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Design of 2×1 single-band microstrip antenna array with proximity coupling for enhanced CCTV performance

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Abstract

The increasing demand for reliable wireless communication in modern surveillance systems, particularly Closed-Circuit Television (CCTV), requires the development of antennas with high efficiency, wide bandwidth, and stable signal performance. To meet these requirements, this study presents the design and analysis of a 2×1 microstrip antenna array with rectangular patches that use proximity coupling, optimized for operation in the 2.4 GHz ISM band. The antenna was designed and simulated using CST Studio Suite to evaluate its electromagnetic characteristics, while measurements using a Vector Network Analyzer (VNA) were performed to validate the performance of the manufactured prototype. Simulation results show that the antenna achieves a reflection loss of −24.62 dB, a voltage standing wave ratio (VSWR) of 1.12, and a frequency bandwidth of 159 MHz, indicating good impedance matching and wide operational capability. Meanwhile, measurement results showed a reflection loss of −12.59 dB, a VSWR of 1.15, and a frequency bandwidth of 86 MHz. Both simulation and measurement results showed directional radiation patterns, ensuring efficient energy radiation and better signal focus for monitoring coverage. The designed antenna also shows a measured gain of 9.25 dBi, exceeding the simulated gain of 6.99 dBi, confirming improved performance. The difference between simulation and measurement is mainly due to variations in substrate thickness, material tolerance, and environmental factors during testing. Overall, the proximal coupling approach has proven effective in improving coupling efficiency without adding design complexity. This antenna is well-suited for reliable and efficient data transmission in CCTV applications. Furthermore, the findings contribute significantly to advancements in antenna technology, particularly in the domains of wireless communication, IoT, and smart city-based surveillance systems.

1. Introduction

Wireless communication technology has profoundly impacted many areas of life, including surveillance systems such as Closed-Circuit Television (CCTV) that commonly rely on Wi-Fi connectivity for data backhaul and control [1],[2]. As deployments scale from public facilities to residential neighborhoods, link reliability and coverage uniformity become central to achieving continuous video streaming and event detection. Within this context, antennas play a critical role in ensuring consistent communication performance—high-efficiency antennas can enhance signal strength, expand coverage, and mitigate interference, yielding more stable and reliable data transmission. Among various candidates, microstrip antennas are particularly popular due to their light weight, low profile, and ease of manufacturing and integration [3]. Building on this foundation, prior studies indicate that proximity coupling in rectangular microstrip patch antennas can deliver attractive bandwidth and gain—e.g., up to 6.86 dB gain and 3.60 GHz bandwidth at 28 GHz—while improving radiation focusing and reducing side-lobe levels, albeit with greater fabrication complexity than inset or probe feeds [4],[5], [6], [7].

However, despite extensive research on microstrip antennas, the application-specific requirements of Wi-Fi-based CCTV systems operating at 2.4 GHz remain insufficiently addressed. In practical deployments, CCTV links often suffer from weak signal quality, limited coverage, and electromagnetic interference due to multipath and obstacles (e.g., walls, foliage), especially in dense co-channel environments; these effects ultimately degrade video throughput and stream stability. Off-the-shelf antennas used in CCTV are typically not optimized for the combined needs of higher realized gain, adequate impedance bandwidth, stable radiation patterns, and robustness against detuning introduced by camera housings, brackets, or nearby platforms. Consequently, while many works investigate single-element patches, alternative feeds, or operation at millimeter-wave bands, a gap persists for a compact array solution at 2.4

GHz that leverages proximity coupling and is engineered explicitly for CCTV constraints, with measurements and analyses mapped to surveillance-relevant metrics.

To address this gap, we design and optimize a compact 2×1 rectangular microstrip antenna array operating at 2.4 GHz using proximity coupling, targeting improved realized gain, operational bandwidth, and radiation stability—thereby enhancing signal quality, monitoring range, and overall efficiency of CCTV systems. Although proximity coupling entails a more involved fabrication process, prior evidence suggests it can improve bandwidth, gain, and radiation directivity while lowering noise and interference impacts; these attributes align with the needs of Wi-Fi-based CCTV at 2.4 GHz [5],[6],[7],[9]. In this paper, our contributions include: (i) an application-driven, low-profile 2×1 proximity-coupled array tailored to CCTV form-factor and mounting constraints; (ii) a parametric exploration of feed overlap, substrate properties, and inter-element spacing to clarify trade-offs among bandwidth, gain, and profile; (iii) prototype measurements reporting $|S_{11}|$, realized gain, and E/H-plane radiation patterns—including, where relevant, pattern stability near a representative camera chassis; (iv) a comparative discussion against inset and coaxial-probe feeding to delineate when proximity coupling is advantageous; and (v) an application-level perspective linking antenna metrics to CCTV link reliability and interference resilience [8], [9]. Collectively, these results substantiate the hypothesis that a proximity-coupled 2×1 array can substantially improve gain, bandwidth, and signal stability for Wi-Fi-based CCTV, offering a practical path toward more reliable and efficient surveillance systems.

2. Research Method

The subject of this research is a 2×1 microstrip antenna array with a rectangular patch design. The 2×1 array configuration was chosen to increase signal gain and beam directionality, as well as to improve performance metrics such as reflection loss and frequency bandwidth [10]. The antenna is designed using the proximity coupling technique to optimize its performance at the 2.4 GHz frequency. The overall structure and design concept of the proposed antenna are illustrated in Figure 1, which shows the configuration of the rectangular patch array and the proximity-fed line arrangement. Key technical parameters such as return loss, Voltage Standing Wave Ratio (VSWR), gain, bandwidth, and antenna dimensions are carefully considered to achieve optimal results [11], [12]. The proximity coupling technique is anticipated to improve signal transmission efficiency while minimizing transmission losses, making the antenna highly suitable for wireless CCTV applications. The 2.4 GHz frequency is specifically chosen as it serves as a standard for numerous wireless communication devices, including modern CCTV systems [13].

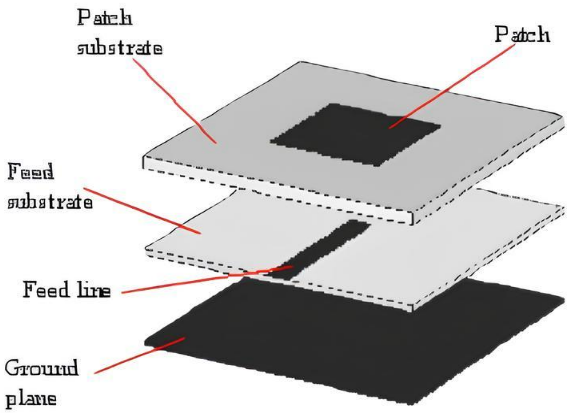


Figure 1 Antenna Structure with Proximity Coupling[14]

2.1 Antenna Specification

The dimensions of the antenna are carefully designed to meet the standard operating frequency requirements of 2.4 GHz, ensuring both compatibility and optimal performance. Table 1 presents the specifications of the 2×1 microstrip antenna array developed in this study.

Table 1. Specifications of Microstrip Antenna

Parameters	Target Value	Unit
Frequency	2.4	GHz
Return Loss	≤ -10	dB
VSWR	≤ 1.5	-
Gain	≥ 5	dBi
Bandwidth	≥ 100	MHz
Substrate	FR4 (εr=4.68, h=1.6 mm)	-

Standard operating frequencies are used to ensure compatibility with common wireless communications such as Wi-Fi and CCTV. Return loss indicates the efficiency of energy transfer; the more negative, the better. VSWR is the standing wave ratio value; ideally close to 1 for optimal efficiency. Gain is the minimum antenna gain to ensure adequate signal coverage. Bandwidth is the frequency range to support stable and flexible data transmission. Substrate is used to support antenna performance at an affordable cost.

2.2 Antenna Measurement Concept

The subjects of this study are the devices and systems being tested, specifically the 2×1 microstrip antenna array designed with the proximity-coupling technique. Simulations are conducted using CST Studio Suite 2019 software to model and evaluate antenna performance prior to physical testing [15]. Following the simulation phase, the antennas are fabricated using FR4 substrate material with a dielectric constant of 4.68. The fabrication process involves creating the antenna patch on the first substrate's surface, while the second substrate is used for the antenna feedline, a configuration required by the proximity-coupling method. Once the antennas are constructed, direct performance measurements are conducted in a laboratory setting. These tests employ specialized equipment, including a Vector Network Analyzer (VNA), a spectrum analyzer, and a signal generator, to accurately evaluate the antennas' characteristics and performance. The antenna measurement configuration is shown in Figure 2.

(a) (b)

Figure 2 Measurement Configuration using (a) Spectrum Analyzer dan (b) VNA

2.3 Consept of Testing Antenna on CCTV

Physical testing was conducted on a wireless CCTV system to evaluate the antenna's performance in improving signal and image quality. The system was tested under controlled environmental conditions to assess the effectiveness of the antenna in supporting stable data transmission. The diagram below shows the test configuration on the CCTV. The router as the transmitter device (Tx) and the CCTV camera will receive the signal (Rx) to send the image to the monitor. Both devices are connected to each other in the same internet connection. The overall configuration of the test setup is illustrated in Figure 3.

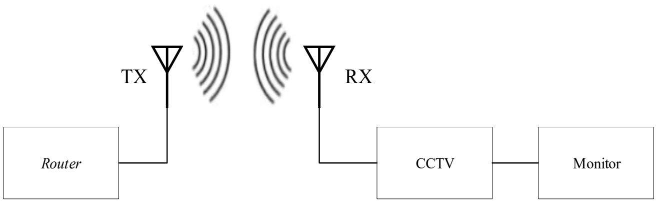


Figure 3 Diagram of Antenna Testing on CCTV

The research process involves multiple stages, including data collection, simulation, and measurement, to analyze the performance of the antenna [16]. CCTV testing technique evaluates received power in dBm units by comparing the reference antenna (router antenna) with the proposed microstrip antenna. Furthermore, the results of CCTV image capture used PSNR as a value that shows the quality of the resulting image by comparing images before and after the use of microstrip antennas [17]. The calculation of the Peak Signal-to-Noise Ratio (PSNR) value is formulated as stated in Equation 1.

$$PSNR = 10\log_{10}(\frac{255^2}{MSE}) \quad (1)$$

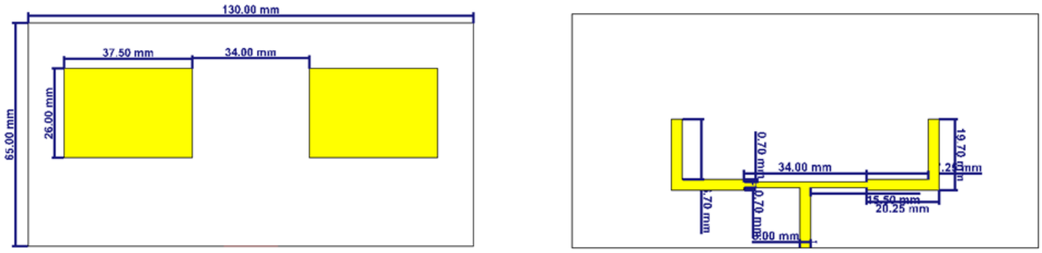
The data analysis methodology follows the Miles and Huberman method, encompassing stages such as data reduction, data presentation, conclusion drawing, and data verification [18]. The data obtained from simulations and physical tests were systematically processed to provide a comprehensive assessment of the antenna's performance.

Data triangulation was employed by comparing, correlating, and validating the results from simulations and physical tests. This approach ensures the validity and reliability of the research data through an objective and thorough analysis.

3. Results and Discussion

3.1 Antenna Dimension

The 2×1 microstrip antenna array designed using proximity coupling is based on precisely calculated dimensions to ensure optimal performance. The patch has a width of 37.06 mm and a length of 28.54 mm, while the substrate has a width of 130 mm and a length of 70 mm. The 50 Ohm channel features a width of 2.92 mm and a length of 16.7 mm, with the T-junction channel measuring 1.5 mm in width and 17.1 mm in length. The distance between the patch elements is 33.96 mm. These dimensions are tailored to the relative dielectric constant (ε_r) of the FR4 substrate, which is 4.68. These specifications form the basis for the antenna's simulation and fabrication, aligning with the requirements for 2.4 GHz operation and the proximity-coupling technique [1], [14], [15], [19], [20]. These formulas are used to determine the dimensions of the antenna so that the complete dimensional specifications are summarized [21]. Figure 4 illustrates the physical layout of the antenna dimensions simulated with CST software.



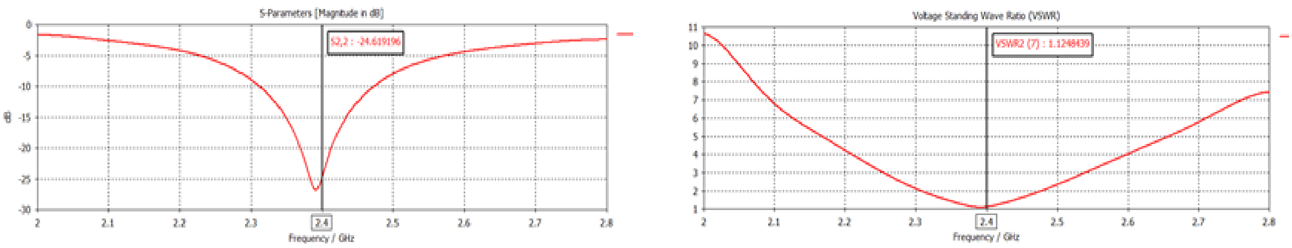
(a) (b)

Figure 4. Antenna Dimensions

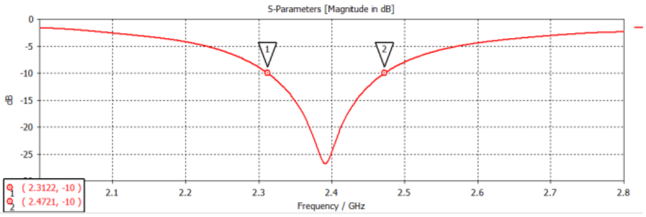
3.2 Antenna Simulation Results

The calculated and simulated results demonstrate that the dimensions of the designed antenna are well-optimized for operation at the 2.4 GHz frequency. As shown in Figure 5(a), the antenna exhibits a return loss of −24.62 dB, indicating a strong impedance match and efficient energy transfer with minimal reflection. Correspondingly, Figure 5(b) presents the VSWR result of 1.12, which confirms excellent matching between the antenna and the transmission line, signifying minimal standing wave formation. Furthermore, Figure 5(c) illustrates the bandwidth performance, showing a wide operating range of 159 MHz, sufficient to support stable communication within the 2.4 GHz ISM band. Finally, Figure 5(d) displays the antenna gain result, achieving a value of 6.99 dBi, which reflects the antenna’s capability to provide directional radiation and high signal strength. These combined results confirm that the antenna, utilizing proximity-coupling techniques [22], performs efficiently and fulfills the operational requirements for CCTV and IoT communication applications at the 2.4 GHz band.

The correlation between calculated and simulated results validates that the antenna design meets the expected parameters for wireless communication in CCTV surveillance systems [23]. This research addresses challenges related to transmission efficiency and signal quality, as the achieved return loss and gain values confirm the antenna’s ability to support high-quality data transmission effectively.



(a) (b)



(c)

farfield (f=2.4) [2]	
Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	2.4 GHz
Rad. Effic.	-2.124 dB
Tot. Effic.	-2.152 dB
Gain	6.994 dBi

(d)

Figure 5 (a) Return Loss Result, (b) VSWR Result, (c) Bandwidth Result, (d) Antenna Gain Result

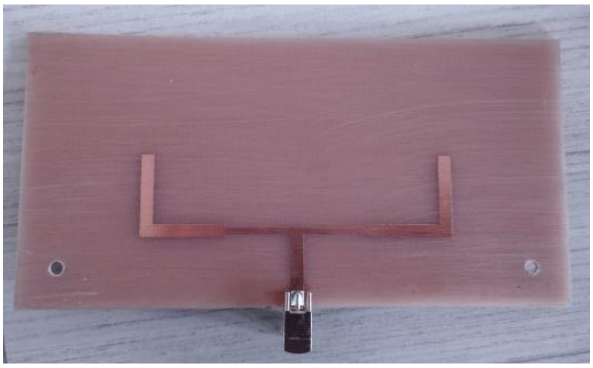
Proximity coupling on a 2×1 microstrip antenna array demonstrates remarkable performance improvements based on simulation results. This technique produces a directional radiation pattern with enhanced coupling efficiency, delivering better signal gain by minimizing energy losses in the feedline [20]. The proximity coupling dimensions include a T-junction channel width of 1.5 mm and a channel length of 17.1 mm. Simulation results confirm that the antenna exhibits a stable radiation pattern at the 2.4 GHz operating frequency.

The data analysis highlights that proximity coupling effectively addresses challenges in antenna design for applications at 2.4 GHz. This technique achieves wide bandwidth and radiation patterns suitable for the requirements of CCTV systems. Simulation tests demonstrate a significant improvement in antenna efficiency through proximity coupling. The strong correlation between simulation results and calculated dimensions validates the effectiveness of this technique in enhancing antenna performance for CCTV applications. Issues related to range and signal quality are effectively resolved with proximity coupling, as evidenced by the simulation outcomes.

3.3 Results of Antenna Measurements

In this research, a microstrip antenna has been fabricated, and its physical implementation is shown in Figure 6. The antenna was fabricated based on the specifications in Table 1 using an FR4 dielectric substrate, with two copper rectangular patch elements arranged in parallel on the top surface. These patches are interconnected by a copper transmission line, which functions as the feedline and is positioned at the substrate's center. The second substrate, featuring the feedline, is coupled to the top substrate indirectly through proximity-coupling. For connectivity, the antenna includes an SMA-type coaxial connector mounted at the bottom of the substrate, enabling integration with measurement devices or RF systems. Practical considerations were also addressed in the design, such as the inclusion of two mounting holes on either side of the substrate to facilitate easy installation and positioning of the antenna during measurements.

(a)

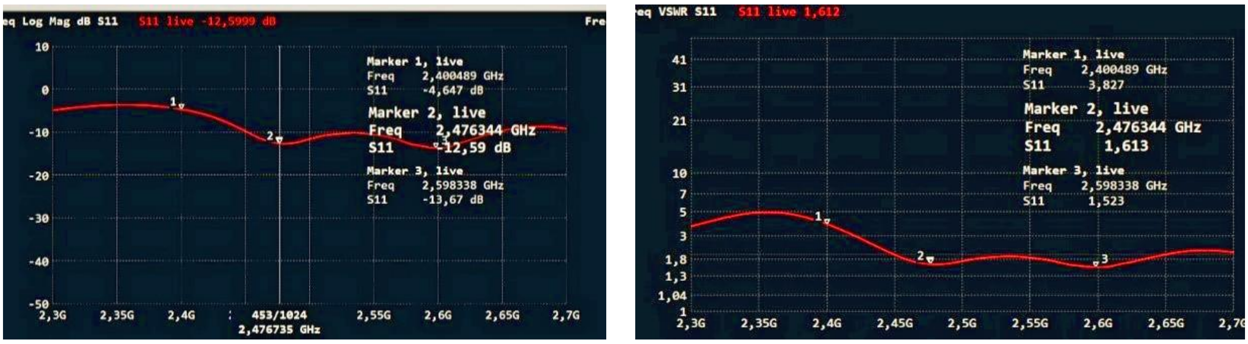


(b)

Figure 6. Fabricated Antenna

The measurement results obtained using a Vector Network Analyzer (VNA) validate the antenna’s performance in terms of return loss and Voltage Standing Wave Ratio (VSWR) at the 2.4 GHz frequency. As shown in Figure 7(a), the measured return loss reaches −12.59 dB, indicating that only a small portion of the transmitted signal is reflected back toward the source, while most of the power is effectively radiated by the antenna. Meanwhile, Figure 7(b) presents the VSWR measurement result of 1.61, demonstrating good impedance matching between the antenna and the transmission line, which ensures efficient power transfer with minimal reflection. These measurement results closely correspond to the simulation data, confirming that the fabricated antenna maintains reliable performance at the target operating frequency.

In microstrip antenna design, return loss values below -10 dB and VSWR values below 2 are considered benchmarks for optimal performance [24]. Addressing the critical challenges in antenna design for CCTV applications—namely, ensuring high energy efficiency and minimizing power loss—the measurement data demonstrate that the proposed antenna satisfies these specifications. With its optimal performance at 2.4 GHz, the antenna aligns well with the requirements of CCTV systems, which demand stable signal transmission and reduced interference.

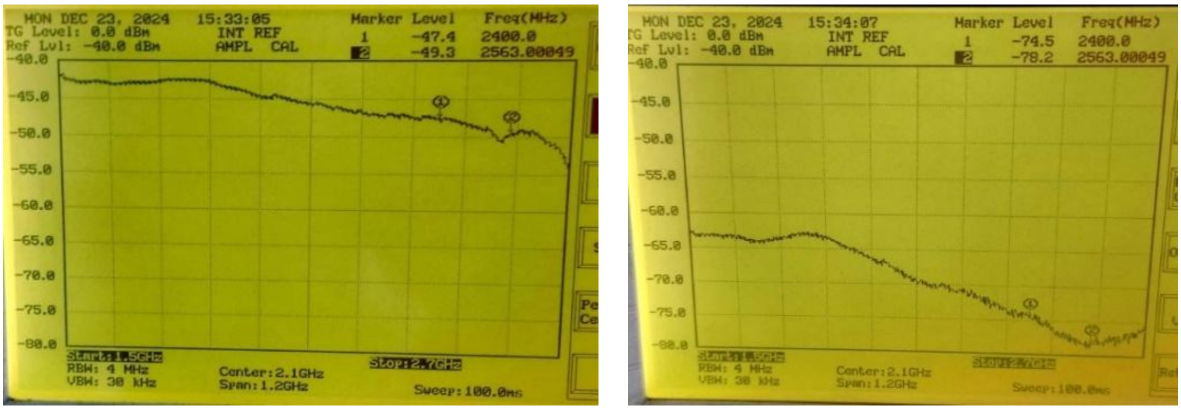


(a) (b)

Figure 7. (a) Return Loss Measurement Results, (b) VSWR Measurement Results

In addition to the measurements using a Vector Network Analyzer (VNA), further evaluations were conducted with a spectrum analyzer, as shown in Figures 8(a) and 8(b). These figures display the return loss parameter (S_{11}) measured across a frequency range of 2.1 GHz to 2.7 GHz, providing additional insights into the antenna's performance in power transmission. Using a reference antenna, the return loss of the microstrip antenna was determined. A particularly low return loss value of -49.3 dB was observed with a -40.0 dB reference level, indicating excellent power transmission at a specific frequency point.

However, a return loss value of -9.3 dB was also observed, which, although slightly above the threshold for good integration, still approaches acceptable levels. Compared to the VNA measurements, which showed a better return loss, the spectrum analyzer results indicate slightly higher power reflection. Despite this, the VNA results confirm that the antenna achieves excellent power coupling with minimal reflection back to the source, emphasizing strong performance in transmission efficiency.



(a) (b)

Figure 8. Measurement of (a) Reference Antenna and (b) Test Antenna on Spectrum Analyzer

The results of antenna gain measurements show variations in values with changes in operating frequency between 2.3 GHz and 2.6 GHz. The highest gain was achieved at 2.4 GHz, with a measured value of 9.25 dBi, which indicates the most optimal radiation performance at the antenna's main operating frequency. At frequencies outside the operating band, such as 2.3 GHz and 2.44 GHz, the gain decreases to a negative value, indicating reduced radiation efficiency. Complete data on the gain measurement results at each frequency confirm that the antenna operates most effectively around 2.4 GHz, meeting the design specifications for CCTV applications.

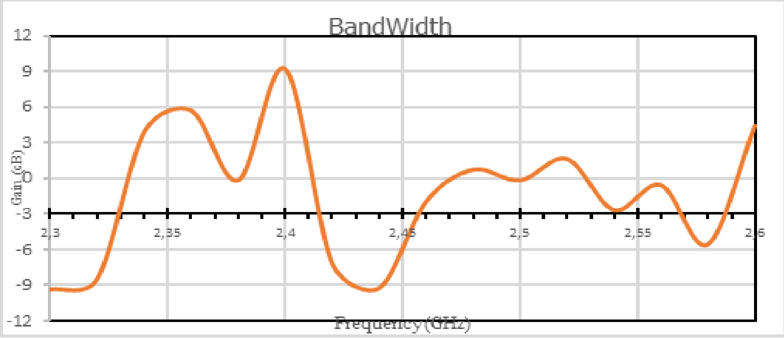


Figure 9. Bandwidth Measurement Results

The measured bandwidth of the antenna is identified from the frequency range where the return loss remains below −10 dB. As shown in Figure 9, the antenna operates effectively within the frequency range of 2.38 GHz to 2.42 GHz, resulting in an effective bandwidth of approximately 112 MHz. This optimal working frequency, combined with the high gain at 2.4 GHz, demonstrates the antenna's suitability for CCTV applications, which require wireless data transmission with high stability and efficiency. Additionally, the bandwidth obtained is sufficient to accommodate the data communication requirements of modern CCTV systems, ensuring reliable performance in transmitting and receiving signals with minimal interference.

With a smartphone transmitting in cellular bands and placed at a distance of ≥ 5 cm, the resonance shift at 2.4 GHz was negligible, and the degradation in $|S_{11}|$ remained < 1.5 dB**.** When the smartphone was placed at 0 cm or mounted flush to a metallic surface, a slight downward shift in the resonant frequency (f_{res}) and increased impedance mismatch were observed, which is consistent with near-field detuning effects commonly reported for compact devices. To mitigate detuning, it is recommended to maintain adequate ground clearance, incorporate via fences near the feed, and avoid direct metal contact with the antenna. Introducing a co-channel AP reduced throughput and increased PER/latency, as expected in congested 2.4 GHz environments. Nevertheless, the proposed directional 2×1 antenna array preserved a higher SNR margin than the reference antenna (ΔSNR > 0 dB in our setup), yielding fewer stalls and higher effective throughput under load.

The design of the microstrip antenna, which achieves a directional radiation pattern with high efficiency, fulfills the requirements of CCTV applications. Although minor discrepancies were observed in some measurement results outside the 2.4 GHz frequency range, the antenna excels in its performance at the target frequency, which is the primary focus of this research. These discrepancies may be attributed to factors such as electromagnetic interference in the measurement environment, the quality of the substrate material, or the resolution limits of the measuring instruments. Overall, the results confirm that the proposed 2×1 rectangular microstrip patch antenna array with proximity coupling delivers reliable and sufficient performance for CCTV applications operating at 2.4 GHz.

3.4 Comparison of Antenna Simulations and Measurements

Overall, the fabricated antenna showed a slight difference in performance compared to the simulation. Several factors can affect antenna performance, such as imperfections when realizing the antenna. Inaccuracies in connector installation and instrument calibration can also cause poor measurements. In addition, environmental conditions, such as external noise and electromagnetic interference, may affect the measurement outcomes.

Table 2. Antenna Parameter Comparison Data

No.	Parameter	Simulation	Fabrication
1	*Gain*	6.9 dBi	9,25 dBi
2	*Return loss*	-24.64 dB	-12.59 dB
3	*Bandwidth*	159 MHz	112 MHz
4	VSWR	1.12	1.613

Table 2 summarizes the differences between the simulated and measured antenna parameters. The gain parameter, the simulated value is 6.9 dBi, while the measured gain is 9.25 dBi. The simulation return loss is -24 dB, whereas the measured return loss is -12.59 dB. The measured bandwidth is 112 MHz. For the VSWR parameter, the simulated value is 1.12, and the measured value is 1.613. Although discrepancies are observed between the simulated and measured results, the overall performance still indicates an efficient level for transmitting power or signals.

3.5 Comparison with Related Works

To contextualize the measured performance at 2.4 GHz, we compare the proposed 2×1 proximity-coupled FR4 array with recent studies that use comparable substrates and feeding strategies. Proximity (electromagnetic) coupling is widely reported to broaden impedance bandwidth and improve impedance matching relative to conventional inset or coaxial feeds, which is consistent with the mechanism adopted in this work [5], [7], [12]. For 2.4 GHz implementations on low-cost laminates, recent reports typically achieve bandwidths on the order of 100–200 MHz (for $|S_{11}| < -10$ dB), with peak gains that scale with the number of elements. Compact single- or few-element designs emphasize manufacturability and cost efficiency, whereas longer linear arrays trade increased footprint for higher broadside gain [3], [8], [11].

Against this backdrop, the proposed antenna achieves a measured $|S_{11}| < -10$ dB bandwidth of approximately 112 MHz and a peak gain of about 7–9 dBi using only two elements on FR4, while maintaining a broadside pattern suitable for corridor/outdoor CCTV coverage. In other words, the design offers competitive gain per element count and bandwidth within the FR4 class, confirming that adopting proximity coupling on a cost-effective laminate can deliver robust matching and useful link margin at 2.4 GHz. For clarity, a consolidated numerical comparison is provided in Table 3, normalized to λ0 at 2.4 GHz and using a uniform bandwidth definition of $|S_{11}| < -10$ dBs.

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3.6 Testing the Antenna on CCTV

The CCTV system tested with the 2×1 microstrip antenna array demonstrated good performance based on the measurement results. As show in Figure 10, the system utilized a TP-Link WA701ND router as the signal transmitter, equipped with the 2×1 microstrip antenna array, and an indoor IP camera connected via the Bardi Smart Home application for capturing images.

(a) (b)

Figure 10. (a) Configuration on Testing on CCTV, (b) CCTV Capture

Measurement data in Tabel 3 show that the received power generated by the microstrip antenna closely aligned with the reference received power, maintaining a stable PSNR (Peak Signal-to-Noise Ratio) value. For instance, at a distance of 1 meter, the received power was -33 dBm, with a PSNR of 13.9 dB, while at 10 meters, the received power decreased to -50 dBm, with a PSNR of 13.47 dB.

Table 3. Power and PSNR Measurement Data

Distance (m)	Acceptability (dBm)		PSNR (dB)
	Reference	Test	
1	-29	-33	13.9
3	-38	-37	13.46
5	-43	-44	13.04
7	-50	-49	17.28
10	-54	-50	13.47
12	-55	-50	11.24

The data analysis reveals that CCTV systems equipped with a 2×1 microstrip antenna array provides stable signal quality across various distances. Measurements indicate that the optimal operating distance between the transmitter and receiver is within a 10 meter radius; beyond this distance, signal degradation becomes significant. Although received power diminishes with increasing distance, factors such as nonuniform illumination and signal noise can cause significant intensity variations between stereoscopic images, reducing the PSNR (Peak Signal-to-Noise Ratio) value. These variations increase the disparity between actual and reference images, thereby impacting the PSNR [25]. Despite these effects, the designed microstrip antenna demonstrates the capability to support stable and reliable data transmission. The correlation between measurement and simulation data confirms that the 2×1 microstrip antenna array effectively addresses the research challenges associated with signal quality in CCTV systems. The measurement results indicate that the antenna maintains data transmission quality across varying distances, ensuring its effectiveness in supporting a more efficient and dependable surveillance system.

4. Conclusion

The proximity coupling design of a 2×1 microstrip antenna array demonstrates outstanding performance at 2.4 GHz, making it highly suitable for CCTV systems. The design achieves high coupling efficiency, a return loss below -10 dB, and a VSWR close to ideal values, ensuring effective impedance matching. Its features include wide bandwidth, high gain, and directional radiation patterns, which collectively enhance signal stability and data transmission quality, even in challenging environments. Theoretically, this research confirms that proximity coupling effectively addresses the coupling limitations commonly associated with microstrip antennas. Practically, the design is well-suited for integration into modern applications such as surveillance systems, IoT networks, and smart city infrastructures. By supporting reliable connectivity and reducing power consumption, this design paves the way for further innovations in wireless communication technologies, broadening its scope for future advancements and practical implementations.

Notation

c	Speed of light ms^{-1}
Z	Impedance (ohm)
BW	Bandwidth (MHz)

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References

[1] R. V Bhatt and G. D. Makwana, "Slot-loaded Dual-Band Microstrip Patch Antenna for 5G and WLAN/WiMAX Wireless Applications," *Indian J. Sci. Technol.*, vol. 17, no. 22, pp. 2324–2330, 2024. https://doi.org/10.17485/ijst/v17i22.810.

[2] M. E. Yassin, H. A. Mohamed, E. A. F. Abdallah, and H. S. El-Hennawy, "Single-fed 4G/5G multiband 2.4/5.5/28 GHz antenna," *IET Journals*, pp. 286–290, 2019. https://doi.org/10.1049/iet-map.2018.5122

[3] A. Arora, A. Rana, A. Yadav, and R. L. Yadava, "Design of microstrip patch antenna at 2.4 GHz for Wi-Fi and Bluetooth applications," *J. Phys. Conf. Ser.*, vol. 1921, no. 1, 2021. https://doi.org/10.1088/1742-6596/1921/1/012023.

[4] S. O. Hasan, O. S. Hammd, S. K. Ezzulddin, and R. H. Mahmud, "Design and Performance Analysis of Rectangular Microstrip Patch Antennas Using Different Feeding Techniques for 5G Applications," *Int. J. Electr. Comput. Eng. Syst.*, vol. 14, no. 8, pp. 833–841, 2023. https://doi.org/10.32985/ijeces.14.8.2.

[5] H. A. Diawuo, K. Anim, and Y.-B. Jung, "Coupled line proximity coupled microstrip linear array antenna for millimetre wave applications," *IET Microwaves, Antennas Propag.*, vol. 14(14), pp. 1886–1894, 2020. https://doi.org/10.1049/iet-map.2020.0052.

[6] W. Gao, W. Withayachumnankul, M. Fujita,and T. Nagatsuma, "3D Printed Terahertz Lens Antenna Fed by Effective-Medium-Clad Dielectric Waveguide," *2023 35th Gen. Assem. Sci. Symp. Int. Union Radio Sci. URSI GASS 2023*, no. August, 2023. https://doi.org/10.23919/URSIGASS57860.2023.10265356.

[7] S. Kamal and P. Sen, "Microstrip-Ministered Proximity-Coupled Stacked Dual-Port Antenna for 6G Applications," *IEEE Access*, vol. 12, no. January, pp. 2817–2829, 2024. https://doi.org/10.1109/ACCESS.2023.3348548.

[8] W. Nie, H. Z. Wen, K. Da Xu, Y. Q. Luo, X. L. Yang, and M. Zhou, "A Compact 4×4 Filtering Microstrip Patch Antenna Array With Dolph-Chebyshev Power Distribution," *IEEE Open J. Antennas Propag.*, vol. 3, no. June, pp. 1057–1062, 2022. https://doi.org/10.1109/OJAP.2022.3204926.

[9] M. Narayan, K. K. Verma, and H. Bhusan Baskey, "Comparison Between Coaxial Probe Feed Rectangular Microstrip Patch Antenna and Proximity Coupled Feed Rectangular Microstrip Patch Antenna for Wireless Application," *Int. Res. J. Eng. Technol.*, no. June, pp. 6652–6655, 2020, [Online]. Available at: https://www.irjet.net/archives/V7/i6/IRJET-V7I61239.pdf

[10] R. Farias, C. Peixeiro, M. Heckler, and E. Schlosser, "Circularly Polarized Single-Layer Microstrip Reflectarray Fed With a 2x2 Microstrip Patch Array," *J. Commun. Inf. Syst.*, vol. 38, no. 1, pp. 85–91, 2023. https://doi.org/10.14209/jcis.2023.10.

[11] T. S. Persada, H. Ludiyati, F. M. Fernanda, and A. D. Maharani, "Bandwidth Enhancement of the Rectangular Patch Antenna Using Artificial Dielectric and Proximity Coupled Line Feed," *Proc. 2nd Int. Semin. Sci. Appl. Technol. (ISSAT 2021)*, vol. 207, no. Issat, pp. 381–386, 2021. https://doi.org/10.2991/aer.k.211106.061.

[12] S. Saxena and N. Saxena, "Proximity coupled microstrip patch antenna for gain enhancement," *Proc. - 2020 Int. Conf. Adv. Comput. Commun. Mater. ICACCM 2020*, vol. 1, pp. 423–426, 2020. https://doi.org/10.1109/ICACCM50413.2020.9212889.

[13] D. E. N.F.A. Hakim et al, "Microstrip array antenna using proximity coupled and dolph chebyshev distribution for wi-fi 6e," *2024 10th Int. Conf. Wirel. Telemat*, pp. 1–5, 2024. https://doi.org/10.1109/ICWT62080.2024.10674729.

[14] F. D. Diba and A. Science, "Analysis And Design Of A Compact Microstrip Patch Antenna With Enhanced Bandwidth And Gain For Wireless Local Area Network (Wlan) Communication," *Addis Ababa Univ.*, no. May, 2021. http://etd.aau.edu.et/handle/12345678/3404.

[15] O. Coskun and N. Erginyurek, "Wideband Microstrip Patch Antenna Design At 2.4 GHz Frequency for Wireless Communication," *Sci. J. Mehmet Akif Ersoy Univ.*, vol. 7, no. 2, pp. 91–98, 2024. https://doi.org/10.70030/sjmakeu.1185245.

[16] B. K. C. Babaiah, K. Naveen, K. Dasari, K.U. Kumar, and M. Sanjay, "Design and implementation of a microstrip array for wifi external antenna," *2022 Int. Conf. Adv. Smart, Secur. Intell. Comput*, pp. 1–5, 2022. https://doi.org/10.1109/ASSIC55218.2022.10088360.

[17] D. Andhika Firmansyah and A. Fashiha Hastawan, "Analisis Perbandingan Kompresi Citra Pada Beberapa Media Sosial," *J. Khatulistiwa Inform.*, vol. 11, no. 2, pp. 135–140, 2023. https://doi.org/10.31294/jki.v11i2.16107.

[18] D. L. S. Wu et al., "A new method for reconstructing building model using machine learning," *J. Intell. Constr*, vol. 3, no. 1, pp. 1–11, 2025. https://doi.org/10.26599/JIC.2025.9180041.

[19] N. W. Kirana, "An Analysis of Slot Dimension Changing in Dual band Rectangular Patch Microstrip Antenna with Proximity Coupled Feed," *J. Informatics Telecommun. Eng.*, vol. 4, no. 1, pp. 246–253, 2020. https://doi.org/10.31289/jite.v4i1.3961.

[20] F. Manalu et al., “Design of A Rectangular Patch Microstrip Array Antenna with Proximity Coupled on ADS-B Receiver,” vol. 11, no. 2, pp. 214–223, 2024, https://doi.org/10.33019/jurnalecotipe.v11i2.4507.
[21] D. Setiabudi et al., “Design and Analysis of Rectenna Using the Cockroft-Walton Method with L Matching Impedance,” *Int. Conf. Clim. Chang. Sustain. Eng. ASEAN (CCSE-ASEAN)2019*, 2019.
[22] K. Manjunath and S. N. Reddy, “Multiband Elliptical Patch Octagon Antenna With And Without Proximity Coupling,” *Int. J. Exp. Res. Rev.*, vol. 39, pp. 129–141, 2024. https://doi.org/10.52756/ijerr.2024.v39spl.010.
[23] G. Zalki dan D. Bakhar, “Design and Implementation of Microstrip patch Antenna Arrays for 2.4 GHz Applications,” 2022, [Online]. Avaibel at: https://doi.org/10.21203/rs.3.rs-994633/v1
[24] M. A. K. Khan et al., “Ultra High Efficient 2x1 Graphene Patch Antenna Arrays for Single and Dual Band Operation,” *1st Int. Conf. Adv. Sci. Eng. Robot. Technol. 2019, ICASERT 2019*, vol. 2019, no. Icasert, pp. 1–6, 2019. https://doi.org/10.1109/ICASERT.2019.8934472.
[25] K. Shin and S. Kim, “A method for extracting 3D-element based on local cost metrics resistant to radiometric distortion for realistic media application,” *Electron. Lett.*, vol. Vol.59, no. No.16, 2023. https://doi.org/10.1049/ell2.12916