Comparative Analysis of various Slot in Patch Antennas: A Review

Sumit Kumar Khandelwal
Electronics and Communication Engg.
Delhi Technological University
Delhi, India
sumit.khandelwal@dtu.ac.in

Anupam Verma
Electronics and Communication Engg.
Delhi Technological University
Delhi, India
iamanupamv@gmail.com

Amarnath Yadav
Electronics and Communication Engg.
Delhi Technological University
Delhi, India
amarnathyadav312696@gmail.com

Arpan Goyal
Electronics and Communication Engg.
Delhi Technological University
Delhi, India
arpangoyal2002@gmail.com

***Abstract*—In the ever-evolving landscape of wireless communication, the demand for compact, high-performance antennas spanning a broad frequency range has become paramount. Microstrip patch antennas have emerged as a promising solution for fulfilling this demand, offering versatility and adaptability in various configurations. This research delves into a comparative analysis of different microstrip patch antenna designs tailored for broadband applications in the 2.4-6 GHz frequency range. As wireless technologies continue to advance, understanding the nuances of antenna performance becomes pivotal in achieving optimal communication systems. By scrutinizing the characteristics of E-shaped, U-shaped, Hexagonal, Circular, H-slot, Octagonal, and Rectangular microstrip patch antennas, this study aims to provide valuable insights that will inform the selection and design process for future wireless communication applications. The investigation spans crucial parameters such as bandwidth, gain, radiation pattern, return loss, impedance matching, and antenna efficiency, aiming to distill practical considerations for engineers and researchers working on the forefront of electronics and communication engineering.**

Keywords—Microstrip Patch Antenna, Gain, Return Loss, Impedance Matching, Antenna Efficiency, Bandwidth, U-shaped, Rectangular, E-shaped, Hexagonal, Circular, H-slot, Octagonal Microstrip Antenna.

I. Introduction

The microstrip antenna, a pivotal innovation in the domain of radio frequency engineering, has played a transformative role in the evolution of wireless communication systems. Its inception can be traced back to the mid-20th century when researchers began exploring planar transmission line technologies for antenna applications. The microstrip antenna, as we recognize it today, emerged as a result of continuous refinement and adaptation to meet the demands of modern communication.

The roots of the microstrip antenna can be found in the development of microstrip transmission lines in the 1950s. Initially conceived for microwave integrated circuits, researchers soon recognized the potential of these planar structures for radiating electromagnetic waves. The transition from transmission lines to antennas marked a significant shift, with notable contributions from innovators like Robert E. Munson and George F. Engen in the 1970s, who played key roles in refining the microstrip antenna design.

The fundamental structure of a microstrip antenna typically consists of a metallic radiating patch positioned on one side of a dielectric substrate, separated by an air or dielectric gap from a conductive ground plane on the other side. This planar configuration not only simplifies manufacturing processes but also lends itself to compact and lightweight designs.

II. Literature Survey

The continual reduction in the size of mobile devices has spurred a significant surge in the development of compact antenna structures, supplanting conventional counterparts in mobile communication. Microstrip patch antennas have emerged as a highly promising solution for handheld electronic devices, thanks to their multiband capabilities and compact configurations. Comprising a rectangular patch on a dielectric substrate over a ground plane, these antennas can take diverse shapes, including octagonal configurations. Commonly fabricated with conducting materials such as Copper or Gold, microstrip patch antennas offer advantages like lightweight construction, cost-effectiveness, and simplicity in fabrication. However, despite their numerous merits, these antennas confront a substantial challenge in terms of low gain. [6] Leveraging the octagonal shape in microstrip patch antenna design optimally addresses the challenge of low gain, capitalizing on its compact and versatile configuration. This strategic utilization enhances antenna performance, offering a refined solution for efficient signal transmission in the evolving landscape of compact electronic devices.

A Microstrip patch antenna for 5G WLAN applications is proposed, operating at a frequency of 4.8 GHz and featuring an H-shaped slot within its rectangular patch. The incorporation of the H-shaped slot serves to enhance key antenna parameters such as VSWR, reflection coefficient, gain, and bandwidth.[4] The design is meticulously crafted to adhere to industrial standards set for 5G WLAN applications, ensuring optimal performance within this advanced communication context. The thin planar profile of the Microstrip patch antenna adds to its appeal, allowing for easy integration onto the flat surfaces of space-borne platforms such as aircraft and missiles. Notably, the antenna design yields a reflection coefficient of -25.44 dB and a VSWR of 1.11 at the specified frequency of 4.8 GHz, demonstrating its effectiveness in meeting stringent performance criteria for 5G WLAN applications.

In biomedical applications, the imperative for low-latency, high-bandwidth transmission of patient information necessitates advanced antenna solutions. This paper proposes a multi-band Hexagonal Shaped Meandering Antenna (HSMP) with a defected ground structure designed to enhance the bandwidth, return loss, and gain characteristics of a Microstrip Patch (MSP) antenna. Leveraging a slotted meandering approach for optimization, our experimental analysis reveals that the suggested HSMP technique outperforms other MSP antennas, exhibiting greater bandwidth and consistently higher gain.[2] Additionally, we advocate for the use of a single-layer substrate to craft a compact, shallow-rejection, low-profile microstrip patch antenna tailored for high-selectivity differential filtering. This research aims to contribute to the evolution of efficient data transmission in biomedical contexts.

The E-shaped microstrip antenna emerges as a distinctive and innovative variant in the realm of microstrip antenna designs, featuring a unique radiating element shaped like the letter 'E.' This configuration departs from traditional patch antenna shapes, providing engineers with an additional degree of freedom to tailor antenna characteristics.[3] The intricacies of the E-shaped microstrip antenna's design significantly influence key parameters such as resonance frequency, bandwidth, and radiation pattern, making it a compelling subject for in-depth exploration. As we delve into the analysis of this specific microstrip antenna type, the goal is to unravel the nuanced performance aspects that contribute to its suitability for various wireless communication applications. Understanding both the strengths and limitations of the E-shaped microstrip antenna is pivotal for engineers aiming to optimize antenna performance in the ever-evolving landscape of radio frequency engineering.

The U-shaped microstrip antenna stands out as an innovative configuration in microstrip antenna designs, featuring a distinctive radiating element shaped like the letter 'U.' This departure from traditional patch antenna shapes offers engineers a novel approach to tailor antenna performance for specific applications. The U-shaped design's structural intricacies play a crucial role in determining key parameters such as resonance frequency, bandwidth, and radiation pattern.[1] In exploring this microstrip antenna variant, the goal is to uncover nuanced performance characteristics that define its utility in modern communication needs. Notably, the U-shaped microstrip antenna presents advantages such as enhanced bandwidth, addressing wideband performance requirements. Its compact and space-efficient nature makes it ideal for integration into portable devices or systems with limited space. Additionally, the U-shaped geometry influences radiation characteristics, leading to improved directivity and radiation efficiency, further enhancing its appeal in wireless communication applications.

The circular microstrip antenna emerges as a notable and versatile design within the microstrip antenna landscape, characterized by its circular radiating element. This configuration has garnered attention for its unique advantages in wireless communication systems, particularly its ability to achieve an omnidirectional radiation pattern, making it well-suited for applications requiring consistent signal coverage in all directions. Delving into the intricacies of the circular microstrip antenna, we explore its design principles, fabrication simplicity, and performance attributes. Notably, the circular shape not only streamlines the fabrication process by eliminating complex structures but also contributes to cost reduction. Beyond its simplicity, these antennas often exhibit robust impedance matching, facilitating efficient power transfer between the antenna and the transmission line.[5] This multifaceted appeal positions circular microstrip antennas as valuable components in diverse communication scenarios, especially where signal uniformity, ease of fabrication, and impedance matching are paramount.

III. Parameters

A. Gain

The review paper explores various antenna designs, each tailored to optimize specific parameters such as gain, return loss, and directivity. The hexagon-shaped antenna is crafted for high throughput biomedical applications, operating at 2.4 GHz with a VSWR less than 2 and achieving a gain of 3 dB[2]. This superior gain can be attributed to the hexagon's geometric characteristics, providing an increased aperture size that captures and concentrates more electromagnetic energy. The enhanced directivity, a result of the hexagon's complexity, further amplifies the gain. The optimization of return loss characteristics and the incorporation of sophisticated matching networks contribute to the overall efficiency of power transfer, making the hexagon-shaped antenna well-suited for higher gain applications.

Similarly, the circular microstrip patch antenna designed for 5G applications at 3 GHz stands out with a high gain of 10.0 dB[5]. Circular patch antennas achieve this high gain through their circular geometry, ensuring a uniform radiation pattern for omni-directional coverage. Symmetry in design facilitates focused and directive radiation, while resonance at the desired frequency ensures efficient energy radiation. Low cross-polarization and low side lobes contribute to the concentration of energy in the main lobe. Surface wave suppression minimizes energy loss, and the simplicity of their structure makes circular patch antennas cost-effective and easy to integrate.

In contrast, the U-shaped antenna excels in gain with a transmitter gain value of 8.019 dBi at the resonating frequency band of 2 to 4 GHz[1]. The U-shaped structure creates a resonant cavity that enhances radiation efficiency, allowing for the concentration and redirection of electromagnetic waves. This results in a more focused radiation pattern, promoting impedance matching, and maximizing power transfer. The curved arms of the U-shaped antenna act as directors, further concentrating radiation in the desired direction. This overall geometry allows for fine-tuning, optimizing performance for specific frequency bands, making the U-shaped antenna a robust choice for applications where high gain and directional radiation are crucial.

The E-shaped antenna, operating at about 6.23 dB gain over its frequency range, showcases its ability to achieve high gain attributed to several key factors[3]. The E-shaped configuration creates multiple radiating arms, increasing the effective aperture of the antenna. This larger aperture allows for the capture and concentration of more electromagnetic energy, resulting in improved gain. The arms of the

E-shaped antenna act as directors, aiding in focusing radiation in a specific direction. The geometry allows better control and manipulation of the electric field, contributing to enhanced radiation efficiency. Additionally, the design facilitates impedance matching, minimizing signal reflections, and optimizing power transfer, making the E-shaped antenna versatile and effective for applications requiring directional and efficient signal propagation.

Examining the octagonal patch antenna, the array reveals a gain increase of 6.25 dB compared to the single patch on the FR4 substrate[6]. The choice of substrate material significantly impacts the antenna's resonance frequencies and gain, with FR4 exhibiting better performance. The octagonal patch antenna demonstrates the importance of substrate selection and geometry in achieving higher gain, as well as the potential for array configurations to further enhance performance.

Lastly, the 4x1 array of rectangular patch antennas radiates with higher gain in the forward direction compared to the single patch. The array achieves a gain of 5.284 dBi, surpassing the 1.369 dBi gain of the single patch. The directivity of the array, measured at 10.59 dBi, outperforms the 6.759 dBi directivity of the single patch. This underscores the advantage of array configurations in achieving higher gain and directivity, crucial for specific applications.

In summary, each antenna design demonstrates its unique attributes in optimizing gain and related parameters. The hexagon-shaped antenna leverages its geometric characteristics, the circular patch antenna excels in uniform radiation, the U-shaped antenna emphasizes resonance and directional focus, the E-shaped antenna utilizes multiple radiating arms, the octagonal patch antenna emphasizes substrate material, and the rectangular patch array showcases the advantage of array configurations. These findings collectively contribute to the understanding of antenna design considerations for various applications, highlighting the significance of geometry, resonance, substrate material, and array configurations in achieving higher-gain

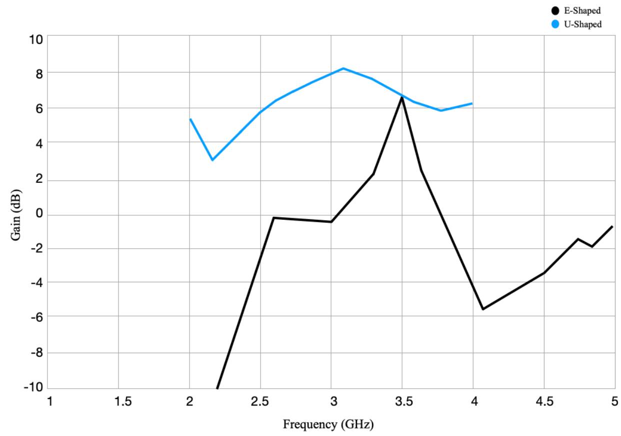

Fig. 1. E-Shaped vs U-Shaped Gain Comparison

B. Return Loss

Return loss is a measure of how much signal is reflected back to the source in a transmission system. It is commonly expressed in decibels (dB) and is defined as the ratio of the power of the reflected signal to the power of the incident signal, expressed as a negative dB value.

Return Loss (RL) can be calculated using the following formula:

$$RL\ (dB) = -\ 20\ *\ log10\left(\frac{Preflected}{Pincident}\right)$$

•RL is the return loss in decibels (dB).

•$P_{reflected}$ is the power of the reflected signal.

•$P_{incident}$ is the power of the incident signal.

Return loss is an important parameter in the characterization of transmission systems, antennas, and other RF (Radio Frequency) components. It provides information about the amount of power that is not effectively transmitted through the system and is instead reflected back.

The U-slot antenna exhibits a remarkable -45.6 dB return loss, attributed to its innovative design that introduces an extra degree of freedom, facilitating enhanced impedance matching and a broader bandwidth[1]. Through simulations, the antenna demonstrates resonance at 3.145 GHz with an impressive bandwidth resolution of approximately 19.5%. Optimal dimensions, specifically an 18 mm length and 2 mm width for the U-slot, are identified, underscoring the significance of these parameters for optimal performance.

Comparatively, the hexagonal patch antenna achieves a return loss of -24.4 dB[2], although the paper doesn't explicitly detail the reasons. Presumably, the hexagonal shape and meandering design, coupled with a defected ground structure and slotted meandering approach, contribute synergistically to improved performance. Meanwhile, the octagonal counterpart exhibits a slightly lower -23.9 dB return loss[6], suggesting a close performance to the hexagonal shape, potentially hinting at the influence of shape geometry on the antenna's characteristics. Overall, the study underscores the importance of geometric variations in achieving superior antenna performance.

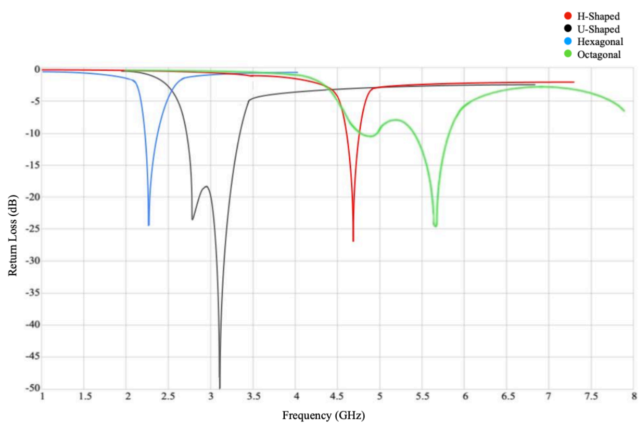

Fig. 2. H vs U vs Hexagonal vs Octagonal Shaped return loss Comparison

C. Impedance Matching

Impedance matching is a crucial concept in electronics, particularly in antenna design, to ensure efficient power transfer between components. It involves adjusting the electrical impedance of connected elements to achieve maximum energy transfer and minimize signal reflections. In the context of antennas, proper impedance matching enhances performance, optimizing signal strength and minimizing losses. Achieving impedance matching involves tuning parameters such as the dimensions of antenna elements and transmission lines. This ensures that the source and load impedances align, preventing signal degradation and enhancing overall system efficiency, a vital consideration for reliable communication systems and electronic devices.

In antenna design, achieving optimal impedance matching is pivotal, and the U-slot antenna presented in this paper exemplifies a successful approach. Operating at 3.1245 GHz, it attains a notable impedance matching bandwidth of 19.5%, a result of meticulous adjustments to the U-slot and patch dimensions[1]. The prescribed slot length and width of 18 mm and 2 mm, respectively, emerge as optimal values for heightened performance, underscoring the critical role of these parameters in impedance optimization. Notably, the designed patch impedance aligns precisely with the resonant frequency, further contributing to effective impedance matching. The reported VSWR of 1.01 at the resonant frequency of 3.1245 GHz adds quantitative support to the antenna's impedance-matching prowess.

In contrast, the E-shaped antenna in the same study focuses on impedance matching between the radiating patch and the transmission feed line[3]. The authors highlight successful impedance matching to a 50Ω standard within the frequency range of the WiMAX operational band, ensuring good efficiency assets for the lanthanides-doped Magnesium ferrite antenna. This emphasizes the versatility of approaches employed in achieving impedance matching across different antenna designs.

D. Antenna Efficiency

Antenna efficiency is a critical metric that gauges the effectiveness of an antenna in converting electrical power into radiated electromagnetic waves. Expressed as a percentage, antenna efficiency accounts for various losses encountered in the antenna system, such as ohmic losses in the conductive elements, dielectric losses in the surrounding materials, and mismatch losses due to impedance mismatches. A highly efficient antenna optimally converts electrical signals into radiation, ensuring that a significant portion of the input power contributes to the desired electromagnetic field. Efficient antennas are pivotal in communication systems, as they enhance signal transmission range, improve overall system performance, and contribute to minimizing power consumption. Design considerations, material selection, and impedance matching are key factors influencing antenna efficiency, making it a crucial parameter in the development of reliable and high-performance wireless communication systems.

The review paper on the E-shaped antenna reports an efficiency of 73.32%[3]. The E-shaped antenna likely achieves this relatively high efficiency due to its carefully designed geometry. The distinctive shape of the E antenna is known for promoting desirable radiation characteristics, including improved directivity and radiation pattern control. The geometric configuration of the E-shaped antenna allows for better impedance matching, reduced losses, and enhanced radiation efficiency compared to some other antenna shapes. On the other hand, the H-slot antenna, with its increased directivity, experiences a boost in efficiency. This is because higher directivity often leads to a more focused and efficient use of radiated power[4]. In contrast, circular microstrip antennas may exhibit lower efficiency[5], possibly owing to broader radiation patterns and impedance matching challenges associated with their circular geometry. These differences highlight the importance of antenna design considerations in achieving optimal performance for specific applications, taking into account factors such as geometry, directivity, and impedance matching.

E. Bandwidth

The bandwidth of an antenna is a fundamental parameter that defines its ability to operate effectively across a range of frequencies. It represents the frequency span within which the antenna can maintain satisfactory performance, typically characterized by parameters such as acceptable radiation patterns, impedance matching, and gain. A wider bandwidth is desirable in communication systems as it allows the antenna to accommodate a broader range of frequencies, facilitating versatility in signal transmission and reception. Bandwidth considerations are particularly crucial in the context of modern wireless communication standards, where diverse frequency bands are allocated for different services. Antennas with broader bandwidths are better equipped to adapt to dynamic and evolving communication environments, making them essential components in systems requiring flexibility and adaptability to various frequency allocations and standards. Achieving optimal bandwidth often involves careful design considerations, including antenna geometry, feeding techniques, and impedance matching strategies, ensuring the antenna's effectiveness across a diverse spectrum of frequencies.

The bandwidth analysis of various microstrip antenna configurations reveals intriguing insights into their performance characteristics. The U-slot microstrip antenna, examined through S-parameter curves at a 10dB threshold[1], demonstrates a bandwidth of approximately 450MHz. However, the proposed Hexagonal patch antenna (HSPA) outshines this with a measured bandwidth of 3.2GHz, constituting a substantial 64% impedance bandwidth[4]. This improvement underscores the efficacy of the HSPA design in achieving a significantly wider frequency range, aligning well with the demands of High-Speed Packet Access (HSPA) technologies. Similarly, the utilization of an E-shaped slot proves advantageous, exhibiting enhanced bandwidth compared to a conventional microstrip antenna.

Moreover, the integration of an H-shaped patch contributes to bandwidth augmentation, with a bandwidth of approximately 140MHz derived from the S-parameter vs frequency curve[4]. Moving beyond shape variations, substrate choices also exert a considerable impact on bandwidth. For octagonal microstrip antennas across different substrates, variations in resonance frequencies and corresponding bandwidths are evident. For instance, the FR4 substrate resonates at two frequencies, resulting in a bandwidth of 200MHz and 500MHz[6], showcasing its versatility. Duroid resonates once but boasts a substantial bandwidth of 1200MHz, highlighting its superior frequency range coverage. Arlon resonates once with a bandwidth of 500MHz, and Rogers resonates once with a bandwidth of 100MHz, further emphasizing the influence of substrate selection on antenna bandwidth. These findings collectively underscore the importance of thoughtful design and material choices in optimizing the bandwidth of microstrip antennas for diverse communication applications.

TABLE I. COMPARISON OF DIFFERENT MICROSTRIP ANTENNA

	Operating Frequency (GHz)	Gain (dB)	Directivity (dB)	Return Loss (dB)	Bandwidth (GHz)
Rectangular[8]	2.4	-	5.63	-54.99	0.081
E-Shaped[3]	3.5	6.93	7.58	-9.79	0.14
U-Slot[1]	3.12	8.01	-	-45.85	0.45
Hexagonal[2]	2.4	3.01	6.2	-24.4	3.2
Circular[5]	3	10.7	6.623	-6.689	-
H-Slot[4]	4.8	-	6.46	-10.7	0.14
Octagonal[6]	4.7-4.9	3.6	-	-10.5	0.2
Octagonal[6]	5.3-5.8	3.6	-	-23.9	0.5

IV. CONCLUSION

The review paper delves into various antenna designs, each tailored to optimize specific parameters such as gain, return loss, and directivity. The hexagon-shaped antenna emerges as a frontrunner for high throughput biomedical applications, operating at 2.4 GHz with a VSWR less than 2 and achieving a gain of 3 dB. This superior gain stems from the hexagon's geometric characteristics, providing an increased aperture size that captures and concentrates more electromagnetic energy. The enhanced directivity, a result of the hexagon's complexity, further amplifies the gain.

The circular microstrip patch antenna, designed for 5G applications at 3 GHz, stands out with a high gain of 10.0 dB. Circular patch antennas achieve this high gain through their circular geometry, ensuring a uniform radiation pattern for omni-directional coverage. Symmetry in design facilitates focused and directive radiation, while resonance at the desired frequency ensures efficient energy radiation. Low cross-polarization and low side lobes contribute to the concentration of energy in the main lobe. Surface wave suppression minimizes energy loss, and the simplicity of their structure makes circular patch antennas cost-effective and easy to integrate.

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