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# Desain Antena MIMO Dengan Defected Ground Structure Dan Stub Slot Pada Aplikasi 5G

# MIMO Antenna Design with Defected Ground Structure and Stub Slot for 5G Application

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**Abstrak**

**Teknologi 5G dikembangkan untuk menjawab tantangan serta memenuhi kebutuhan akan peningkatan efisiensi dan kapasitas jaringan, kecepatan data yang lebih tinggi, jangkauan yang lebih luas, dan konsumsi daya yang rendah. Oleh karena itu, diperlukan rancangan antena yang sesuai untuk komunikasi nirkabel 5G agar mampu menyediakan bandwidth yang lebar, pola radiasi yang optimal, efisiensi antena yang tinggi, serta kinerja keseluruhan yang baik. Sistem Multiple-Input Multiple-Output (MIMO), yang memanfaatkan beberapa antena pemancar dan penerima, memungkinkan pemanfaatan jalur multipath secara lebih efektif. Namun, penempatan elemen antena yang berdekatan dapat menyebabkan timbulnya mutual coupling. Maka dari itu, tantangan utama dalam merancang antena MIMO adalah meminimalkan efek mutual coupling tersebut. Dalam penelitian ini, dirancang antena MIMO menggunakan teknik Defected Ground Structure (DGS) dan stub slot. Teknik DGS diterapkan dengan memodifikasi bidang ground antena untuk meningkatkan kinerjanya. Untuk memperoleh bandwidth yang luas dan gain yang tinggi, konsep DGS dan stub slot diintegrasikan ke dalam desain antena. Antena ini memiliki dimensi 84 mm × 34 mm dan disimulasikan menggunakan perangkat lunak Ansys HFSS. Hasil pengujian menunjukkan bahwa antena dengan substrat FR4 Epoxy menghasilkan nilai mutual coupling sebesar –30,65 dB, return loss sebesar –14,15 dB, gain sebesar 5,23 dB, serta bandwidth yang cukup luas. Parameter-parameter tersebut memenuhi syarat performa antena untuk mendukung implementasi sistem komunikasi 5G, khususnya pada pita frekuensi menengah. Dengan demikian, antena ini dinilai mampu beroperasi pada frekuensi 3.5 GHz dan memenuhi kebutuhan sistem komunikasi 5G.**

**Kata kunci:** DGS, MIMO, Mutual Coupling, Stub Slot, 5G

**Abstract**

**5G technology has been developed to address challenges and meet the demands for improved network efficiency and capacity, higher data rates, wider coverage, and lower power consumption. Therefore, an appropriate antenna design is essential for 5G wireless communication, capable of providing wide bandwidth, optimal radiation patterns, high antenna efficiency, and overall strong performance. The Multiple-Input Multiple-Output (MIMO) system, which utilizes multiple transmitting and receiving antennas, allows for more effective exploitation of multipath propagation. However, closely spaced antenna elements can lead to mutual coupling. Thus, the main challenge in designing MIMO antennas is to minimize the effects of mutual coupling. In this study, a MIMO antenna was designed using the Defected Ground Structure (DGS) technique and stub slots. The DGS technique was applied by modifying the antenna's ground plane to enhance its performance. To achieve wide bandwidth and high gain, the DGS and stub slot concepts were integrated into the antenna design. The antenna has dimensions of 84 mm × 34 mm and was simulated using Ansys HFSS software. The testing results showed that the antenna with an FR4 Epoxy substrate achieved a mutual coupling value of –30.65 dB, a return loss of –14.15 dB, a gain of 5.23 dB, and a sufficiently wide bandwidth. These parameters meet the performance requirements of the antenna to support the**

**implementation of 5G communication systems, particularly in the mid-frequency band. Therefore, this antenna is considered capable of operating at a frequency of 3.5 GHz and meets the requirements of 5G communication systems.**

**Keywords:** DGS, MIMO, Mutual Coupling, Stub Slot, 5G

# I. INTRODUCTION

The rollout of 5G networks has been made possible by several key technologies, including millimeter-wave (mmWave), massive MIMO (multiple-input multiple-output), small cells, mobile edge computing, non-orthogonal multiple access (NOMA), and beamforming techniques [1] [2]. 5G is designed to support a wide range of applications, such as large-scale events with numerous users, vehicular and industrial automation, environmental and remote sensing, as well as smart infrastructure like cities, homes, grids, healthcare, transportation, and more. These networks will operate across low, mid, and high-frequency spectrums to meet diverse service demands. By incorporating multi-band support, antennas can accommodate various frequency ranges and adjust to different applications, thereby ensuring robust coverage and performance [3] [4]. To manage this wide variety of high-demand services and vast user base, multiband MIMO systems are expected to be implemented. Additionally, emerging technologies such as virtual reality, artificial intelligence, the Internet of Things (IoT), and 3D media are accelerating progress in communication systems, driving the need for even faster data transmission and paving the way for a transition from 5G to 6G [5].

Recent works showcase the efficacy of these methods. A 2-port MIMO antenna featuring an M-shaped DGS achieved strong isolation (≥20 dB) and broad resonances including 3.5 GHz [6]. Similarly, a dual-band design using DGS on FR-4 achieved –23 dB coupling at 3.4 GHz with stub-loaded elements [7]. In conjunction with DGS, stub-slot loading in the radiating patch has emerged as a powerful method to further augment bandwidth and gain while offering frequency tuning flexibility. Studies have shown that incorporating stub-loaded slot elements, particularly when used with DGS, yields superior performance in terms of bandwidth broadening and impedance matching for sub-6 GHz 5G MIMO antennas [8].

Design MIMO antenna at 3.5 GHz introduces challenges such as mutual coupling, limited bandwidth, and degradation of radiation characteristics. To overcome these, techniques like Defected Ground Structure (DGS) and slot/stub-based decoupling have gained attention. DGS disrupts surface currents by etching intentional patterns on the ground plane, thereby reducing coupling and enhancing isolation [9]. Complementarily, incorporating stub or slot elements enables improved bandwidth and resonance control [10]. Among these, the Defected Ground Structure (DGS) stands out as one of the most effective solutions. This approach involves modifying the ground plane of the antenna to improve its overall performance. The Defected Ground Structure (DGS) is widely recognized in current literature as a highly effective method for improving the performance of wideband and multiband MIMO antennas[11]. By introducing deliberate defects in the ground plane, the surface current distribution is altered, leading to changes in the equivalent impedance, which helps suppress cross-polarization effects [12].

A slot antenna is created by carving out a slot circular, rectangular, or of any specific shape on a conductive surface. When an alternating current is applied through the feed line connected to the patch, electromagnetic waves are excited within the slot [13]. The size and shape of the slot directly influence the antenna's operating frequency and radiation behavior. As described in [14], a penta-band MIMO antenna can be achieved by incorporating multiple slots into a square patch design. The difference in slot lengths for each port leads to the generation of two distinct resonant frequencies [15]. The synergy of these two techniques offers a compact design approach without compromising on key performance metrics.

Although various studies have successfully applied techniques such as Defected Ground Structure (DGS) and stub/slot loading in the design of 5G MIMO antennas, many existing works still face notable limitations. Several designs only support limited frequency bands, provide suboptimal isolation levels (typically less than –25 dB), or fail to deliver sufficient gain for demanding 5G applications [16]. Moreover, few prior works have effectively combined both DGS and stub-slot techniques in a compact, optimized structure specifically targeting the 3.5 GHz mid-band using a cost-effective FR4 substrate [17]. This study addresses these gaps by proposing a novel MIMO antenna design that integrates DGS and stub-slot loading into a unified configuration. As such, this design offers a compact, low-cost, and high-performance solution suitable for 5G communication systems operating in the mid-frequency band.

In this study, a MIMO antenna was developed using a combination of Defected Ground Structure (DGS) and stub slot techniques. These methods were chosen due to their simplicity in antenna design. Following a detailed design process, the antenna is rigorously simulated in Ansys HFSS, focusing on key performance indicators such as return loss, mutual coupling, gain and bandwidth. The resulting configuration delivers high gain and broad bandwidth across the operating frequencies. By integrating both DGS and stub slot concepts, the antenna achieves enhanced performance in terms of bandwidth and gain. The design outcomes indicate a significant reduction in mutual coupling, enabling the proposed antenna to effectively operate at 3.5 GHz, which is suitable for 5G applications. This study contributes to the development of compact and efficient antenna solutions for future wireless communication systems.

## II. ANTENNA DESIGN

### A. Identification of Antenna Design Specifications

The first step in designing an antenna involves identifying the target performance specifications, including the operating frequency, impedance bandwidth, return loss, mutual coupling, and gain. The initial step in antenna design is to establish clear performance targets that align with the intended application requirements. The target gain of approximately > 3 dBi was selected to ensure sufficient radiation strength for effective coverage in 5G communication systems operating at 3.5 GHz, consistent with recommendations found in recent literature [18].

A return loss target of better than –10 dB, was chosen to guarantee good impedance matching, which minimizes signal reflection and maximizes power transfer efficiency. These values correspond with established IEEE antenna design standards and common practices in wireless system design [19].

For mutual coupling, a target isolation level below –20 dB was set to ensure minimal interference between MIMO antenna elements, thus preserving channel independence and enhancing overall system performance. This threshold aligns with findings in prior research that demonstrate significant MIMO performance improvements when isolation is maintained below this level [20]. By grounding these performance targets in both standards and prior studies, the antenna design aims to deliver optimized functionality tailored for mid-band 5G applications.

The specific parameters aimed for in this design are summarized in Table I.

Table I. Antenna Parameters

| Parameter | Antenna Charateristic |
|---|---|
| Frequency | 3.5 GHz |
| Return Loss | < -10 dB |
| Mutual Coupling | < -20 dB |
| Gain | > 3 dB |

For this design, the substrate dimensions are specified in Table II:

Table II. Dimensions Of The Substrate

| Specification | Value |
|---|---|
| Type of Substrate | FR4 Epoxy |
| Dielectric Constant | 4.3 |
| Thickness (h) | 1,6 mm |
| Loss Tangent | 0,0265 |

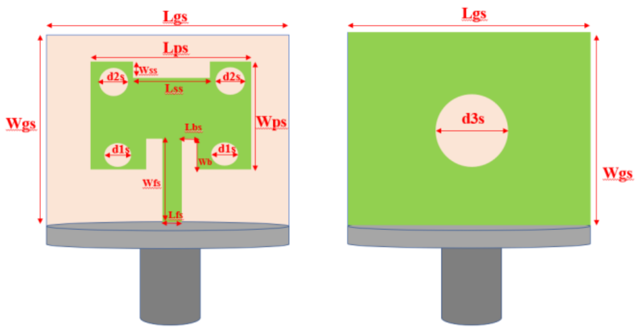
Table III outlines the theoretical equations used to determine the optimal dimensions of a microstrip patch antenna. The antenna's overall performance is largely governed by its physical structure, as these dimensions have a direct effect on the behavior of the electromagnetic fields it generates. Specifically, the length and width of the patch control the operating frequency and radiation characteristics, while the substrate and feedline dimensions influence impedance alignment, field propagation, and bandwidth efficiency. Inadequate dimensioning may result in undesirable effects such as electromagnetic leakage, inter-element coupling, or impedance mismatches, all of which negatively affect antenna functionality. Therefore, maintaining a precise relationship between the antenna's geometry and material properties is essential to achieve stable field distribution, low transmission losses, and reliable radiation performance, especially in advanced wireless systems like 5G networks.

Table III. Antenna Calculation

| Parameter | Size (mm) |
|---|---|
| Length of Patch | 26.32 |
| Width of Patch | 20.22 |
| Length of Substrate | 35.92 |
| Width of Substrate | 29.82 |
| Length of Feed | 173.58 |
| Width of Feed | 3.52 |
| Distance of Antenna | 42.85 |

### B. Single Antenna Design with DGS and Stub Slot

The single antenna is designed as a rectangular patch structure incorporating both Defected Ground Structure (DGS) and Stub Slot techniques, based on calculated dimensions derived from standard antenna design formulas. These calculations are performed for a target frequency of 3.5 GHz, utilizing an FR4 Epoxy substrate as the base material. The configuration of the single antenna employing DGS and stub slot is illustrated in Figure 1.




(a) (b)

Fig. 1. Single Antennas with DGS and stub slot (a) Front View (b) Back View

### C. 1x2 MIMO Antenna

The 1x2 MIMO antenna design integrates multiple antenna components, with overall dimensions tailored to 84 × 34 mm in length and width. This configuration, illustrated in Figures 2 and 3, is developed using Defected Ground Structure (DGS) and stub slot techniques. The design is based on the optimized results obtained from the single antenna configuration. Figures 2 and 3 depict the layout of the 1x2 MIMO antenna system incorporating DGS and stub slot features.

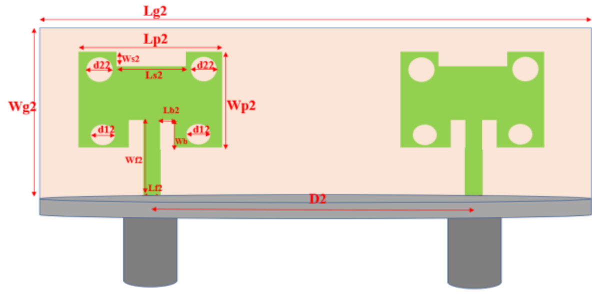



Fig. 2. 1x2 MIMO Antenna with DGS and Stub slot (Front View)

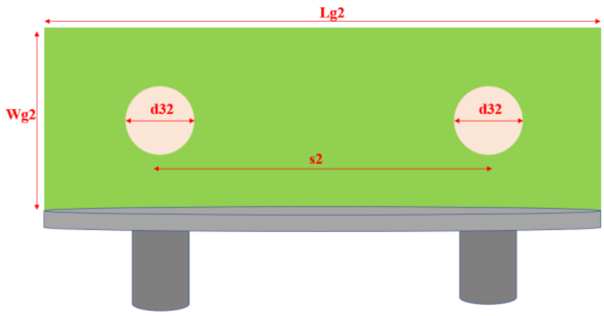



Fig 3. 1x2 MIMO Antenna with DGS and Stub slot (Back View)

## D. 2x2 MIMO Antenna

The design of 2x2 MIMO Antenna integrates multiple antenna components where the size is adjusted to the length and width of 84x84 mm. Figures 4 and 5 depict the layout of the 2x2 MIMO Antenna system incorporating DGS and stub slot features.

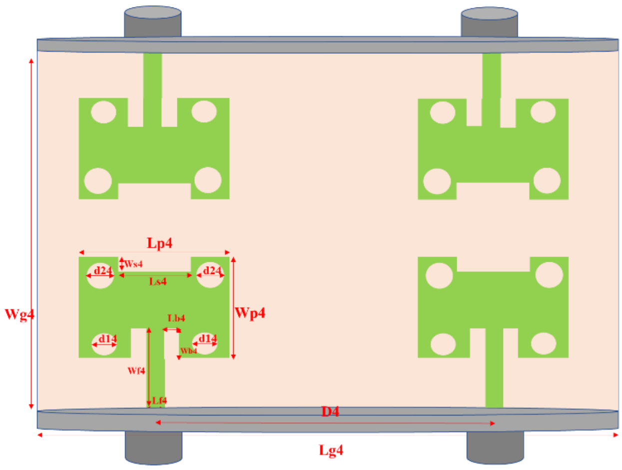



Fig. 4. 2x2 MIMO Antenna with DGS and Stub slot (Front View)

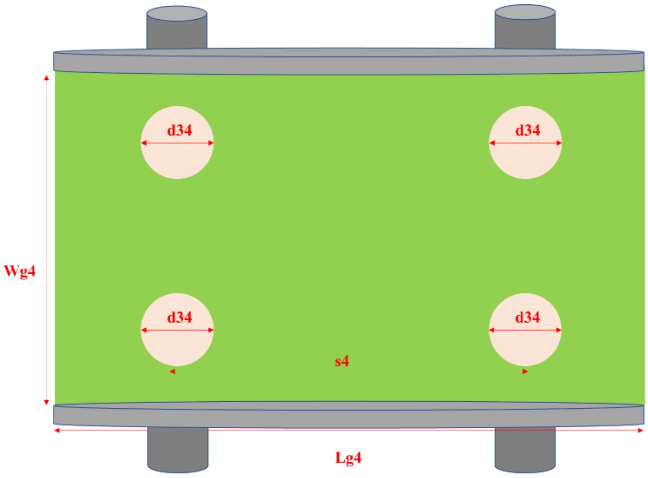



Fig. 5. 2x2 MIMO Antenna with DGS and Stub slot (Back View)

Table IV outlines the parameters of Single Antenna, 1x2 MIMO Antenna and 2x2 MIMO Antenna along with the simulation results derived from the optimization process. The optimized antenna configuration exhibits marked improvements in performance when compared to the results obtained before optimization.

Table VI. Parameters of Single Antenna, 1x2 MIMO Antenna and 2x2 MIMO Antenna With DGS And Stub slot

| Parameter | Symbol | Size (mm) |
|---|---|---|
| Lenght of Ground Single | Lgs | 34 |
| Width of Ground Single | Wgs | 34 |
| Length of Patch Single | Lps | 22 |
| Width of Patch Single | Wps | 19 |
| Length of Feedline Single | Lfs | 3 |
| Width of Feedline Single | Wfs | 17 |
| Length of Top Stub Slot Single | Lss | 9 |
| Width of Top Stub Slot Single | Wss | 2 |
| Length of Bottom Stub Slot Single | Lbs | 6 |
| Width of Bottom Stub Slot Single | Wbs | 2 |
| Diameter of Small Slot Single | d1s | 2 |
| Diameter of Big Slot Single | d2s | 2.5 |
| Diameter of DGS Single | d3s | 6 |
| Lenght of Ground 1x2 | Lg2 | 84 |
| Width of Ground 1x2 | Wg2 | 34 |
| Length of Patch 1x2 | Lp2 | 22 |
| Width of Patch 1x2 | Wp2 | 19 |
| Length of Feedline 1x2 | Lf2 | 3 |
| Width of Feedline 1x2 | Wf2 | 17 |
| Length of Top Stub Slot 1x2 | Ls2 | 9 |
| Width of Top Stub Slot 1x2 | Ws2 | 2 |
| Length of Bottom Stub Slot 1x2 | Lb2 | 6 |
| Width of Bottom Stub Slot 1x2 | Wb2 | 2 |
| Diameter of Small Slot 1x2 | d12 | 2 |
| Diameter of Big Slot 1x2 | d22 | 2.5 |
| Separation Between 2 Antenna 1x2 | D2 | 50 |
| Diameter of DGS 1x2 | d32 | 6 |
| Separation Between 2 DGS 1x2 | S2 | 50 |
| Lenght of Ground 2x2 | Lg4 | 84 |

| | | |
|---|---|---|
| Width of Ground 2x2 | Wg4 | 84 |
| Length of Patch 2x2 | Wp4 | 22 |
| Width of Patch 2x2 | Lp4 | 19 |
| Length of Feedline 2x2 | Wf4 | 3 |
| Width of Feedline 2x2 | Lf4 | 17 |
| Length of Top Stub Slot 2x2 | Ws4 | 9 |
| Width of Top Stub Slot 2x2 | Ls4 | 2 |
| Length of Bottom Stub Slot 2x2 | D4 | 6 |
| Width of Bottom Stub Slot 2x2 | Wb4 | 2 |
| Diameter of Small Slot 2x2 | Lb4 | 2 |
| Diameter of Big Slot 2x2 | D4 | 2.5 |
| Separation Between 2 Antenna 2x2 | S4 | 50 |
| Diameter of DGS 2x2 | d34 | 6 |
| Separation Between 2 DGS 2x2 | S4 | 50 |

## III. RESULT AND DISCUSSION

### A. Antenna Comparison Results

Both the single and MIMO antenna designs were simulated using Ansys HFSS version 15. After completing the simulation, characterization, and optimization processes, several key performance parameters were obtained, including return loss, mutual coupling, and gain. These results are presented through a comparative chart illustrating the differences between the single and MIMO antenna configurations. Figure 6 displays a comparison of the return loss (S11) for various antenna configurations: a single antenna without DGS and stub slot, a single antenna without DGS, a single antenna without the stub slot, a single antenna with both DGS and stub slot, as well as 1x2 MIMO Antenna and 2x2 MIMO Antenna designs. Figure 7 displays a comparison of the mutual coupling (S21) for 1x2 MIMO Antenna and 2x2 MIMO Antenna.

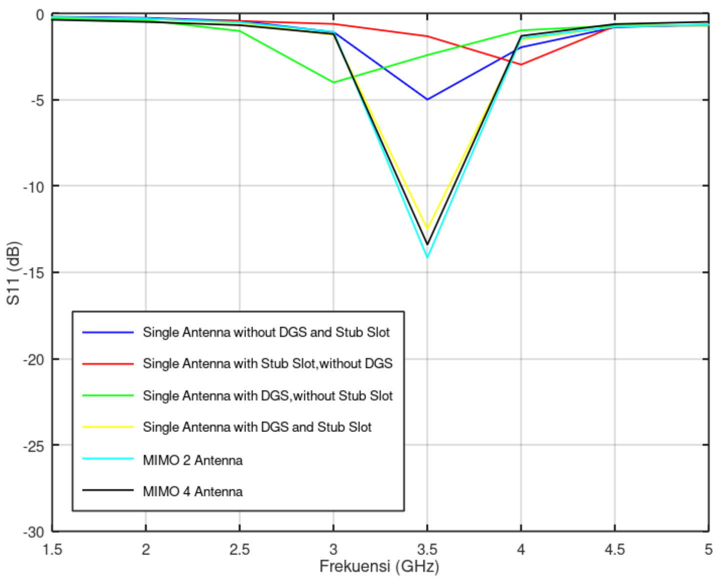



Fig. 6. Comparison of Return Loss Results on Single Antenna and MIMO

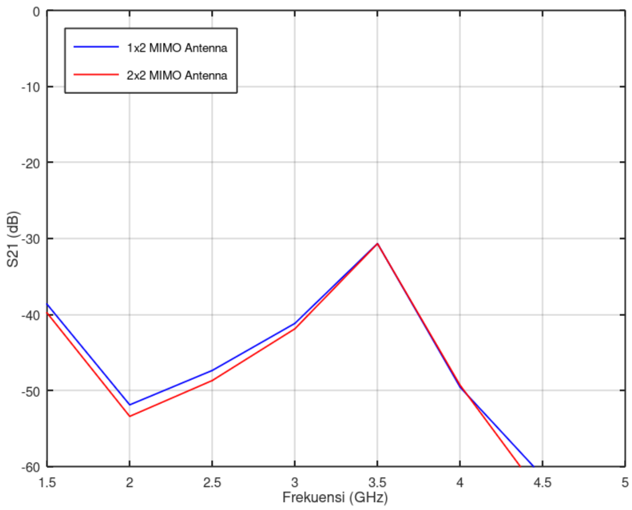



Fig. 7. Comparison of Mutual Coupling Results on 1x2 MIMO Antenna and 2x2 MIMO Antenna

This study of MIMO antennas for mid-band 5G applications at 3.5 GHz, the implementation of a Defected Ground Structure (DGS) plays a significant role in enhancing overall antenna performance. DGS involves etching specific patterns or slots into the ground plane of the antenna, which disrupts the surface current distribution and alters the electromagnetic behavior of the structure. Stub slot structures are widely used in antenna design to enhance key performance parameters such as bandwidth, impedance matching, gain, and isolation especially for modern systems like 5G. The distance between antenna elements has a significant impact on isolation in MIMO antenna design. the distance between antenna elements directly influences isolation greater spacing typically results in better isolation but practical designs require balancing spacing with additional technical solutions to maintain compactness and optimize performance.

Figure 8 shows the S Parameters result on 1x2 MIMO Antenna. The S11 and S22 parameter represent the input reflection coefficients of Port 1 and Port 2, indicating good impedance matching around the resonant frequency. Meanwhile, the S12 and S21 parameters reflect the transmission and isolation characteristics between the two ports. The S12 and S21 values remain below –30 dB across most frequencies, demonstrating excellent isolation performance suitable for MIMO applications.

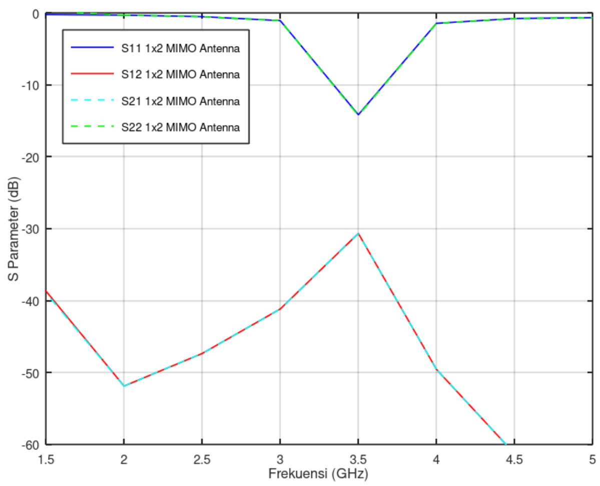



Fig. 8. The S Parameters Results on 1x2 MIMO Antenna

Figure 9 shows the S-parameter of 2x2 MIMO Antenna system on 3.5 GHz. The curves represent the mutual coupling between different antenna ports: S12, S14, S23, and S34. Across the frequency band, all S-parameters remain below –30 dB, indicating excellent isolation among the antenna elements. These results confirm that the antenna design ensures minimal interference between ports, which is essential for optimal MIMO performance.

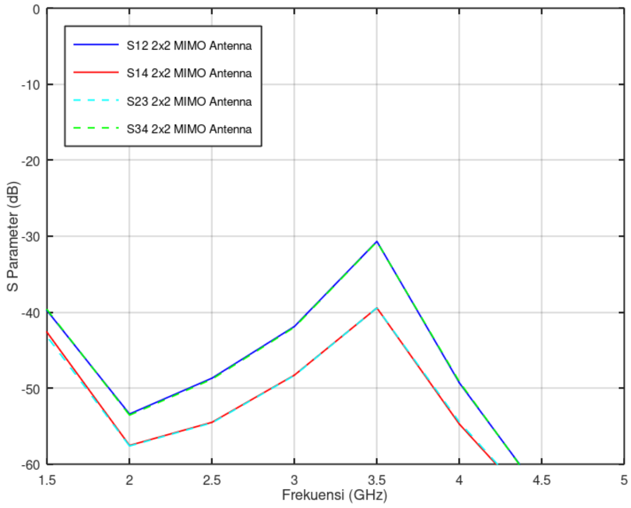



Fig. 9. The S Parameters Results on 2x2 MIMO Antenna

Table VII shows the total gain values on single and MIMO antennas. It can be seen that the total gain value on the MIMO of 2 antennas and 4 antennas is greater than that of the single antenna. 1x2 MIMO Antenna configurations may demonstrate higher gain due to more power per element, reduced mutual coupling, and simpler, more efficient physical design.

Table VII. Total Gain Simulation Table

| Type | Antenna | 3.5 GHz Frequency Gain (dB) |
|---|---|---|
| Single Antenna | 1 Antenna | 2,21 |
| Single Antenna with Stub Slot, without DGS | | 1.96 |
| Single Antenna with DGS, without Stub Slot | | 2.43 |
| Single Antenna with DGS and Stub Slot | | 3.39 |
| 1x2 MIMO Antenna | 2 Antenna | 5.23 |
| 2x2 MIMO Antenna | 4 Antenna | 4.35 |

Figure 10 shows the radiation pattern of 1x2 MIMO Antenna and 2x2 MIMO Antenna, plotted in polar coordinates. The pattern demonstrates a bidirectional (figure-eight) shape, which is typically observed in dipole-type or linearly polarized antennas.

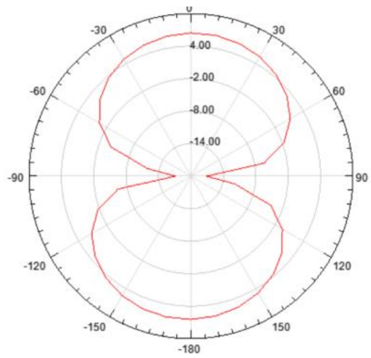


Fig. 10. Radiation Pattern on 1x2 MIMO Antenna and 2x2 MIMO Antenna

The 1x2 MIMO Antenna structure with dimensions of 84 × 34 mm offers a more compact footprint, making it more practical for integration into mid-sized wireless devices such as portable 5G modules, IoT gateways, or compact routers. The 2x2 MIMO Antenna structure with a physical size of 84 × 84 mm is not yet suitable for direct integration into compact devices such as smartphones, where internal space is highly limited and tightly optimized. However, this design is highly applicable for non-handheld 5G applications such as routers, IoT modules, fixed wireless terminals, or vehicular communication systems.

## IV. CONCLUSIONS

This research applied the Defected Ground Structure (DGS) and stub slot techniques to evaluate and compare the measurement results of 2x2 MIMO Antennas and 1x2 MIMO Antennas. The highest S11 measurement was recorded at –14.15 dB for the 1x2 MIMO Antenna, while the best S21 measurement value was observed in the 2x2 MIMO Antenna configuration at –30.68 dB. The integration of DGS and stub slot techniques in the MIMO antenna design proved effective in minimizing mutual coupling between antenna elements. Moreover, these methods contributed to enhanced antenna performance by increasing gain and expanding bandwidth. This was demonstrated in the research, where the MIMO antenna achieved a gain of 5.23 dB, representing a 1.84 dB improvement compared to the single microstrip antenna, which achieved a gain of only 3.39 dB. These enhancements are particularly significant for 5G applications operating in the mid-band frequency range near 3.5 GHz, which offers a balanced trade-off between coverage and capacity. The increased gain strengthens signal transmission and reception, improving link quality, while the expanded bandwidth accommodates higher data throughput and more reliable communication. The bandwidth expansion from approximately 200 MHz in the single antenna design to over 350 MHz in the MIMO configuration ensures that the antenna can effectively support wideband 5G channels, accommodating diverse and demanding data services. Furthermore, the lowered mutual coupling improves channel isolation in MIMO arrays, enabling more efficient spatial multiplexing and higher system capacity. Consequently, the proposed antenna design is well-equipped to fulfill the rigorous performance requirements of current 5G wireless networks, supporting faster and more stable connectivity.

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