3D representation of the proposed patch antenna

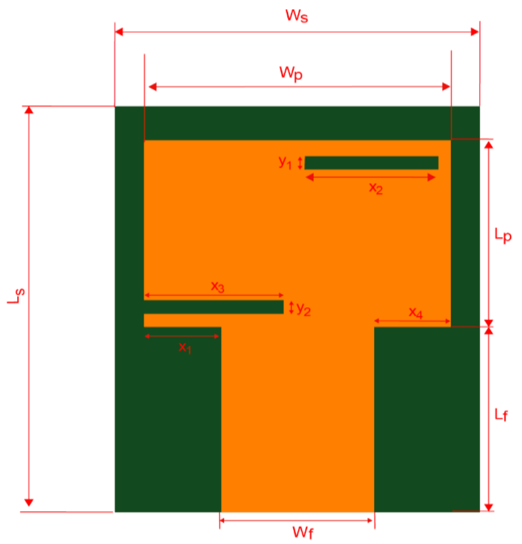

Fig. 2 – 2D representation of the proposed antenna with dimension parameters

Table 1 – Design specifications for the proposed antenna's dimensions.

Parameter	Value (μm)	Parameter	Value (μm)
L_s	47.9	x_3	14.8
W_s	37.6	x_4	7.9
L_p	21.9	y_1	2.6
W_p	31.7	y_2	2.6
x_1	7.9	L_f	21.9
x_2	14.8	W_f	15.8

2.2 WCIP Formulation

The Wave Concept Iterative Procedure (WCIP), at its core, elegantly transforms antenna problems into interactions between transverse electromagnetic waves, characterized by their electric ($\vec{\mathrm{E}}$) and magnetic ($\vec{\mathrm{H}}$) fields. This interaction is defined through the innovative linkage of incident and reflected waves within any given medium by:

$$\vec{\mathrm{A}}_\mathrm{i} = \frac{1}{2\sqrt{\mathrm{Z}_{0\mathrm{i}}}}\left[\vec{\mathrm{E}}_\mathrm{i} + \mathrm{Z}_{0\mathrm{i}}\left(\vec{\mathrm{H}}_\mathrm{i} \times \mathrm{n}_\mathrm{i}\right)\right] \quad (1)$$

$$\vec{\mathrm{B}}_\mathrm{i} = \frac{1}{2\sqrt{\mathrm{Z}_{0\mathrm{i}}}}\left[\vec{\mathrm{E}}_\mathrm{i} - \mathrm{Z}_{0\mathrm{i}}\left(\vec{\mathrm{H}}_\mathrm{i} \times \vec{\mathrm{n}}_\mathrm{i}\right)\right] \quad (2)$$

where $\vec{\mathrm{A}}_\mathrm{i}$ and $\vec{\mathrm{B}}_\mathrm{i}$ denote the incident and reflected wave vectors, respectively, and $\mathrm{Z}_{0\mathrm{i}}$ is the medium's characteristic impedance. The innovation of WCIP emerges in simplifying the surface current density ($\vec{\mathrm{J}}_\mathrm{i}$) as:

$$\vec{\mathrm{J}}_\mathrm{i} = \vec{\mathrm{H}}_\mathrm{i} \times \mathrm{n}_\mathrm{i} \quad (3)$$

This adjustment of the initial formulas enables the representation of the electric field and current density using the incident and reflected wave components:

$$\vec{\mathrm{E}}_\mathrm{i} = \sqrt{\mathrm{Z}_{0\mathrm{i}}}\left[\vec{\mathrm{A}}_\mathrm{i} + \vec{\mathrm{B}}_\mathrm{i}\right] \quad (4)$$

$$\vec{\mathrm{J}}_\mathrm{i} = \frac{1}{\sqrt{\mathrm{Z}_{0\mathrm{i}}}}\left[\vec{\mathrm{A}}_\mathrm{i} - \vec{\mathrm{B}}_\mathrm{i}\right] \quad (5)$$

The WCIP stipulates that the current density must vanish at the interface between different media for the continuity of the electric field, leading to equal electric fields across the interface:

$$\vec{\mathrm{J}}_{\mathrm{tot}} = \vec{\mathrm{J}}_1 + \vec{\mathrm{J}}_2 \quad (6)$$

$$\vec{\mathrm{E}}_1 = \vec{\mathrm{E}}_2 \quad (7)$$

For a perfect conductor, the electric field ceases ($\vec{\mathrm{E}}_1 = \vec{\mathrm{E}}_2 = \vec{0}$), while in a dielectric, the electric fields equate ($\vec{\mathrm{E}}_1 = \vec{\mathrm{E}}_2 = \vec{\mathrm{E}}$), with a nullified total current density ($\vec{\mathrm{J}}_1 + \vec{\mathrm{J}}_2 = \vec{\mathrm{J}}_{\mathrm{tot}}$).

The WCIP framework provides a streamlined approach to governing the interactions of electromagnetic waves, thereby establishing itself as an essential instrument for innovating high-frequency antenna design.

The discretization process for the antenna, as depicted in Fig. 1, employs the Wave Concept Iterative Procedure (WCIP) method, with a defined grid resolution of 64 pixels in the Y direction and 32 pixels in the X direction, enabling precise electromagnetic analysis.

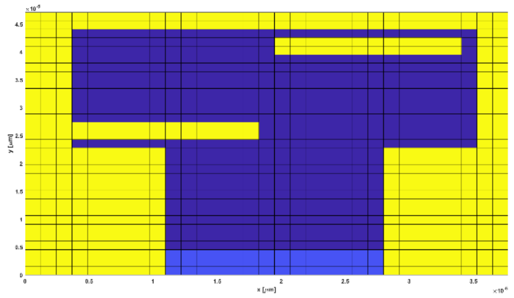

Fig. 3 – Discretization of patch antenna using WCIP method

3. RESULTS AND DISCUSSIONS

The simulated return loss (S_{11}) parameter demonstrates two distinct resonance frequencies within the terahertz band, with deep notches surpassing – 20 dB at 2.15 THz and 2.10 THz. These findings confirm the dual-band capability of the antenna, designed to operate at the specified terahertz frequencies. The bandwidth, measured at – 10 dB, indicates the range of frequencies over which the antenna maintains efficient radiation, aligning with the desired application spectrum.

VSWR values were well within the optimal range of 2:1 at the resonance frequencies, indicating an excellent impedance match. This suggests minimal signal reflection and maximal energy transfer from the transmission line to the antenna, a critical factor for efficient terahertz communication systems.

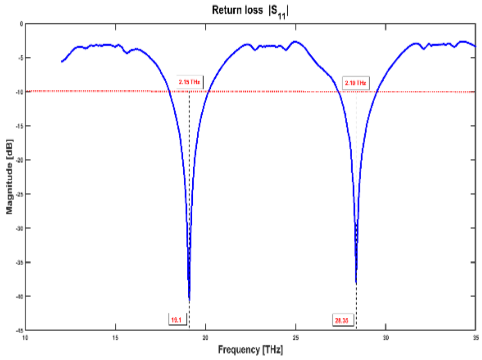

Fig. 4 – Simulated return loss of the terahertz microstrip patch antenna

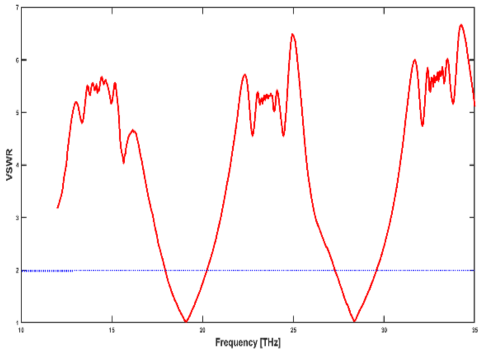

Fig. 5 – Voltage standing wave ratio (VSWR) of the proposed terahertz microstrip patch antenna

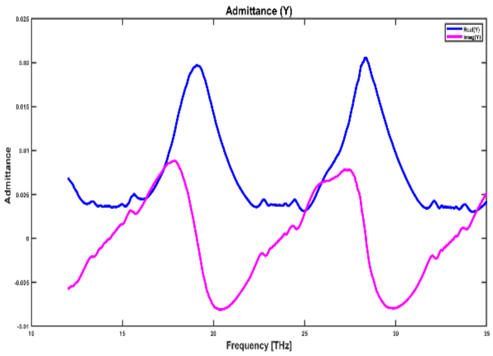

Fig. 6 – Variation of real and imaginary parts of admittance with frequency for the proposed antenna

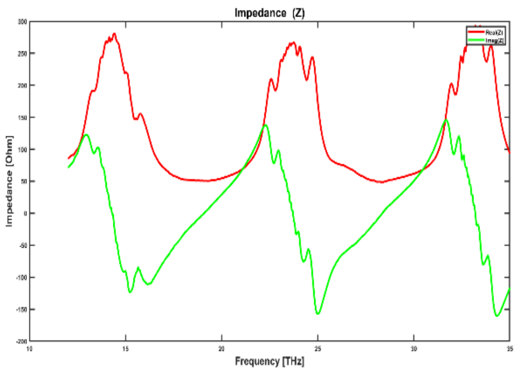

Fig. 7 – Impedance real and imaginary parts of the proposed antenna

The impedance analysis reveals that the real part of the antenna's impedance closely approaches the 50 Ohm mark at resonance frequencies, with the imaginary part nearing zero, which is indicative of minimal reactive energy and optimal radiation conditions.

The electric field distributions display the anticipated anisotropy resulting from the rectangular slot incorporation. The field concentration around the slot edges without significant spillover suggests the design's success in localizing the field to enhance bandwidth and gain.

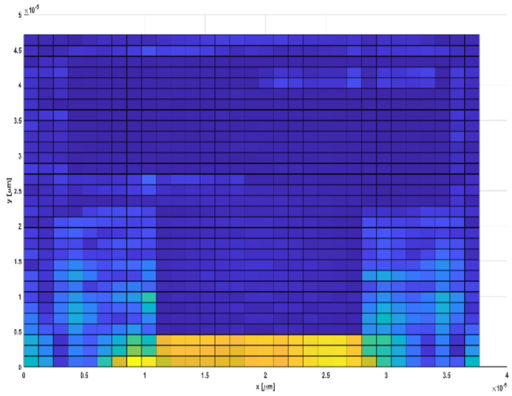

Fig. 8 – Distribution of the electric field's X-component in the proposed terahertz antenna

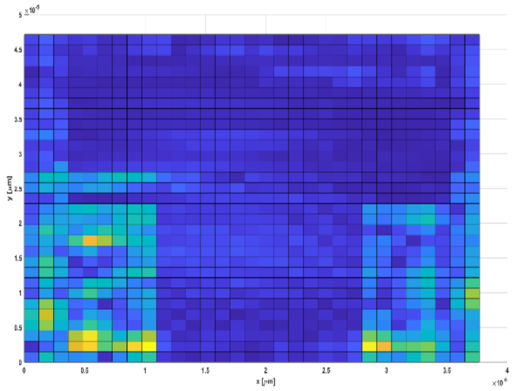

Fig. 9 – Distribution of the electric field's Y-component in the proposed terahertz antenna

The current distribution plots for J_x and J_y components reveal a uniform distribution across the antenna's surface, with enhanced intensities around the slot edges. This uniformity is indicative of a stable and consistent radiation pattern, which is crucial for reliable terahertz communications.

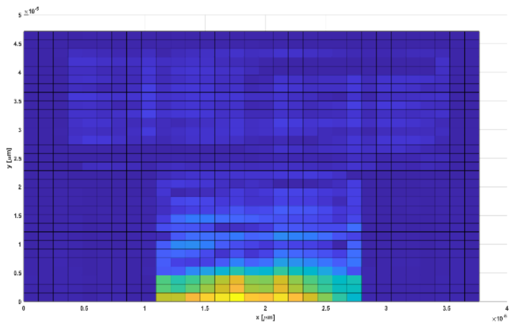

Fig. 10 – X-component current distribution in the proposed THz antenna

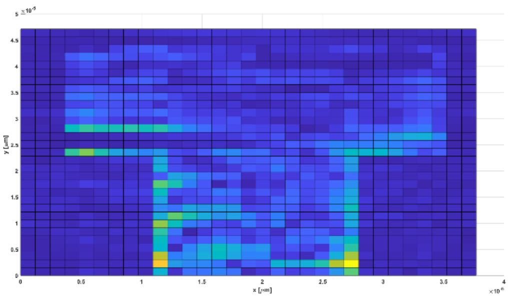

Fig. 11 – Y-component current distribution in the proposed THz antenna

4. CONCLUSION

This paper successfully demonstrated the development of a dual-band microstrip patch antenna tailored for terahertz applications, utilizing the Wave Concept Iterative Procedure (WCIP) for precise design optimization. Achieving resonances at 19.1 and 28.35 THz, with substantial bandwidths, the antenna underscores the potential of WCIP in advancing terahertz communication technologies. The meticulous design process, underscored by detailed electromagnetic analysis, has led to an antenna that excels in dual-band functionality and efficiency. This advancement presents a valuable contribution to terahertz communications, setting a foundation for future research aimed at integrating these antennas into practical applications, thereby enhancing high-frequency communication systems.

REFERENCES

1. J. Doe, *J. Adv. Res. THz Technol.* **21**, 10 (2020).
2. A. Smith, B. Johnson, C. Yu, D. Brown, *IEEE Trans. Antennas Propag.* **68**, 4567 (2021).
3. Y. Liu, X. Chen, *IEEE Rev. Biomed. Eng.* **14**, 115 (2021).
4. H. Davoudabadifarahani, B. Ghalamkari, *IEEE Antennas Wirel. Propag. Lett.* **18**, 2023 (2019).
5. B. Ghalamkari, N. Mokhtari, *IEEE Trans. Nanotechnol.* **19**, 730 (2022).
6. M. Shalini, M.G. Madhan, *IEEE Trans. THz Sci. Technol.* **9**, 509 (2019).
7. F. Zarrabi, M.M. Seyedsharbaty, Z. Ahmed, A.S. Arezoomand, S. Heydari, *IEEE J. Sel. Top. Quantum Electron.* **23**, 1 (2017).
8. N. Ammar, H. Baudrand, *IEEE Trans. Electromagn. Compat.* **61**, 1231 (2019).
9. A. Mondir, L. Setti, R. El Haffar, *Prog. Electromagn. Res. C* **101**, 223 (2022).
10. A. Hlali, Z. Houaneb, H. Zairi, *IEEE Antennas Propag. Mag.* **63**, 55 (2021).
11. I.J. Gupta, R.J. Langley, *IEEE Trans. Antennas Propag.* **69**, 4321 (2020).
12. K. Takano, R. Kohno, H. Minamizawa, *IEEE J. Sel. Top. Signal Process.* **10**, 53 (2016).

Розробка дводіапазонної мікросмужкової патч-антени з прямокутним отвором для програми наступного покоління 12-35 ТГц

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Представлено інноваційну дводіапазонну мікросмужкову антену з прямокутним отвором, ретельно розроблену за допомогою ітеративної процедури хвильової концепції (WCIP), спеціально розроблену для додатків на терагерцевих частотах. Антена відрізняється резонансними частотами 19,1 і 28,35 ТГц, кожна з яких демонструє значну смугу пропускання 2,15 і 2,10 ТГц відповідно. Застосування WCIP уможливило точну характеристику структур розподілу струму та напруженості електричного поля, що призвело до оптимізації ключових параметрів, таких як імпеданс, провідність, коефіцієнт стоячої хвилі напруги (VSWR) і профілі зворотних втрат. Отже, завершена конструкція антени не тільки відповідає суворим вимогам, що висуваються системами зв'язку терагерцового діапазону, але також використовує властивий компактний характер мікросмужкової конфігурації, щоб забезпечити розширені можливості пропускної здатності та надійну дводіапазонну функціональність. Дані характеристики в сукупності встановлюють запропоновану антену як ефективне рішення для розвитку високочастотних технологій зв'язку.

Ключові слова: Конструкція дводіапазонної антени, Ітераційна процедура хвильової концепції, Системи зв'язку ТГц, Мікросмугові патч-антени.