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International Journal of Innovations in Science & Technology

Design of a Modified Wilkinson Power Divider for Ultra-Wideband Antipodal Vivaldi Antenna Arrays

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Citation | Ahmed. S, Khan. F. S, Keerio. I. K, Ahmed. A, Qutaba. S, "Design of a Modified Wilkinson Power Divider for Ultra-Wideband Antipodal Vivaldi Antenna Arrays", IJIST, Vol. 07 Issue. 02 pp 689-701, April 2025
Received | March 20, 2025 **Revised |** April 11, 2025 **Accepted |** April 13, 2025 **Published |** April 14, 2025.

This paper presents the design of a two-way Modified Wilkinson power divider (MWPD) feeding network for a two-element Antipodal Vivaldi Antenna (AVA) array, operating in the 3–10 GHz ultra-wideband (UWB) frequency range. The proposed feeding network is optimized by incorporating bent corners, which help reduce unintended radiation and improve signal distribution. Additionally, the antenna design is enhanced using a compact structure to improve radiation performance and impedance matching. The design, simulation, and optimization of both the feeding network and antenna array are conducted using CST Microwave Studio. Experimental validation confirms that the proposed array meets UWB specifications, making it a suitable candidate for wideband communication and imaging applications.

Keywords. Feeding Network; Antenna Array; Imaging; Modified Wilkinson Power Divider; UWB; AVA; CST.

Introduction:

Power dividers play a critical role in microwave and RF systems [1][2], ensuring efficient signal distribution across multiple antenna elements with minimal loss and distortion [3][4]. The Wilkinson Power Divider (WPD) is a popular choice due to its superior impedance matching, high isolation, and minimal insertion loss [5][6]. Traditionally, it employs quarter-wave transformers [7][8] and isolation resistors for efficient power splitting with minimal reflection. However, modern communication systems require Ultra-Wide Band (UWB) performance, necessitating design modifications to enhance bandwidth [9][10] and efficiency.

Bandwidth enhancement can be achieved by incorporating stubs or increasing the number of sections [11][12]. This paper presents a two-way MWPD optimized for equal power splitting, low insertion loss, and improved return loss across 3–10 GHz, ensuring efficient signal distribution and impedance matching in an antenna array. Simulated and measured results confirm its effectiveness as a feeding network for a two-element AVA array, making it a strong candidate for UWB imaging applications. UWB antennas are valued for their broad frequency range, high data transmission capability, and low power consumption [13][14]. Among them, the AVA stands out for its high gain, directional radiation pattern, and ease of fabrication [15][16][17][18]. An optimized feeding network is essential for maximizing its performance in array configurations.

This paper presents an MWPD feeding network for a UWB AVA array, designed to enhance impedance matching, power distribution, and radiation characteristics. The MWPD ensures minimal insertion loss and optimal phase distribution, improving beamforming and efficiency.

Objectives of the Study:

- To design a two-way Modified Wilkinson Power Divider (MWPD) feeding network for a two-element Antipodal Vivaldi Antenna (AVA) array operating in the 3–10 GHz ultra-wideband (UWB) frequency range.
- To enhance the feeding network by incorporating bent corners to minimize unintended radiation and improve signal distribution.
- To develop a compact antenna structure that enhances radiation performance and impedance matching.
- To simulate, analyze, and optimize the feeding network and antenna array using CST Microwave Studio.
- To validate the performance of the proposed array through experimental testing, ensuring it meets UWB specifications for wideband communication and imaging applications.

Novelty of the Study:

The novelty of this study lies in the design of a compact two-element MAVA array integrated with a two-way MWPD feed**,** optimized for enhanced signal distribution and reduced unintended radiation through a bent-corner MWPD design. Additionally, the incorporation of a slotted structure in the MAVA ensures superior impedance matching **(**S11 < -10 dB**)** across the 3–10 GHz UWB band.

Literature Review:

The Wilkinson Power Divider (WPD) has been widely recognized as an optimal choice for antenna array feeding networks due to its simple geometrical structure, low insertion loss, and compact size [9], [12]. Its ability to provide electrical isolation between output ports enhances performance in multi-element antenna arrays [2][6]. The AVA and WPD combination are particularly advantageous for array systems, as they enhance imaging resolution due to the wide bandwidth inherent in both components. The array configuration improves spatial resolution, allowing for highly detailed imaging. Additionally, the directional nature of AVA improves signal penetration and detection, making it suitable for radar and imaging applications. The integration of AVA with WPD ensures uniform signal distribution, where each antenna element receives equal power, leading to clearer signals and reduced noise in imaging data. Moreover, the low insertion loss and high isolation properties of the WPD help maintain signal integrity.

Several studies have investigated the integration of AVA arrays with UWB WPD feeding networks. In [19], a two-element AVA array was implemented with a UWB WPD for radar applications, where the antennas were arranged in a stacked configuration to minimize crosstalk between the transmitter and receiver. This design successfully met the return loss requirements. Another study [20] examined a four-element AVA array integrated with a UWB WPD for UWB applications, demonstrating compliance with return loss specifications while highlighting its capability for broadband signal transmission and high-resolution imaging. Similarly, [21] employed a four-element AVA array with a UWB WPD for imaging applications, validating its operational frequency range of 1 to 4 GHz with an S11 parameter of less than -10 dB. A notable advantage of using a two-element AVA array configuration is the reduction in system complexity, making it a practical choice for applications requiring a balance between performance and implementation feasibility. Compared to conventional antenna designs, such as horn and spiral antennas, an AVA array combined with a UWB WPD is both compact and lightweight, making it a more efficient alternative for modern communication, radar, and imaging systems.

Methodology:

This paper presents an MWPD Feeding Network designed for a UWB AVA Array, with Figure 1 depicting the flowchart outlining the design and development process. The flowchart illustrated the design, simulation, fabrication, and validation process of a two-way MWPD and AVA system. The process began with designing a two-way MWPD and AVA using CST software. After completing the design, a simulation was conducted to evaluate its feasibility. If the simulation yielded successful results, the process advanced to the fabrication stage. However, if the simulation was not successful, the design underwent revisions, and the simulation was repeated until the desired outcome was achieved. After a successful simulation, the two-way MWPD and AVA were fabricated. Once fabricated, the MWPD was connected with two AVA elements to form an array antenna. This assembled array antenna then underwent experimental validation to assess its performance. During the validation phase, the S11 parameter (Return Loss) was evaluated. If it was less than -10 dB, the antenna met the required performance criteria, and the process was finalized. If the S11 parameter failed to meet the -10 dB threshold, the MWPD and AVA were re-fabricated, and the validation process was repeated. This iterative approach guaranteed that the final antenna system satisfied the required performance standards.

Two-way UWB Modified Wilkinson Power Divider (MWPD) Design:

The design and optimization of the two-way UWB-modified Wilkinson power divider (MWPD) involved several critical steps. First, a 1.5 mm thick FR4 epoxy laminate substrate with a relative permittivity of $\varepsilon r = 4.3$ was selected as the base material. Structural modifications were then implemented to enhance performance, including the incorporation of bent corners to reduce unwanted radiation at the output terminals and dimensional adjustments to the stubs [22] to optimize impedance matching and improve reflection characteristics. Additionally, a lumped element resistor was strategically placed at the output port to ensure balanced power distribution across ports while accounting for practical insertion loss and maintaining a reflection coefficient below -10 dB.

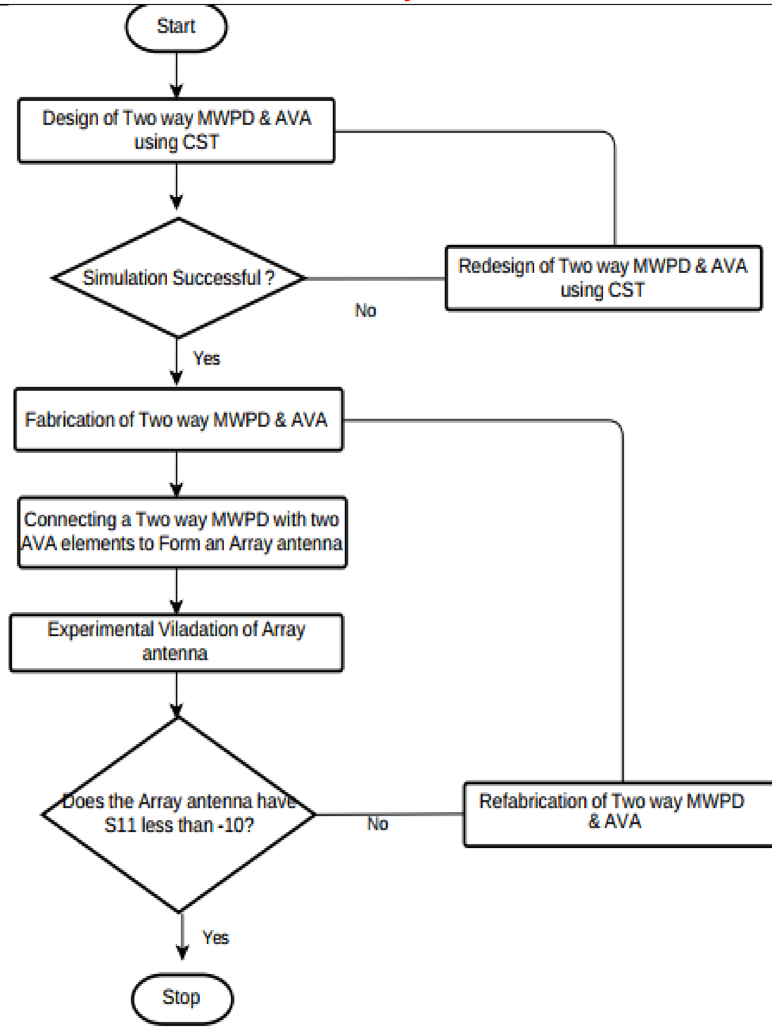

Figure 1. Flow diagram of the development of MWPD Feeding Network with the UWB AVA Array

To achieve optimal impedance matching and isolation performance, each port was carefully designed to maintain reasonable impedance values, ensuring acceptable isolation performance over the 3 GHz to 10 GHz frequency range. The key dimensions, outlined in Table 1, were optimized to strike an effective balance between power distribution, insertion loss, and radiation performance. Figure 2 presents the two-way modified Wilkinson power divider (MWPD) with optimized dimensions in millimeters. Each parameter corresponds to a specific electrical characteristic of the MWPD, carefully adjusted to ensure optimal power distribution, impedance matching, and isolation performance. The total length of the MWPD structure is represented by V (50 mm), while V1 (3.10 mm), V2 (5.80 mm), V3 (7.80 mm), V4 (23.06 mm), and V5 (3.10 mm) define specific segment lengths, likely associated with transmission line sections, stub lengths, or spacing between components to enhance performance. The overall width of the MWPD layout is denoted as S (34.80 mm), whereas S1 (3.41 mm), S2 (5.70 mm), S3 (2.0 mm), S4 (18.50 mm), and S5 (17.70 mm) correspond to the width of different sections, impacting impedance matching, isolation, and signal propagation characteristics. Each of these parameters was fine-tuned through optimization techniques to ensure the MWPD meets the required performance standards, including low insertion loss, effective power distribution, and minimized radiation loss.

Table 1. Optimized dimensions of two-way (MWPD)

Parameters	Value (mm)	Parameters	Value (mm)

V	50	S	34.80
V_1	3.10	S_1	3.41
V_2	5.80	S_2	5.70
V_3	7.80	S_3	2.0
V_4	23.06	S_4	18.50
V_5	3.10	S_5	17.70

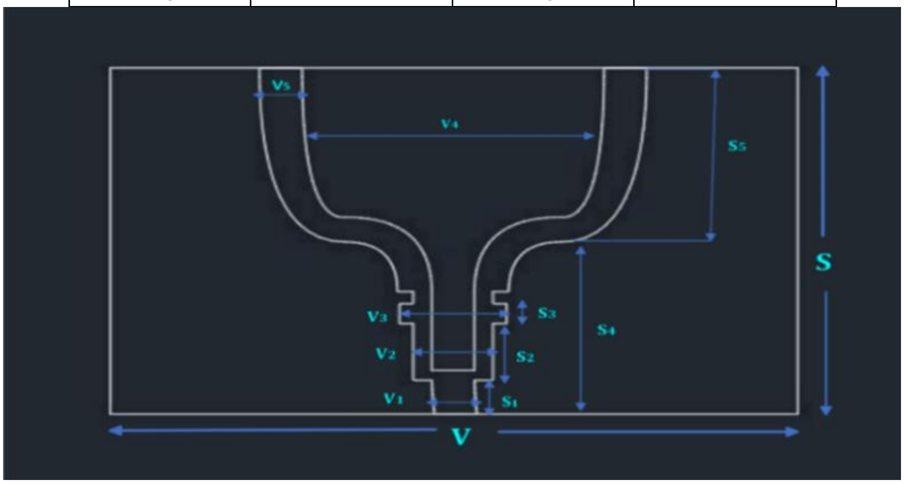

Figure 2. Schematic diagram of two-way (MWPD) using AUTOCAD

The input terminal, designated as Port 1, serves as the entry point for the signal into the modified Wilkinson power divider (MWPD). The divided signals are transmitted through the two output terminals, Port 2 and Port 3**.** The impedance of all ports is maintained at approximately 50 Ω to ensure optimal impedance matching, minimizing signal reflections and maximizing power transfer efficiency. The proposed structural layout of the modified power divider has been designed and optimized using CST MWS® software, as illustrated in Figure 3**.**

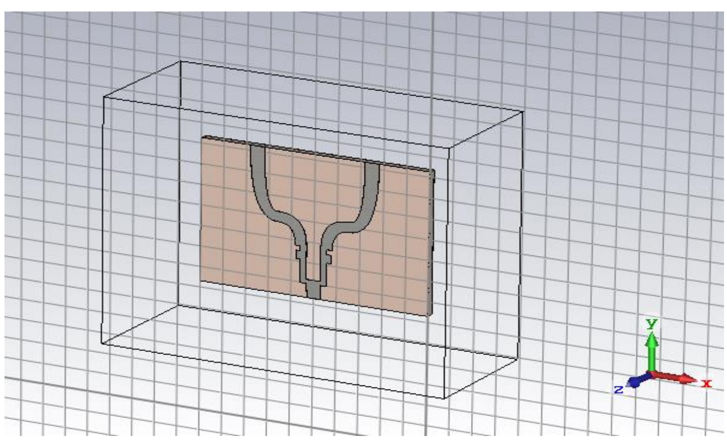

Figure 3. Two-way (MWPD) design using CST

UWB Modified Antipodal Vivaldi Antenna (MAVA) Design for Array Configuration:

The UWB MAVA Design is developed for array configurations to achieve enhanced broadband performance, directional radiation characteristics, and improved impedance matching. The design and optimization of MAVA follow a systematic approach, beginning with substrate selection. FR-4, a cost-effective glass-reinforced epoxy laminate, is chosen due to its favorable material properties, including a dielectric constant (εr) of 4.3, a dielectric loss tangent (δ) of 0.02, and a thickness of 1.5 mm. The antenna geometry is structured using two identical elliptical curves [23][24], which contribute to smooth impedance transitions between the feed line and radiation flares, thereby reducing reflection losses. With an aperture width of 60 mm, the compact design optimizes gain, bandwidth, and directional radiation properties. A crucial aspect of MAVA's performance is its slot design for radiation pattern control. Each antenna arm incorporates 17 rectangular slots with a fixed width of 1 mm and varying lengths, allowing precise tuning of both the radiation pattern and impedance characteristics.

For excitation and impedance matching, the antenna is energized via a 50-Ω microstrip feed line with a width of Wc = 4.85 mm. The elliptical design further aids in achieving optimal impedance matching across the ultra-wideband spectrum. To ensure optimal performance, the MAVA design undergoes simulation and refinement using CST Microwave Studio (CST MWS). Various parameters, including slot dimensions, elliptical curve configurations, and the feed structure, are iteratively adjusted to enhance gain and bandwidth. Figures 8 and 9 illustrate the geometric layout and CST simulation model of MAVA, respectively, while Table 2 provides the optimized dimensions. This comprehensive design and optimization approach ensures that MAVA is well-suited for array configurations, offering superior radiation efficiency and wideband characteristics.

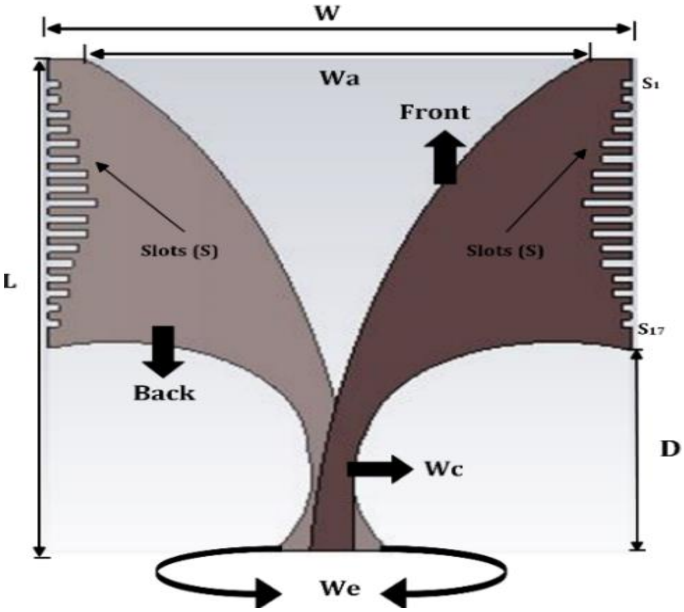

Figure 8. Geometry of the MAVA

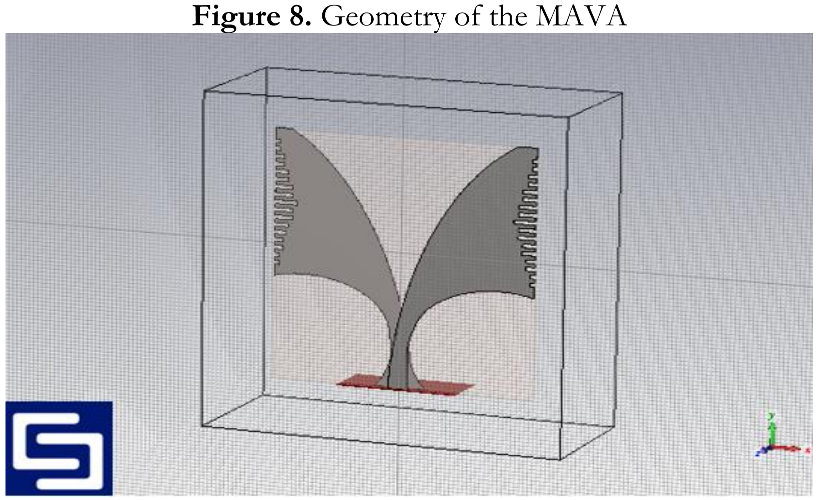

Figure 9. CST layout of MAVA

Table 2: Optimized dimensions of MAVA

Parameters	Values (mm)
W	60
L	65.50
D	27

Wa	55
Wc	4.58
We	11.80

Results & Discussion:

Simulation Result of Two-Way UWB MWPD:

As shown in Figure 4, all output ports exhibit acceptable reflection levels, with values better than -10 dB across the 3 to 10 GHz frequency range, while maintaining a suitable input impedance matching of 50 Ω. The designed two-way (MWPD) bandwidth is increased from 3 GHz to 10 GHz, reaching the ultra-wideband range.

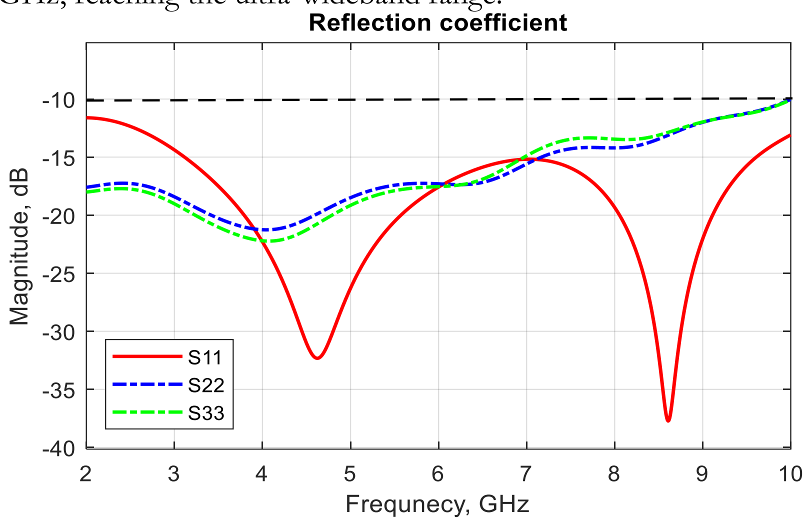

Figure 4. Reflection coefficient (S_{11}, S_{22}, S_{33}) of two-way (MWPD)

Figure 5 demonstrates the uniform distribution of input power across all output ports, validating the system's efficient performance with minimal insertion loss [25]. The simulated insertion loss (S_{21}, S_{31}) ranges from -0.4 dB to -0.6 dB across the entire operating frequency range, ensuring effective power transmission. The spacing between the output ports may contribute to the observed maximum insertion loss, potentially affecting signal coupling and distribution.

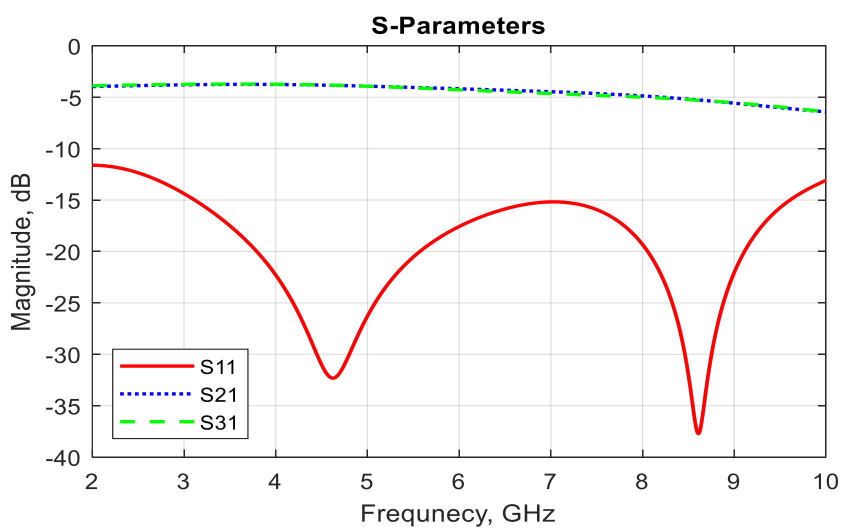

Figure 5. Insertion loss (S21, S31) of two-way (MWPD)

All the output ports of two-way (MWPD) received equal power from the input port. Additionally, inter-port isolation levels remained above -10 dB across the frequency range, except between 8 GHz and 8.5 GHz, where isolation dropped below -10 dB. The two-way

(MWPD) offers good performance in the frequency range of 3 GHz – 10 GHz due to its isolation result, as shown in Figure 6.

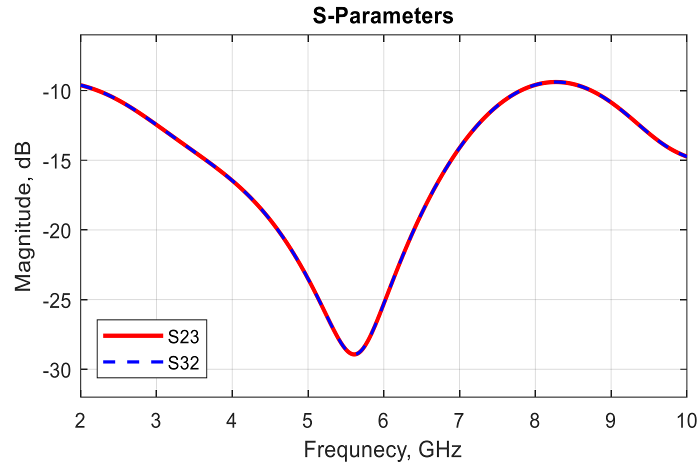

Figure 6. Isolation (S_{23}, S_{32}) of two-way (MWPD)

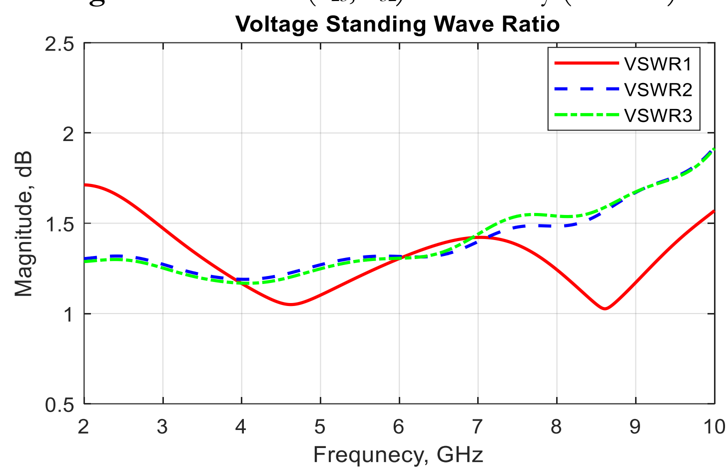

Figure 7. VSWR of two-way (MWPD)

As shown in Figure 7, the VSWR of the two-way MWPD in this design remains below 2 across the entire frequency range of 3–10 GHz. Since the simulation results align well with the standard requirements, the designed two-way UWB MWPD proves to be an efficient power divider for an antenna array feed network.

Simulation result of UWB MAVA:

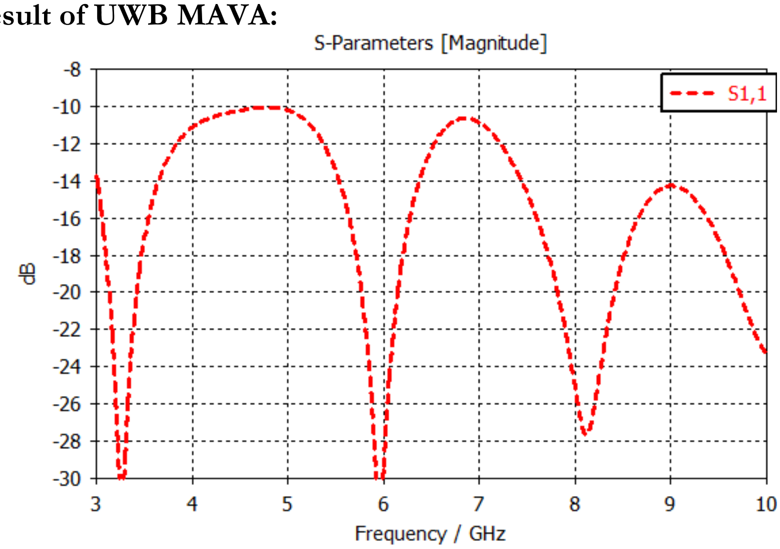

Figure 10. Simulated S11 of MAVA

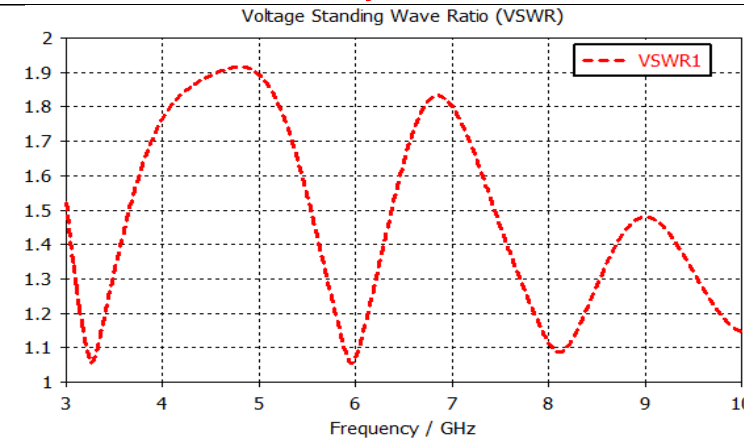

Figure 11. Simulated VSWR of MAVA

The simulated reflection coefficient (S11) of the proposed antenna, designed for operation within the UWB frequency spectrum, was analyzed to evaluate its impedance-matching performance. The acceptable threshold for S11 was set at -10 dB, ensuring minimal reflected power, efficient energy transfer, and reduced signal loss. As depicted in Figure 10**,** the simulated reflection coefficient consistently remained below -10 dB across the entire UWB band, demonstrating effective impedance matching. The results indicated that the antenna maintains stable impedance characteristics, which is critical for enhancing signal integrity and overall communication reliability over a broad frequency range.

Figure 11 presents the simulated Voltage Standing Wave Ratio (VSWR), a key parameter for assessing impedance matching efficiency. A lower VSWR value signifies improved impedance matching, with the acceptable limit defined as 2. The simulation results confirm that the VSWR remains consistently below this threshold, further validating the antenna's capability to achieve effective impedance matching throughout the UWB spectrum. This ensures minimal power loss and optimal energy transmission, reinforcing the antenna's suitability for wideband applications.

Experimental Results of Array Antenna:

The fabricated two-element UWB MAVA array, integrated with a two-way MWPD, is designed to achieve efficient power distribution and impedance matching. The implementation of the array configuration is shown in Figure 12, highlighting the physical realization of the proposed design. The measured reflection coefficient (S11), presented in Figure 13, confirms that the array meets the required performance criteria. The results indicated that S11 remains below -10 dB across the operational bandwidth, which is essential for maintaining effective impedance matching and minimizing power reflection. This ensures that the antenna array efficiently channels power to the radiating elements, enhancing overall performance.

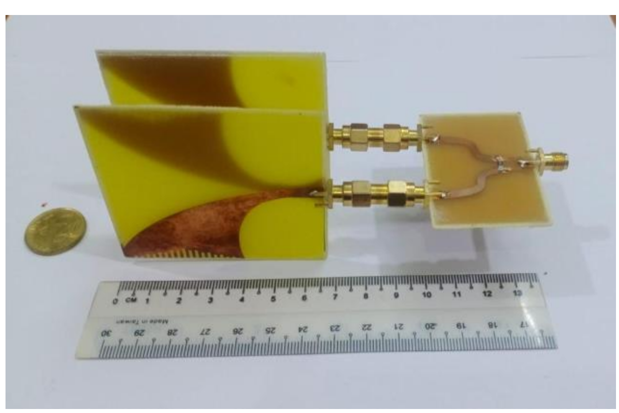

Figure 12. Fabricated model of two-element MAVA array system

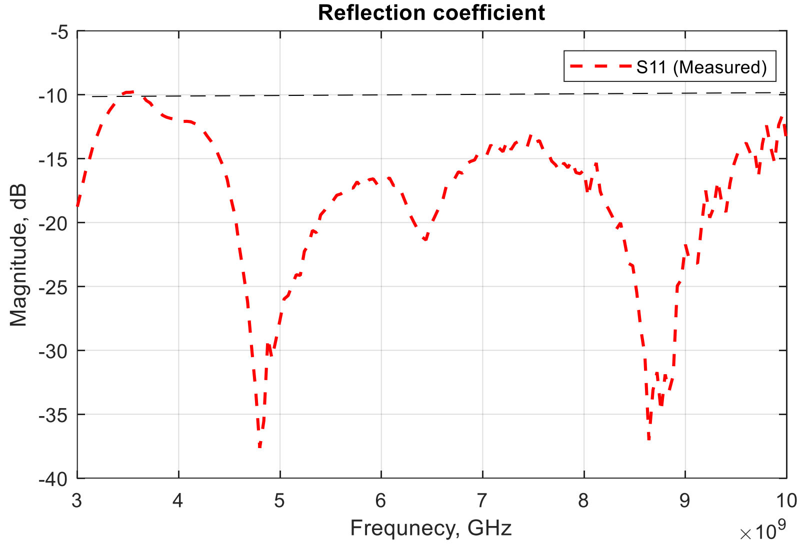

Figure 13. Reflection coefficient S_{11} of two-element MAVA array system

Table 3. Comparison of Antipodal Vivaldi Antenna designs fed through a Wilkinson power divider based on array antenna size, Frequency, and number of antennae elements

Array Antenna	Size (mm)	Frequency (GHz)	No. of an antenna element
[19]	149 x 60	3-11	2
[20]	186 x 100	2-6	4
[21]	203 x 187	1-4	4
This work	135 x 50	3-10	2

Table 3 compares different Antipodal Vivaldi Antenna designs fed through a Wilkinson power divider in terms of size, operating frequency range, and the number of antenna elements. Among the referenced designs, [19] uses two antenna elements but has a significantly larger size, while [20] and [21] employ four elements, resulting in even larger overall dimensions. This indicates that while increasing the number of antenna elements can improve performance, it also leads to a bulkier design, which may not be suitable for space-constrained applications.

The proposed Array design offers a more compact form factor, measuring 135 × 50 mm, making it the smallest among the listed designs. This reduced size enhances its applicability for modern UWB systems, where minimizing antenna dimensions is critical. In terms of frequency coverage, the proposed antenna operates between 3 GHz and 10 GHz. Compared to [19], which covers 3–11 GHz, the proposed design has a slightly narrower range but still ensures efficient UWB performance. In contrast, antennas [20] and [21] operate at lower frequencies, ranging from 2–6 GHz and 1–4 GHz, respectively, making them suitable for applications that require lower frequency operation but limiting their broadband capabilities. Regarding the number of antenna elements, both the proposed design and [19] utilize two-element arrays, making them more compact while still supporting array configurations for beamforming and directional radiation. On the other hand, [20] and [21] incorporate four-element arrays, which may enhance the cost of increased size and complexity. Overall, the proposed array design effectively balances compactness and broad frequency coverage while maintaining a simplified two-element configuration. Compared to the referenced designs. This makes it particularly well-suited for UWB imaging applications, where both size and bandwidth are crucial factors in achieving optimal system performance.

Conclusion: This paper presents the design of a two-element MAVA array with a two-way MWPD feed, operating within the 3–10 GHz UWB frequency range. Fabricated on an FR4 substrate, the proposed array antenna features a compact 135 × 50 mm² form factor while ensuring optimal performance. Measured results confirm that the reflection coefficient (S11) remains below -10 dB across the entire UWB band, demonstrating excellent impedance matching. The proposed array antenna proves to be a strong candidate for UWB imaging applications, offering reliability and efficiency in high-resolution imaging systems.

Acknowledgement:

The author sincerely expresses gratitude to the Microelectronic Fabrication LAB at University Tun Hussein Onn Malaysia for providing the necessary fabrication facilities. Special thanks are also extended to the Advanced Telecommunication Research Center (ATRC), University Tun Hussein Onn Malaysia, for offering the experimental measurement facilities.

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