JPPIPA 11(9) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

KU Band Proximity-Coupled Supply Based Microstrip Array Antenna for Microwave Imaging Applications

Fauzia Anis Sekar Ningrum[1*], Yudha Riwanto[1]

[1] Department of Informatics, Faculty of Computer Science, Universitas Amikom Yogyakarta, Sleman, Yogyakarta, Indonesia.

Received: July 03, 2025
Revised: August 22, 2025
Accepted: September 25, 2025
Published: September 30, 2025

Corresponding Author:
Fauzia Anis Sekar Ningrum
fauzianingrum@amikom.ac.id

DOI: 10.29303/jppipa.v11i9.11991

Abstract: This research focuses on the design and simulation of a 4x1 microstrip array antenna with a proximity-coupled supply technique for Ku frequency band applications, especially in microwave imaging. The antenna is designed to operate in the frequency range 12 - 16 GHz, with a resonance frequency of 14 GHz, using a Duroid 5880 substrate which has a thickness of 3.15 mm and a relative permittivity of 2.2. Array configuration and proximity-coupled techniques are applied to improve impedance matching as well as expand bandwidth. Evaluation through simulation includes important parameters such as return loss, gain, and radiation patterns. The simulation results show a return loss of -26.46 dB at a frequency of 14 GHz, which shows high transmission efficiency with minimal reflections. The radiation patterns in the azimuthal and elevation planes show consistent directivity, with stable gain throughout the frequency range. These results confirm that the designed microstrip array antenna is suitable for microwave imaging applications in the Ku band. The antenna design in this research produces high efficiency, directional radiation, and minimal signal loss, so it is able to support accurate and detailed imaging.

Keywords: Ku-Band; Microstrip array antenna; Proximity-coupled feed; Radiation pattern; Return loss

Introduction

The Ku frequency band, operating in the 12 - 18 GHz frequency range, plays an increasingly important role in satellite communication applications (Zhong et al., 2021; Carkaci et al., 2020), radar systems (Nikulin et al., 2024; Xiao et al., 2020), and broadband applications (Phaneendra et al., 2022; Sadadiwala et al., 2022; Qiao et al., 2023). This frequency band supports high data rates, enabling high-speed large data transmission capacity, which is highly desirable for systems where efficient information transfer is important. This frequency is also ideal for commercial satellite operations (Ho et al., 2019), where higher frequencies provide greater capacity and wider coverage. However, designing antennas for high frequency bands is challenging, especially in maintaining high efficiency, consistent gain, and impedance matching across the frequency range. Microstrip array antennas, with their low profile, ease of fabrication, and compatibility with integrated circuits, offer advantages that make them ideal for Ku frequency band applications (Madiawati et al., 2022a; Anindito et al., 2021; Aulia et al., 2021).

Various studies have also tested power supply techniques to improve antenna performance at high frequencies (Elijah et al., 2020; Chen, 2022; Mishra et al., 2019). One technique that has proven effective is proximity-coupled power, which increases bandwidth and improves impedance matching by separating the layer between the power line and the transmitter patch. Research by Ccoillo-Ramos et al. (2021) and Shirkolaei (2020) shows that this technique widens the bandwidth of microstrip antennas for X-band applications, with return loss below -10dB and wider impedance bandwidth. Research by Satrusallya et al. (2021), also shows that this method can increase the gain and

How to Cite:
Ningrum, F. A. S., & Riwanto, Y. (2025). KU Band Proximity-Coupled Supply Based Microstrip Array Antenna for Microwave Imaging Applications. *Jurnal Penelitian Pendidikan IPA*, *11*(9), 943–950. https://doi.org/10.29303/jppipa.v11i9.11991

radiation efficiency of Ku-band microstrip antennas, although it focuses more on maximizing the gain. Various supply techniques have been explored to improve antenna performance at high frequencies, one of which is the proximity-coupled supply technique which has been shown to be effective in improving impedance matching and widening the bandwidth. In this study, simulations were conducted to evaluate the performance of Ku-band microstrip antennas with this technique. The simulation results show that the design of Ku-band microstrip antennas with the proximity-coupled supply technique is not only able to increase transmission efficiency, but also maintain gain stability, improve more directional radiation patterns, and significantly reduce return loss.

Method

This research methodology follows a systematic workflow summarized in the flowchart in Figure 1. However, before each stage of the methodology is described in detail, the theoretical foundations that serve as the main foundation for the design and analysis of this antenna will be presented first. These relevant theoretical foundations include:

Microstrip Array Antenna

Microstrip antennas are a type of antenna that is widely used because they have advantages in terms of small size, light weight, and ease of integration with circuits (Madiawati et al., 2022b). However, microstrip antennas have several disadvantages, such as limited bandwidth and relatively low gain (Madiawati et al., 2020). Nevertheless, microstrip antennas are ideal for applications that require compact and efficient designs, especially in the Ku frequency band, which has a frequency range of 12–18 GHz and is widely used in satellite communications and radar applications.

Proximity-Coupled Feed

The proximity-coupled feed technique is one method used to improve the performance of microstrip antennas at high frequencies. This feed separates the layers between the patch and the feed line, and the feed line is placed in a separate layer from the substrate. The main advantage of this technique is that it can increase bandwidth and improve impedance matching (Sowjanya et al., 2022; Fistum, 2017). By separating the feed and patch layers, interference can be reduced, resulting in a more stable radiation pattern and increasing antenna efficiency. In addition, this feed allows for better impedance matching and minimizes signal reflections. This feed also reduces cross-polarization, which is often a problem in microstrip antennas with direct feed methods.

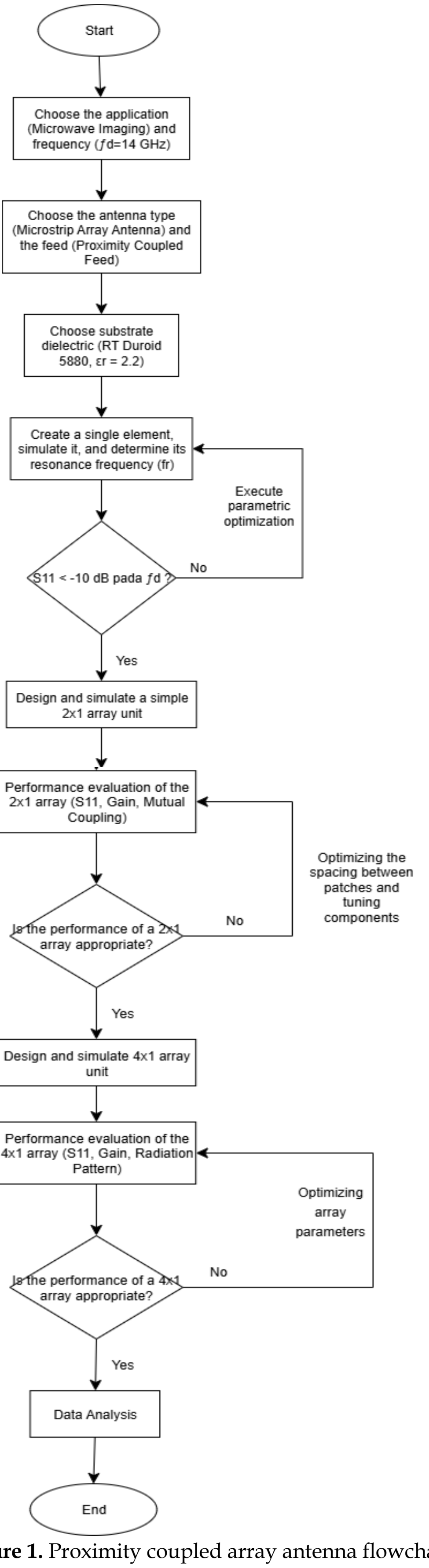

Figure 1. Proximity coupled array antenna flowchart

Ku Frequency Band

Microwave frequencies cover the range of 1–300 GHz, with wavelengths ranging from 1 mm to 30 cm, making them very suitable for various applications such as satellite communications, radar, and broadband systems. In the Ku band (12–18 GHz), microwaves offer large data transmission capabilities with high efficiency and wide coverage, although there are challenges such as material losses, interference, and decreased antenna efficiency at high frequencies. Therefore, antenna design in this range must consider precise element dimensions to achieve optimal parameters, such as low return loss, stable gain, and directional radiation patterns. A mature theoretical and simulation approach is essential, especially in applications such as microwave imaging, where the accuracy of the antenna response at high frequencies plays a critical role in producing high-quality imaging.

Microwave Imaging

Microwave imaging is a technology that utilizes electromagnetic waves at microwave frequencies to detect, visualize, or map objects or environments based on the interaction of microwaves with materials, such as reflection, transmission, and absorption. This technology is widely used in various applications, such as security, medical, and subsurface structural imaging, because it has good penetration ability on non-metallic materials and provides high resolution. In medical applications, microwave imaging can detect dielectric changes in body tissues, such as for breast cancer diagnosis (Wang, 2023; Benny et al., 2020) or brain imaging (Rodriguez-Duarte et al., 2021), while in the security field, it is used to detect hidden objects under clothing or building structures (Wang et al., 2019). The Ku frequency band, with its short wavelength, allows for more precise imaging, especially when supported by a microstrip array antenna capable of producing a directional and efficient radiation pattern. Therefore, antenna design for microwave imaging requires parameter optimization, such as gain, radiation pattern, and return loss, so that the system can produce accurate imaging with high resolution. This study aims to design a microstrip array antenna that can be used in microwave imaging applications in the Ku frequency band, which is expected to improve imaging accuracy while maintaining transmission efficiency in high-frequency systems.

Simulation Testing Parameters

In the evaluation of antenna performance, there are several main parameters that are analyzed to ensure the design functions as needed. These parameters reflect the effectiveness of the antenna in various aspects, especially in applications in the Ku band. The following are the parameters tested in this study (Yuliarto et al., 2021).

Return Loss (S11)

Return loss is a measure of power reflection in logarithmic format. This parameter describes the amount of power that cannot be transmitted optimally due to a mismatch between the antenna and the transmission line. As a result of this mismatch, some of the power is reflected back instead of being radiated. The smaller the return loss value, the greater the power transmitted, which indicates the efficiency better antenna performance.

Gain

Gain measures the ratio of the power radiated by an antenna to the power of a reference antenna. This parameter indicates the increase in power radiated in a particular direction compared to a reference antenna that radiates power in the same direction. The higher the gain, the stronger the antenna focuses energy in one direction, which increases transmission efficiency.

Radiation Pattern

The radiation pattern describes the distribution of energy radiated by an antenna in three-dimensional space. This parameter is evaluated in two main areas, namely: (a) Elevation plane, describes the distribution of antenna signals in the vertical plane. (b) Azimuth plane, describes the distribution of antenna signals in the horizontal plane.

Analysis of these parameters is very important to ensure that the antenna performance is in accordance with the application needs in the Ku frequency band. Low return loss, optimal gain, and directional radiation patterns are the main indicators of the success of antenna design in supporting transmission efficiency and signal quality. By understanding the relationship between these parameters, antenna design can be improved to provide the best performance in satellite communications and microwave imaging applications.

Proposed Antenna Design

A microstrip array antenna designed to operate in the Ku-Band with a center frequency of 14 GHz, using a proximity-coupled supply technique. This supply technique separates the patch layer and the supply channel layer. The antenna design in this study has 5 layers consisting of the top layer as a layer of 4 patches arranged in a 4x1 configuration, each measuring 7 mm. Then the second layer is the substrate which is located directly below the patch. Then the supply channel, located between the substrates which are placed in the third layer. This supply channel is a quarter wave long, connected to a 100 Ω supply. Finally, the bottom layer is the ground plane connected to the SMA connector. The antenna design that has been done can be seen in more detail in Figure 2.

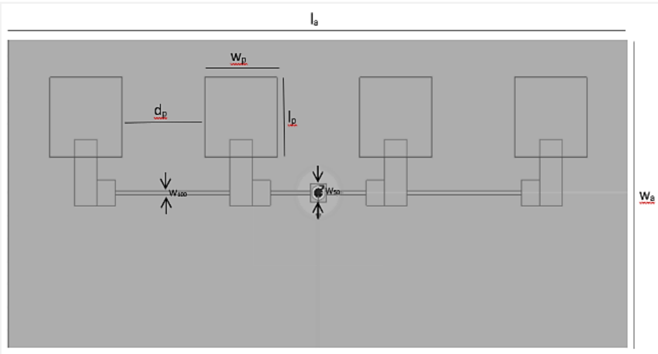

Figure 2. 4x1 Microstrip antenna configuration

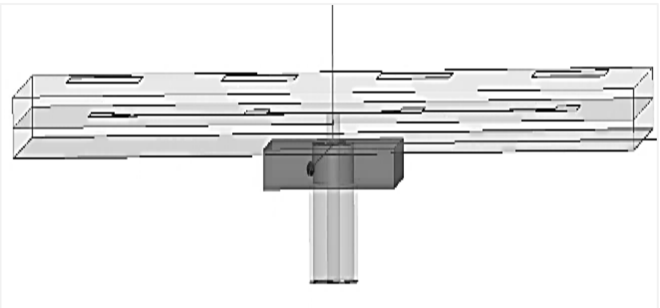

Figure 3. Side view of 4x1 microstrip antenna

The substrate material used is RT Duroid 5880 with a thickness per layer of 1.575 mm, resulting in a total thickness of 3.15 mm. The dimensions of the proposed antenna are 60 mm x 27.3 mm which is in accordance with the characteristics of the Ku-band. The resonant frequency is determined by the dimensions of each patch element and the dielectric substrate. The proposed working frequency is determined by the working frequency of each patch element. Theoretically, the resonant frequency (f_r) of the patch can be calculated using the dimensions and the relationship of its parameters, including patch length (l_p), patch width (w_p), substrate relative permittivity (ε_r), and antenna thickness (t_a). This relationship is shown by the following formula (1) - (3): (Mar Phyo et al., 2020; Joshi et al., 2019; Natalia et al., 2025).

$$l_p = \frac{c}{2f_r}; \quad w_p = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

$$\frac{\Delta l_p}{t_a} = 0.412\frac{(\varepsilon_{eff}+0.3)\left(\frac{w_p}{t_a}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{w_p}{t_a}+0.8\right)} \tag{2}$$

$$\varepsilon_{eff} = \frac{\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}}{\sqrt{1+\frac{12t_a}{w_p}}} \tag{3}$$

where l_p, w_p, and f are the length and width, and the resonant frequency of the antenna, respectively, c is the speed of light $3 \times 10^8\ m/s$, ε_r and ε_{eff} are the relative permittivity and effective relative permittivity of the substrate dielectric, respectively, Δlp and ta are the length of the fringe extension and the thickness of the antenna. The detailed dimensions of each element in the proposed antenna can be seen in Table 1.

Table 1. Microstrip Antenna Dimensions

Element	Value (mm)
Antenna length (l_a)	60
Antenna width (w_a)	27.3
Patch length (l_p)	7
Patch width (w_p)	7
Distance between patches (d_p)	8
Transmission line width 50Ω (w_{50})	1.6
Transmission line width 100Ω (w_{100})	0.3

The proximity-coupled feed technique was chosen because of its ability to overcome the drawbacks of microstrip antennas, including smaller bandwidth, lower emissions, and better gain. It separates the patch from the transmission line through different substrate layers, which helps reduce interference and produces a more stable radiation pattern. Compared with the direct feed method, the proximity-coupled technique offers the advantage of reduced cross-polarization. It also allows for better impedance matching, minimizes signal reflections, and provides greater flexibility in tuning the resonant frequency, making it particularly advantageous for high-frequency applications such as the Ku-band.

Result and Discussion

After the dimensions of each antenna element are determined, simulations are run to evaluate the performance of the proposed antenna. Simulations are performed with several parameters such as gain, radiation pattern, and return loss using the ANSYS HFSS software program. Matching the antenna impedance to the operating frequency is determined by the return loss parameter, also known as the scattering parameter (S-parameter). An efficient antenna, with little energy reflection is indicated by a return loss value of less than -10 dB. In addition, radiation pattern parameters are measured to assess the direction of the signal radiation. Finally, analysis of the simulation results of the gain parameters will determine the capacity of the antenna to focus energy in a certain direction. In addition, the antenna bandwidth is also checked to ensure that the antenna can operate properly in the desired frequency range.

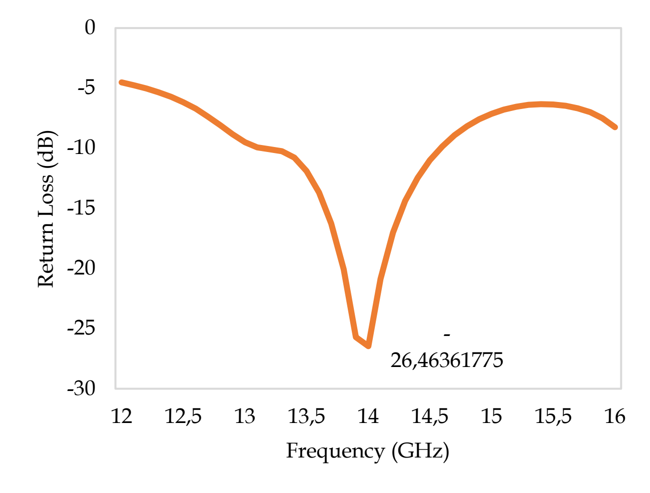

Figure 4. Return loss simulation of 4x1 microstrip array antenna

Figure 4 shows the simulation results of the return loss of a 4x1 microstrip array antenna designed to operate in the Ku band with a center frequency of 14 GHz. From the graph, the antenna achieves a return loss value of -26.46 dB at a frequency of 14 GHz. This result shows excellent power delivery performance and indicates that only a small portion of the energy is reflected to the source. In addition, the graph also shows that the return loss value is below -10 dB in the frequency range of 12.8 GHz - 15.4 GHz, indicating that the antenna can operate efficiently in that frequency range. This shows that the antenna has a bandwidth of about 2.6 GHz, which is wide enough for applications in the Ku band.

Figure 5 shows the simulation results of the radiation pattern on the H-plane, which shows good signal focus on the horizontal plane with a strong main lobe pointing to 0°. Meanwhile, the side lobes are very small, indicating the antenna's ability to focus the signal in one direction very well. Applications that require directional antennas, such as microwave imaging, can benefit from the strong main signal and excellent directivity of this antenna, as shown by the radiation pattern on the H-plane. By focusing the signal in a certain direction, this antenna can improve the efficiency of signal transmission at Ku-band frequencies, as measured by the resulting radiation pattern. Figure 6 shows the simulation results of the radiation pattern on the E-plane. The radiation pattern on the E-plane shows a more spread-out signal but still has a main lobe centered at 0°. Although the main lobe remains focused at 0°, the larger side lobes on the E-plane indicate that the signal is radiated more widely in the vertical plane. Although the radiation pattern of the E-plane is more spread out compared to the H-plane, this antenna still has good directivity, which is useful in applications that require signal spread over a wider area, such as microwave imaging at Ku-band frequencies.

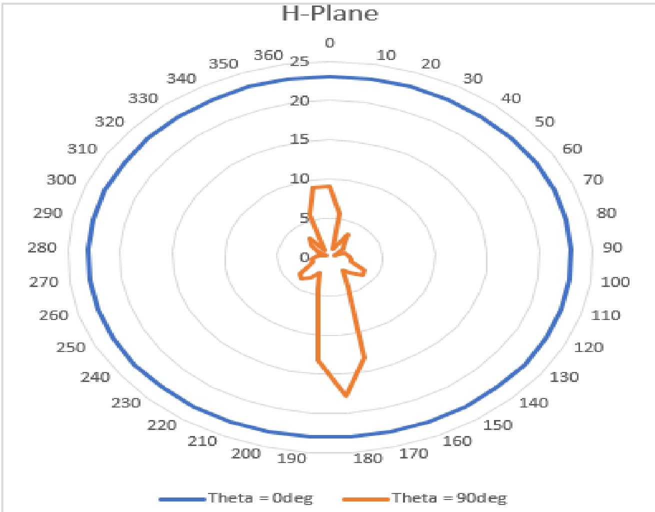

Figure 5. Simulation of azimuth radiation pattern of 4x1 microstrip antenna

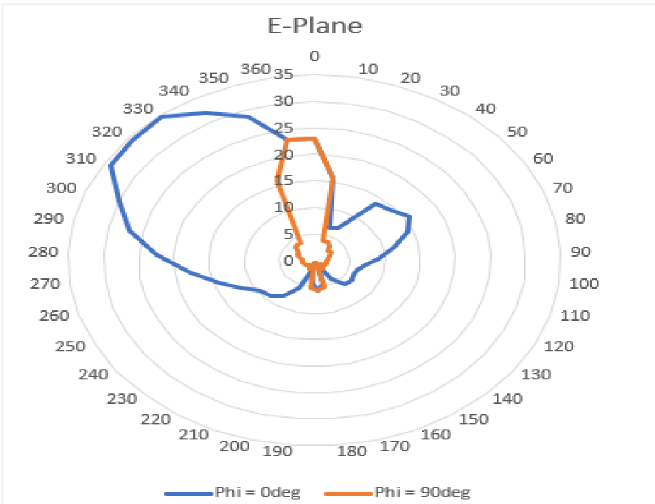

Figure 6. Simulation of the elevation radiation pattern of a 4x1 microstrip antenna

The gain simulation results in Figure 7 show that the microstrip array antenna for Ku band applications has a peak gain of 9.50 dBi at a frequency of 14 GHz. In the frequency range of 12.8–14.5 GHz, the gain remains stable between 9.00–9.50 dBi, indicating that the radiation emitted by the antenna remains focused in the main direction. This is supported by optimal impedance matching, thus ensuring good supply performance. However, after passing the frequency of 14.5 GHz, there is a significant decrease, with the gain dropping below 0 dBi at a frequency of 15.5 GHz. This decrease indicates the limitations of the antenna's performance for applications at frequencies above 15 GHz.

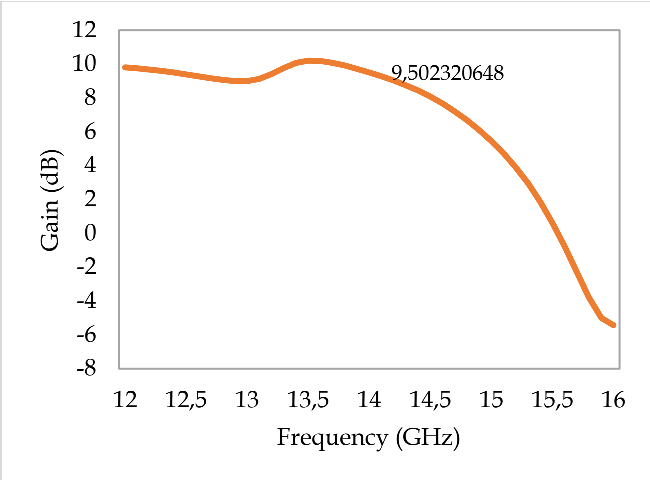

Figure 7. Simulation of 4x1 microstrip antenna gain

Conclusion

The proximity-coupled feed technique for microstrip array antennas operating in the Ku band has been simulated. The results of the simulation show that the return loss produced is -26.46 dB at a frequency of 14 GHz, which is in accordance with the target frequency and indicates good performance in impedance matching. Then, the directivity and main lobe also produce a stable pattern in the H plane, so that it matches the characteristics of microwave imaging. In addition, in the frequency range of 12.8 - 14.5 GHz, the antenna is able to focus energy efficiently as seen in the peak gain results of 9.50 dBi and the gain range of 9.00 - 9.50 dBi. Overall, these results indicate that the proposed antenna design meets the expected specifications and has great potential for use in microwave imaging applications. However, the results on the return loss parameters may be even better if a patch is added or used in a higher frequency, for example in the Ka Frequency Band.

Acknowledgments

Thanks are given to Universitas Amikom Yogyakarta and the Institute for Research and Community Service for providing the facilities and resources needed to carry out this research. This support means a lot to us in order to study the topic of KU Band Proximity-Coupled Supply Based Microstrip Array Antenna for Microwave Imaging Applications, as well as all parties involved in this research until the completion of this research.

Author Contributions

Fauzia Anis Sekar Ningrum is the first author to conduct a literature review on previous research, data collection, idea research, testing, analysis, and implementation, while Yudha Riwanto as the second author provides suggestions and input on the research concept.

Funding

This research was funded by Dikti through the Beginner Lecturer Research Grant (PDP), grant number 0609.20/LL5-INT/AL.04/2024 and APC was funded by the same funds.

Conflicts of Interest

The authors declare no conflict of interest.

References

Anindito, A., Putranto, A., Alam, S., Surjati, I., Sari, L., & Vaswani, R. (2021). Desain Antena Mikrostrip Array 2x1 Elemen dengan Teknik Inset dan Slit untuk Sistem Komunikasi 5G. *Jurnal Telematika*, *16*(1), 18–24. https://doi.org/10.61769/telematika.v16i1.388

Aulia, N., & Elisma. (2021). Desain Antena Mikrostrip Array 2x4 dengan Teknik Pencatuan Proximity Coupled untuk Aplikasi 5G pada Frekuensi 2,6 GHz. In *Prosiding The 12th Industrial Research Workshop and National Seminar* (Issue 5, pp. 717–723). Retrieved from https://jurnal.polban.ac.id/proceeding/article/view/2787/2177

Benny, R., Anjit, T. A., & Mythili, P. (2020). An Overview Of Microwave Imaging For Breast Tumor Detection. *Progress In Electromagnetics Research B*, *87*, 61–91. https://doi.org/10.2528/PIERB20012402

Carkaci, M. E., & Secmen, M. (2020). Design and prototype manufacturing of a feed system for Ku-band satellite communication by using 3D FDM/PLA printing and conductive paint technology. *International Journal of RF and Microwave Computer-Aided Engineering*, *30*(4), 1–15. https://doi.org/10.1002/mmce.22062

Ccoillo-Ramos, N. R., Aboserwal, N., Qamar, Z., & Salazar-Cerreno, J. L. (2021). Improved analytical model for a proximity coupled microstrip patch antenna (pc-mspa). *IEEE Transactions on Antennas and Propagation*, *69*(10), 6244–6252. https://doi.org/10.1109/TAP.2021.3082570

Chen, C. (2022). A Compact Wideband Endfire Filtering Antenna Inspired by a Uniplanar Microstrip Antenna. *IEEE Antennas and Wireless Propagation Letters*, *21*(4), 853–857. https://doi.org/10.1109/LAWP.2022.3151800

Elijah, A. A., & Mokayef, M. (2019). Miniature microstrip antenna for IoT application. *Materials Today: Proceedings*, *29*, 43–47. https://doi.org/10.1016/j.matpr.2020.05.678

Ho, S. C., Shah, R., Garrison, J. L., Mohammed, P. N., Schoenwald, A., Pannu, R., & Piepmeier, J. R. (2019). Wideband Ocean Altimetry Using Ku-Band and K-Band Satellite Signals of Opportunity: Proof of Concept. *IEEE Geoscience and Remote Sensing*

Letters, *16*(7), 1012–1016. https://doi.org/10.1109/LGRS.2019.2891976

Lakshmi, M. B., Naga, P. A. S., Poojitha, K., & Nikitha, B. (2024). Design and Analysis of Microstrip Patch Antenna for Wi-fi Communication. *2024 3rd International Conference for Innovation in Technology, INOCON 2024*, *97*, 163–176. https://doi.org/10.1109/INOCON60754.2024.10511784

Madiawati, H., & Simanjuntak, A. B. (2020). Desain dan Realisasi Antena Mikrostrip Patch Rectangular Array dengan Slit pada Frekuensi 2620-2690 MHz untuk Aplikasi LTE. *Jurnal Teknik: Media Pengembangan Ilmu Dan Aplikasi Teknik*, *19*(2), 110–119. https://doi.org/10.26874/jt.vol19no02.232

Madiawati, H., Simanjuntak, A. B., Sulaeman, E., & Hibban, M. S. I. (2022). Antena Mikrostrip Array untuk Aplikasi Radar Cuaca pada Frekuensi C-Band Menggunakan Metode Defected Ground Structure. *JTERA (Jurnal Teknologi Rekayasa)*, *7*(2), 181. https://doi.org/10.31544/jtera.v7.i2.2022.181-188

Mar Phyo, Z., May Nway, T., Kyu Kyu Win, K., & Myo Tun, H. (2020). Development of Microstrip Patch Antenna Design for GPS in Myanmar. *American Journal of Electromagnetics and Applications*, *8*(1), 1. https://doi.org/10.11648/j.ajea.20200801.11

Natalia, Quzwain, K., Olivia, L. N., & Rahmawati, P. (2025). Performance Analysis of a Unidirectional Double E-Shaped Microstrip Antenna in the ISM Band. *Jurnal Penelitian Pendidikan IPA*, *11*(8), 1062–1067. https://doi.org/10.29303/jppipa.v11i8.12118

Nikulin, A. V., Kosmynin, A. N., Burtsev, V. D., Prokhorov, S. Y., Vosheva, T. S., & Filonov, D. S. (2024). Towards phased array antenna operating in Ku-band for satellite communications. *Photonics and Nanostructures - Fundamentals and Applications*, *58*. https://doi.org/10.1016/j.photonics.2023.101216

Phaneendra, C. N., Ram, K. V. V., Naveen, D., Sreekar, L., & Naik, K. K. (2022). Design a Multi-Band MIMO Patch Antenna at X, K, and Ku Band for Wireless Applications. *4th International Conference on Emerging Research in Electronics, Computer Science and Technology, ICERECT 2022*. https://doi.org/10.1109/ICERECT56837.2022.10060667

Qiao, H., Zhang, P., Li, Z., Huang, L., Zhao, C., Gao, S., Liu, C., Wu, Z., Liang, S., Zhou, J., Sun, W., & Wang, L. (2023). Snow profile reconstruction from tomographic UAV SAR. *International Journal of Applied Earth Observation and Geoinformation*, *118*, 103291. https://doi.org/10.1016/j.jag.2023.103291

Rana, M. S., & Smieee, M. M. R. (2022). Design and analysis of microstrip patch antenna for 5G wireless communication systems. *Bulletin of Electrical Engineering and Informatics*, *11*(6), 3329–3337. https://doi.org/10.11591/eei.v11i6.3955

Rodriguez-Duarte, D. O., Vasquez, J. A. T., Scapaticci, R., Crocco, L., & Vipiana, F. (2021). Assessing a microwave imaging system for brain stroke monitoring via high fidelity numerical modelling. *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology*, *5*(3), 238–245. https://doi.org/10.1109/JERM.2020.3049071

Sadadiwala, V., Singh, V., & Sharma, D. (2022). Ku band metamaterial absorber for stealth applications against Radar and Military Satcom. *PriMera Scientific Engineering*, *1*(3), 2834–2550. https://doi.org/10.56831/psen-01-018

Satrusallya, S., & Mohanty, M. N. (2021). Design of antenna array for Ku-band wireless application. *Instrumentation Mesure Metrologie*, *20*(2), 107–112. https://doi.org/10.18280/i2m.200207

Shirkolaei, M. M. (2020). High efficiency X-band series-fed microstrip array antenna. *Progress In Electromagnetics Research C*, *105*, 35–45. https://doi.org/10.2528/pierc20061003

Sowjanya, P. D., Alsath, M. G. N., Kirubaveni, S., Govindaraj, R., & Santhosh, N. (2022). Design and Experimental Evaluation of a Proximity Coupled Transparent Patch Antenna for WLAN. *IETE Journal of Research*, *68*(1), 77–84. https://doi.org/10.1080/03772063.2019.1588174

Wang, L. (2023). Microwave Imaging and Sensing Techniques for Breast Cancer Detection. *Micromachines*, *14*(7), 1462. https://doi.org/10.3390/mi14071462

Wang, X., Qin, T., Qin, Y., Abdelrahman, A. H., Witte, R. S., & Xin, H. (2019). Microwave-Induced Thermoacoustic Imaging for Embedded Explosives Detection in High-Water Content Medium. In *IEEE Transactions on Antennas and Propagation* (Vol. 67, Issue 7, pp. 4803–4810). https://doi.org/10.1109/TAP.2019.2908267

Xiao, L., Xiang, Y., Zhai, Y., Shi, J., Liu, G., Wu, Y., Peng, T., & Yang, Z. (2020). Development of frequency synthesizer for Ku band surface surveillance radar. *Proceedings of 2020 IEEE 3rd International Conference of Safe Production and Informatization, IICSPI 2020*, 411–414. https://doi.org/10.1109/IICSPI51290.2020.9332374

Yuliarto, M. N. T., & Wagyana, A. (2021). Rancang Bangun Antena Mikrostrip Triangular Patch Planar Array 2x2 Elements Frekuensi 1,2 GHz untuk Penerima Video Wireless LCD Projector. *Spektral*, *2*(1), 50–57. https://doi.org/10.32722/spektral.v2i1.3801

Zhong, J., Zhao, D., & You, X. (2021). A Ku-Band CMOS power amplifier with series-shunt LC notch filter for satellite communications. *IEEE Transactions on Circuits and Systems I: Regular Papers*, *68*(5), 1869–1880. https://doi.org/10.1109/TCSI.2021.3056537