Review of U-Slot Microstrip Patch Antenna for Multiband Applications

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ABSTRACT
An increasing amount of attention is being paid to Microstrip Patch Antenna (MPA) because it is both compact and very effective. As a result of the growth of current wireless communication systems, there has been a considerable increase in the need for antennas that are not only lightweight and small but also adaptable and capable of functioning across many frequency bands. Specifically, the exploitation of U-slot microstrip patch antennas for multiband applications is the primary topic of this research, which provides a complete evaluation of these antennas. It has been established that the U-slot arrangement, which is a popular modification to typical microstrip patch antennas, is effective in increasing the bandwidth of the antenna and offering flexibility for multiband operation. The first part of the paper is an overview of the basic concepts that underlie microstrip patch antennas, as well as the reason for the incorporation of U-slot designs. Detailed discussions are held on the most important design parameters, which include slot size, location, and shape. These discussions focus on the influence that these factors have on the performance of the antenna in terms of bandwidth, gain, and radiation characteristics.

Keywords
Microstrip, U-slot, Antenna, Bandwidth, Gain.

1. INTRODUCTION
In the world of contemporary wireless communication systems, there has been an increase in the need for antennas that are not only efficient but also tiny, lightweight, and capable of functioning over several different frequency bands. The ever-increasing need for adaptable communication devices that can cross different and crowded frequency spectrums smoothly is the driving force behind this boom. In response to this need, researchers and engineers have investigated a variety of antenna designs, to improve the overall performance, as well as the bandwidth and flexibility of the antenna.

Microstrip patch antennas have become more popular for a broad variety of applications due to their low profile, simplicity of manufacture, and compatibility with integrated circuits. These characteristics have contributed to their widespread adoption. Conventional microstrip patch antennas, on the other hand, often display restrictions in terms of bandwidth, which limits their capacity to function efficiently over several different frequency bands. Researchers have proposed novel alterations to the fundamental architecture of the microstrip patch to solve these restrictions. One of the most prominent enhancements that has been implemented is the introduction of U-slot structures.

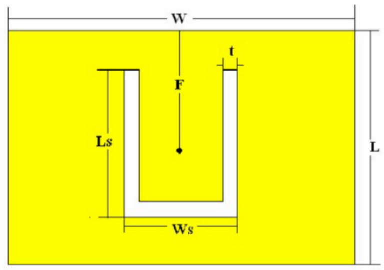

Figure 1: U-Slot Antenna

The U-slot configuration is achieved by inserting a slot in the form of a U into the radiating patch of the microstrip antenna. Although it may seem to be a simple alteration, it has turned out to be an effective instrument that has substantially improved the antenna's bandwidth and made it possible for it to function across several different frequency bands. Not only does the U-slot change the way the current is distributed on the patch, but it also generates extra resonances, which effectively broaden the frequency response of the antenna. This improvement is especially useful in the context of contemporary communication systems, which need antennas that are capable of covering a wide range of frequency frequencies for applications such as satellite communication, broadband wireless access, and Internet of Things (IoT) devices.

Using U-slot microstrip patch antennas for multiband applications is motivated by the fact that these antennas can overcome the inherent restrictions that are associated with classic microstrip designs. The researchers hope that by strategically inserting U-slot structures, they will be able to strike a balance between size, weight, and performance. This will allow these antennas to be suited for a range of communication situations in which multiband operation is critical.

A full investigation of U-slot microstrip patch antennas is going to be presented in the next parts, and this detailed introduction will set the scene for that investigation. In this paper, the basic concepts of microstrip patch antennas are discussed in depth. Additionally, the logic for the incorporation of U-slot structures is explained, and an overview of the important design factors that impact the performance of these antennas is provided. As an additional point of interest, the introduction draws attention to the larger context of multiband applications in wireless communication systems and emphasizes the significance of U-slot microstrip patch antennas as a potentially useful solution to address the problems that are provided by the ever-changing landscape of communication technologies.

2. LITERATURE REVIEW

A. K. Pathak et al., [1] The wealth of satellite resources and the growing need for satellite communication have both contributed to an increase in the demand for extending the C band of the satellite frequency band in the area of communication. This expansion has occurred concurrently with an increase in the use of the C band. There is a ground plane with a triangular slot and a patch in the form of a U that is included in the proposed antenna design. Microstrip antennas that include slots have several advantages, the most prominent of which is that they have a greater gain. Other favorable characteristics include a low profile, a simple construction, easy feeding, and simple system integration. Within the scope of this investigation, a microstrip patch antenna that incorporates a U-shaped radiating element and microstrip line operation is presented.

A. A. Almohammedi et al., [2] A frequency range known as 28 GHz has been designated for usage in 5G mobile communication networks. This band has been assigned for implementation. The millimeter wave spectrum, which encompasses a range of frequencies ranging from 30 GHz to 300 GHz, includes this particular frequency range. Within the scope of this research, the 28 GHz 5G networks are proposed and investigated. A modified single-element patch antenna that has three grooved U-shaped holes is depicted below. This antenna is utilized to suggest a high gain and efficiency for a 28 GHz 5G antenna.

Z. Deng et al., [3] demonstrated a microstrip patch antenna that was both small and capable of operating in the Beidou B2 frequency spectrum. Through the use of probe coupling feeding and the loading of parasitic patches, the bandwidth is considerably expanded. A profile of 4.6 millimeters (0.018 $\lambda 0$) is shown by the suggested antenna, which covers an area of 80 millimeters by 80 millimeters (0.31 $\lambda 0(\times 0.31)\lambda 0$). According to the simulation, the impedance bandwidth is 7.7% when the value of S11 is less than -10 dB. Over 1.5% of the bandwidth for B2 bands is more than the predicted axial-ratio bandwidth of 3 dB. This is a rather compact wideband patch antenna that has a broad range of potential applications.

Research conducted by A. A. Bhat et al., [4] investigates a potential Substrate Integrated Waveguide (SIW) based U-Slot Microstrip Patch Antenna (MPA) that operates in the X-band. The purpose of this antenna is to provide a high gain, broad scan coverage, and wideband, particularly for radar applications. A broader bandwidth operation is achieved by the use of a U-slot in conjunction with a thick substrate. In addition to this, it results in a decrease in the form factor, which tends to spread the beam and contributes to a reduction in scan loss. An ideal form factor with a fabricable via diameter to via spacing ratio has been meticulously developed while the SIW structure has been meticulously created.

H. Dungrani et al., [5] Machine learning and antenna design are two domains that are experiencing rapid growth in the scientific and technological sectors, and the objective of this study is to combine them. The genetic algorithm, which is a member of the class of evolutionary algorithms, takes its inspiration from the process of natural selection. In this process, the individuals who are the most physically mature are chosen for reproduction to discover the most effective method for achieving the desired results. The design parameters of the U-Slot antennas that have been suggested have been developed with the assistance of genetic algorithms. The dual-band antenna that is being suggested has two bands, one at 0.87–0.92 GHz and the other at 1.14–1.22 GHz.

R. Tiwari et al., [6] Electronic gadgets and wireless communication equipment are compatible with MPA, which is compatible with both 4G and 5G communication. The purpose of this work is to show a design for a rectangular MPA array that is built and constructed for a 5G wireless communication system. The array designs are 2×2 and 4×4 in form. Through the use of a maximum gain of 7.69 dBi and a bandwidth of 829 MHz, it is possible to acquire four distinct frequencies, namely 4.1 GHz, 4.5 GHz, and 5.5 GHz. A rectangular patch antenna with a partial ground is the basis for this design, which is based on the most cutting-edge design currently available. The printed circuit board (PCB) that is used to construct the hardware design is constructed of copper and has two sides.

R. Thakur et al., [7] It is suggested that a dual band antenna that makes use of a defective ground plane for wireless communication with dual purposes be used. They function as electronic band gap tuning, and by adjusting this, they can tune the frequency for a variety of wireless communication applications. The antenna is utilized to have twelve slots in a ground plane. 4.2 GHz to 5.1 GHz and 7 GHz to 13 GHz are the two bands that it operates in according to the design that has been presented. An exciting patch, also known as a radiator patch, is made up of a TI slot and a ground and exciting patch that are separated by an FR4 dielectric substrate from one another. The ground and the radiation patch are linked using a Via hole of 0.5 millimeters.

A. Rajput et al. [8] The suggested cloak has a total scattering cross section of 0.11 and 0.25 concerning the perfect electric conductor cylinder at 2.06 and 4.11 GHz, respectively. These values are shown by the total scattering cross-section. According to the parametric studies, the ratio of operating frequencies to scattering cross section at operational frequencies is dependent on geometrical factors. This shows that the ratio is reliant on the operating frequencies. At a frequency of 2.06 and 4.11 GHz, respectively, the dual-band cloak that has been presented exhibits a decrease in forward scattering that is 12 and 10 dB lower than that of the ideal electric conductor in the far field application. The invisibility is seen at both of the operating frequencies, as confirmed by the results of the numerical simulations of the bistatic scattering patterns and the electric field distributions.

Mr. Khan et al., [9] The experimental evidence that supports the U-slot microstrip patch antenna that is reported here is based on a single-layer grounded substrate. To design the U-slot microstrip patch, the first approach, known as resonant frequency (ResF), makes use of the fact that there are four different ResFs. The second way, known as dimensional invariance (DI), is dependent on the property of DI. The tuning of the probe placement is required in each of these procedures to achieve an additional increase in the 10-dB return loss bandwidth.

S. Liu et al., [10] The purpose of this letter is to describe a novel design for a single-feed dual-layer dual-band patch antenna that utilizes linear polarization. The dual-band performance is accomplished by the use of U-slot and E-shaped patches. The WLAN (2.40-2.4835 GHz) and WiMAX (3.40-3.61 GHz) bands are the ones that are being considered for integration into the antenna. It is possible to establish a high level of band isolation between the two bands since the peak gains of the two distinct bands are 7.1 and 7.4 dBic respectively. An antenna with a straightforward construction, excellent gains, and broad performance at low band frequencies are all benefits of the antenna.

Mr. He et l., [11] It is recommended that a small circularly polarized U-slot patch antenna with dual-feed be used for broadband applications. For the traditional singly fed square U-slot patch antenna that is printed on a high-permittivity substrate, the introduction of an extra feeding probe close to the vertical slot allows for the excitement of two series resonances that are located near one another. By adding a nonquadrature phase difference between two feeding ports, it is possible to create broadband circular polarization. It has been discovered that the two resonant frequencies are not dependent on the orientation of the U-slot about the patch.

S. Liu et al., [12] To accommodate WiMax and WLAN systems, a single-layer single-patch four-band U-slot patch antenna that has linear polarization has been developed. Utilizing this antenna, it was possible to attain impedance bandwidths (|S 11 |\;-10 dB) of 2.1%, 3.3%, 7.1%, and 5.0% at central frequencies of 3.35 GHz, 3.70 GHz, 5.20 GHz, and 5.80 GHz. Additionally, the antenna was able to obtain gains of 7.6 dBi, 8.6 dBi, 8.5 dBi, and 9.0 dBi, respectively. Cutting four asymmetrical U-slots into the patch was the method that was used to create this antenna.

A. Khidre et al., [13] Within this communication, a broadband dual-beam microstrip antenna is offered as a potential solution. Instead of operating the patch antenna in the basic mode, which emits a broadside beam, the patch antenna is operated in the higher order TM 02 mode, which results in the generation of two radiation beams off the broadside. The U-slot approach is used to accomplish the goal of expanding the antenna's bandwidth. The influence of the U-slot inclusion on the performance of a patch antenna operating at the TM 02 mode is explored over the whole attainable bandwidth, in contrast to the work that was done in the past on the standard U-slot microstrip antenna.

H. Sun et al. [14] The purpose of this communication is to introduce a U-slot patch antenna array that is situated on low-temperature cofired ceramic (LTCC) and has a wideband circularly polarized (CP) U-slot antenna array operating at 60 GHz. A stripline sequential rotation feeding technique is utilized to obtain a large axial ratio (AR) bandwidth, and a CP U-slot patch antenna is used as the array element to improve the impedance bandwidth. In the meanwhile, a transition from a grounded coplanar waveguide (GCPW) to a stripline is being constructed to measure probe stations. A constructed antenna array has dimensions of 14 × 16 × 1.1 mm 3, indicating its dimensions.

3. CHALLENGES

Even though U-slot microstrip patch antennas have several attractive benefits for multiband applications, several obstacles need to be overcome before their full potential can be realized. Understanding and addressing these obstacles is essential for the effective deployment of U-slot microstrip patch antennas in actual settings. These challenges involve a variety of design, manufacturing, and performance elements, and it is essential to understand and address these concerns. Among the most significant difficulties are the following:

1. **Bandwidth Optimization:** Although U-slot designs are effective in increasing the bandwidth of microstrip patch antennas, it is still difficult to achieve optimum bandwidth for all of the frequency bands that are sought. For U-slots to be designed in such a way that they concurrently cover many bands without causing interference or sacrificing other performance metrics, significant attention and new design strategies are required.
2. **Complexity in Design:** The incorporation of U-slots into the design process increases the level of complexity. To obtain the required multiband performance, it is necessary to properly tune the geometric characteristics of the U-slot. These factors include the shape, size, and placement of the U-slot location on the patch. This level of complexity may make the design process more difficult and may need the use of sophisticated simulation tools and optimization methods.
3. **Mutual Coupling:** In multiband applications, where numerous antennas may be situated near one another, the issue of mutual coupling between antennas becomes a particularly important problem. While the existence of U-slots may affect the coupling between antennas, it can also affect the performance of the antennas individually and collectively. It is a difficult effort to mitigate concerns related to reciprocal coupling while also retaining the integrity of the design of the U-slot microstrip patch antenna architecture.
4. **Radiation Pattern Control:** It is not an easy undertaking to achieve radiation patterns that are consistent and desirable throughout all working bands. The change of the U-slot may affect the radiation characteristics of the antenna. It is a problem that requires careful attention to ensure that the antenna maintains a stable and efficient radiation pattern across various bands.
5. **Material Considerations:** The selection of substrate materials is an essential factor in determining the performance of microstrip patch antennas. It is possible for U-slot layouts to display sensitivity to variations in dielectric characteristics, substrate thickness, and material losses. In particular, applications that have tight size and weight limits provide a problem when it comes to selecting appropriate materials that deliver consistent performance over many bands.

4. U-SLOT ADVANCEMENT

Because of its low profile, lightweight, and conformability to a variety of surfaces, microstrip patch antennas are used extensively for a broad range of applications. Conventional rectangular microstrip patch antennas, on the other hand, normally resonate at a single frequency. The modification of the patch form, the introduction of slots, and the use of stacked configurations are some of the different ways that have been suggested in order to overcome this constraint and enable multiband functioning. Within this group of methods, U-slot microstrip patch antennas have garnered a considerable amount of interest because they are easy to use, small, and efficient in producing various resonant frequencies.

4.1 U-Slot Design

Modifying the patch geometry and introducing extra resonant frequencies is a typical approach that is accomplished via the usage of the U-slot shape. The U-slot is normally formed by removing a section of the patch in the shape of a 'U,' with the arms of the 'U' extending towards the corners of the patch. This is the standard method when creating the U-slot. To influence the resonance frequencies, it is possible to change both the size and the location of the U-slot.

4.2 Multiband Operation

Additional current routes are introduced into the patch as a result of the incorporation of the U-slot, which also causes the field distribution inside the patch to remain unchanged. Consequently, this disturbance causes the development of new resonant modes, which ultimately results in the functioning of many bands. Through the manipulation of the size, location, and quantity of U-slots, it is possible to exert control over the number of resonant frequencies and the bandwidths that correspond to them.

4.3 Advantages of U-Slot Microstrip Patch Antennas

U-Slot Microstrip Patch Antennas Offer Several Different Benefits

There are various benefits that U-slot microstrip patch antennas have over traditional rectangular microstrip patch antennas for multiband applications. These advantages include the following:

- Ease of Design and Fabrication: U-slot antennas are very easy to design and build, which makes them appropriate for mass production without incurring significant additional costs.
- Because of their tiny size, U-slot antennas are suited for applications that have restricted space limitations. This is because they keep the compact size typical of microstrip patch antennas.
- Effectiveness: U-slot antennas are capable of efficiently generating several resonant frequencies with suitable bandwidths, which enables them to be adaptable for a variety of applications that need multiband capabilities.
- Controllable Resonance: The size, location, and quantity of U-slots may be modified to regulate the resonant frequencies and bandwidths, which provides flexibility in antenna design. This feature allows for more possibilities in antenna design.

4.4 Applications of U-Slot Microstrip Patch Antennas

U-slot Applications for U-slot microstrip patch antennas have been discovered in a variety of sectors, including the following:

- Wireless Communication Systems: U-slot antennas are used in wireless communication systems to accomplish multiband operation. This allows for the support of numerous communication protocols and frequency bands.
- The Global Navigation Satellite Systems (GNSS): U-slot antennas are used in GNSS receivers to receive signals from a variety of satellite constellations, including GPS, GLONASS, and Galileo.
- Radio Frequency Identification (RFID) Systems: U-slot antennas are used in RFID systems to tag and track items at numerous resonant frequencies. This improves the efficiency of RFID applications and expands their scope of usage.
- Radar and Sensing Systems: U-slot antennas are employed in radar and sensing systems because of their capacity to create various resonant frequencies. These qualities allow for wideband operation and increased detection capabilities.

5. CONCLUSION

The relevance of U-slot microstrip patch antennas for multiband applications is highlighted by the review, which highlights their potential as a viable solution to the ever-evolving difficulties that are present in wireless communication systems. It has been established that the inclusion of U-slot structures into typical microstrip patch antennas has resulted in significant gains in bandwidth. As a result, these antennas are well-suited for applications that need varied frequency coverage. The complexity of achieving optimal multiband performance is highlighted by the challenges that are associated with U-slot microstrip patch antennas. These challenges include optimizing the bandwidth, taking into consideration complex design considerations, mutual coupling, controlling the radiation pattern, integrating with RF front-ends, selecting the appropriate material, and dealing with environmental variability. Even though these issues provide obstacles, they also present opportunities for innovation and improvement in the design of antennas. To overcome these limitations and unleash the full potential of U-slot microstrip patch antennas, researchers and engineers are constantly researching innovative design approaches, optimization techniques, and technology advancements in the material. Because U-slots add a layer of complexity to antenna performance, it is necessary to have a comprehensive grasp of how they affect antenna performance. Additionally, it is necessary to include expertise from a variety of fields.

6. REFERENCES

[1] A. K. Pathak, M. Dwivedi and N. Srivastava, "Performance Evaluation of a Compact U-Shaped Patch Antenna for C-Band Applications," 2023 14th International Conference on Computing Communication and Networking Technologies (ICCCNT), Delhi, India, 2023, pp. 1-6, doi: 10.1109/ICCCNT56998.2023.10307299.

[2] A. A. Almohammedi, A. Raad, S. Darshi, V. Shepelev, M. H. Mohd Yusof and M. Balfaqih, "High Gain and Efficiency Triple U-shaped Slots Microstrip Patch Antenna for 5G Applications," 2023 3rd International Conference on Computing and Information Technology (ICCIT), Tabuk, Saudi Arabia, 2023, pp. 573-576, doi: 10.1109/ICCIT58132.2023.10273936.

[3] Z. Deng, X. Xu, Z. Tian, C. Duan, J. He and G. Li, "A Compact circularly polarized Beidou antenna loaded with U-slot parasitic patch," 2022 International Applied Computational Electromagnetics Society Symposium (ACES-China), Xuzhou, China, 2022, pp. 1-3, doi: 10.1109/ACES-China56081.2022.10065199.

[4] A. A. Bhat, R. Chikkodi, A. Mahesh and A. Kedar, "High Gain, Wide Band and Wide Scanning Substrate Integrated Waveguide based U-Slot Phased Array Antenna for X-band," 2022 IEEE Microwaves, Antennas, and Propagation Conference (MAPCON), Bangalore, India, 2022, pp. 1032-1036, doi: 10.1109/MAPCON56011.2022.10046847.

[5] H. Dungrani, Y. Gotad, U. S. Giridhar and P. Malame, "Application of Genetic Algorithm for Designing of

Microstrip Patch Antenna with a U-Slot," 2021 IEEE International Conference on Signal Processing, Information, Communication & Systems (SPICSCON), Dhaka, Bangladesh, 2021, pp. 22-25, doi: 10.1109/SPICSCON54707.2021.9885658.

[6] R. Tiwari, R. Sharma, and R. Dubey, "4×4 Rectangular Shape Microstrip Patch Antenna-Array With DGS For 5G Wi-Fi Communication Application," 2023 1st International Conference on Innovations in High-Speed Communication and Signal Processing (IHCSP), BHOPAL, India, 2023, pp. 281-285, doi: 10.1109/IHCSP56702.2023.10127192.

[7] R. Thakur, A. Dubey and R. Karn, "Dual Wideband Microstrip Patch Antenna by Using U shape and Rectangular slot through via hole technique for Pervasive Communication," 2020 IEEE 5th International Conference on Computing Communication and Automation (ICCCA), Greater Noida, India, 2020, pp. 30-34, doi: 10.1109/ICCCA49541.2020.9250723.

[8] A. Rajput and K. V. Srivastava, "Dual-Band Cloak Using Microstrip Patch With Embedded U-Shaped Slot," in IEEE Antennas and Wireless Propagation Letters, vol. 16, pp. 2848-2851, 2017, doi: 10.1109/LAWP.2017.2749507.

[9] M. Khan and D. Chatterjee, "Characteristic Mode Analysis of a Class of Empirical Design Techniques for Probe-Fed, U-Slot Microstrip Patch Antennas," in IEEE Transactions on Antennas and Propagation, vol. 64, no. 7, pp. 2758-2770, July 2016, doi: 10.1109/TAP.2016.2556705.

[10] S. Liu, W. Wu and D. -G. Fang, "Single-Feed Dual-Layer Dual-Band E-Shaped and U-Slot Patch Antenna for Wireless Communication Application," in IEEE Antennas and Wireless Propagation Letters, vol. 15, pp. 468-471, 2016, doi: 10.1109/LAWP.2015.2453329.

[11] M. He, X. Ye, P. Zhou, G. Zhao, C. Zhang and H. Sun, "A Small-Size Dual-Feed Broadband Circularly Polarized U-Slot Patch Antenna," in IEEE Antennas and Wireless Propagation Letters, vol. 14, pp. 898-901, 2015, doi: 10.1109/LAWP.2014.2384496.

[12] S. Liu, S. -S. Qi, W. Wu and D. -G. Fang, "Single-Layer Single-Patch Four-Band Asymmetrical U-Slot Patch Antenna," in IEEE Transactions on Antennas and Propagation, vol. 62, no. 9, pp. 4895-4899, Sept. 2014, doi: 10.1109/TAP.2014.2335816.

[13] A. Khidre, K. -F. Lee, A. Z. Elsherbeni and F. Yang, "Wide Band Dual-Beam U-Slot Microstrip Antenna," in IEEE Transactions on Antennas and Propagation, vol. 61, no. 3, pp. 1415-1418, March 2013, doi: 10.1109/TAP.2012.2228617.

[14] H. Sun, Y. -X. Guo and Z. Wang, "60-GHz Circularly Polarized U-Slot Patch Antenna Array on LTCC," in IEEE Transactions on Antennas and Propagation, vol. 61, no. 1, pp. 430-435, Jan. 2013, doi: 10.1109/TAP.2012.2214018.