# Highly Compact and Cost-Efficient Metal-Coated UWB 3D Vivaldi Radial Array for RADAR Applications

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***Abstract*—This study introduces a compact and cost-effective metal-coated ultra-wideband (UWB) 3D Vivaldi antenna (VA) and its associated radial array designed for Radio detection and ranging (RADAR) applications. The proposed 3D radial Vivaldi antenna array (RVAA) comprises eight outer radial elements positioned at angular intervals of $45^\circ$, along with four inner radial elements strategically located to maintain $90^\circ$ angular spacing between them to enhance gain in end-fire direction and to mitigate side lobe issues. Thus, the array encompasses a total of twelve 3D Vivaldi antenna elements arranged radially. Each antenna element is bottom-fed through coaxial SMA ports individually. The array features an aperture diameter of 84 mm and a base thickness of 12 mm. Operating within the frequency range of 3.3 GHz to 11.9 GHz, the proposed antenna array achieves a peak gain of 20 dBi at a center frequency of 7.6 GHz. Fabrication of the proposed antenna is envisioned to utilize Acrylonitrile butadiene styrene (ABS) plastic-based 3D printing combined with electroplating techniques, aimed at reducing fabrication costs without compromising antenna performance. Consequently, the proposed radial 3D Vivaldi antenna array offers a promising alternative to prohibitively expensive all-metal antennas and holds significant potential for ultra-wideband RADAR applications.**

***Index Terms*—Additive manufacturing, UWB, radial array, Vivaldi antenna, 3D antenna, electroplating, RADAR, low-cost antenna, 3D printing.**

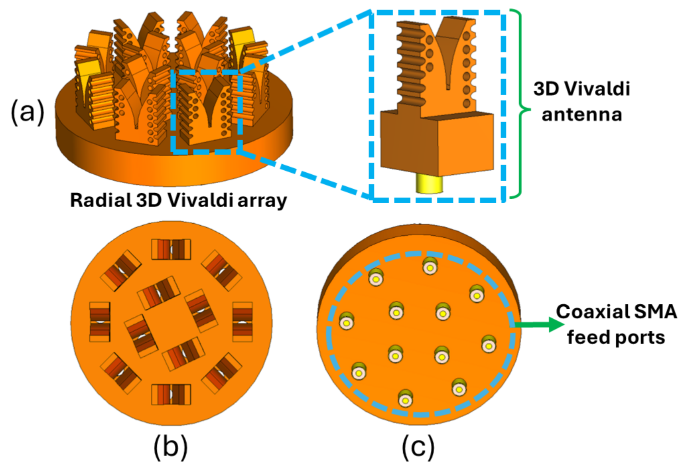


Fig. 1. The proposed RVAA design (a) Perspective side view, (b) top view, and (c) bottom view.

## I. Introduction

The advancement of wireless communication and UWB radar systems has seen notable progress [1]–[6], with a significant focus of current research directed toward addressing critical hurdles in UWB antenna design. This includes the development of cost-effective, compact, and high-gain antenna structures essential for typical radar applications. Researchers are particularly concentrating on highly directional Vivaldi antenna arrays due to their exceptional wideband operation, broad beamwidth, high gain, and reduced design complexity. These attributes facilitate easy fabrication and improve target detection and communication across various radar frequency bands [7]–[11].

While prior research predominantly focused on 2D configurations of the Vivaldi antenna (VA), there exists a scarcity of studies addressing the 3D Vivaldi designs aimed at enhancing bandwidth and gain, while also emphasizing cost-efficient fabrication [12]–[15]. In this context, our work introduces a novel approach by implementing a 3D Radial Vivaldi antenna array (RVAA) structure with the incorporation of 3D semi-elliptical corrugations for bandwidth enhancement and cylindrical slots to improve the impedance bandwidth. In addition, the 3D Vivaldi antenna elements are arranged in a configuration where eight outer radial elements are spaced at intervals of $45^\circ$, complemented by four inner radial elements strategically positioned to maintain a $90^\circ$ angular separation between each element to enhance the gain in the end-fire direction and to mitigate side lobe issues associated with array configurations. Through this work we aim to pave the way for further advancements in 3D Vivaldi antenna designs, addressing the growing demand for high-performance antennas with improved bandwidth and gain while ensuring cost-effectiveness in fabrication.

The structure of the paper is as follows: Section II presents the design methodology for radial Vivaldi antenna array (RVAA). Section III elaborates on the envisioned low-cost metal-coated antenna fabrication procedure. Section IV discusses the simulation results of the proposed RVAA. Section V provides the concluding remarks and outlines future directions.

## II. Design Methodology of RVAA

The proposed design is inspired by the conventional Vivaldi antenna (VA) design and 3D printed antenna techniques. The proposed RVAA entails a 3D radial Vivaldi antenna array (RVAA) consisting of eight outer radial elements positioned at angular intervals of $45^\circ$, complemented by four inner radial

TABLE I
DESIGN PARAMETERS OF RVAA

| Variable | Value ($mm$) | Variable | Value ($mm$) |
|---|---|---|---|
| $a$ | 8 | $e$ | 16 |
| $b$ | 20.5 | $f$ | 1.9 |
| $c$ | 12.3 | $x$ | 84 |
| $d$ | 1 | $y$ | 12.3 |

elements strategically placed to maintain a consistent 90° angular spacing between them. The strategic placements of elements are implemented to mitigate the side lobe issues. The 3D semi-elliptical corrugations are incorporated to enhance the bandwidth, and the cylindrical slots within the flares of the proposed 3D Vivaldi structure are incorporated primarily to enhance the impedance bandwidth of the antenna. In total, the array comprises twelve 3D Vivaldi antenna elements arranged radially as aforementioned. Each antenna element is fed from the bottom through individual coaxial SMA ports. The array exhibits an aperture diameter of 84 mm and a base thickness of 12 mm. The proposed antenna design is depicted in Fig. 1, with a perspective side view shown in Fig. 1(a), top view in Fig. 1(b), and perspective bottom view in Fig. 1(c). The design variables for the proposed antenna array are presented in Table I and the corresponding design variables are labeled in Fig. 2. The tapered opening ($t$) of the proposed 3D Vivaldi antenna is determined using equations (1), (2), and (3). Calculating the tapered opening (t) is essential as it significantly impacts the antenna gain, especially in the desired end-fire direction. This calculation enables precise shaping of the radiation pattern, concentrating energy in desired directions, thereby enhancing the antenna's directionality and gain performance.

$$t = E_1 e^{\alpha x} + E_2 \tag{1}$$

Where,

$$E_1 = \frac{y_2 - y_1}{e^{\alpha x_2} - e^{\alpha x_1}} \tag{2}$$

$$E_2 = \frac{y_1 e^{\alpha x_2} - y_2 e^{\alpha x_1}}{e^{\alpha x_2} - e^{\alpha x_1}} \tag{3}$$

Where $\alpha$ represents the rate of opening, E1 and E2 denote the design variables corresponding to the initial and final coordinates of the Vivaldi flares in the analyzed 2D Vivaldi structure. Both sides of this 2D Vivaldi configuration can be extended and transformed into a 3D Vivaldi structure. The linearly tapered slot with slope ($S$) has a corresponding taper flare angle ($\alpha$) and is estimated using (4).

$$\alpha = \tan^{-1} S \tag{4}$$

## III. ENVISIONED FABRICATION APPROACH

The proposed 3D radial Vivaldi antenna array (RVAA) is planned to be fabricated utilizing ABS plastic-based 3D printing technique and subsequent metal coating through electroplating. The 3D printed structures are presented in Fig.

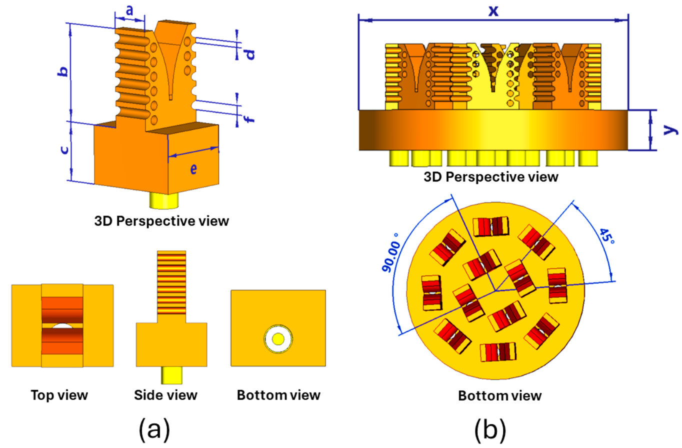


Fig. 2. Antenna design architecture (a) Single 3D Vivaldi antenna, and (b) Radial 3D Vivaldi array.

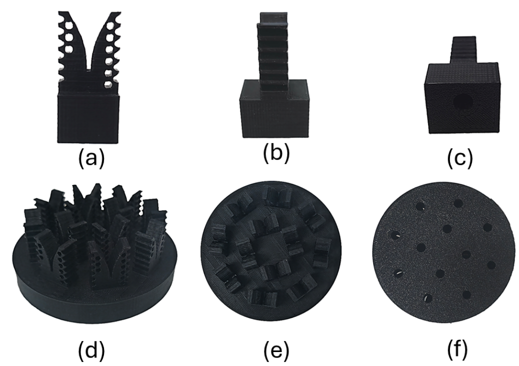


Fig. 3. 3D printed ABS plastic-based antenna structures: Single unit (a) front view, (b) side view, (c) perspective bottom view; Radial Vivaldi array (d) perspective side view, (e) top view, and (f) bottom view.

3. The concept of electroplating-based metal-coating on 3D printed ABS antenna array structure is illustrated in Fig. 4. The electroplating procedure involves several pivotal steps utilizing components such as copper anodes, copper sulfate electrolyte solution, copper paint, 3D ABS printed antenna structure, connection wires, and DC supply. Firstly, it is crucial to ensure that the ABS plastic antenna structure is coated with conductive copper paint before immersion in the glass container filled with the readily available copper sulfate (CuSO4) electrolyte solution.

Two thick copper anode plates are strategically positioned at opposite corners of the container, fully submerged in the electrolyte solution. Both anode plates are then connected to the positive terminal of the DC power supply. Simultaneously, the negative terminal is connected to the ABS plastic antenna structure, which is coated with conductive copper paint. Upon powering the supply and setting the voltage to the desired level, the electroplating process initiates. Here, the positive terminal of the power supply attracts copper ions from the electrolyte solution towards the conductive copper-coated ABS

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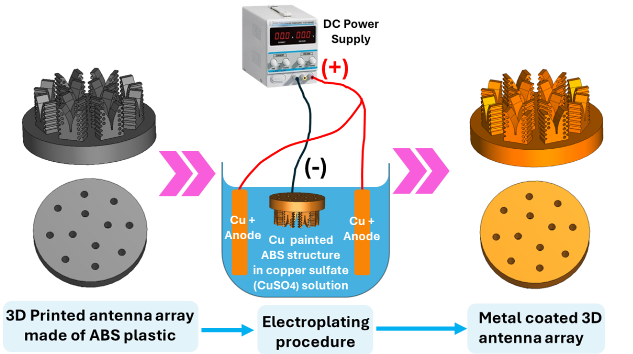


Fig. 4. Graphical visualization of electroplating procedure for cost-efficient metal-coated 3D antenna fabrication.

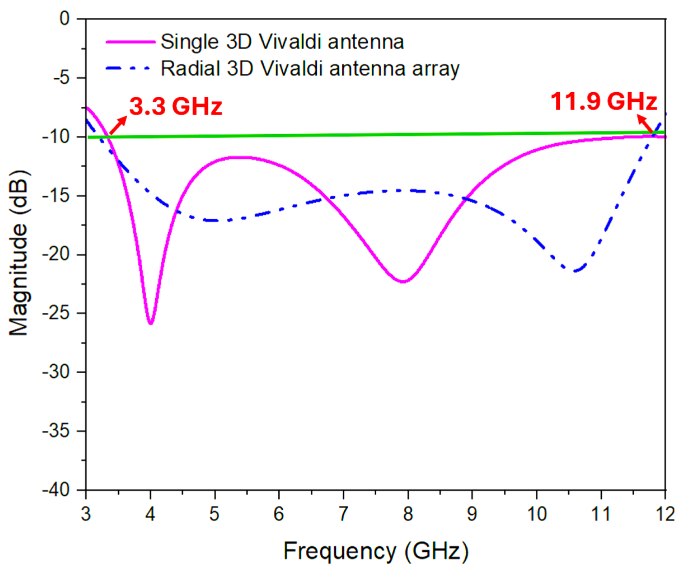


Fig. 5. $S_{11}$ parameters.

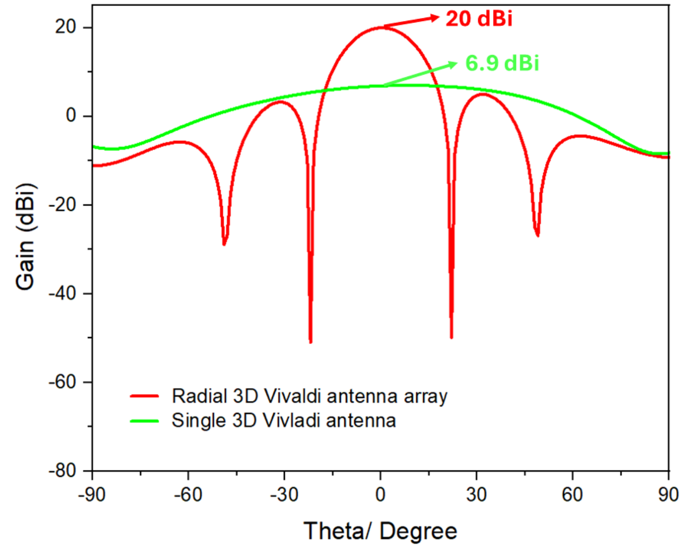


Fig. 6. Gain vs Theta (degrees) plots for single antenna element and radial antenna array at center operating frequency of 7.6 GHz.

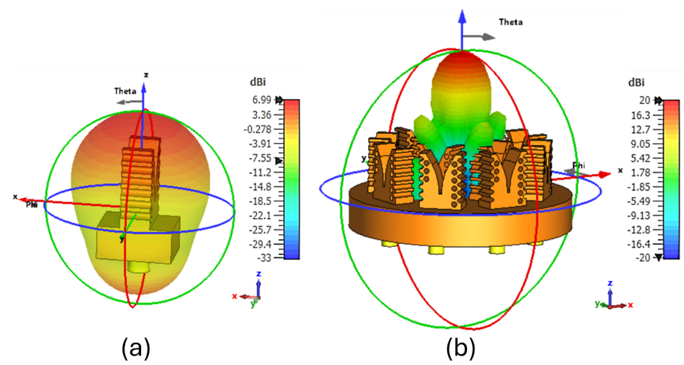


Fig. 7. 3D Radiation patterns (a) Single 3D Vivaldi antenna (b) Radial 3D Vivaldi array.

plastic antenna structure, facilitating the deposition of a copper layer onto its surface. Throughout the process, close monitoring is essential to prevent overplating or uneven coating, with adjustments made to voltage and current as necessary to maintain optimal plating conditions. Once the desired thickness of the copper coating is achieved, the power supply is turned off, and the antenna structure is carefully removed from the electrolyte solution. Thorough rinsing with distilled water follows to eliminate any residual electrolyte solution, after which the antenna structure is left aside to cure for 24 to 48 hours. The antenna structure is ready to use once it is completely dried. The long-pin SMAs (Amphenol RF 132146) are intended to be utilized to feed the antenna structure from the bottom via the cylindrical slot opening allocated at the bottom of each antenna structure within the RVAA.

## IV. Results and Discussion

The simulated results of the proposed RVAA and corresponding single-unit 3D VA are analyzed. Fig. 5 provides the $S_{11}$ parameter results for both, where the operational frequency range is observed as 3.3 GHz to 11.9 GHz, which covers a few radar bands such as S, C, and X bands. The gain versus theta plots for single 3D VA and 3D RVAA are presented in Fig. 6, which portray the peak gain values of 6.9 dBi for single VA and 20 dBi gain for RVAA at the center operating frequency of 7.6 GHz. The corresponding 3D radiation gain patterns were presented in Fig. 7 for the aforementioned case scenario. Table II presents the performance comparison of the proposed work with similar prior works. The proposed work has shown balance in the performance parameters by maintaining a wide operational bandwidth from 3.3 GHz to 11.9 GHz and achieving high gains of 6.9 dBi for a single element and 20 dBi for the RVAA. It covers radar bands including S, C, and X.

## V. Conclusion

In conclusion, this study introduces a compact and cost-effective metal-coated ultra-wideband (UWB) 3D Vivaldi an-

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TABLE II
COMPARISON WITH OTHER WORKS

| | [16] | [17] | [18] | This Work* |
|---|---|---|---|---|
| Operating frequency range (in GHz) | 2 to 12 | 1 to 8 | 0.5 to 18 | 3.3 to 11.9 |
| Frequency bands covered | S, C, X | S and C | L to Ku | S, C, X |
| Peak Array Gain (in dBi) | 20 | 15 | 10 | 20 |
| Aperture size $mm^2$ | 182×20 | 110 × 60 | 240 × 120 | 84×32.4 |

* This work is based on simulation

tenna (VA) and its associated radial array tailored for Radio detection and ranging (RADAR) applications. The proposed 3D radial Vivaldi antenna array (RVAA) comprising twelve elements demonstrates significant advancements in gain enhancement and side lobe mitigation. Operating within the frequency range of 3.3 GHz to 11.9 GHz, the array achieves a peak gain of 20 dBi at a center frequency of 7.6 GHz, making it suitable for various radar bands including C, S, and X. Fabrication techniques employing Acrylonitrile butadiene styrene (ABS) plastic-based 3D printing combined with electroplating are proposed to reduce costs without compromising performance. Through simulated analyses, the proposed RVAA exhibits a balanced performance with wide operational bandwidth and high gains, making it a promising alternative to expensive all-metal antennas. The antenna achieved a peak array gain of 20 dBi with respect to co-polarization, while cross-polarization levels were adequately suppressed across the 3D radiation patterns. The gain is referenced to linear polarization. The proposed metal-coated 3D printing technique is anticipated to perform well under standard environmental conditions, though further testing is required for comprehensive validation The comprehensive evaluation presented in this study lays the groundwork for further research and development in ultra-wideband RADAR applications. Future work aims to complete the fabrication of the proposed RVAA and carry out a comparative analysis between simulated and measured results. Additionally, the beam steering capability of the proposed array will be investigated by simultaneously varying the input phases of all twelve feed ports.

## ACKNOWLEDGMENT

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