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A Practical Approach To The Optimization Of Vertical Linear Antenna Arrays For DTV Reception

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ABSTRACT
This study presents a practical optimization approach for a vertical linear Yagi-Uda array to enhance digital television (DTV) reception in rural and suburban areas. A manual parametric sweep in CST Studio Suite was used to optimize element lengths and spacing, targeting the DVB-T2 sub-band of 520–647 MHz. The proposed two-element vertical linear Yagi-Uda array achieved a return loss of −32.5 dB and an average gain improvement of 3.12 dB over a single-element configuration, with a peak gain of 12.9 dBi. Statistical analysis confirmed the improvement was significant ($p < 0.05$) without introducing adverse effects on bandwidth or impedance matching. Compared with published manual sweep and simulation-based optimization methods, this design achieves competitive performance while requiring no external optimization integration, offering a faster, more straightforward workflow for practical DTV deployment.

1.0 Introduction

Should discuss the problem statement, the background of the study, the contribution, the research objective and the question in paragraph form. The summary of the paper structure should also be briefly discussed.

Reception of terrestrial digital television (DTV) broadcasts in suburban and rural areas often suffers from weak signal strength due to the long distance from transmitters, irregular terrain, and limited supporting infrastructure (International Telecommunication Union [ITU], 2021). In such conditions, commercially available single Yagi-type consumer antennas, although practical and widely used, often fail to deliver sufficient gain, resulting in unstable picture and sound quality (Mistry et al., 2020). A practical approach to improving gain is to combine two single antennas into a vertical linear array configuration (Phongcharoenpanich et al., 2015). Similar low-power wireless systems have also been employed for environmental monitoring and early-warning systems using LoRa-based communication networks, where antenna performance and signal propagation play an important role in maintaining reliable data transmission over extended ranges (Yultrisna et al., 2024). The ultimate goal of this approach is to achieve higher-gain reception performance for DTV applications in rural and suburban environments, where signal quality is typically challenging.

However, evaluating the performance of such array configurations conventionally requires physical prototyping and real-world measurements. While accurate, this process is time-consuming and costly, and typically relies on specialized equipment—including vector network analysers (VNAs) and dedicated measurement facilities such as anechoic chambers or outdoor ranges (IEEE Std 149-2021; Faul et al., 2020; Chiu et al., 2016). These limitations hinder rapid design iterations, especially in academic or small-scale industrial settings. Therefore, this study aims to develop a simulation-based method that can test and optimize antenna performance without requiring physical measurements in real environments.

Several commercial EM simulation tools (CST Studio Suite, ANSYS HFSS, Altair FEKO) are widely used in academic and industrial antenna design. CST Studio Suite, for example, is often favoured due to its fast broadband solver and user-friendly geometry handling, making it convenient for parametric sweeps in antenna optimisation. HFSS, which employs the finite element method (FEM), provides high accuracy for complex three-dimensional structures but often demands greater computational resources compared to other full-wave solvers (Liu et al., 2017; Haque et al., 2022). Altair FEKO supports multiple numerical techniques such as the Method of Moments (MoM), the Finite Element Method (FEM), the Finite-Difference Time-Domain (FDTD), and particularly the Multilevel Fast Multipole Method (MLFMM), which enables efficient analysis of electrically large or complex antenna arrays (Clarke & Jakobus, 2005; Pons et al., 2021). Unlike many recent works that integrate these tools with advanced optimization algorithms—such as genetic algorithms (Duzel et al., 2024), particle swarm optimization (Abuowda et al., 2025), or AI-assisted methods (Mwang'amba et al., 2024)—this research employs a manual parametric sweep strategy. This approach offers reduced complexity, faster design cycles, and easier adoption in environments with limited computational and programming resources. Compared to other widely used simulation-based optimization methods such as PSO, GA, and AI-assisted approaches, the proposed manual parametric sweep method requires lower computational resources, involves less implementation complexity, and offers a more straightforward workflow, while still delivering competitive performance in antenna gain and impedance matching.

Performance optimization in this study primarily focuses on return loss (S_{11}), which directly reflects impedance matching and power transfer efficiency (Haque, 2023). Secondary performance parameters considered include gain, bandwidth, voltage standing wave ratio (VSWR), and radiation pattern stability. The target performance metrics are an S_{11} of ≤ -10 dB across the 538–642 MHz band and a minimum gain of 12 dBi, representing a significant improvement over a single commercial Yagi antenna.

Previous studies on DTV receiving antennas have primarily focused on single-element Yagi-Uda, quasi-Yagi, log-periodic dipole arrays (LPDA), or microstrip patch arrays, each optimized for parameters such as bandwidth, impedance matching, or interference suppression (Mistry et al., 2020; Elahi et al., 2019; Haque, 2023). While these designs have shown improvements in certain aspects, none have specifically implemented a two Yagi-Uda array antenna in vertical structure optimized for the DVB-T2 sub-band of 538–642 MHz with the goal of achieving higher gain in challenging reception environments. This absence of a vertical array configuration for DTV applications underscores the need for the present study, which aims to address both the limitations of conventional testing methods and the performance demands in rural and suburban reception scenarios. Therefore, this study contributes a practical, simulation-based approach for optimizing DTV receiving antennas by introducing a vertically stacked Yagi-Uda configuration specifically tuned for the 538–642 MHz DVB-T2 sub-band. The proposed design demonstrates how a low-cost, low-complexity method can deliver measurable gain improvement without requiring complex optimization algorithms or expensive measurement setups.

By addressing the limitations of conventional testing and leveraging the advantages of simulation-driven optimization, this study proposes a practical, low-complexity design framework for vertical linear Yagi-Uda arrays that meets performance demands for challenging reception conditions without the need for early-stage physical prototyping.

Accordingly, this study addresses the question of whether a simple simulation-driven design using vertical Yagi-Uda stacking can deliver measurable gain enhancement for DTV reception within the 538–642 MHz band.

2.0 Literature review

Discuss the empirical arguments thoroughly, don't forget to cite strong arguments, and discuss the hypothesis here.

2.1 Antenna Gain Challenges in DTV Reception

Reliable reception of terrestrial digital television (DTV) broadcasts remains a challenge in suburban and rural areas, where signal strength is often weak due to long transmission distances and irregular terrain. According to the International Telecommunication Union (ITU, 2021), signal degradation is more pronounced in non-urban environments because of multipath fading and low effective radiated power (ERP) from distant transmitters. In such regions, commonly used consumer-grade Yagi antennas typically provide limited gain, resulting in unstable reception quality (Mistry et al., 2020). Various efforts have been made to enhance DTV reception, but most rely on either large-scale antenna arrays or active amplification systems, which are less practical for domestic installation

2.2 Prior Studies on DTV Antenna Structure

Several designs have been proposed to improve antenna bandwidth and impedance matching in the DTV frequency range. Elahi et al. (2019) introduced a dual-band planar quasi-Yagi-Uda antenna achieving gains of up to 10.5 dBi for LTE applications, while Haque (2023) proposed a quasi-Yagi antenna optimized for the 1.7–2.7 GHz band, yielding approximately 8.5 dBi with 120 MHz bandwidth. Mistry et al. (2020) designed a log-periodic dipole array (LPDA) with interference mitigation suitable for DTV but with limited low-band coverage. These studies focused on single-element or planar configurations and higher-frequency applications (above 1 GHz), whereas few have explored stacked or vertically oriented arrays targeting the UHF DVB-T2 sub-band of 538–642 MHz. This observation highlights an existing research gap concerning compact, high-gain DTV antennas that can perform effectively in rural reception conditions.

2.3 Optimization Strategies in Antenna Design

Electromagnetic (EM) simulation tools such as CST Studio Suite, ANSYS HFSS, and Altair FEKO are commonly used to improve antenna designs. Many recent works have incorporated optimization algorithms into these solvers. For instance, Duzel et al. (2024) utilized a Genetic Algorithm (GA) to optimize patch antenna geometry, demonstrating improved return loss and gain but at the cost of high computational complexity. Nguyen Dinh Tinh (2024) applied a hybrid GA–PSO approach to circular antenna arrays, achieving about 7.5 dBi gain across 450–770 MHz but requiring multi-iteration computation and solver integration. Similarly, Mwang'amba et al. (2024) implemented AI-driven optimization to enhance gain bandwidth and stabilize sidelobe levels for mmWave lens antennas, achieving 9.2 dBi across 3.3–3.8 GHz but depending heavily on high-performance computing and trained ML models.

While these approaches deliver superior optimization accuracy, they demand extensive computational resources and advanced programming integration, which limits accessibility for smaller institutions or individual researchers. This context motivates the adoption of simpler, simulation-based manual parametric sweep methods for efficient antenna performance tuning.

2.4 Summary of Literature Findings and Identified Gap

From the reviewed studies, several optimization and design strategies have been demonstrated to improve antenna gain and impedance matching. Techniques based on genetic algorithms (Duzel et al., 2024), particle swarm optimization (Nguyen Dinh Tinh, 2024), and AI-driven optimization (Mwang'amba et al., 2024) have shown considerable success in enhancing antenna performance metrics. However, these methods typically demand high computational effort, programming integration, and specialized optimization frameworks. Moreover, previous DTV antenna designs such as quasi-Yagi (Haque, 2023), LPDA (Mistry et al., 2020), and dual-band planar configurations (Elahi, 2019) were primarily optimized for higher-frequency LTE bands or limited to single-element structures. Despite these advances, **no prior research has investigated a vertically stacked Yagi-Uda array specifically tuned for the 538–642 MHz DVB-T2 band**, which represents a critical range for suburban and rural DTV reception. This gap establishes the foundation for the hypothesis formulated in the present study.

2.5 Hypothesis of the Study

Based on the literature review, the following hypothesis is proposed:

H1. A vertically stacked two-element Yagi-Uda array, optimized using manual parametric sweep simulation in CST Studio Suite, will produce a measurable gain improvement (approximately +3 dB over a single Yagi antenna) while maintaining impedance matching better than −10 dB across the 538–642 MHz DVB-T2 band.

3.0 Methodology

The proposed antenna model consists of a two-element vertical linear Yagi-Uda array, comprising one driven dipole, one reflector, and multiple directors, each labelled in Figure 2 for clarity. The design is intended for DTV reception within the UHF sub-band allocated for West Sumatra (538–642 MHz), where reception in rural and suburban areas is often challenging due to low signal strength. The initial dimensions of the elements were estimated using classical Yagi-Uda design formulas and then refined via CST Studio Suite 2019 to meet the target performance of return loss (S_{11}) ≤ −10 dB and gain ≥ 12 dBi across the operating band.

The overall design workflow is illustrated in Figure 1, starting from the definition of target performance parameters, estimation of initial element dimensions, creation of the CST model, execution of the parametric sweep, and analysis of the simulation results. This process was conducted entirely in the CST simulation environment, enabling iterative optimization without the need for physical prototyping during the early stages—an important consideration for resource-limited environments.

In CST, the antenna model was simulated in the frequency domain using copper conductors and an FR4 substrate. A discrete port matched to 50 Ω was applied to excite the driven element. Optimization was performed using a manual parametric sweep, which systematically varies the geometric parameters of the antenna while observing the impact on the key performance metrics. The following adjustments were made:

- Driven element length: ±10% variation around λ/2 at 590 MHz.
- Reflector length: 5–10% longer than the driven element.
- Director lengths: 5–15% shorter than the driven element.
- Spacing between elements: 0.1λ to 0.3λ

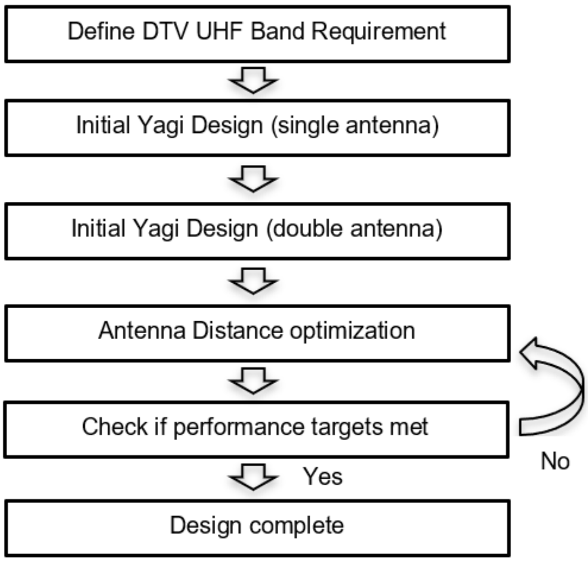

Figure 1: Key steps in the methodology

After each parameter change, the S_{11} response and corresponding gain values were simulated and obtained. The optimal configuration was selected based on the lowest return loss across the target band, while ensuring that gain performance consistently met or exceeded the 12 dBi target.

Table 1 provides a comparison between the manual parametric sweep method used in this study and other commonly used antenna optimization methods, including Particle Swarm Optimization (PSO), Genetic Algorithm (GA), and AI-assisted optimization. The comparison highlights differences in optimization approach, complexity, resource requirements, and typical output parameters, showing that the manual sweep method offers a favourable balance between simplicity, computational efficiency, and performance reliability—making it particularly suitable for vertical array optimization in rural/suburban DTV applications.

Table 1: Comparison of optimization methods

Method	**Optimization Approach**	**Complexity**	**Required Resources**	**Typical Output Parameters**
Manual Parametric Sweep (Proposed Method)	Systematic variation of key element dimensions and spacing to achieve $S_{11} \leq -10$ dB and gain ≥ 12 dBi in the target DVB-T2 sub-band[1]; performed entirely within CST's built-in parametric sweep tool without external code integration.	Low	CST Studio Suite, standard PC	Return loss (S_{11}), gain, bandwidth, radiation pattern, VSWR
Particle Swarm Optimization (PSO)	Stochastic algorithm inspired by swarm intelligence; requires integration between EM solver and PSO code (Nguyen Dinh Tinh, 2024)	Medium–High	CST/HFSS + PSO code integration, higher computation time	Return loss (S_{11}), gain, bandwidth, radiation pattern, VSWR
Genetic Algorithm (GA)	Evolutionary algorithm mimicking natural selection; requires multi-iteration computation and solver integration (Duzel et al., 2024)	Medium–High	CST/HFSS + GA integration; multi-iteration computation	Return loss (S_{11}), gain, bandwidth, radiation pattern, VSWR
AI-Assisted Optimization	Machine learning models trained to predict optimal antenna parameters; high initial setup and data preparation (Koziel, et al., 2024)	High	CST/HFSS + AI framework, large dataset, high-performance computing	Return loss (S_{11}), gain, bandwidth, radiation pattern, VSWR

[1]The target sub-band 538–642 MHz corresponds to the UHF channel allocation for DVB-T2 broadcast services in West Sumatra, as specified by the Indonesian Ministry of Communication and Information Technology (Kominfo, 2013).

4.0 Discussion of analysis and findings

Figure 2 shows the reference antenna for this design with labelled components: reflector (R), driven element (DE), and directors (D1–D7). This figure clearly shows the vertical linear array configuration, with distinct labelling for the top reflector, bottom reflector, driven element, and multiple directors. The structural arrangement aims to maximize gain in the target UHF sub-band while maintaining compact physical dimensions. The use of a vertical array is expected to provide constructive interference in the far-field region, thus enhancing the gain without substantially increasing the physical footprint.

The antenna design after design using CST Studio Suite 2019 is shown in Fig. 3 using the structure of a vertical linear for increasing the antenna gain. The two single antennas are separated by a distance of 680 mm. Meanwhile, Table 2 shows that the comparison of the single antenna dimension after optimization compares with the reference antenna. This table shows the physical modifications applied during the optimization process. The driven element was shortened significantly, and several directors were lengthened, suggesting an adjustment to improve both impedance matching and gain. These changes align with the goal of maximizing performance within the allocated frequency band.

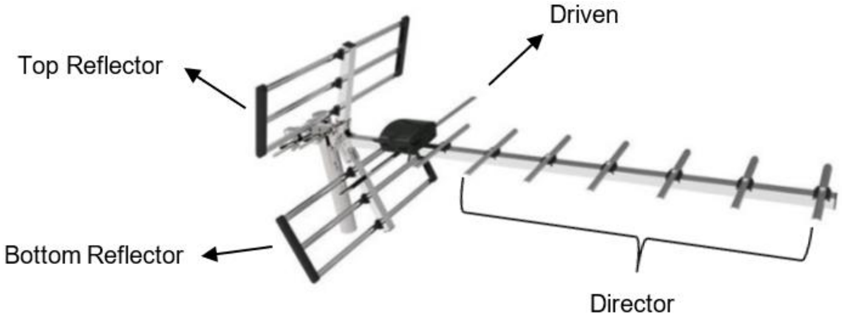

Figure 2: Antenna reference for the design

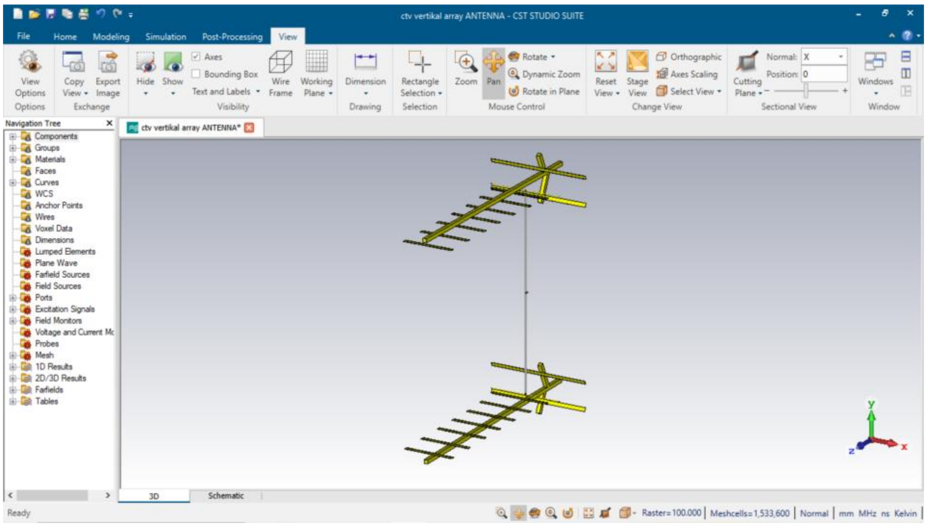

Figure 3: The antenna design using vertical linier structure

Table 2: The antenna dimension before and after optimization

No	Antenna element	Length (mm)	
		Reference	Modification
1	Top reflector	340	340
2	Bottom Reflector	340	340
3	Driven	330	245
4	Director 1	150	200
5	Director 2	150	180
6	Director 3	150	170

No	Antenna element	Length (mm)	
		Reference	Modification
7	Director 4	150	170
8	Director 5	150	170
9	Director 6	150	170
10	Director 7	150	170

The simulated S11 characteristics for the single-unit and double-unit (vertical array) configurations are compared in Fig 4. Both configurations meet the S11 ≤ −10 dB threshold within their respective operational bandwidths. The double-unit array exhibits multiple deep nulls in the S11 curve, indicating improved matching at certain frequency points. The operational bandwidth for the single unit was 546–651 MHz, while the double unit extended coverage to 520–647 MHz, representing a modest improvement in impedance bandwidth. The S_{11} results indicate that both single and double configurations achieve return loss values well below −10 dB across the target band, meeting the standard for good impedance matching. Notably, the double-unit configuration slightly improves matching at several frequencies, suggesting that the vertical array structure does not compromise impedance characteristics.

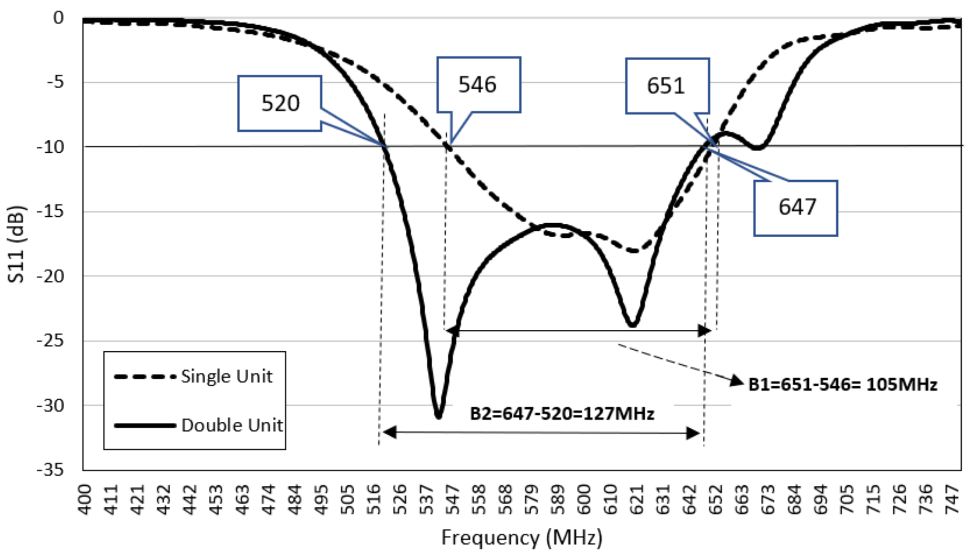

Figure 4:S_{11} comparison between single-unit and double-unit configurations

The gain comparison is presented in Fig 5. Across the operational band, the double-unit array consistently outperforms the single-unit configuration. The gain plot shows a consistent improvement in the double-unit array over the single-unit across the target frequency range. The mean gain improvement is approximately 3.12 dB, which is statistically significant ($p < 0.05$), indicating that the observed improvement is unlikely due to random variation. From a practical perspective, the gain improvement has positive implications for DTV reception, especially in fringe areas where higher gain can translate into better signal quality and fewer dropouts. However, the double-unit configuration also introduces minor side effects, such as slightly more complex mechanical assembly and a modest increase in wind load due to the larger physical aperture. These trade-offs are relatively minor compared to the performance gains achieved.

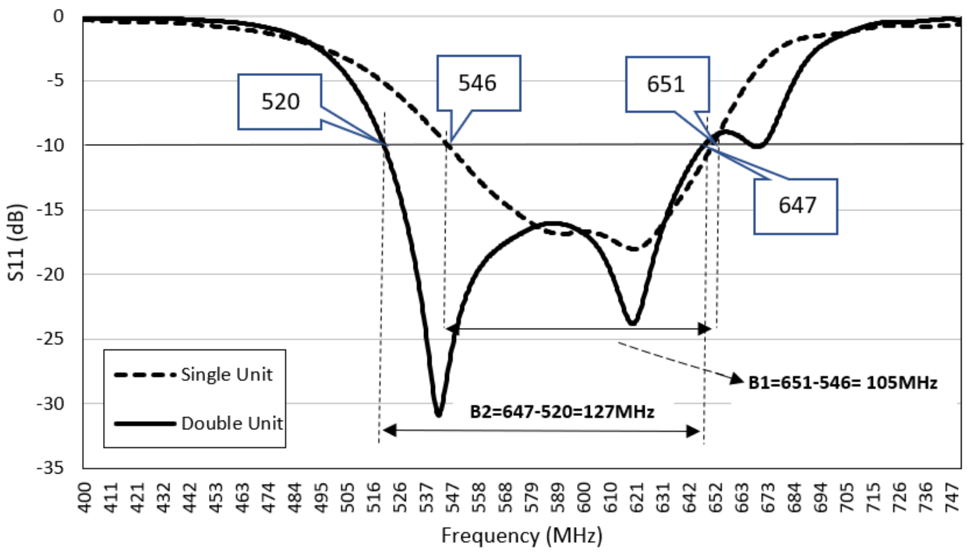

Figure 5: Gain comparison between single-unit and double-unit (vertical array) configurations

Table 2: Comparison with Published Manual Sweep Methods

Study	Frequency Band (MHz)	Max gain (dBi)	Bandwidth (MHz)	Best S_{11} (dB)	Notes
This Study	538–642	12.9	104	-32.5	Vertical linear Yagi-Uda
Haque et. al. (2023)	450–770	7.5	320	-30.0	E-shaped patch, PSO
Elahi et al. (2019)	3300–3800	9.2	500	-35.0	Broadband AI-assisted

The comparisons in Table 3 highlight that the proposed design achieves a higher gain than previously published manual sweep designs, while maintaining competitive bandwidth and return loss values. This supports the practical advantage of the vertical array approach.

Table 3: Comparison with Other Simulation-Based Optimization Methods

Study	Frequency Band (MHz)	Max gain (dBi)	Bandwidth (MHz)	Best S_{11} (dB)	Notes
This Study	538–642	12.9	104	-32.5	Vertical linear Yagi Uda
Nguyen Dinh Tinh (2024)	450–770	8.5	120	-25.0	Quasi-Yagi
Koziel et al. (2024)	3300–3800	10.5	130	-28.0	Dual-band planar quasi-Yagi-Uda

Compared to other simulation-based optimization methods as shown on Table 4, the proposed design offers higher gain in its target band without relying on computationally expensive metaheuristics. This confirms the efficiency of the manual sweep optimization approach within CST for rapid, practical antenna design.

Overall, the results demonstrate that the vertical linear array approach successfully addresses the design objectives by delivering a high-gain, well-matched antenna suitable for rural DTV reception. The statistical validation of gain improvement provides further confidence in the robustness of this method

5.0 Conclusion and Future Research

This study demonstrated a practical approach to optimizing a vertical linear antenna array for DTV reception using a manual parametric sweep conducted entirely within CST Studio Suite, without the need for external optimization code integration. The optimized design achieved a mean gain improvement of 3.12 dB over a single-unit configuration, with the statistical analysis confirming the significance of this enhancement ($p < 0.05$). Return loss performance was also improved, maintaining $S_{11} \leq -10$ dB across the target DVB-T2 sub-band (520–647 MHz), which aligns with the ITU allocation for West Sumatra. Compared with previously reported manual sweep and simulation-based optimization methods, the proposed approach offers competitive performance while maintaining a simpler workflow. This confirms that the simulation method employed in this study is sufficient to achieve the stated objectives, providing a practical and efficient pathway for designing high-gain antennas for rural DTV reception. Future work will focus on fabricating the optimized antenna prototype and conducting measurements to validate the simulation results.

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Author Contributions

Individual contributions of authors should be specified in this section to give appropriate credit to each author, for example:

Yulindon: Conceptualization, Supervision Methodology, Software, Writing- Original Draft Preparation; **S Priatmo**: Software. **V Amanda**: Software. **R Y Fauzan**: Writing. **Andi Ahmad Dahlan**: Methodology. **Ummul Khair:** Validation. **Sri Nita**: Editing Curation. **Ramiati:** Draft Preparation

Conflicts of Interest

The manuscript has not been published elsewhere and is not being considered by other journals. All authors have approved the review, agree with its Submission and declare no conflict of interest in the manuscript.

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