Comparison of RF Characteristics of a Novel OCSRR Embedded Triangle Antenna with a Triangle Slot Antenna for L-Band Applications

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Keywords: Novel OCSRR Embedded Triangle Antenna, Triangle Slot Antenna, RF Performances, Return Loss, Gain, VSWR, Antenna Design, HFSS, Communication Technology.

Abstract: This study aims to assess and compare the radio frequency (RF) efficiency of a Novel Open Complementary Split Ring Resonator (OCSRR) embedded in a triangular antenna with that of a triangular slot antenna, operating at a frequency of 1.8 gigahertz and a characteristic impedance of 50 Ω for L band applications. Materials and Methods: The RF performance of the unique OCSRR-embedded triangular antenna and the triangular slot antenna was evaluated at a characteristic impedance of 50 Ω, utilizing return loss, gain, and Voltage Standing Wave Ratio (VSWR) as performance indicators. A total of 34 measurements were taken, with 17 measurements for each type of antenna. Results: The Novel OCSRR-embedded triangular antenna exhibited notable enhancements in gain, VSWR, and return loss when compared to the triangular slot antenna. Specifically, the Novel OCSRR-embedded triangular antenna displayed a return loss of -24.1400 dB, a gain of 2.42 dB, and a VSWR of 1.0799. In contrast, the triangular slot antenna had a return loss of -17.5379 dB, a gain of 1.208 dB, and a VSWR of 1.3062. Both antennas shared dimensions of 85mm by 80mm. Statistical analysis demonstrated the significance of these results, with p-values for return loss, VSWR, and gain being 0.024, 0.000, and 0.000 respectively ($p<0.05$). Conclusion: The OCSRR-embedded triangular antenna outperforms the triangular slot antenna, showcasing substantially improved performance characteristics.

1 INTRODUCTION

The primary goal of the ongoing research is to utilize the HFSS (High-Frequency Structure Simulator) program to model and compare the radio frequency (RF) capabilities of two distinct antenna designs: the Novel Open Complementary Split Ring Resonator (OCSRR) Embedded triangular antenna and a triangular slot antenna. This comparison is focused on a specific frequency of 1.8 GHz and a characteristic impedance of 50 ohms. The term "OCSRR" refers to a resonator configuration commonly utilized in antenna design. The term "complementary" denotes that the resonator consists of two complementary components, often taking the form of split rings. A previous study (Pandeeswari et al 2021) aimed to enhance the isolation properties of antennas. In this work, a three-layered aperture combined with a two-element metamaterial (MTM) antenna was employed. The enhancement was achieved through a strategic arrangement involving rectangular Complementary Split Ring Resonators (CSRR) placed between circular non-bianisotropic CSRR emitting elements. By arranging the Metamaterial Negative Index (MNG) structure within the frequency spectrum and maintaining a separation equivalent to 0.11 times the wavelength ($\lambda 0$) between the two antenna components, an impressive maximum isolation of 47 dB was realized.

The ongoing research expands upon this previous work by examining the RF capabilities of the Novel OCSRR Embedded triangular antenna and the triangular slot antenna. This investigation employs the HFSS program at the 1.8 GHz frequency and a characteristic impedance of 50 ohms. The goal is to gain insights into the performance characteristics of these antenna designs, with the potential to contribute to the advancement of RF communication and signal processing technologies.

The proposed antenna design exhibits several key performance metrics that contribute to its effectiveness. It achieves a peak gain of 8.15 dB, and its bandwidth impedance maintains a proportional decline of -10 dB within a range of 18.94%. The

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efficiency of the antenna is measured at 84.14%, indicating its ability to convert input power into radiated electromagnetic waves efficiently. Additionally, the antenna's operating-band envelopes correlation factor is impressively low, measuring less than 0.03. These parameters collectively contribute to the antenna's robust performance and suitability for various applications.

In a related study (Reddy et al 2023), the research focuses on the design and modelling of square Split Ring Resonators (SSRR) both with and without triangular slots at a frequency of 10 GHz. The return loss and bandwidth efficiency of SSRR with a triangular slot are compared to those of SSRR without a slot. The analysis is conducted across the bandwidth up to 10 GHz. The study uses a sample size of 56 specimens, with a statistical power of 80% and an alpha value of 0.05. The results indicate that SSRR with a triangular slot outperforms SSRR without a slot in terms of return loss and bandwidth efficiency. Parameters such as Lb (width of the triangular slot), Wb (width of SSRR), and Tb (thickness of SSRR) are finely tuned to achieve improved performance.

Furthermore, another work (Sukanya et al 2021) presents a novel patch antenna design that incorporates a meandering coplanar waveguide (CPW) feed and complementary split ring resonator (CSRR). By introducing slots and meandering CPW feed on the emitting component, a highly efficient triple-band antenna structure is formed. The inclusion of engraved circles beyond the patch and metamaterial slots, along with a modified ground plane, allows for the creation of a compact triple-band antenna. The antenna performs well across various resonant levels, exhibiting increased bandwidth, favourable return losses, and low VSWR. The research delves into discussions and comparisons of modelled outcomes for different designs, including variations in etching patterns and parametric analyses for ring widths and radii.

Overall, these studies showcase innovative approaches to antenna design and optimization, highlighting the importance of performance metrics such as gain, bandwidth, efficiency, and return loss in achieving efficient and effective RF communication capabilities.

The following paper (Al-Bawri et al 2020) presents WLAN, 5G Wi-Fi and LTE-A technologies, applications in S-band (Prakash et al 2023), and multiband radio applications (Christydass & Gunavathi 2022).

2 RELATED STUDY

The field of antenna research has seen significant attention recently, with numerous publications emerging in reputable platforms. Within the IEEE database, 84 papers have been published, while a substantial 1820 papers have appeared in Google Scholar within the past five years. One study (Nurhayati et al 2022) proposes a novel approach to address the requirements of the 28 GHz 5G network connectivity by introducing a trilateral Microstrip Patch Antenna (MPA) utilizing a combination of CPW (Coplanar Waveguide) and DGP (Defective Ground Plane) techniques. The antenna design employs the Rogers RT 5880 substrate, characterized by a loss tangent of 1.9, relative permittivity of 2.2, and a substrate height of 0.5 mm. Model findings indicate a return loss of approximately -20 dB and a voltage standing wave ratio (VSWR) of 1.2. Operating within the range of 27.85 GHz, the antenna achieves its performance through the manipulation of feed length, feed width, and patch size. The measured bandwidth of the antenna is 2.036 GHz. Another study (Parandhaman 2023) presents an antenna design featuring a triangular patch, optimized for Wireless Local Area Network (WLAN) use at 5 GHz. The antenna's performance is evaluated using CST Studio Suite 2021 and is constructed using a milling device. The proposed architecture demonstrates the feasibility of WLAN 5 GHz operation. With a gain exceeding 2 dB, the antenna achieves a 50 Ohm impedance match. The antenna's dimensions are 27.5 mm by 25.2 mm by 1.6 mm. At 5.0964 GHz, the antenna showcases a VSWR of 1.04 and an S11 value of 33.94 dB. These modelling results indicate that the antenna design aligns with the requirements of WLAN 5 GHz operation. The substrate material utilized is FR4.

These publications underscore the ongoing efforts to develop innovative antenna designs that cater to the specific needs of modern communication systems, including 5G networks, WLANs, and beyond.

The Triangular slot antenna has been associated with a drawback of low RF performance. To overcome this limitation, various endeavors have been undertaken to enhance its performance parameters. These efforts involve modifications and adjustments to the antenna layout, particularly in terms of the positioning and location of the slot within the patch. This research aims to address these challenges by evaluating and comparing the RF performance of two distinct types of antennas at a frequency of 1.8 GHz.

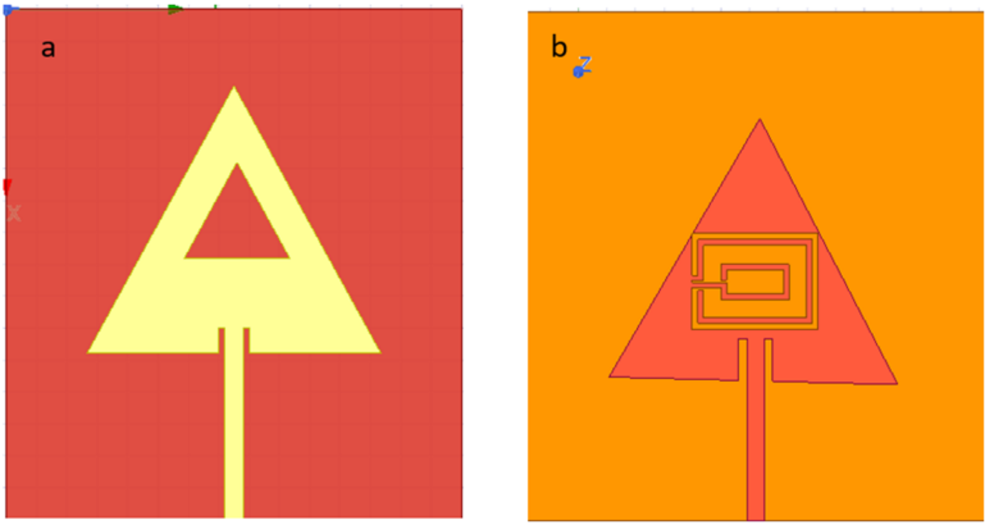

Figure 1: (a) Proposed OCSRR Embedded triangle antenna 9b) Triangular Slot Antenna configuration. The first type of antenna under investigation is a unique triangle antenna featuring an Open Complementary Split Ring Resonator (OCSRR) embedded within it. The second type is a conventional triangle slot antenna. By examining the performance of these antennas, the research seeks to uncover strategies and approaches that can effectively enhance the RF performance of antennas with triangular geometries. The study's findings have the potential to contribute valuable insights into improving the design and efficiency of such antennas for various applications.

3 METHODOLOGY

In this section, the methodology employed in the study is outlined. The research involves the comparison of two distinct preparation procedures, denoted as Group 1 and Group 2. For Group 1, the research involves designing and simulating a Novel OCSRR Embedded triangular antenna using HFSS software. The dimensions of various primary elements, including the earth, base material, segment, transmission line, and supply, are presented in Table 1. HFSS software is utilized to model and develop the Novel OCSRR Embedded triangular antenna as per the specified dimensions. Similarly, Group 2 follows a similar procedure to Group 1. The research designs and simulates a triangular slot antenna using HFSS software. The software facilitates the modelling and design process of the triangular slot antenna, leading to the determination of component dimensions, which are presented in the relevant table. By comparing the outcomes of these two preparation procedures, the study aims to draw meaningful insights into the performance and effectiveness of the antennas in question.

High-Frequency Structure Simulation (HFSS) is a widely used electromagnetic simulation software tool for designing antennas, radio frequency components, and various other high-frequency electrical devices. HFSS is a part of the comprehensive Ansys suite

Table 1: Dimensions of The Innovative OCSRR-Embedded Triangle Antenna and Triangle Slot Antenna.

Variables	Group 1 values	Group 2 values
Frequency of Resonance	1.8GHz	1.8GHz
Material of substrate	FR4_epoxy	FR4_epoxy
Length of substrate (Lsub)	85mm	80mm
Width of substrate (Wsub)	80mm	75mm
Substrate Thickness	3.6mm	3.6mm
Ground plane length (Lg)	85mm	80mm
Ground plane width (Wg)	80mm	75mm
Width of the patch (Wp)	50.55mm	48.49mm
Length of the patch (Lp)	50.55mm	48mm
Length of feed	3.6mm	3.6mm
Width of feed	3mm	3mm
Length of feedline	30.38mm	30mm
Width of feedline	3mm	3mm
Feedline gap	1.5mm	1mm
Length of inner patch	Line Feed	Line Feed

suite of simulation tools. In this study, HFSS was employed to analyse and measure the radio frequency (RF) performance of two types of antennas: the unique triangular antenna with OCSRR embedded and the antenna with a triangular slot. The analysis was conducted by configuring HFSS to operate at a frequency of 1.8 GHz and then recording and analysing the simulation results. To analyse the collected data and draw meaningful conclusions, the statistical software SPSS (Statistical Package for the Social Sciences) was utilized. SPSS is commonly used for analysing data, computing standard deviations, calculating mean values, and identifying statistically significant differences in simulation data. This statistical analysis assists in interpreting the outcomes of the simulations and determining the performance characteristics of the antennas under consideration.

Position a layer of material (substrate) over the ground plane, and then position a piece of material (patch) over the substrate. Table 1 displays the information regarding measurements that was used to make the triangular pattern above the patch. Having employed FR4 epoxy as the stabilized substrate material, a feed mechanism was affixed to the patch element. The design was looked at and the results were verified. For the Group 2 samples, the identical process was used, but modifications to the patch's size and design were made in accordance with the values shown in Table 1. These procedures aided the modelling and evaluating process, allowing the attainment of the required outcomes for both the novel OCSRR embedded triangle patch antenna (Group 1) and the triangle slot antenna (Group 2), which were both new antenna designs.

3.1 Statistical Analysis

SPSS and HFSS played vital roles in this study, with HFSS for modelling/validation and SPSS for statistical investigation. Frequency and dielectric depth were the only variables that were independent taken into account in the examination, whereas other variables changed. At the opposite hand, the dimension, placement, and impedance matching of the patch were among the variables that depended factors being examined. To comprehend their effects and behaviours inside the antenna system, these factors underwent rigorous examination.

4 RESULTS

The unique triangle OCSRR embedded and the antenna with triangular slot were successfully constructed and tested at 1.8 GHz on a 50ohm characteristic impedance. The given dimensions were used in the input testing technique, and the result was generated by the setting limits and energizing factors. The resulting graph was put into SPSS for evaluation of statistics after being sent out as an Excel document. The suggested dimensions and processes increased performance. Tables 2 and 3 provide a comparison of RF performance between two antennas operating at 1.8 GHz: the Novel OCSRR Embedded triangle antenna and the triangle slot antenna. The Novel OCSRR design shows better results in key metrics: Return Loss: Novel OCSRR: -24.1400 dB, Triangle Slot: -17.5379 dB. VSWR: Novel OCSRR: 1.0799, Triangle Slot: 1.3062. Gain: Novel OCSRR: 2.42, Triangle Slot: 1.208.

Clearly, the Novel OCSRR Embedded triangle antenna exhibits superior performance, making it preferable for L-band applications. Figure 1a presents visual depictions of the upper and frontal viewpoints of the distinctive triangular antenna, highlighting its incorporation of OCSRR. In contrast, Figure 1b illustrates these identical perspectives, but pertains to the antenna employing a triangular slot. The performance results of the suggested design are showcased in Figure 2. On the contrary, Figure 4 showcases a bar chart that aptly differentiates the return loss and VSWR performances of the two antennas. This comparison accentuates the consistent superiority of the Novel OCSRR Embedded triangular antenna over its counterpart, the triangle slot antenna, in both aspects of performance.

5 DISCUSSION

The RF performances of both the Novel OCSRR Embedded triangular antenna and the triangular slot antenna were designed and evaluated. In terms of RF performance, the Novel OCSRR Embedded triangular antenna exhibited superior performance compared to the triangular slot antenna. The data was then recorded in a CSV file and validated using the SPSS software.

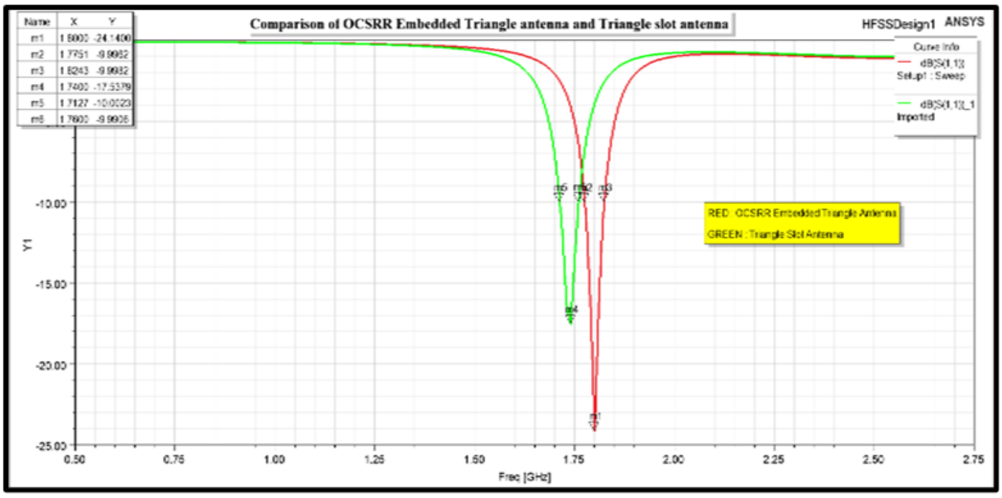

Figure 2: Comparing the unique OCSRR triangular antenna (-24.1400 dB) and triangle slot antenna (-17.5379 dB) by its performance in return loss.

Table 2: Comparative Antenna Performance: OCSRR Triangle Patch vs. Triangle Slot Antenna.

Antenna	RL (dB)	VSWR	Gain (dB)	Bandwidth (MHz)
OCSRR antenna	-24.1400	1.0799	2.42	49.2 MHz
Triangle slot antenna Antenna	-17.5379	1.3062	1.208	47.3 MHz

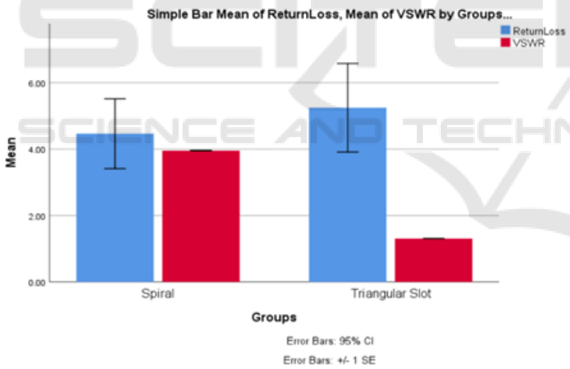

Figure 3.

Triangle slot antenna performance compared to unique OCSRR Embedded triangle antenna in a bar chart for Return Loss, VSWR, and Gain. The OCSRR Embedded triangular antenna has a high return loss performance (blue bar), a low VSWR performance (red bar), and a high gain performance (green bar). The performance of an OCSRR Embedded triangle antenna appears to be superior to that of a triangle slot antenna. The research presents the modelling and analysis of the Novel OCSRR Embedded triangular antenna and the triangular slot antenna with a characteristic impedance of 50 ohms at 1.8 gigahertz. In a related experiment (Ayyadurai et al 2021), wireless power transfer at 2.4GHz is achieved using a triangular MPA (Microstrip Patch Antenna). The initial operation of the basic patch antenna is examined, followed by the implementation of an updated layout to enhance its effectiveness and transmission ratio. By tuning the dimensions of the basic patch to 56 mm, a reflection coefficient of -28.2 dB is achieved at the resonance frequency of 2.4 GHz. A similar patch is positioned 50mm away from the primary patch to serve as a receiver, allowing the measurement of power transmitted between them. The transmission coefficient between the two patches at the resonant frequency of 2.4 GHz is found to be -3.5 dB. This paper aims to design and evaluate a novel dual-band patch antenna with a rectangular microstrip for frequencies of 3.8 GHz and 5 GHz, aiming to reduce return loss (in decibels) compared to the triangle patch antenna, as detailed in references (Khan and George 2022) (Paramasivam et al 2021). Copper is used for the patch and ground, while FR4 epoxy serves as the substrate layer. By adjusting the antenna's resonance frequency, a total of 10 measurements are collected for each of the two groups. Ansoft HFSS, version 13.0, is used for efficiency analysis, with a statistical power (G Power) set at 80% and a sample size of 20. Both simulation and experimental data reveal a reduction in return loss for the dual-band patch antenna with a rectangular microstrip, reaching -25.6 dB and -25.9 dB at radio frequencies of 3.8 GHz and 5.0 GHz, respectively.

The size of the patch and the operating frequency are two pivotal factors that significantly impact an antenna's gain performance. The functional size of an antenna exhibits an inverse relationship with its gain at a specific frequency. Moreover, the physical length of the antenna is inversely linked with both its radiation resistance and the square root of its gain across the frequency spectrum. Due to tolerance considerations, an antenna's gain remains equal during signal transmission and reception. Enhancing an antenna's gain can be achieved through various approaches, such as incorporating alternative substrates and metamaterials onto the patch. Additionally, gains can be improved by implementing strategies like introducing partial slots in the substrate or employing multi-layer dielectric substrates.

6 CONCLUSION

The present study aimed to assess the gain and return loss characteristics of both the distinctive OCSRR Embedded triangle antenna and the antenna equipped with a triangle slot at a frequency of 1.8GHz, with the intention of enhancing their RF efficiency. The results revealed that the unique triangle antenna with OCSRR embedding exhibited superior performance compared to the triangle slot antenna (Return Loss: -24.1400, Gain: 2.42, VSWR: 1.0799). Consequently, the Novel OCSRR Embedded triangle antenna emerges as a more viable choice for applications in the L-band frequency range.

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