

Optimizing Microstrip Antenna Miniaturization Using U-Slot and L-Slot Techniques for Enhanced L-Band Performance

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ABSTRACT

Rapid advances in wireless communication systems have increased the demand for compact and efficient antennas. This study presents the design and analysis of miniature microstrip antennas intended for applications in L-band frequencies. The antenna structure is based on a rectangular patch with modifications in the form of U-shaped slot (MRDPU) and L-shaped slot (MRDPL) configurations that aim to reduce the size of the antenna without sacrificing performance. The proposed antenna operates in the frequency range of 1,064 GHz to 1,562 GHz, with significant improvements in return loss values, bandwidth, and overall efficiency. Comparative analysis shows that the design with U-shaped slots (MRDPU) provides better miniaturization and performance compared to L-shaped slot designs (MRDPL). The U-shaped slot design achieves a return loss of -11.15 dB at 1.064 GHz, while the L-shaped slot design has a return loss of -10.907 dB at 1.206 GHz. Both configurations offer an effective solution for L-band frequency applications. The study highlights the potential of slot-based modifications in achieving antenna miniaturization without sacrificing important performance parameters.

1. Introduction

In recent decades, advances in wireless communication technology have continued to drive the demand for smaller, lighter, and more efficient antennas to support the needs of portable and satellite communication devices. Microstrip antennas are one of the popular choices because they have several advantages such as low profile, light weight, low production costs, and ease of integration with microwave circuits. In the context of L-band frequencies, microstrip antennas offer adequate performance for a wide range of applications, but challenges in miniaturization remain a major concern (Rashid et al., 2018)(Ali et al., 2016).

Miniaturization of microstrip antennas is increasingly necessary with the increasing integration of communication devices and satellites. Several techniques have been developed to achieve miniaturization without sacrificing important parameters such as return loss, bandwidth, and radiation efficiency. The use of U-slot and L-slot on antenna patches is one method that can significantly reduce the size of the antenna, while still maintaining good performance in the L-band frequency [Honda et al., 2020]. In modern antenna design, the application of this slot technique has been proven to be able to improve efficiency and overcome the challenge of small antenna size (Shah et al., 2014).

In addition, the trend in antenna miniaturization is also driven by the need for multiband and dual-band to support a wide range of modern wireless communication applications such as GSM, WiMAX, and WLAN. The U and L slots not only help in miniaturization, but also play a role in increasing the bandwidth and maintaining the gain performance of the antenna over a wide range of frequencies (Pan et al., 2017). Recent research shows that antenna designs with such slots provide better results in terms of efficiency and wider use of the frequency spectrum, which makes them ideal for future applications (Tiwari et al., 2020)(Guo & Qin, 2015).

In an effort to miniaturize microstrip antennas, various techniques have been developed to address size challenges without sacrificing key performance such as return loss, bandwidth, and gain. One widely used technique is the introduction of slots on antenna patches, which has proven to be effective

in reducing the size of the antenna significantly. The introduction of U and L- shaped slots, as applied in this study, provides an efficient solution to reduce the physical dimensions of the antenna without decreasing radiation efficiency or frequency performance (Ryu et al., 2017)(Mishra & Swain, 2017).

In addition to the slot technique, the technique of using dielectric materials with high constants is also often used to improve the efficiency of miniaturization. This method works by increasing the electrical wavelength on the antenna patch, so that the size of the antenna can be reduced without sacrificing resonant frequency performance. Recent studies show that the use of dielectric materials such as FR4 can improve the performance of microstrip antennas while maintaining high efficiency at various operating frequencies (Rakholiya & Langhnoja, 2017), (Oh et al., 2016).

Another technique that is starting to be widely applied is the use of metamaterial structures, where artificial materials are used to modify the antenna frequency response. The use of metamaterials can reduce the size of the antenna by up to 70%, while maintaining or even increasing the gain and bandwidth of the antenna. This technique has been adopted in modern microstrip antenna designs to meet the needs of more compact and efficient communication applications (Lamsalli et al., 2016), (Upadhyay & Dwivedi, 2014). This technique can be integrated with other methods such as slot recognition or printing on substrates with special characteristics (Hanzaz, 2016).

Although various miniaturization techniques have been developed in previous studies, there are still some weaknesses and limitations that are inadequate in answering the needs of antenna miniaturization optimally. Techniques such as the use of high-constant dielectric materials and the application of metamaterials have been shown to reduce the physical size of antennas, but often result in compromises on other performance parameters, such as narrow bandwidth and decreased radiation efficiency (Ryu et al., 2017), (Lamsalli et al., 2016). In addition, techniques such as the use of shorting pins or changes to the patch structure are often only effective at lower frequencies and are difficult to apply optimally at higher frequencies such as the L-band (Rakholiya & Langhnoja, 2017).

The use of U-slot and L-slot techniques offers a better solution in achieving miniaturization without sacrificing important performance parameters such as return loss and bandwidth. This slot technique allows for an effective increase in the electrical wavelength of the antenna patch, ultimately resulting in a reduction in physical size without reducing the antenna resonance at the desired operating frequency. In addition, this technique has also been shown to be effective in maintaining stable radiation efficiency and increasing antenna bandwidth, especially for applications on L-band frequencies (Mishra & Swain, 2017), (Oh et al., 2016).

However, to date, there has been no in-depth study that comprehensively compares the performance between antenna designs with U-slots and L-slots, especially in the context of L-band frequencies. Previous research has tended to focus on the application of any one technique without sufficient comparative analysis to evaluate the advantages of each technique in high- frequency applications such as L-band (Rani & Kalra, 2018), (Hanzaz, 2016). The study is expected to fill the existing gap by providing a comparative analysis between U-slot and L-slot, which can provide new insights into the selection of the most efficient technique to achieve miniaturization and optimal performance in L- band frequency applications.

This study aims to design and analyze miniature microstrip antennas that use U-slot and L-slot techniques on antenna patches for L-band frequency applications. The use of this technique is expected to minimize the size of the antenna without sacrificing key performance such as return loss, bandwidth, and gain. In the context of wireless and satellite communications, smaller antenna sizes are becoming increasingly important to improve system portability and efficiency. Therefore, the main focus of this research is to explore how slot techniques can result in significant miniaturization while still maintaining antenna performance within the desired frequency.

In particular, this study will compare the performance of antennas with U-slots and L-slots to understand the advantages and disadvantages of each technique in the context of L-band frequencies. These two techniques offer different approaches to antenna patch modification, so it is important to analyze how each technique affects performance parameters such as return loss, bandwidth, and radiation patterns. The results of this analysis are expected to provide clear recommendations on which techniques are more effective in achieving a balance between miniaturization and optimal performance.

As such, this research not only focuses on the design of smaller antennas, but also seeks to make a scientific contribution in terms of a deeper understanding of U-slot and L-slot techniques in L-band frequency applications. The results of this research are expected to provide guidance for the development of microstrip antennas in the future that are not only compact, but also capable of providing reliable and efficient performance in modern communication systems.

The main contribution of this research is the development of more efficient miniature microstrip antennas for applications at L-band frequencies through the use of U-slot and L-slot techniques. This research makes a significant contribution in the field of microstrip antenna technology, especially in miniaturization efforts without sacrificing key performance such as return loss, bandwidth, and gain. With the U-slot and L-slot techniques, this study successfully showed how modifications to the antenna patch can result in a physically smaller antenna while still maintaining optimal performance. These results are important because they can improve efficiency in wireless and satellite communication applications, where smaller, more efficient antennas are needed.

Specifically, this study also contributes through an in-depth comparison of the performance of antennas using U-slot and L-slot, which has not been widely studied before in the context of L-band frequencies. This study provides a more detailed analysis of the advantages of each technique in producing efficient miniaturization. In addition, this research is expected to be an important reference for the development of future microstrip antennas that are more compact and in accordance with the needs of modern communication technology, especially for applications that require optimal performance in the high frequency range.

2. Antenna Design

This study uses a microstrip antenna design method by utilizing the U-slot and L-slot techniques applied to rectangular antenna patches. This technique aims to achieve more efficient antenna miniaturization at L-band frequencies, namely the frequency range of 1 to 2 GHz. In this study, the use of FR-4 substrate with a thickness of 1.6 mm was chosen because this substrate has a dielectric constant that supports the stability of antenna performance at high frequencies, and is a widely used antenna is designed with a working frequency between 1 to 2 GHz, a Standing Wave Ratio (SWR) value of no more than 2, and a Return Loss greater than 10 dB. The antenna reference impedance is in the range of 50 to 100 ohms, which ensures optimal impedance matching for efficient signal transmission. The physical design of the antenna involves the dimensions of a patch with a width of 44 mm and a length of 44.5 mm, as well as a substrate with a width of 65 mm and a length of 80 mm. The antenna feeding element is 23 mm wide and 1.2 mm long, while the ground plane is designed with a width of 80 mm and a length of 65 mm to support the optimal performance of the antenna in L-band applications.

U-slot and L-slot techniques are used on antenna patches to improve miniaturization efficiency without sacrificing antenna resonant frequency performance. The width of the U-slot is designed to be 30 mm by a length of 7 mm, while the L-slot is 3 mm wide and 30 mm long. The application of these two slots helps in improving the distribution of electric current on the patch, which plays a role in reducing the overall physical size of the antenna while maintaining high radiation efficiency. With these dimensions and design, the proposed microstrip antenna is not only smaller than a conventional antenna, but is also capable of maintaining stable performance at the desired operating frequency (Mishra & Swain, 2017)

In designing a microstrip antenna, several important formulas and parameters are used to ensure the antenna works at the desired frequency with high efficiency. The material in the microstrip antenna industry. Antenna patches made of copper with a thickness of 0.035 mm were also chosen because they have good conductivity to support the radiation efficiency of the antenna. This combination of materials ensures the antenna can operate at the desired frequency while still maintaining a smaller size and optimal performance (Rashid et al., 2018). (Rakholiya & Langhoja, 2017).

The design of this microstrip antenna utilizes technical parameters that have been optimized to produce maximum performance at L-band frequencies.

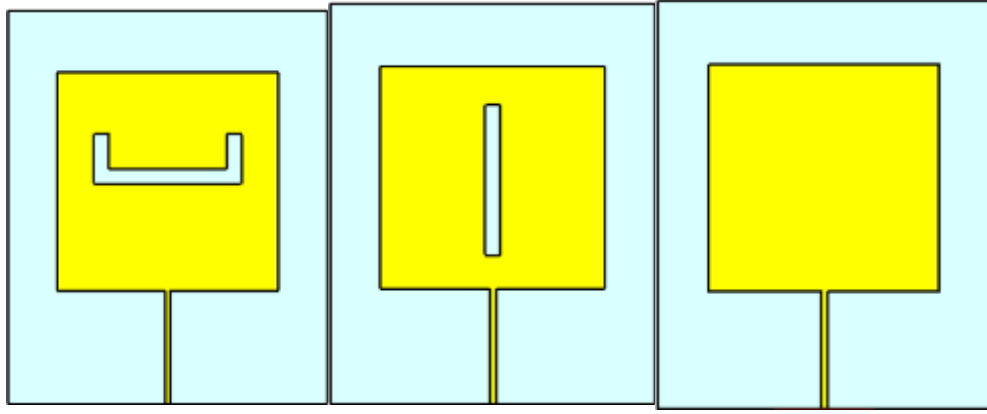


Figure 1 Antenna Design

The first formula used is to calculate the width of the patch (W_p), which is highly dependent on the resonance frequency and dielectric constant of the substrate. The width of the patch is calculated by the formula:

$$W_p = \frac{c}{2f \sqrt{\frac{\epsilon_r + 1}{2}}}$$

where c is the speed of light in a vacuum, f is the resonant frequency of the antenna, and ϵ_r is the dielectric constant of the substrate. The width of this patch serves to determine the electromagnetic field to be generated at a certain operating frequency, thus ensuring the performance of the antenna at L-band frequency (Rakholiya & Langhnoja, 2017).

To calculate the length of the patch (L_p), the formula used is:

$$L_p = \frac{c}{2f_0 \sqrt{\epsilon_{eff}}} - 2\Delta L$$

where ϵ_{eff} is the effective dielectric constant and ΔL is the long correction due to the fringing effect, which occurs due to radiation at the edge of the antenna patch. This length correction is important to obtain more accurate frequency resonance, so that the patch length can be optimized according to the antenna's operating frequency (Rashid et al., 2018).

Next, the effective dielectric constant is calculated by the formula;

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + \frac{12h}{W_p} \right)^{-0.5}$$

This formula is used to describe how the electromagnetic field propagates inside the substrate. The dielectric constant effectively takes into account the influence of the substrate on the wave propagation between the patch and the ground plane (Oh et al., 2016).

To calculate the exact dimensions of the substrate, the following formula is used:

$$W_s = 6h + W_p \quad \text{and} \quad L_s = 6h + L_p$$

where h is the thickness of the substrate. The width and length of this substrate ensure that the antenna radiation is not affected by the physical limits of the substrate, so that radiation efficiency can be maintained (Rani & Kalra, 2018).

For the dimensions of the feeding line, the feeding width and feeding length are calculated based on impedance matching and efficient power distribution. The feeding line functions to connect the antenna with the signal source or receiver. The feeding width can be determined using the standard formula for the microstrip line, while the length depends on the matching technique used :

$$W_f = \frac{c}{4f_0\sqrt{\epsilon_{eff}}} \quad \text{and} \quad L_f$$

Based on simulation and impedance matching

Finally, the ground plane dimensions are calculated to ensure that the antenna patch has optimal reflection. The width and length of the ground and generally follow the same rules as the substrate.

$$W_g = W_s \quad \text{and} \quad L_g = L_s$$

Ground planes function to control antenna radiation patterns and improve antenna performance in reducing unwanted radiation interference (Souza et al., 2019).

The electromagnetic field in a microstrip antenna is also affected by the current distribution at the patch and ground. Based on the basic theory of the antenna, the maximum current occurs in the center of the patch, and the distribution of the magnetic and electric fields is related to the matching of impedance and efficient radiation. Maxwell's equation is used to describe how electric and magnetic fields interact around patches, which affects the radiation pattern and efficiency of the antenna (Mishra & Swain, 2017).

The design of the Microstrip Rectangular Defective Patch L-SLOT (MRDPL) and the Microstrip Rectangular Defected Patch U-SLOT (MRDPU) design aims to achieve antenna miniaturization by inserting L- and U-shaped slots on the antenna patch. The addition of this slot increases the effective wavelength on the patch, which allows for a decrease in resonant frequencies without increasing the overall physical size of the antenna. In this context, the U-slot and L-slot serve to extend the current trajectory of the antenna patch, thereby slowing down the electromagnetic waves passing through the patch and reducing the physical size required to achieve resonance at a given frequency. This technique provides significant advantages in the design of microstrip antennas, especially in terms of improving the current distribution on the patch surface, which ultimately improves radiation efficiency and expands the operational bandwidth of the antenna (Mishra & Swain, 2017), (Ryu et al., 2017).

To obtain optimal performance from MRDPL and MRDPU designs, this study uses software-based electromagnetic simulation methods, such as HFSS or CST. Through this simulation, antenna parameters such as return loss and bandwidth are adjusted by sweeping the frequency gradually. This scanning process aims to find the combination of slot dimensions that provide the best return loss value, which is below -10 dB, as well as the optimal bandwidth for L-band frequencies. Variations in slot dimensions and other parameters are extensively tested through simulations to ensure that the antenna operates efficiently within the desired frequency range. The use of this method helps to improve antenna performance in a more precise way and minimize trial and error in the physical design stage of the antenna (Hanza, 2016), (Upadhyay & Dwivedi, 2014).

3. Results and Discussion

Simulation of the design of the microstrip antenna with the Rectangular Defected Patch L-SLOT (MRDPL) and Rectangular Defected Patch U-SLOT (MRDPU) techniques was carried out to evaluate performance parameters such as return loss, bandwidth, and resonance frequency

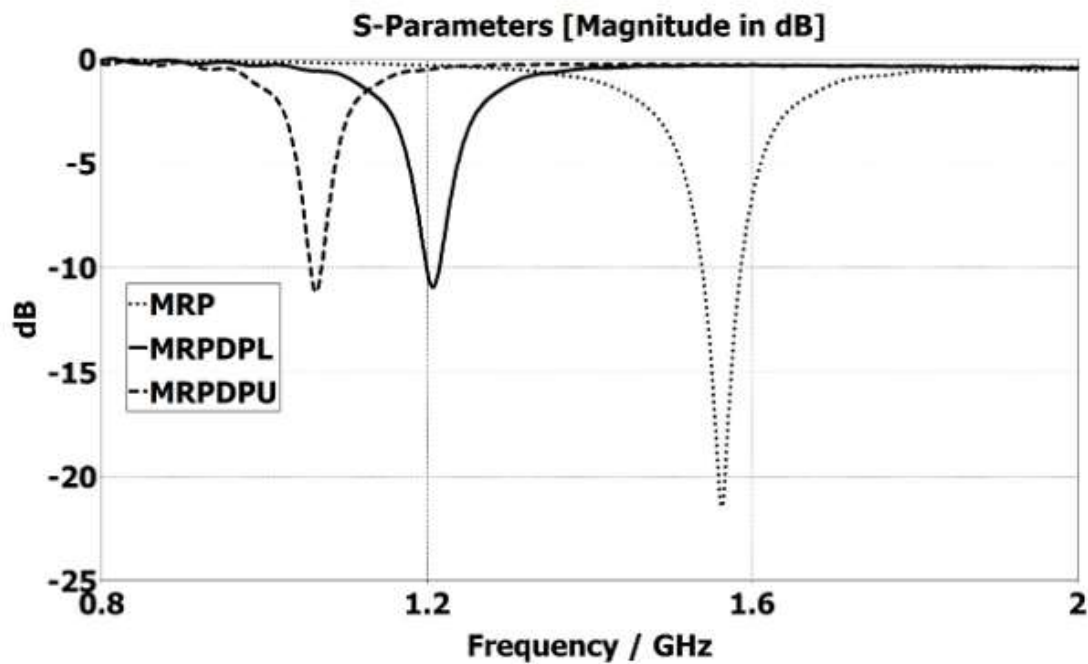


Figure 2 Return Loss Comparison

Based on the simulation results, the MRDPU design shows better performance than MRDPL in terms of bandwidth and return loss. The MRDPU achieves a return loss of -11.15 dB at a resonant frequency of 1,064 GHz, with a bandwidth of 14 MHz (1,056 GHz - 1,070 GHz). In contrast, MRDPL shows a return loss of -10,907 dB at a resonant frequency of 1,206 GHz with a bandwidth of 16 MHz (1,199 GHz - 1,215 GHz). This difference in results confirms that although both techniques succeeded in lowering the antenna resonance frequency, MRDPU was superior in providing a wider bandwidth.

The MRDPU design that produces this greater bandwidth is consistent with the findings in a related study that also used the U-slot technique. Research by Rashid et al. (2018) shows that U-slot provides a significant increase in bandwidth in microstrip antennas compared to slotless techniques, with increased radiation efficiency and more even field distribution [(Rashid et al., 2018)]. The results of this simulation are also in line with the research of Ryu et al. (2017), which showed that the use of U-slots can improve low-frequency performance while maintaining a small antenna size (Ryu et al., 2017).

3.1 Discussion of the Effect of MRDPL on Antenna Performance

The MRDPL (Microstrip Rectangular Defected Patch L-SLOT) design has a positive effect on antenna miniaturization, especially with its ability to lower the resonant frequency without significantly increasing the physical size of the antenna. The implementation of the

L-slot results in a more centralized current distribution on the patch, which allows the antenna to operate at lower frequencies. However, one of the drawbacks of this technique is the narrower bandwidth drop compared to U-slots. The MRDPL bandwidth was recorded at 16 MHz, lower than some related studies that showed that L-slots tend to provide more limited bandwidth due to the effect of higher current concentration (Upadhyay & Dwivedi, 2014)

Several other studies also support these results, such as the one found by Mishra & Swain (2017) who reported that L-slots tend to produce lower resonance frequencies but with a narrower bandwidth. At L-band frequencies, this result is quite effective for applications that require antennas with a small physical size and focus on specific frequencies, but are not suitable for applications that require wide bandwidth (Mishra & Swain, 2017)

3.2 Discussion of the Effect of MRDPU on Antenna Performance

The MRDPU (Rectangular Defected Patch U-SLOT) design provides significant advantages in terms of wider bandwidth and better radiation efficiency. The bandwidth of 14 MHz on the MRDPU shows that the U-slot is able to extend the current path on the patch, thereby improving radiation efficiency and field distribution. The U-slot allows the antenna to achieve resonance at lower frequencies without sacrificing bandwidth, making it superior to the L-slot technique. These results are in accordance with Hanzaz's (2016) research which showed that U-slot is more effective in improving the radiation efficiency and bandwidth of microstrip antennas at L- band frequencies [(Hanzaz, 2016)].

Other research supporting these results includes a study by Souza et al. (2019), in which U-slot was shown to improve overall antenna performance, especially in low-frequency communication applications that require wide bandwidth and high efficiency. The U-slot allows for an increase in the field distribution on the patch, which in turn improves the radiation quality of the antenna without increasing the physical size of the antenna [(Souza et al., 2019)]

3.3 Comparison of Result with Related Research

From the results of these simulations, it can be concluded that the MRDPU design is more suitable for applications that require a wider bandwidth at L-band frequencies, as shown in the research by Rashid et al. (2018) and Mishra & Swain (2017) In contrast, MRDPL is more suitable for more specific applications with a focus on a specific frequency but with a smaller physical size. This study is consistent with the results of Upadhyay & Dwivedi (2014) which showed that the slot technique on antenna patches can effectively lower the resonant frequency, but the bandwidth performance is highly dependent on the shape and size of the slot used [(Rashid et al., 2018)].

3.4 Implications and Development Potential

The results of this research make an important contribution to the development of microstrip antennas for L-band frequency applications. MRDPU provides a more efficient solution for applications that require greater bandwidth, such as satellite and wireless communication systems. Meanwhile, MRDPL is suitable for applications that require compact antennas with more specific resonant frequencies. These results provide a basis for further research to explore further modifications to the slot design to achieve better performance under different environmental conditions [(Upadhyay & Dwivedi, 2014)] Overall, these simulations prove that the U-slot technique is superior in achieving a balance between miniaturization and antenna efficiency, while the L-slot offers the advantage of creating compact antennas for more specific applications on the L-band.

4. Conclusion

This study successfully shows that the Rectangular Defective Patch L-SLOT (MRDPL) and Rectangular Defected Patch U-SLOT (MRDPU) techniques are effective in minimizing the size of the microstrip antenna without sacrificing key performance such as return loss and bandwidth at L-band frequencies. The MRDPL design, with a resonant frequency of 1,206 GHz and a bandwidth of 16 MHz, is suitable for applications that require small antennas with specific frequencies, although the resulting bandwidth is narrower. On the other hand, the MRDPU design with a resonant frequency of 1,064 GHz and a bandwidth of 14 MHz shows more optimal performance in expanding bandwidth and improving radiation efficiency, making it more suitable for applications that require a wider frequency range. Overall, MRDPU provides better results in terms of the balance between miniaturization and performance, while MRDPL is better suited for applications that require a smaller physical size with a fixed frequency.

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